Energy-saving attitudes and behavioural influences in large organisations: The case of

Network Rail

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Volume 2: EngD portfolio

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EngD Portfolio

This supporting volume contains additional materials for the thesis entitled ‘Energy-saving attitudes and behavioural influences in large organisations: The case of Network Rail’, by Rupert Zierler. This thesis was originally submitted on 10 April 2017, as part of an Engineering Doctorate (EngD) with the Engineering Doctorate (EngD) with the Centre for Environment and Sustainability at the University of Surrey. This was sponsored by the Sustainability for Engineering and Energy Systems Doctoral Training Centre (SEES DTC), with funding from the UK Engineering and Physical Sciences Research Council (EPSRC), and Network Rail.

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Please note that some paper drafts, questionnaires and posters were originally included with EngD progress reports – their locations have been noted below. Powerpoint files for oral presentations delivered at major conferences are available on the same disc as this portfolio – filenames are given below (list continues on page 3)

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6-monthly EngD Progress Report
1: October 2012 - March 2013

Rupert Zierler
(URN: 6248587)

Date due: 4 April 2013
Date submitted online: 3 April 2013

Academic supervisors: Dr Walter Wehrmeyer
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Executive Summary

Justification for research

This EngD research project aims to investigate corporate sustainability and innovation frameworks, for enabling reductions in costs and carbon emissions through reduced- and more efficient use of railway infrastructure energy.

Research questions are aligned with and justified against the goals of the Network Rail Strategic Business Plan, the Sustainable Development Strategy, and draft Energy and Emissions strategy (see section 2 for details).

Literature Review Summary

This review (section 4 in this report) takes a top-down approach, looking at sustainability frameworks in general, before investigating those specific to rail, and finally the individual innovations which enable these. The three main sections are as follows:

Frameworks and innovation

Optimal methods of management organisation to achieve sustainable business operations are investigated for infrastructure companies and others. The benefits of robust sustainability reporting are discussed, along with recommendations for future Network Rail offerings.

Transport studies – the economic and carbon credentials of rail

A key shortcoming of current Network Rail sustainability reporting is the lack of demonstration of their importance to the UK economy and social structures, and the benefits of implementing a sustainability strategy. The impacts of infrastructure schemes on travel behaviour, and other methods of encouraging modal shift need to be understood in order to fulfil this requirement. This can then benefit development of business cases for implementing energy-saving infrastructure improvements.
Traction and infrastructure energy – policy, supply and technologies

Some specific energy-saving infrastructure technologies are investigated, including energy storage, conductor rail heating and control systems, and power distribution infrastructure. The impact of increasing railway traction electrification on domestic supply grids is also discussed. Lineside electrical equipment, used for purposes other than traction electricity supply, is identified as key area for energy efficiency improvements at Network Rail. Future challenges may include providing infrastructure for battery-powered trains as fossil fuel prices increase, and smart control systems to avoid negative impacts on domestic electricity supply grids.

A summary of the literature review can be found in section 4.4 of this document.

Planned research pathway, April – September 2013

Overall, progress with reading-based research has been satisfactory, particularly regarding technical aspects of lowering energy use, and best practice in sustainability reporting. However, although information about generalised business frameworks for sustainability has been researched, the method by which these could be applied to Network Rail requires further study. Summaries of research progress can be found in Table 2 and Table 3 in this document.

The next phase of research will identify specific projects to conduct with different Network Rail departments in order to achieve original contributions to knowledge. In contrast to this literature review, this will take a bottom-up approach, observing how individual innovations filter through business practices, first throughout Network Rail and later throughout the industry and beyond. This is likely to require at least one of the following potential projects:

- Social research into how devolved company structures impact sustainability at Network Rail
- Monitoring of any cooperation mechanisms established between Network Rail Routes which may support sustainable objectives
- A Life Cycle Assessment of a specific energy saving infrastructure technology
- Ongoing literature research into sustainability transitions, reporting structures and specific technological innovations
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Glossary

CHP - Combined Heat and Power
CP4 - Control Period 4: 2009-2014
CP5 - Control Period 5: 2014-2019
CSR - Corporate Social Responsibility
DfT - Department for Transport
EngD - Engineering Doctorate
EV - Electric [road] Vehicle
FOC - Freight Operating Company
GaBi 6.0 - Life cycle assessment software
GHG - Greenhouse Gas
GRI - Global Reporting Initiative
HSR - High Speed Rail
HST - High Speed Train (referring to fast, but not ‘high speed’ intercity services over conventional track)
KPI - Key Performance Indicator
LCA - Life Cycle Assessment
MLP - Multi-Level Perspective
NR - Network Rail
ORR - Office of Rail Regulation
PV - Photo-Voltaics, referring to solar electrical generation panels
R&D - Research and Development
RRUKA - Rail Research UK Association
RSSB - Rail Safety and Standards Board
S&SD - Safety and Sustainable Development, Network Rail department
SBP - Strategic Business Plan (Network Rail)
SBS - Sustainable Business Strategy, Network Rail team
STAR - Scottish Transport Applications Research conference
TOC - Train Operating Company (passenger)
WTW - Well-To-Wheel, referring to life cycle assessment of vehicle fuels
1. Introduction

This report summarises all work conducted over the period October 2012 – March 2013, towards this EngD project in business sustainability frameworks and their application to infrastructural energy-saving technological innovation.

The primary focus of this first report is a review of scientific literature. This is based around three main sections. ‘Frameworks and innovation’ discusses these in relation to sustainable rail operation, and best practice in sustainability reporting. ‘Transport studies – the economic and carbon credentials of rail’ presents the economic case for developing railways as a form of sustainable transport, and how Life Cycle Assessment can support this. Finally, ‘Traction and infrastructure energy – policy, supply and technologies’ discusses specific innovations which could contribute to a reduction in infrastructure-based carbon emissions.

Report Structure

Section 2 discusses the process of problem definition as a guide to literature research, and how research questions have been formulated.

Section 3 outlines the university-taught modules covered in the last 6 months, and what contribution these have made to answering the research questions.

Section 4 contains the main literature review. A summary of this is available at the end of this section, on page 53.

Section 5 covers key work and events conducted at Network Rail, which may later support EngD research topics.

Section 6 assesses progress made towards answering the research questions, and outlines the next intended phases of research, along with revised questions to enable this.

Section 7 reflects upon the findings of this report and time spent at Network Rail so far. Immediate actions for the next 6 months are also proposed.

Appendices include a (A) research reading checklist, (B) a Gantt chart showing a rough plan of activities until the end of 2014, and (C) a summary table of key current and potential stakeholders for this project.
2. Problem definition process

The initial briefing for this EngD was defined by the following statement:

“To contribute to the development of - and embedding of sustainability thinking within management frameworks, suitable for implementation across Network Rail’s devolved company structure.”

The Sustainable Business Strategy (SBS) team at Network Rail identified that energy use and security are key concerns for the continued operation of Britain’s railway infrastructure.

2.1 Fitting research with Network Rail business strategy

The Strategic Business Plan (SBP) sets out what Network Rail needs to do over the period 2014-2019 (known as Control Period 5/CP5) in order to meet the requirements of customers and other stakeholders. Separate editions are produced for England & Wales (Higgins 2013), and Scotland (Higgins 2013), but the sustainability themes are very similar.

Research and development spending is planned to increase dramatically over the course of CP5. This is driven by a strong benefit : cost ratio estimated at 11:1 in the Plan.

Given this increased investment, it is important that the benefit ratio is maintained or improved upon. This will require robust frameworks to ensure money is spent in the most effective ways, and to sustainable ends. Therefore this EngD research into sustainability frameworks will support any technological innovations which may occur or start over the course of CP5.

The strategic themes for CP5 are listed below. Where this project is to address one of these themes, a description is given beneath (starts overleaf).
- Everyone home safe every day
- **Reliable infrastructure**

Ensuring that trackside electrical infrastructure is robust and resistant to increasing pressures on fuel cost and climate change will support Route reliability, as will tailoring these measures to the areas they serve.

- Reliable timetables
- **The biggest investment since the Victorian era**

It is important that this increased investment is directed toward long-term sustainable projects. Enabling smarter use of energy will ensure that no money is wasted.

- **A technology enabled future**

Electrification of services will reduce operational carbon emissions. Some study is required to ensure construction of electrification schemes do not adversely impact domestic supply grids and support the communities they serve.

- A customer focused organisation
- Investing in our people
- **Opening up**

Sustainability reporting is an increasingly important method of providing company transparency and directing businesses towards long-term sustainability. Supporting the ability to report on energy use and carbon emissions will enable NR reporting to be internationally recognised and act as a market leader for sustainability.

- **A railway fit for the future**

This goal discusses the embedding of sustainability within NR’s practices. This summarises the other points; improving sustainability reporting, investing in innovation and ensuring efficient use of energy all enable this goal.

- **Reducing public subsidy**

Reducing energy use will directly reduce the cost of supplying electricity to the railway, lowering reliance on government subsidy.
2.2 Fitting research with draft Energy and Emissions strategy

Network Rail’s draft energy and emissions strategy features a hierarchy of Carbon Reduction. This is currently under development and does not form part of an active policy document at present. However, the hierarchy can be summarised as the following list of goals:

- Use less energy
- Use energy efficiently
- Use renewables/zero carbon energy sources
- Improve use of non-renewables (e.g. through CHP, voltage optimisation etc)
- Reduce carbon intensity of non-renewables

This research project is likely to primarily support the first three aspects of this hierarchy. Reducing the carbon intensity of non-renewable electrical supplies is largely subject to the recent deal with EDF Energy, which this research is unlikely to materially affect. Improving the use of non-renewables is likely to take place beyond the realm of infrastructure; CHP, for example, typically applies to buildings and offices, not directly associated with the operation of trains.

2.3 Fitting research with external stakeholder goals

The main stakeholders in a sustainability transition at Network Rail are listed below, along with descriptions of how this research corresponds to their goals.

The Office of Rail Regulation (ORR)

This is the independent safety and economic regulator for Britain's railways, appointed by the Secretary of State for Transport. They have recently established a transparency programme, which aims to improve accountability and reporting throughout the rail industry. This EngD research can support this goal through improved reporting on Network Rail's economic activities, and how railways support the economic goals of others.

The Rail Safety and Standards Board (RSSB)
RSSB is an independent not-for-profit company owned and funded by major stakeholders in the UK railway industry, which supports a wide range of cross-industry activities. Their Sustainable Development Principles demonstrate the public interest in environmental and social themes, and represent the stakeholder interest in developing economic ones. Developing energy efficiency with the SBS team in parallel with RSSB will demonstrate the sustainable credentials of energy-saving infrastructure improvements.

**Passenger Focus**

This is an independent passenger watchdog, who typically campaign around fare and ticket prices, service quality and investment levels in the railways. Addressing energy efficiency and security will support the continuation of railway services throughout economic shocks. Targeting investment towards sustainable goals is also likely to boost public support for railways.

### 2.4 Fitting research with the Sustainable Development Strategy

The Sustainable Development Strategy was developed by the SBS team and completed in December 2012, for integration with the Strategic Business Plan.

The sustainable development vision, ‘A railway fit for the future’, is summarised by the objectives given below. Under each objective is a description of how this research can support them:

#### 2.4.1 ‘Rail travel is a cornerstone of economic growth’

Reading has highlighted how changes to the railway network supported a shift to a service-based economy in the UK during the 1970s-80s (Chen and Hall 2011). A transition to a sustainable economy could therefore be partially driven by further railway development. Research into energy frameworks and efficiency can contribute to the environmental and economic aspects of this shift.
2.4.2 ‘Rail travel supports a greener environment’

Electrification of railway routes could significantly reduce operational carbon dioxide emissions. Using less energy, more efficiently could also achieve this.

2.4.3 ‘Rail travel improves social and economic opportunities’

Literature discussed in section 4.2 discusses how rail has contributed to economic opportunities in recent years, particularly fast intercity travel. In a more direct sense, increasing use of renewable energy technologies may boost jobs involved with their manufacture.

2.4.4 ‘Sustained community support recognising the importance of rail’

The ability to travel has become highly prized over the last two centuries. In a world of increasing resource pressures and fuel prices, it is important that rail’s low carbon methods of enabling travel are supported, developed, and advertised publicly. Researching infrastructure energy topics increases this understanding, and supports mobility in a world where fuel prices may make this more difficult.

2.4.5 Network Rail as a great place to work

Energy use does not directly impact on this. However, research into energy-related topics is likely to enable further employee engagement with sustainability practices, and support development of training courses to ensure future efficiency.

Research into energy-driven topics can therefore be seen to directly support the first four of these objectives, with no foreseen negative impacts on the fifth.

The key outcomes for sustainable development by 2019, out of a total of 7 goals, feature:

- A 14% reduction in the carbon intensity of electricity supply
It is therefore clear that energy use forms a significant proportion of the intended changes to Network Rail’s policies, and that management frameworks need to accommodate this. This supports a key addition to the briefing for this EngD research, to focus upon the handling of infrastructure energy assets. This would not preclude study of sustainability frameworks for other parts of the business, but energy-related ones would take priority owing to their prominence in NR’s various strategies.

These outcomes also closely resemble the first three aspects of the Carbon Reduction hierarchy. Reducing the carbon intensity of supply can be supported by increasing use of small scale renewables. A large component of reducing total carbon emissions is believed likely to come from a reduction in energy use. Development of energy efficient assets is required to improve overall energy efficiency, given the age of some UK railway infrastructure. This reaffirms the importance of increased energy efficiency to Network Rail, and the remit for this EngD research to support this.

2.5 Initial research questions

A series of potential research questions was produced in January 2013, in response to a request from supervisors. These were based on recommendations from industrial supervisors, and the progress of reading to this point. In response to meeting with Energy Services, some additional questions were added following further reading in February.

A research outline document, currently used as a reading checklist was produced by the industrial supervisors to support topic selection during literature research following the first all-supervisor meeting in November. This document is provided in 'Appendix A: Research '.

This document, combined with reading from module coursework, could be summarised into four main research categories. A fifth, ‘Trackside energy savings’ was added following discussions with members of the NR Energy Services department.

These research categories are justified in terms of their contribution to achieving the Sustainable Development Strategy in the section below:
2.5.1 Innovation patterns

Supporting technological and managerial innovation can ensure that rail continues to provide a cornerstone of economic growth (see 2.4.1) through directed research and development.

2.5.2 Traction energy technology

Reducing energy use directly supports a greener environment through lowering carbon emissions by trains (see 2.4.2). It will also help to maximise the economic benefits of electrification, through reducing impacts on supply grid requirements (see 2.4.1).

2.5.3 Network Rail frameworks

Investigating effective sustainability frameworks and reporting structures will demonstrate social and economic opportunities of working with Network Rail to major stakeholders (see 2.4.3). It also supports communities through enabling greater transparency of operations, and how other local areas may have already benefitted (see 2.4.4).

2.5.4 Travel demand influences

Understanding the impact of rail on UK travel demand and patterns supports the development of an economic sustainability case for rail (see 2.4.1). It could also help identify specific communities where rail has the greatest social impacts, and thereby support their development (see 2.4.4).

2.5.5 Trackside energy savings

Similarly to 2.5.2, reducing energy use by lineside infrastructure components brings environmental benefits through carbon emission reduction (see 2.4.2).
A series of potential research questions was produced on 24 January 2013, in response to a request from supervisors. These were based on recommendations from industrial supervisors, and the progress of reading to this point. In response to meeting with Network Rail’s Energy Services team in Asset Management Services, some additional questions were added following further reading on 14 February 2013. Some lower-level specific questions were also added as reading continued. This document is provided in the next section (2.6):
2.6 Research questions guidance document

Innovation patterns

1. Do new devolved route structures in Network Rail encourage or discourage energy-related innovation and efficiency?
   - Do these new, smaller divisions encourage competition and drive traction energy innovation?
   - Do reduced economies of scale impede innovation in this case?
   - Is this devolved structure more conducive to other aspects of sustainability (such as community involvement), but not traction energy?
   - Are new frameworks required for sustainable technology roll-out in a devolved organisation?

Traction energy – policy and supply

2. What effects will increasing reliance on electric railway traction have on peak electricity demand in the UK?
   - What methods are available to reduce this, and how viable are they?
     What is used at present? Can they continue to be used sustainably?
     - What is the potential for on-board supercapacitors to achieve this on mainline- or high-speed rail systems (study available for metro trains)?
     - Can static electronic trackside power converters achieve this?
   - Would conversion from DC $\to$ AC power supplies achieve carbon reductions, despite requirement for new electrical infrastructure?
   - Do predictions of electricity demand in the UK adequately represent increased mobility-based electrical requirements?

3. Can increased electric railway traction operate alongside increased electric vehicle recharging without compromising sustainability?
   - Can smart grid technology cope with the increased electrical demand, or are demand management measures needed to meet sustainability objectives?

4. What are the rebound effects of increasing traction energy efficiency and sustainability on Train Operators?
   - Does this lead on to changes in travel demand?
     - Does this take the form of modal shift, or just general increases in travel?
   - Do these effects counteract lifetime carbon benefits in life cycle analyses of NR projects?

Network Rail frameworks
5. What is the potential for cooperation frameworks between Network Rail, National Grid, energy suppliers, to achieve carbon emission reduction and sustainability objectives?
   - What role should infrastructure operators take in pursuing railway sustainability? [Facilitator for local routes vs. top-down strategic administration]

6. What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?
   - How applicable are they to the UK?
   - Particularly good examples of sustainability integration are found in Hong Kong, the Netherlands and Sweden – how transferable are their ideas?

Travel demand influences

7. Using modal shift as a factor in life cycle- or comparative analysis of rail development scheme sustainability – pitfalls and standardisation issues?

8. Can rail act as a market leader for sustainability across all transport modes?
   - Following on from (Chiou, Lan et al. 2013)-- are transport modes in Nash- or Stackelberg equilibrium in terms of sustainable development? What are the implications? Does the whole transport sector require a market leader in order to develop sustainably?
     - In this case, what can NR do to act as this market leader?

Trackside energy savings (added 2013-02-14)

9. Which technologies can best be applied to save or manage energy use by track-based or trackside infrastructure?
   - Which technologies are favoured by comparative life cycle analysis?
   - Is satellite communication reliable enough to replace trackside infrastructure and save material costs?
2.7 Research questions and the literature review

Upon re-evaluation of these research questions for this report, 3 main research themes were identified, replacing the 5 headings in the Research Questions Summary. As some questions and sub-questions were added after the original 8 were laid out, there were several cross-overs in topic, and some headings were redundant.

In particular, trackside energy savings and traction energy have several similar themes, especially regarding energy storage and impacts on the grid. ‘Traction energy’ was also deemed too limiting as a title, as it excluded electrical technologies beyond those used to propel trains.

‘Innovation patterns’ and ‘Network Rail frameworks, while researching different topics, were felt to have similar aims for Network Rail. Developing sustainable innovations requires understanding of how current- and possible future regulatory frameworks support them.

Hence, these questions have been re-categorised under 3 headings as given below (Table 1). These are roughly in order of increasing detail – strategies and frameworks first, their application to industry second, and specific enabling technologies third.
Table 1 - How the main research questions fit the literature review structure for this report.

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<td><strong>Traction and infrastructure energy – policy, supply and technologies</strong></td>
<td>2</td>
<td>What effects will increasing reliance on electric railway traction have on peak electricity demand in the UK?</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Can increased electric railway traction operate alongside increased electric vehicle recharging without compromising overall sustainability?</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Which technologies can best be applied to save or manage energy use by track-based or trackside infrastructure?</td>
</tr>
</tbody>
</table>

These three main headings have been used as a basis for the main literature review structure, provided in section 4. This is to address problems with the large number of research questions previously identified, as discussed with supervisors.

A research outline document was subsequently produced by the industrial supervisors to support topic selection during literature research. This is currently used as a checklist during reading sessions, to prevent duplication of effort week-on-week, but points on this are not phrased as research questions. Therefore, reading progress on these topics has been appraised separately from the research questions given above (see section 6.3). This document is provided in Appendix A.
3. Module-related research and coursework

This section discusses how university-based lecture courses have affected research as part of this EngD project. A significant portion of the first 6 months has been dedicated to university module-related work and coursework; at least 12 out of the past 26 weeks have been engaged in either lecture weeks or coursework completion. Therefore, some discussion of their output is appropriate, especially as this lecture-heavy period is unusual for the course structure as a whole.

Most projects have provided research leads which are likely to be useful to later projects. In particular, the coursework for Life Cycle Thinking allowed exploration of themes relevant to the railway infrastructure industry. Sustainable Development Applications also provided key insights into sustainability reporting structures.

Feedback on the overall quality of the courses has been omitted here, as there is a separate official process for this; comment here is limited to how relevant material was for this particular EngD research topic.

These modules have been discussed in chronological order of completion.

3.1 Social Research Methods
(01-03 October 2012)

Previous work undertaken by the author as part of a Masters dissertation in Transport Engineering and Operations featured a social research project. This involved interviews with- and questionnaires distributed among members of the general public, regarding a small heavy rail station in Dunston, near Gateshead. Despite going over some old ground, this course was useful as several of the topics had not been formally taught during the aforementioned Masters course – techniques had previously only been learnt through discussions with supervisors and extra-curricular reading.

At present, it is not anticipated that social research with members of the general public in this way will be required for this research project, as trackside infrastructure is not widely understood.

However, there remains a possibility that this may go ahead in some form among Network Rail staff or management. Some research has already been
performed in this area, regarding the integration of sustainability reporting into management practices (Adams and Frost 2008). Adams and Frost’s paper suggests some approaches to doing this, but a specific set of questions for this project still requires formulation. Some hypothesised topics are:

- Ascertaining attitudes surrounding energy use, i.e. whether energy-saving policies are implemented on localised (Route) scales
- Interviews with senior management of departments beyond Safety and Sustainable Development, regarding attitudes toward sustainable development in general, or whether they think it is embedded in some of their processes already.
- Online questionnaires of awareness of the services provided by the Sustainable Business Strategy team, particularly following development of the internal website
- Interviews with frontline staff on environmental and social considerations made by them on a day-to-day basis.

These and other potential topics are to be discussed with supervisors within the next 6 months. Some specific potential social research questions pertinent to Network Rail, based on these calls for new insight, are given below.

- Niche dynamics
  - Given Network Rail’s size, which socio-technical niche-regime-landscape pattern is most applicable to sustainable innovation?
    - Route-National-Government
    - R&D-Asset Management-National Infrastructure
- Regime unlocking
  - How is Network Rail becoming more open to sustainable practices?
  - How is leadership playing a role in sustainable development within Network Rail?
- Spatial aspects of transitions
  - How do Routes respond differently to sustainable development?
  - How many developments are transferable between Routes?
  - Why might some Routes respond at different rates than others when implementing sustainable practices?
- Interactions with public policy
  - Are there any other businesses globally in a similar situation? How do they interact with government, as a heavily-regulated not-for-profit monopoly infrastructure provider?

This is thought, by the author, to be vital for understanding the embedding of management sustainability frameworks, but it is less clear how these may
contribute to understanding energy use and its relationship with management at present. This will be resolved in future discussions with supervisors.

3.2 Environmental Science and Society
(08-12 October 2012)

As a whole, this module provided useful overviews of scientific topics relating to environmental damage, the sustainability of several modern day industrial processes, and surprises regarding the impact levels of some of these. The discussion of nuclear power was, in hindsight, particularly to Network Rail, given their adoption of a 10-year supply deal with EDF Energy, who will shortly own all of the UK’s operational nuclear power plants.

However, coursework questions from the post-module assignment were on highly specific topics, such as genetically modified crops, and were short in length and scope. As a result, with the exception of one question this module did not feature much transferable literature research. The exception was a question titled ‘Which level of government should have responsibility for environmental policy and sustainability’, which facilitated research into the Multi-Level Perspective (MLP) of sustainability transitions.

3.3 Foundations of Sustainable Development
(29 October – 02 November 2012)

This module provided a ‘potted history’ of global sustainable development thinking, plotting the development from early environmentalism to the present day. This provided useful insight into important UN documents, such as the Brundtland Report (1987), and global legislation and summits supporting sustainable development. These documents provide a basis for global sustainability reporting (see section 4.1.3), and are often cited in scientific literature around sustainable innovation frameworks (section 4.1.2). As previous courses studied by the author did not focus primarily on sustainable development, this history broadened the author’s perspective on sustainability, particularly beyond the environmental aspects familiar from geological modules as an undergraduate.
Reading undertaken for the post-module assignment highlighted the importance of supporting technological innovation as part of any sustainability strategy. This was found to largely be as a result of increasing societal awareness of environmental variables, enabled by improvements in information technology. These findings assisted with the formulation of the ‘innovation patterns’ research category for this EngD project. This module was closely related to and built upon by Sustainable Development Applications (see section 3.5).

3.4 Life Cycle Thinking
(19-23 November 2012)

This module primarily discussed the various methods used to perform life cycle studies, and the scales and systems to which these should be applied. Literature researched as part of this module has proven valuable for the main body of research. Section 4.2.1 features several references carried over from the post-module project from this module. The availability of life cycle assessments and similar studies surrounding high speed rail projects is relatively high, but there are few available for individual trackside technologies. This highlights an area for possible study as part of this research project

3.5 Sustainable Development Applications
(04-08 March 2013)

The pre-module coursework for these lectures focused around a review of a sustainability report. Unfortunately there were no infrastructure or transport operators among the limited list of organisations given to us at the outset. However, the comparative study of sustainability reports from several employment sectors has improved understanding of what any future Network Rail reports should achieve (see section 4.1.3).

This module provided a platform for investigating sustainability reporting. Greater knowledge of reporting from other industries supported the ‘Network Rail frameworks’ research category.
This module has also assisted with discussions relating to website development with SBS colleagues, highlighting examples of best practice to carry forward with any future NR online reporting structure.

On completion, coursework from this module will be adapted into a report for the SBS team at Network Rail.

### 3.6 Life Cycle Assessment
(Scheduled for 15-19 April 2013)

This module has not yet taken place; however, this will build upon topics from the earlier Life Cycle Thinking module. LCA software GaBi 6.0 has been uploaded in preparation for this module. The intention is to eventually use this or similar software to perform detailed life cycle assessments for energy-saving trackside technologies.

### 3.7 Conclusions from module work

Assignments have occasionally contributed useful research leads for the main EngD project. The impacts- and importance of supporting technological innovation, and the environmental credentials of rail have been ascertained largely through work for these courses. Best practice in sustainability reporting has also been identified and carried over to useful projects for the SBS team. However, they have not consistently contributed useful output literature research material. This has occasionally been due to the required format of the assignment (e.g. short answer-style questions for Environmental Science and Society). It is hoped that future assignments will produce more useful copy for integration into subsequent reports and eventual dissertation piece.
4. Exploratory Literature Review

This review discusses all reading conducted outside university lecture modules over the first 6 months of this course. Some references have also been taken from module coursework where appropriate, as discussed in section 3. This review takes a top-down approach, looking at sustainability frameworks in general, before investigating those specific to rail, and finally the individual innovations which enable these.

Section 4.1 investigates sustainability frameworks and reporting, to establish the quality of Network Rail’s present sustainability updates, and whether sustainable innovation is adequately supported by current internal governance structures.

The second part, section 4.2, progresses to discuss application of these frameworks and life cycle analysis to transport infrastructure operators, and then Network Rail specifically. This is done to determine the extent to which life cycle thinking has been applied to transport, and where there may be gaps in present knowledge for future study. This is also to provide economic justification for development of railway infrastructure as part of an integrated sustainable UK transport system.

Section 4.3 then reviews how specific energy policies and technical innovations can be applied to support the intended outcomes of these frameworks and reporting structures. This is done to determine what trackside technical energy-related innovations have already been developed, their potential application to Network Rail infrastructure, and opportunities for new developments. Some discussion is also made of on-train innovations, to determine potential future support infrastructure requirements.

The review is then reflected upon, concluded and summarised in section 4.4.
4.1 Sustainability frameworks and innovation

There are many individual technological innovations which may enable a transition to a low carbon railway network, as discussed in section 4.3. However, implementing these requires a series of frameworks to ensure that they are cost effective, are demonstrable within the business and beyond, and do not negatively impact safety.

Although Network Rail has produced Corporate Social Responsibility (CSR) reports since 2010, sustainability has not become a top priority for the business until relatively recently, compared with some other industries. The field of sustainability framework development and reporting is maturing, with the availability of the third generation of GRI guidelines (2011), highly developed reporting in other industries (e.g. Bolland 2012), and foreign rail companies developing their own reports (e.g. Chung 2011). It is therefore essential that best practice is learnt from these examples for Network Rail’s own reporting, along with identifying potential areas for reporting innovatively and tailoring it to local sustainability issues.

This section investigates framework methodologies for supporting sustainable innovation across transport in general, and railways in particular. The emerging field of sustainability transitions is also discussed, as a possible field of contribution for this EngD research project, given the current period of culture change across Network Rail. The way by which sustainability reporting can contribute to integration of these frameworks is then investigated, highlighting best practice, and suggestions are made for possible alterations to Network Rail’s own reporting structures.

4.1.1 Supporting sustainable innovation

Business and governance structures to support sustainable innovation have been a major research area in recent years, as discussed by Musango and Brent (2011). Gimenez, Sierra et al. (2012) state that environmental programmes have the greatest impact on all three parts of the sustainability triple bottom line (environmental, social and economic factors – as described by Elkington, 2002), compared to those which address social issues, which only tend to impact on environmental and social areas. This supports the business case for developing energy saving trackside technology. Gimenez, Sierra et al. (2012) also state that supply chain collaboration (rather than simple internal assessment) contributes significantly to improving on the triple
bottom line. This suggests that close collaboration with suppliers in the process of acquiring new trackside technology is required to achieve carbon and cost savings. Network Rail’s sustainability update currently has a heavy emphasis on social programmes, containing approximately three times as much information as the environmental section. This implies that additional emphasis should be placed on developing environmental programmes, and that their economic benefits should be clearly demonstrated.

The Multi-Level Perspective (MLP) offers a method of describing how sustainable innovations spread from niches, through regimes and eventually embed themselves in technological landscapes (Geels 2002). This evolutionary perspective on sustainability transitions could help to develop a framework for sustainable innovation in Network Rail. This technique has also been applied to transport studies, regarding the market penetration of alternative-fuel road vehicles (Geels 2012). As a large organisation, Network Rail could encompass all 3 scales discussed by the MLP within itself. Smith, Voß et al. (2010) suggest research into how socio-technical niche, regime and landscape relate to other dimensions, such as administrative, territorial and communicative spaces. Within Network Rail, Routes could be considered administrative niches, regime could be the whole organisation, with landscape being the whole UK rail industry. Mapping the progress of trackside technological innovations could support this suggested research. An attempt to overlay Network Rail’s strategic landscape on to the MLP has been made in Figure 1.
4.1.2 Rail sustainability frameworks

Network Rail has the unusual position of being a monopoly operator with multiple regulation bodies, responsible for railway infrastructure alone. This will limit the relevance of understanding foreign railway sustainability frameworks, as most other companies encompass both track and train. However, as overall sustainability performance seems closely tied with reporting structures (see section 4.1.3), there are more general lessons to be learnt from the implementation of business and sustainability strategies.

Sørensen and Longva (2011) suggest that the division between track and train in the British railway system is a challenging obstacle to achieving sustainability. This implies that any attempts to improve the sustainability of railway operation require greater coordination between infrastructure and rolling-stock operators, particularly on the efficiency of economic exchanges between these two stakeholders.

Some analysis, such as that by Preston and Robins (2013), concludes that the rail privatisation process in the UK has been ‘welfare negative’. Increased coordination between track and train would therefore to counter this welfare deficit. Network Rail’s division into Routes may facilitate this, but powers are still in the process of being transferred from centralised control; human resourcing and financial powers have only been handed to Routes as of April 2013. This sets a precedent for research into cooperation and coordination techniques to channel research and development efforts into low-carbon technologies, whilst maintaining this degree of Route autonomy.

Ollivier-Trigalo and Barone (2011) discuss how railways in France have been a catalyst for national administrative reorganisation and localisation. Evidence from this administrative reorganisation suggests that rail could have a similar effect on energy generation policies. Localised energy generation is a potential method of reducing the material cost of energy distribution networks through removing the need to transmit power over long distances. Hence, a major intervention in the form of a rail construction project may support development of a domestic or industrial power supply network.

Sustainability transitions
Gond et al (2012) identify sustainability integration across several large business, and defines eight categories. Network Rail appears to fit into the ‘Strategy emergence through sustainability’ category, whereby management control- and sustainability control systems are not integrated, but sustainability strategies are deployed nonetheless. This method impacts well on non-financial dimensions of sustainability, but with potential economic problems over the medium-to-long term. This sets a precedent for the application of transport studies to integrate the economic element with positive social and environmental outcomes, as discussed in section 4.2.

Sustainability transitions are an emerging field of innovation and technology studies (Markard, Raven et al. 2012). Observations of how Network Rail undergoes its own sustainability transition would provide unique insight into how large businesses undergo these transitions. Smith, Voß et al. (2010) discuss how the Multi-Level Perspective may be applied to sustainability transitions, and the challenges inherent in doing so. Several possible future lines of transition research are posited by Smith, Voß et al., including niche dynamics, regime unlocking, spatial aspects of transitions, and interactions with public policy. Spatial aspects are of particular relevance to this research project, owing to the devolution of Network Rail routes, and therefore highlights a potential contribution to knowledge to be made here.
### 4.1.3 Sustainability reporting

Sustainability reporting enables specific sustainable, individually-targeted goals to be set by large organisations. This facilitates transparency of businesses’ operations, building public confidence in the brands they support. Marks and Spencer (Bolland 2012) is a prime example of this, having set no fewer than 180 ‘commitments’ since 2007, most of which have already been achieved. Unilever (Polman 2009) is also a strong example, and shows a greater degree of integration with their central brand. This allows external businesses and members of the general public to track a company’s progress toward achieving higher levels of sustainability, whilst potentially acting as a driver for sustainable innovations within that organisation. This section explores best practice from other sustainability reports, and makes recommendations for future Network Rail contributions.

**Reporting by other industries – best practice**

These reports are discussed as being good- but not necessarily best practice due to their origin in other commercial sectors. Definitions of sustainability are likely to vary strongly between industries, but elements of the reporting style can be assessed.

Although from the retail and manufacturing sectors, these reports can be considered good examples of strongly-embedded sustainable principles within a large organisation. The branding and design of their website layouts demonstrates their intentions to the public.

**Best practice examples from other industries:**

A review of the Marks and Spencer sustainability report (Bolland 2012) is the subject of my pre-module coursework for Sustainable Development Applications. Their reporting is extremely thorough, with a wide range of specific commitments, which have been added to over time. This is believed by the author to be critical to the apparent success of their sustainability strategy, as several firms prevent the publication of information which may be detrimental to their business (Adams and Frost 2008). Each subsequent report critiques the outcome of these commitments, with consistent but improving presentation style year-on-year. The only major drawback of their reporting style is that it is aligned with their separate ‘Plan A’ sustainability brand; it is probably not appropriate to develop a separate brand for Network Rail’s sustainability initiatives, as they do not sell a product directly to the public.
Unilever’s sustainability reporting shows promise for development (Polman 2009). Their ‘Sustainable Development Overview’ has not been updated since 2009, although it received much praise from reviewers. However, their online reporting is coherent, listing several commitments in a similar manner to Marks and Spencer. These commitments are shown to be at various stages of development, and are updated on a continuous basis, rather than laid out in static report documents, as is common elsewhere.

**Reporting by other transport operators and logistics firms**

MTR Corporation, the operators of the Hong Kong Metro, produce arguably the most comprehensive sustainability report for a transport operator (Walder 2012). MTR are also a stakeholder in the Global Reporting Initiative, indicating they are a key innovator in the reporting field. An apparently unique feature of their report is an identification of priority risks to sustainability for the year passed. Their report is also tied in with the equivalent of Network Rail’s Public Performance Measure (PPM) for punctuality and train performance. Although Network Rail is not directly in control of train operation, their activities impact on train performance through maintenance-based disruption; this implies some indication of these impacts should be provided by future reports.

CSX, a major railway operator in the eastern USA, features extensive discussions of their economic impacts in their sustainability reports (Ward 2012). These discussions are reactive, and do not feature any specific goals. However, these reports feature extensive coverage of the materials they transport, and identify emerging markets for the freight they carry, such as military cargos and waste. UPS (Davis 2012) produce a lengthy report, which again features an outline of their economic activities, including compensation paid and dividends. Identification of specific markets in the UK that would benefit from additional rail transportation should be a priority for future Network Rail reporting, and would assist integration with intermodal freight to reduce GHG emissions.

**Current Network Rail sustainability reporting**

Network Rail has released one online sustainability ‘update’, in an online format. However, this does not meet GRI guidelines at present. At present, their sustainability update is divided into the following sections:
There is a strong social focus to this update structure, as illustrated by all but ‘Environmental Stewardship’. However, as Gimenez, Sierra et al. (2012) discuss, social programmes tend to impact mostly on environmental and social aspects of sustainability, but do not sufficiently benefit economic benefits to the company implementing them. Environmental programmes, on the other hand, bring benefits to all three aspects of sustainability described by the ‘triple bottom line’, therefore implying that there should be a greater focus on these for Network Rail in the long term. As energy savings help reduce CO\textsubscript{2} emissions, and have a direct impact on financial costs, this gives a strong imperative for developing energy-efficient trackside technologies.

At present, there are no specific sustainability commitments with quantitative targets, in the manner of Marks and Spencer or Unilever. GRI reporting guidelines suggest implementation of a commitment structure similar to these reports, and which areas these explicitly-stated commitments should consider.

The economic benefits of a railway network are currently unrepresented in Network Rail’s sustainability update. The GRI reporting guidelines (2011) recommend descriptions of these, including how economic performance may be affected by climate change. Discussions relating to development of the ‘Connect’ internal website have also highlighted this as a key shortcoming of current public online information. This justifies further research into the carbon credentials of rail, as discussed in section 4.2.
The report is less accessible than it is for retailers (e.g. Marks and Spencer) and some logistics companies (e.g. UPS – Davis 2012). A link to the current 2012 update is available on the front page of the public website, but is not particularly prominent, being available under the heading ‘Corporate documents’; this link could potentially inadvertently be replaced as other important documents are published as it is so inauspiciously positioned.

Considerations for future Network Rail reporting

Considering the above discussion, it is recommended that Network Rail take the following reporting-related actions:

- Consider greater focus on environmental programmes
- Develop a series of specific commitments, in line with or improving upon GRI 3.0 guidelines, to demonstrate their overall sustainability commitment to other businesses
- Demonstrate the economic benefits of railways as part of a sustainable transport system.

4.1.4 Sustainability frameworks and innovation – Summary

The field of sustainability transitions offers an opportunity for contributions to knowledge from this Doctorate. Observing and contributing to the transition process, both to a sustainable- and a devolved business, could provide insight into the most effective methods of achieving sustainable innovations and behaviour changes. However, indications suggest that Network Rail’s environmental and social performance, but there could be economic shortcomings with the current structure of sustainability integration in the long term (Gond 2012).

Internal social research at NR could identify which teams need the most instruction in sustainable development themes, and who could act as leaders in this regard (beyond the S&SD department); initial literature research suggests these may lie at the top of the business hierarchy. However, this review has identified a clear and present need for some form of social research to support this EngD project, particularly revolving around the newly-devolved structure of Network Rail and cooperation mechanisms which may arise.
The best examples of sustainability reports are clearly presented and aimed at the general public, highly specific in their commitments without fear of subsequent critical review, and tightly integrated with the brand they support. Network Rail needs to emulate these in order to support embedding of sustainability principles across all levels of operation. Further research is therefore required into the specifics of best practice for reporting structures. In particular, the methods by which reporting can support sustainability innovation require further study.
4.2 Transport studies – the economic and carbon credentials of rail

Lowering greenhouse gas emissions, particularly carbon dioxide, is critical to tackling climate change, to prevent an excessive increase in global temperature (Höök and Tang 2013). Electrification of railways and associated infrastructure can tackle this, as discussed in section 4.3. However, there is an increasing trend in demand for rail travel to counter this (Melbourne 2011).

Life Cycle Assessment (LCA) of railway infrastructure projects offers a method of accounting for scope 1, 2 and 3 emissions. These are necessary because electrification, localised generation and energy storage projects have low operational emissions, but also have high financial- and carbon costs for construction, reducing their overall benefit. However, conducting these is a complicated process, often requiring long periods of time to complete. Therefore investigation of best practice will expedite any future efforts by Network Rail in this field, ideally confirming and quantifying the sustainability benefits of UK mainline railways.

A key shortcoming of current Network Rail sustainability reporting, identified in the previous section, is the lack of demonstration of the company’s importance to the UK economy and local social structures, and the economic benefits of implementing a sustainability strategy. The impacts of infrastructure schemes on travel behaviour, and other methods of encouraging modal shift need to be understood in order to fulfil this requirement. These factors can have significant impacts on the outcome of speculative infrastructure project LCAs.

4.2.1 Life Cycle Studies

The operational energy savings of electrified railway systems (compared to internal combustion engines) are well-known (Hoffrichter 2012, Chang 2011, reis 2012). However, the construction of power lines and other supporting infrastructure to achieve this requires large material inputs. If uncontrolled, these material costs could severely reduce the overall benefit to emissions and financial costs of a given scheme. LCAs offer a tool with which to identify these costs, and hence potential savings at an early stage, to prevent unnecessary waste and inefficiency.
Construction of new railway routes is known to be material-intensive; Vihermaa, Lettenmeier et al. (2006) highlight that there should be additional focus on increasing traffic on existing rail routes which have not yet reached capacity, and smaller-scale improvements to routes which are already operating at capacity.

Hoffrichter, Miller et al. (2012) have performed a Well-to-Wheel (WTW) analysis of potential alternative future fuels for railway locomotives. Extensive support infrastructure will be required for any form of alternative-fuelled vehicle. Assurance from Hoffrichter, et al that the operation of the trains themselves has lower life cycle costs in this way, supports the business case for constructing this support network. However, life cycle analysis of support infrastructure will be highly subjective to the geography of specific routes, particularly depending on the layout of existing depots on the rail network.

Life cycle analyses for individual trackside infrastructure applications have not been found, beyond those for the electrification of routes. This sets a precedent for researching the impacts of systems such as points heaters and other potentially energy-intensive railway support systems.

Life cycle analysis can hence be seen to support the business case for developing new rail routes, or upgrades to existing ones (Chang and Kendall 2011). However, insights from analysis of high-speed rail from other countries demonstrate that estimating carbon savings based on modal shift is highly dependent on system boundary definitions, and very few studies in this area show similarity to others (Federici, Ulgiati et al. 2009, Åkerman 2011). Åkerman, for example, points out the complete absence of freight transport modal shift from an earlier LCA which concluded against the construction of a new HSR route (Kageson 2009). Life Cycle Assessment of small-scale route upgrades (as opposed to new route construction) and their enabling technologies require further investigation, particularly as the smaller scale is more suitable for LCA methodology.

4.2.2 Transport research – travel demand and management

Understanding UK transport policies will allow insight into what is being done at present to encourage sustainable travel practices. The impacts of these are assessed, discussing whether further action is required in order to achieve a sustainable transport system, and the place of rail within this.
Knowledge of travel patterns could also facilitate predictions of peaks in energy demand (as explored by Grenier and Page, 2012), particularly if these change with increased environmental and scarcity issues. Transport research can therefore facilitate development of specific technological methods to overcome impacts on energy supply infrastructure. This is especially important, as rail travel in the UK in terms of passenger miles is known to have been increasing steadily in recent years, and is predicted to continue doing so (DfT 2011). The importance of rail to the UK economy is also discussed here, as it is hoped that energy savings will result in reduced costs to Network Rail, operators, and ultimately the taxpayer, passenger or railfreight customer.

**UK Transport Policy**

Network Rail is a monopoly infrastructure provider, regulated, supported and monitored by several bodies, some of which are discussed in section 2.3. The need to report to all these separate bodies heightens the case for an integrated sustainability reporting system, as discussed in section 4.1.3.

In recent years, sustainable transport policies have been focused on packages of small-scale, high value-for-money 'soft measure' schemes aimed at travel demand management, particularly those described by ‘Smarter Choices’ (Cairns 2004). Sustainable travel towns, such as Peterborough, have been used as demonstrators for integrated collections of these schemes. A review of this (Sloman, Cairns et al. 2010) found that although some demand management measures had met with success, some had not had any measurable success, and may require more time to determine this. If travel demand management is not as effective as previously thought, the case for developing greater energy efficiency and smarter control systems becomes more urgent, if UK climate change and carbon reduction targets are to be met, even if this means the initial financial costs are higher.

**Sustainable Transport**

When viewing transport as a whole, railways with high occupancy rates offer a low-carbon solution for long distance travel. Scarpellini, Valero et al. (in press) demonstrate that trains offer comparatively high ratios of CO\textsubscript{2} savings per km-traveller, while also providing employment in their operation (see Figure 2). This supports the sustainability case for developing rail networks,
as they support communities through employment whilst benefitting carbon emissions more than alternatively-fuelled cars. Train occupancy rates are therefore known to be a critical factor when determining the carbon costs of a rail infrastructure project, and should probably be taken into account in any LCA of support technologies.

If sustainable national transport policies are successfully implemented, it is therefore reasonable to assume that there will be an increased focus on railway development and construction. If this is the case, and railways become the predominant means of long-distance transportation, then sustainable improvements to them will have the greatest impact on transport-derived CO\(_2\) emissions and other Key Performance Indicators (KPIs).

Armstrong and Preston (2011) discuss a range of possible futures for the structure of railway service provision, based on whether or not there is acceptance of intelligent infrastructure, and the level of environmental, social and economic impacts caused by railways. This is based on earlier scenario development by the UK government’s ‘Foresight’ programme (King 2006). Network Rail produced a similar set of scenarios for their Route Utilisation Strategies, this time plotting consumption levels against levels of centralisation.

Armstrong and Preston (2011) reiterate the importance of continued global energy supply, and dealing with the consequences of anthropogenic climate change.
change to global transport systems. All four of the scenarios envisage the importance of rail transport increasing. If sustainable energy sources become more readily available, rail’s role is likely to shift toward high-speed provision, in which case emphasis will be on security of energy supply for this. If these sources do not become widespread and carbon pricing or even rationing come into force, public attention will shift to rail transport due to the high level of present efficiency, and emphasis will shift to dealing with the consequences of climate change. Increasing energy efficiency of railways therefore supports both these objectives, reducing the cost of energy provision in the case of the former, and reducing impacts on carbon emissions for the latter scenario.

The UK’s rail system is known to be integral to its economy. Chen and Hall (2011) discuss how the introduction of HST services in the 1970s and 80s paralleled the shift from an industrial- to a service economy. The time reductions for travel between major cities made by HST offered major boosts to the economic strength of cities. This transitional period parallels that toward sustainable practices in the present day. As the number of passengers and freight units travelling by rail are increasing, this implies that the embedding of rail’s importance to the economy during this period is paying off. These points are recognised by NR’s Strategic Business Plan, as discussed in section 2. This in turn suggests that embedding of sustainable practices into railway infrastructure at this relatively early stage will benefit the national (and European) economy through any transition to sustainability.

Multi-modal transport could also reduce carbon emissions for long-distance freight. Reis, Fabian Meier et al. (2013) investigate barriers to successful implementation of integrated multi-modal transport, focusing on rail-road, rail-sea and rail-air connections. Increasing multi-modal rail freight services would place additional demands on power supply, but improve the economic case for increasing railway capacity.
4.2.3 Transport studies – Summary

Variations in travel demand predictions can therefore be seen to have a significant impact on the outcome of LCA studies for large rail infrastructure projects. This implies that assessment of individual lineside or traction technologies could also be affected by usage levels of railways, impacting payback time for their installation.

If demand management practices are less effective than first anticipated, or reach a saturation point (as discussed by Sloman, Cairns et al., 2010), responsibility for reduction in lifecycle carbon costs falls upon infrastructure operators. This improves the business case for innovative energy efficiency improvements, as less costly ‘soft’ schemes may not be achieving the desired impact on carbon emissions.

The operational carbon and electricity savings of rail travel are well understood, as demonstrated by the payback estimates in some of these LCAs (e.g. Chang and Kendall, 2011). Therefore, a business case for developing railways as a backbone to a sustainable UK economy in context with other forms of transport is required, if Network Rail is to continue upgrading and expanding in the face of economic uncertainties. As much information as possible should be publicly reported, as discussed in section 0, in order to communicate this to local communities and gain their support.

There are several uncertainties regarding the carbon costs of railway infrastructure schemes, whether new-builds or upgrades. Therefore, it is intended that LCA investigations into the implementation of one or more specific technical innovations should be conducted as part of this EngD research.
4.3 Traction and infrastructure energy – policy, supply and technologies

The trend for greenhouse gas emissions in the UK is lowering, but provisional figures for 2012 show an increase over 2011 due to increased coal consumption by power stations (DECC 2013). This introduces uncertainty for future UK emissions, along with recent discussions of a ‘dash for gas’. Therefore reducing energy use should be a key priority, as the fuel mix of electricity supply beyond 2023 (the scheduled end of the current deal with EDF Energy) may increase carbon dioxide output.

Network Rail has little direct control over energy generation sources; only a few isolated examples of supplementary solar PV (such as the redeveloped Blackfriars station) and small-scale wind generation are in use at present. Therefore it is important to understand the energy supply context that Network Rail sits within, taking into account the increasing electrification of many routes, and the possibility of battery-driven vehicle operation in future. In particular, the impacts on electrical grid supplies are discussed, notably the likely increase in peak demand without smart controls. Given the questionable effects of market liberalisation on UK railways discussed in section 4.1.2, energy market liberalisation has also been investigated, to determine possible future economic pressures on supplying electricity to the railway.

After a discussion of the case for reducing fossil fuel- and overall energy consumption, specific emissions- and energy-saving infrastructure technologies are investigated in detail.

4.3.1 Fossil fuels – present-day regime

Oil prices are steadily increasing in both real and nominal terms, and all fossil fuels have seen a dramatic upturn in price in recent years, as shown in Figure 3 (from Shafiee and Topal 2010). This trend is predicted to continue, although oil costs are currently well above the predicted trend. Fluctuations in oil price are also seen to be increasing in severity in Shafiee and Topal’s model (see Figure 4).

The multiplication of uncertainties surrounding fuel prices implies that reducing railways’ reliance on fossil fuels will reduce the impact of price shocks on the railway industry. This is especially true if governments feel increasing pressure to increase fuel taxes or remove subsidies in order to
meet carbon emission reduction targets, as suggested by Burke and Nishitateno (2013). Therefore electrification of railways will reduce sensitivity to the uncertainties of the energy market.

Figure 3 - The average yearly historical trend of real fossil fuel prices from 1950 to 2008. From Shafiee and Topal (2010).

Figure 4 - Real oil price jump/dip distribution and prediction of real oil price in long-term. From Shafiee and Topal (2010).

Schipper and Fulton (2013) discuss how recent efficiency increases among diesel engines has had little effect on overall vehicle CO₂ emissions. This is due to a parallel increase in vehicle size and weight, despite 25% lower emissions than their petroleum-fuelled equivalents, and the market penetration they have achieved in recent years. This reinforces the case for
reducing reliance on internal combustion engines, as technological fixes to reduce their emissions have had limited effect.

### 4.3.2 Increased electricity demand

Network Rail is currently undertaking several electrification projects, an effect of which will be a reduction in operational carbon emissions. However, other industries are shifting to an electrification of demand to achieve the same ends, and reduce their reliance on increasingly-expensive fossil fuels.

Barton, Huang et al. (2013) discuss this in the context of heat pumps in buildings, and expanding numbers of electric road vehicles. They highlight the importance of demand-side management of electricity use, to moderate the peak energy demand requirement through altering the time at which electric vehicles recharge. Pudjianto, Djapic et al. (2013) state that growth in electric vehicles could push peak demand to 2-3 times current UK levels, despite only a 50% increase in total energy demand. This scenario looks increasingly likely, given the steady emergence of an electric mobility trajectory as a means of addressing carbon emissions (Dijk, Orsato et al. 2013). Peak railway operation times generally coincide with (and to an extent cause) peak national electricity demand, therefore increased rail traffic will drive these peaks higher.

Hence, any reduction in energy use at the trackside will serve to moderate these peaks in demand, without introducing a limit on operation levels or forcing blackouts elsewhere. If battery-powered trains are implemented in future, demand-side management could be relatively easy to implement, as recharging periods for trains are potentially more likely to take place at times of low energy demand than electric road vehicles.

### 4.3.3 Impacts of energy market liberalisation

Similarly to the liberalisation of the railway industry (as discussed by Sørensen and Longva, 2011), energy liberalisation is not believed to have led to clearly visible direct benefits to households (Pollitt 2012). This implies that costs have risen or stayed the same, despite efficiency gains and improvements to environmental emissions controls. Rising energy costs
imply that rail operators in particular should do as much as possible to improve their operational efficiency to counter them. Pollitt (2012) also discusses how levels of liberalisation have had little bearing on the transition to a low-carbon economy, and that future governments may wish to intervene more strongly to achieve decarbonisation. This suggests that more needs to be done by infrastructure providers to achieve decarbonisation, as energy suppliers are not necessarily making significant progress in this area.

Reducing energy costs is a fairly self-explanatory method of supporting the business case for energy-saving improvements. It is particularly pertinent to Network Rail, as infrastructure costs have, by some estimates, been rising at an artificially heightened rate. Jupe (2009) attributes this to increased money transfer to a ‘financial elite’, as a result of structural changes brought about under Railtrack. Therefore any financial savings through energy use reduction would be of added interest to Network Rail, and would serve to improve stability of the system in the eyes of policy makers.

4.3.4 Trackside energy savings

Energy storage

Energy storage offers a method of internalising the externality of electricity supply. This could address the problem of increasing fuel prices, discussed earlier. Internalisation has been identified as a key means of addressing the triple bottom line of sustainability, and subsequently encouraging technological innovation (Elkington 2002). As discussed by Armstrong and Preston (2011), availability of energy supply is likely to have impacts on decisions to electrify or build railway routes in the coming century. Energy storage devices have the potential to help overcome these difficulties through supplying electricity during power shortages, and recharging during periods of low demand. This section investigates on-train and trackside energy storage innovations which could enable resilient railway operation.

Although specifications of trains in the UK are not directly controlled by Network Rail, it is important to note the potential storage technologies currently under consideration in scientific literature. These will need to be accommodated by lineside infrastructure, particularly electrical systems if recharging points are required.
Battery development is likely to be spurred by increases in the number of electric road vehicles. As Dijk, Orsato et al. (2013) point out, this is looking increasingly rapid due to the recent emergence of an electric mobility trajectory, after an initial period of market experimentation with different alternative fuel types.

On-board energy storage is not limited to battery technology. Trains occasionally require high energy discharge rates to overcome sharp gradients; a battery-powered train would require supplemental power in order to achieve this. On-board supercapacitors offer a solution to this (Ciccarelli, Iannuzzi et al. 2012). Estimates suggest the energy consumption of trains could be reduced by 12%, and the energy cost of their installation could be recovered in 3-4 years.

According to research conducted by the Transport Research Laboratory (TRL), as fuel prices increase, battery-powered trains become increasingly cost-effective. Molyneux, Bird et al. (2010) estimate that operational cost parity with diesel trains will occur when diesel prices rise to approximately £0.80, twice the price at the time of their report. They also state that current battery technology is sufficient to develop trains with comparable range to diesels.

However, Molyneux et al do not factor in maintenance costs for the batteries, implying that reliability of the batteries and other components may still be problematic. Sharpe, Ramdas et al. (2013) also advise that caution is required when evaluating the potential development of battery technologies, citing failed companies which were working on these.

So, although battery technologies are improving, the business case for developing widespread support infrastructure for them is not yet sufficient, particularly given the uncertainties around maintaining the batteries. If reliance on diesel is to continue for the time being, energy efficiency savings need to be made elsewhere, namely through infrastructure applications.

**Power electronics**

Abrahamsson, Schütte et al. (2012) discuss the advantages and disadvantages of using power electronic-based power converters to supply power for electric railways.
They allow greater flexibility when connecting power from public electricity grids, and allow more than one supply to feed one track power section. They also allow the possibility of feeding back power from regenerative brakes, benefiting their economic case to train operators due to recovered energy costs.

The primary disadvantages are their high financial cost, and their limited overloading capacity relative to rotating- and substation transformers. This offers an opportunity for further comparative life cycle analysis, to determine whether their material- and operational cost savings outweigh the cost of their implementation.

Power electronics therefore offer a highly flexible solution for providing traction energy from sustainable sources. This is of particular interest if energy generation from renewables is adopted on a more localised basis, as power electronics facilitate phase alignment of AC current.

**Points heating**

Smart control systems for points heating are currently available through SAN Railway Systems, a Denmark-based company (SAN 2009). They produce the ‘Blue Point’ system, which uses the following inputs to control activation:

- Local weather stations for air temperature, snow fall detection, wind speed and humidity
- Rail temperatures
- A seasonal climate calendar
- Weather forecast feeds from meteorological organisations

These systems use conventional strip heating elements, with a shock-absorbent design to resist movements caused by trains. It also features built-in self-diagnostic systems to counter failures. Control can be achieved through several forms of communication, including wireless 3G-based systems. This brings into question whether an original contribution to knowledge can be gained by studying this, due to the prior existence of this technology. However, the possibility exists to develop an integrated control system for multiple types of infrastructure support technologies.

**Impacts on power supply infrastructure**
As discussed in section 4.3.2, the increasing electrification of household heating and road vehicles are likely to increase peak demands on electricity supply grids.

Grenier and Page (2012) conduct a comparative analysis of power supply impacts for a light rail scheme and increases in electric road vehicle recharging. The overall energy demand for light rail was lower than for electric vehicle recharging. However, demand from electric vehicles was more manageable, due to inherent night-time recharging, and the scope for smart control systems to shift their demand to off-peak periods. This brings into question the assumption that railway electrification is the most sustainable option, particularly in areas where demand is already strained.

However, demand-side measures can be applied to reduce this impact. Train speeds can be optimised to reduce their overall energy use. Feng (2011) discusses control regimes for this to be achieved for high speed trains, while Liu and Golovitcher (2003) study a more general optimised control system for use with known track profiles. As Network Rail has no direct control over train driving styles, greater coordination with TOCs and FOCs is required to ensure that these control regimes are in place.

**Smart control systems**

The benefits to peak power supply requirements from implementing a smart control system for EV recharging in the UK are discussed by Pudjianto, Djapic et al. (2013). However, railways at present require a more constant power output – recharging can be re-assigned to more convenient times, but direct power feeds cannot. Peak railway travel occurs at approximately the same time as peak electricity demand in the UK (Melbourne 2011, National Grid 2013). Shifting these peaks requires demand-side management of business opening and operating times, which are beyond Network Rail’s direct control, and would require regular stakeholder engagement. Proliferation of sustainability reporting may inform other businesses to achieve this shift.

Direct satellite control can also be used for track heating systems. Wireless receivers by the trackside would prevent unnecessary deployment of material-intensive cables and casings, complementing the savings made through reduced energy use.
However, simulations of satellite systems for localisation of train monitoring purposes by Beugin and Marais (2012) suggest their dependability is still found wanting, especially in rough terrain. Although their study was primarily concerned with train monitoring and control systems, this highlights possible communication problems for potential points heating systems. The adverse weather conditions associated with the time of use of points heating systems may introduce further reliability issues. Further investigation of the specifics of smart control systems for track heaters is required.

4.3.5 Traction and infrastructure energy – Summary

The increasing electrification of railways will place additional strain on domestic electricity supply networks. Demand-side management is required if material-intensive new generator construction is to be avoided. Rising energy costs caused by increased fuel prices and complexities of liberalised energy markets may provide a barrier to successful economic performance of railway infrastructure in future. All this heightens the business case for reducing infrastructure-based energy use where possible, and for smart control systems to mitigate its impact, in order to reduce strain on energy suppliers and increase energy security.

Improvements in battery technology offer a promising future alternative to diesel traction on railways. However, costs need to be further reduced in order to support the business case for providing trackside infrastructure. Other forms of trackside storage under Network Rail control could deal with excessive peak loads, if domestic energy supply networks become more strained. Investigation into a specific technology, possibly track heaters and their control systems would help to determine the likely overall impact of energy saving technologies at the point of consumption.

Packages of energy-savings measures are likely to have the strongest effect, as down-time for installation will be reduced, and new control systems will require less training time to operate. For example, new points heating technologies should be implemented alongside new control systems so that both pieces of infrastructure could be installed together. However, further investigation into the specifics of doing this is required, and is likely to form a significant research project for this Doctorate.
4.4 Discussion and conclusions

The business case for making energy efficiency improvements has been made clear. Aside from the reduction in carbon dioxide emissions, although some initial costs for installation of new technologies will need to be incurred, fossil fuel markets are becoming unstable, and resilience against price shifts needs to be built into Network Rail’s business plan. Integration of sustainable objectives such as these appears closely linked with the quality of an organisation’s sustainability reporting, and the level of the business from which such initiatives originate. Successful economic impacts from sustainability strategy can be supported by transport studies, i.e. impacts on travel demand and travel patterns. These in turn can determine the outcome of LCA studies on specific infrastructure technologies.

Some potential research projects have been identified, for investigation over the course of this Doctorate. Further identification of the specific nature of each question is required, but identified problems form the basis of goals for the next 6-month period, as discussed in section 6.

4.4.1 Frameworks and innovation

Business frameworks can support sustainable innovation, especially through applying understanding of the Multi-Level Perspective (Geels 2002 and 2012). However, the precise means by which a devolved company structure at Network Rail will achieve this will need monitoring. In fact, very few examples of companies which have performed this devolution have been found, owing to the unique regulatory circumstances under which Network Rail operates. On one hand, they could act as developmental niches and nurture sustainable innovation, but on the other, they could act in isolation and prevent the most efficient spread of new information. This may signify a unique opportunity for research as part of this project, but further reading is needed to ascertain this.

Several examples of sustainability reporting have now been examined, both in this report and as separate coursework. This has formed a basis for best practice suggestions for Network Rail’s own reporting. In particular, specific commitments and aims need to be set by these reports, similar to some retailers, in order to be most effective.
Transitions to sustainable operations are an emerging area of research for potential contribution by this research. Current indications suggest that the current configuration of Network Rail’s sustainability management may only achieve ‘medium’ impacts on the triple bottom line, with social and environmental benefits offset by poorer economic performance (Gond et al 2012). Social research into the mechanisms by which a devolved company structure can benefit the sustainability of Network Rail is thought to be required to ascertain this fully.

4.4.2 Transport studies

Variations in travel demand are seen to have a significant impact on the outcome of life cycle studies, and other assessments of the emissions-savings credentials of rail travel. Future determinations of carbon savings need to have a consistent, holistic approach, taking into account both passenger and freight usage, and likely modal shifts as a result of construction or upgrades. This research could go some way to developing this approach for Network Rail.

A combination of life cycle analysis and study of transport demand, modal shift and benefits to the UK economy can all contribute to supporting the business case for new rail schemes, or improvements to existing ones (as demonstrated by Chang and Kendall (2011). However, boundary conditions on the extent of modal shift and demand change studied need to be standardised to allow any spatial or temporal comparisons to be drawn.

Any LCA study into the effectiveness of infrastructure technologies will require input from travel demand studies, possibly modelling more than one scenario, in order to adequately predict any savings in emissions, owing to the importance of occupancy rates (Scarpellini, Valero et al. 2013). Taking this into account, an LCA into the implementation of a specific energy-saving infrastructure technology would support the requirements of this EngD project.
4.4.3 Infrastructure energy technologies

Fossil fuel prices are increasing and energy markets are becoming less stable (Shafiee and Topal 2010). Energy-saving trackside technologies are steadily becoming more economically feasible, through the emergence of dominant battery technologies in other marketplaces (Dijk, Orsato et al. 2013). However, battery-powered trains still face barriers to their development, particularly regarding their maintenance. Development focus should instead be made on other railway infrastructure to reduce emissions.

Promising technologies for improvement on UK infrastructure include track and points heaters, smart control systems for their operation, power electronics to enable maximum efficiency from regenerative braking, and renewable power supplies with energy storage systems to regulate them. Some of these systems exist elsewhere in the world, limiting this research project to best practice studies at present. However, there is potential for assessing an integrated smart control system for multiple infrastructure applications. Identification of innovations to be made in this field will be conducted over the next 6-month period.
5. Team integration

The Sustainability business function is relatively new to Network Rail. Members of the Sustainable Business Strategy (SBS) team have been recruited over the course of the past year. This team is comprised of specialists in separate sustainability-related fields – their specialist areas are listed below.

- Governance – Katrina Keeling
  - Sustainable infrastructure – Dexter Davis
    - Resources and waste – Christopher Ndubuisi
    - Buildings – Garry Bosworth
    - Climate change adaptation – Kate Avery
  - Sustainable operations – Mike Goodfellow-Smith
    - Community investment – Suzanne Hardy
    - Land management – Neil Strong
    - Emissions and water – Kent Farrell

This section discusses specific activities with the SBS team which have contributed to the EngD project, beyond autonomous literature research and university coursework. Stakeholder engagement is also discussed here, identifying Network Rail departments and external organisations relevant to this research.

5.1 Team meetings

5.1.1 Defining the team’s services

So far, members of the team have made relatively small-scale interventions in their respective areas of interest. Although these have been effective, the functions of the team as a whole were not definitively organised until a pair of away days in January 2013.

The team’s main functions were defined as follows:

- Innovation and design
- Training and capability building
- Business intelligence
- Policy development
- Regulation and compliance
My role within the team primarily encompasses the innovation and design (through later original research), and business intelligence (through continuous literature review) functions.

5.1.2 ‘Master class’ presentations

These sessions are intended to inform members of the team about each others’ specialist areas, and as preparation for developing team strategy and implementation plans. This is intended to support communication within the team, allowing external queries to be redirected to other members if the area in question falls outside their individual specialism. These will feature a short presentation by each member of the team (including the two Research Engineers), followed by an extended question-and-answer session. This is intended to occur over two days, 24-25 April 2013.

To achieve this, selected material from this report will be redesigned into a presentation format. A brief history of my education and employment to this point will be included, in an effort to help guide supervision of this research, and to highlight potential contributions to Network Rail, particularly in the field of transport studies.

5.1.3 Thameslink upgrade visit

The Thameslink upgrade programme features a series of capacity enhancements for the eponymous north-south connection route, which runs through the City of London from the East Midlands route to Brighton.

A meeting was held on 29 January 2013 to establish how the Thameslink Programme team have been applying sustainable development principles to their construction project. Future meetings are intended with this team, but so far there has been difficulty in coordinating the two large groups of people involved. It is hoped that insights from this could benefit both framework investigations, and potentially allow comparison of LCA data if this has been conducted or consulted by their team. It is intended to build upon the information gained from this and seek a similar meeting with the Crossrail project team.
5.2 ‘Connect’ website development

Network Rail has an intranet system known as ‘Connect’. Until recently, the Sustainable Business Strategy team has not had a presence on this site. Various pieces of legislation relating to the team’s activities were accessible through now out-of-date channels, and pages for groups now dissolved or restructured. Having centrally-available sustainability information available to all parts of the business could play a vital role in raising the profile of sustainability within the business.

There is currently a home page, from which additional pages will be linked once appropriate data becomes available. The structure of these was discussed during the development of the home page, and an Excel-based hierarchical map of this has been produced. The possibility of coordinating development of the publicly-available website with these internal pages has also been discussed, directly benefitting from the sustainability reporting research discussed in sections 3.5 and 4.1.3.

5.3 Stakeholder identification

A stakeholder map has been produced as an Excel file. The main document is too large to reproduce as part of this report, and details individual people within each division and organisation. However, a summary list of key internal and external stakeholders is given in Appendix C.

Contact with Network Rail departments with a stake in energy management is steadily increasing. Individuals are still being identified, but cooperation with industrial supervisors is enabling further meetings and contacts to be made.

Meetings held with the RSSB have facilitated contact with some Train Operating Companies (TOCs). Further engagement may be required regarding energy use on-board trains, or energy procurement frameworks.

Network Rail’s recent 10-year contract with EDF Energy for the supply of traction power secures them as the main provider over this period. This will be sourced from EDF’s eight nuclear power stations, reducing the carbon intensity of railway operations. The scope for generating energy from renewable sources owned by Network Rail is expected to be on a small scale.
Contacts have not yet been made with construction contractors. Potential areas for discussion here include life cycle analysis of procured materials, and the scope of energy use during construction. Which contractors are contacted will depend on which Network Rail projects are worked with at a later stage, such as Crossrail or the Thameslink upgrade team.

Further contact is also required with governance bodies associated with UK railways. RSSB have been the main point of contact thus far in this regard, with two meetings in 2012 surrounding discussion of application of their Sustainable Development Principles (RSSB 2009).

Overall, contact with internal Network Rail stakeholders for this project has been satisfactory, but needs further exploration. Meetings are planned for April 2013 in order to achieve this, as discussed with industrial supervisors recently. However, a greater number of meetings with external regulators, operators and contractors are likely to be required to fully understand the framework environment, and to align this project with their goals. This is especially true for the DfT, RSSB and ORR.

5.4 Discussion with Energy Services team

Initial research on energy technologies focused on potential efficiency improvements to the distribution network for traction energy.

However, following a meeting with Richard Stainton of the NR Energy Services team on 31 January 2013, it was found that there was greater potential for development of lineside applications, rather than distribution. Development of a smart control system for points heating was found to be of particular interest to their team. Conductor-rail heating for third-rail DC systems

A follow-up to this meeting is intended for April. This is intended to lead to a series of investigations regarding the efficiency of new heating and control systems. This could potentially involve LCA studies of

6. Research Progress

This section considers whether the research objectives discussed in section 2 have been met, require further work, or require reappraisal or removal. A
new set of questions for the next 6-month period are then developed from this analysis.

The internal- and external contacts required to achieve these goals are also appraised, including the extent to which relationships need to be developed.

6.1 Research question progress

Table 2 summarises approximately how much progress has been made around each existing research question.

‘Conclusions drawn’ means that sufficient evidence has been found to support research in other areas, at least for the time being. Other areas should be prioritised. ‘Good progress’ indicates that reading in this area has brought forth useful information, but there are still areas that are not sufficiently understood to draw conclusions. This may also indicate that a topic requires continued monitoring due to rapidly changing global situations, or yearly reporting structures. Any question that ‘needs more work’ should be prioritised for the next 6 month period, as either insufficient time has been dedicated to researching them, or detailed information has not yet been found.

Table 2 - Research progress measured against research questions (see section 2)

<table>
<thead>
<tr>
<th>Question</th>
<th>Status</th>
<th>Summary of results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INNOVATION PATTERNS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Do new devolved route structures in Network Rail encourage or discourage energy-related innovation?</td>
<td>Needs more work</td>
<td>Needs monitoring as increased responsibility is devolved to routes.</td>
</tr>
<tr>
<td><strong>TRACTION ENERGY – POLICY AND SUPPLY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 What effects will increasing reliance on electric railway traction have on peak electricity demand in the UK?</td>
<td>Conclusions drawn</td>
<td>Possibilities raised for battery-powered trains. Battery technology development trajectory emerging from initial alternative fuel market turbulence.</td>
</tr>
<tr>
<td>3 Can increased electric railway traction operate alongside increased electric vehicle recharging without</td>
<td>Conclusions drawn</td>
<td>Highlights the need for integrating increased railway traction electricity requirements with increased reliance on grid for EV recharging.</td>
</tr>
<tr>
<td></td>
<td>What are the rebound effects of increasing traction energy efficiency and sustainability on Train Operators?</td>
<td>Good progress</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>What is the potential for cooperation frameworks between Network Rail, National Grid, energy suppliers, to achieve carbon emission reduction and sustainability objectives?</td>
<td>Needs more work</td>
</tr>
<tr>
<td>6</td>
<td>What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?</td>
<td>Good progress</td>
</tr>
<tr>
<td>7</td>
<td>Using modal shift as a factor in life cycle- or comparative analysis of rail development scheme sustainability – pitfalls and standardisation issues?</td>
<td>Conclusions drawn</td>
</tr>
<tr>
<td>8</td>
<td>Can rail act as a market leader for sustainability across all transport modes?</td>
<td>Good progress</td>
</tr>
<tr>
<td>9</td>
<td>Which technologies can best be applied to save or manage energy use by track-based or trackside infrastructure?</td>
<td>Conclusions drawn</td>
</tr>
</tbody>
</table>

### 6.2 Reformulating research questions

A key point raised by supervisors was that the number of questions was too high; lack of conciseness is likely to impede later communication efforts.
Therefore the number of main questions has been reduced from 9 to 6 for the next 6-month period.

The numbering system for these questions will remain consistent between reports, even if certain questions are removed or altered. Therefore the numbers on this list will appear out-of-order. However, this is intended to form the basis of a fuller assessment of research outcomes for the 2-year stage dissertation and final thesis, which will require appraisal of all past research questions and the contributions they have made over the course of the entire project.

‘Innovation patterns’ has been merged with ‘Network Rail frameworks’ to form ‘Sustainable innovation patterns and frameworks’. This allows better integration of research into Network Rail structures and how they can support infrastructure energy innovation. This also aligns more closely with the structure of this report, facilitating continuity with future versions.

The list of questions given earlier in section 2 has been revised on the following pages.
[PRIORITY AREA] Sustainable innovation patterns and frameworks

1. Do new devolved route structures in Network Rail encourage or discourage energy-related innovation?
   - Do these new, smaller divisions encourage competition and drive infrastructure energy innovation?
   - Do reduced economies of scale impede innovation in this case?
   - Is this devolved structure more conducive to one aspect of sustainability (e.g. community involvement) but not others (e.g. energy use)?
   - Are new frameworks required for sustainable technology roll-out in a devolved organisation?

5. What is the potential for cooperation frameworks between Network Rail, National Grid, energy suppliers, to achieve carbon emission reduction and sustainability objectives?
   - What role should infrastructure operators take in pursuing sustainability?

6. What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?
   - How applicable are they to the UK?
   - Particularly good examples of sustainability integration are found in Hong Kong, the Netherlands and Sweden – how transferable are their ideas?

Transport studies – the economic and carbon credentials of rail

7. Can rail act as a market leader for sustainability across all transport modes?
   - To what extent could sustainability reporting play a role in achieving this?
   - [NEW] Is the regulatory framework which Network Rail sits within conducive to sustainable development?
   - [NEW] Is Network Rail unique in being a not-for-profit heavily-regulated monopoly operator
   - [NEW] What lessons for sustainability management can be learnt from this? Is this a situation for an industry to avoid?
   - [NEW] Will increased emphasis on rail development impact on travel demand and economic viability of other modes? Will this be properly integrated
Infrastructure energy technology

2. What are the most effective methods available to Network Rail for reducing infrastructure energy use?
   - What effects will increasing reliance on electric railway traction have on peak electricity demand in the UK?
   - Would conversion from DC → AC power supplies achieve carbon reductions, despite requirement for new electrical infrastructure?
   - Which technologies can best be applied to save or manage energy use by track-based or trackside infrastructure?
     - Can smart grid technology cope with the increased electrical demand, or are demand management measures needed to meet sustainability objectives?
     - Which technologies are favoured by comparative life cycle analysis?
     - Is satellite communication reliable enough to replace trackside infrastructure and save material costs?
     - Can static electronic trackside power converters achieve this? What new energy-saving applications can they enable?

8. [NEW] How strong is the business case for energy saving/efficiency technologies?
   - [NEW] What are the financial benefits?
   - [NEW] What are the social benefits of responsible energy use by railways on a local level?
   - [NEW] What are the drivers for improving this business case?

Previous questions

Innovation patterns

7. Removed – sufficiently answered at present

Infrastructure energy technology

3. Removed and merged with question 2

Travel demand influences

4. Removed and merged with question 8.

Trackside energy savings

9. Removed and merged with question 2
6.3 Reading topic appraisal

Table 3 (overleaf) illustrates how progress has been made against topics identified in the reading checklist prepared by industrial supervisors.

The regulatory framework that Network Rail sits within is a particular area for future focus. The areas highlighted in red require additional contact with specific Network Rail actors, and ongoing monitoring for changes in company policy. The requirement to make additional contacts beyond the Sustainable Business Strategy team has been noted by both academic and industrial supervisors, and is discussed in section 5.3.

Sections labelled ‘Good’ have already been investigated thoroughly, and therefore require less research emphasis over the coming months. Sections have been labelled as ‘Okay’ if reading has been sufficient, but have an ongoing component which will need updating as policies change or additional university courses are attended. Any section that ‘Needs more work’ is either behind schedule with reading, requires additional contact with NR stakeholders, or needs continuous monitoring as it is highly susceptible to change.
Table 3 - Research progress measured against reading checklist (see Appendix A: Research)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Progress</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Government energy policy</td>
<td>Good</td>
<td>Information found through <em>Energy Policy</em> journal in particular</td>
</tr>
<tr>
<td>3. European transport and energy policy</td>
<td>Needs more work</td>
<td>EU directives require further reading; some progress on carbon reduction requirements, but not much rail-specific information</td>
</tr>
<tr>
<td>4. Rail Regulation</td>
<td>Needs more work</td>
<td>Need more contact with regulating bodies and stakeholders</td>
</tr>
<tr>
<td>5. Economics</td>
<td>Good</td>
<td>Rising energy costs well-understood; impacts of economic recession fairly well – slightly more reading reqd. here.</td>
</tr>
<tr>
<td>6. Company structure</td>
<td>Okay</td>
<td>Impacts of Route devolution are ongoing – needs monitoring. HR and finance powers only devolved from April 2013.</td>
</tr>
<tr>
<td>7. Industry structure</td>
<td>Good</td>
<td>Sustainable Development Applications coursework particularly useful, especially regarding barriers to change and reporting structures.</td>
</tr>
<tr>
<td>8. Energy procurement and management</td>
<td>Okay</td>
<td>Need to investigate billing arrangements for customers and management systems. Carbon reporting and grid mix well-understood.</td>
</tr>
<tr>
<td>9. Investment for sustainability</td>
<td>Okay</td>
<td>Whole-life costs and life cycle analysis shortly to benefit from LCA lecture course.</td>
</tr>
<tr>
<td>10. Sustainability in major Network Rail projects</td>
<td>Needs more work</td>
<td>Need more contact with project teams. Possible topic for future interviews with staff.</td>
</tr>
<tr>
<td>11. Culture</td>
<td>Okay</td>
<td>Good comparisons drawn with safety culture. Ongoing monitoring required to test culture change.</td>
</tr>
<tr>
<td>12. Technology and innovation</td>
<td>Good</td>
<td>Good knowledge of technological solutions available to improve energy efficiency. Innovation patterns well-understood following Foundations of Sustainable Development module.</td>
</tr>
<tr>
<td>13. Overseas railway infrastructure operators and rail groups</td>
<td>Good</td>
<td>Sustainability reporting from Hong Kong, Sweden, S. Korea investigated. Sustainable Development Applications coursework useful for this topic.</td>
</tr>
<tr>
<td>14. Other infrastructure providers</td>
<td>Okay</td>
<td>Some information found from airports and logistics companies. Need more investigation of Highways Agency and port operators.</td>
</tr>
</tbody>
</table>
6.4 Research timetable

A Gantt chart summarising the intended timetable for research to the end of 2014 is given in Appendix B.

This chart is divided into sections representing the two main lines of inquiry for this project; Traction Energy which now encompasses rail infrastructure energy, and corporate sustainability frameworks. This sits alongside a general research outline for the entire EngD course, some aspects of which are beyond the end of 2014.

6.5 Towards future publication

Some refereed journals have been noted as valuable sources of information for the literature review in this report. Additional titles have been listed from some review articles for further investigation, notably (Schwanen, Banister et al. 2011), (Stechemesser and Guenther 2012), and (Romo-Fernández, Guerrero-Bote et al. 2012). As refereed journal publication is required for this EngD course, some of these may be considered for approaching for this purpose. However, training courses for this are scheduled to take place in 2014, so further action towards this will be postponed until nearer this time.

6.6 Towards future conference contributions

Some conferences have been identified as being of future interest, for attendance or potential presentation.

The Rail Research UK Association (RRUKA) has recently commenced a series of annual conferences. I attended this at the Royal Society buildings on 7 November 2012. This offers a potential future forum for publishing findings from this research project.

The Scottish Transport Applications Research (STAR) conference (typically in Glasgow) offers another future opportunity for attendance, with a section dedicated to rail, albeit localised to Scottish interests. Unfortunately this
year’s conference coincides with a critical module week at Surrey, but subsequent years may be of interest.

The EngD conference in June requires production of a poster describing project work so far. This is likely to be a good source of training for any later external conferences, as are its associated training sessions.

6.7 Restatement of objectives

Through reflecting on topics covered during the writing of this report, a series of actions to take before the next 6-month report have been listed below. Alongside the new research questions discussed in section 6.2, progress will be measured against these objectives in the next 6-month report, and later reports if appropriate.

- Establish more regular contact with the Energy Services team, to design future tests and experiments
- Investigate the Thameslink upgrade programme and Crossrail as potential case studies, for understanding how sustainable innovations have been embedded (e.g. solar PV, smart control systems)
- The forthcoming EngD conference on 4-5 June 2013 requires a poster presentation of work conducted so far. Methods for integrating this output into useful material for Network Rail should be investigated.
- Continue developing literature review, particularly technical information about available trackside technologies and control systems
- Liaise further with Energy Services team at NR, and develop research plans with them for 2013-14
- Continue internal website development, and use this to determine where sustainability interventions can be made.
- Support Sustainable Business Strategy team wherever possible, including Sustainability Report development
- Identify possible areas of business for social research, and whether this should be qualitative or quantitative
- Identify at least one technological infrastructure innovation for an LCA study
- Produce all coursework and conference material as required, and integrate this into work for Network Rail, and vice versa.
7 Personal reflections

The first few months have been enjoyable, and progress has felt steady. There has been a stronger emphasis on university work than was originally anticipated, but this is known to be peculiar to the first few months of an EngD project.

There were some initial concerns immediately following arrival at Network Rail regarding the availability of industrial supervisors on a day-to-day basis. However, this has been resolved with the appointment of Kent Farrell as an additional supervisor, and he has been a regular point of contact for queries and gaining a better understanding of Network Rail’s structure.

Future 6-month reports are intended to have less emphasis on a review of literature, and increased focus on the outcomes of contributory research projects, discussions, and work for the Sustainable Business Strategy team. Hence, future reports are intended to be shorter and more concise. This report is being reproduced in a shorter version for updating SBS team colleagues other than supervisors.

Extensive further contacts need to be made within Network Rail. It is likely that further work will involve a major infrastructure project such as Crossrail, which are still at least partially in the planning phase.

The Sustainable Business Strategy team is about to undergo a major change, with the imminent departure of the interim head, Katrina Keeling, and at least one other member of the team. This heightens the imperative to establish further contacts beyond the SBS team, so that any future projects will have additional stability, and will better-inform any successors.

Word Count:
Overall (excluding title page, contents, glossary, executive summary, appendices, references): 15,841
Literature Review section: 7,743
Executive Summary: 518
Appendix A: Research reading checklist

Written by Kent Farrell, industrial supervisor.

Rupert Zierler EngD Programme

Revision ‘A’ 31 January 2013

“Sustainable energy in railway infrastructure operations - creating a framework for sustainable development in the UK rail industry including implementation and technology deployment with particular reference to infrastructure electricity”.

This document sets out a high level structure (“the bones”) of Rupert’s EngD programme and will be the subject of further refinement.

Broad 4 Year Plan

Year 1 - October 2012 to September 2013
Carry out wider research and evidence review of the above to develop the topic area

Years 2 & 3 - October 2013 to September 2015
From work in year 1 propose a more focused area for research for the next 2 years

Year 4 - October 2015 to September 2016
Refinement and write up of findings

1. Government Transport Policy
The McNulty Value for Money Study
The carbon credentials of rail
Network Rail’s CP5 determination

2. Government Energy Policy
UK energy strategy
Energy security

3. European Transport & Energy Policy
Relevant EU Directives eg interoperability

4. Rail Regulation
The effects of being a monopoly company with an active regulator
The impact of 5 year control cycles

5. Economics
Current UK economic situation
Rising energy costs

6. Company Structure
Devolving power to Route organisations
Creation of a separated business unit to be the deliverer of capital projects (Dime)
The role of Asset Management / Energy Services
Company reorganisations
Structure for more effective implementation of sustainability measures

7. Industry Structure
Current structure
Barriers to change, conflicts preventing introduction of new technologies
Energy efficiency measures impact on train performance

8. Energy Procurement & Management
Grid mix
Lower carbon electricity tariffs
Ability to influence electricity supply market as a major purchaser
Billing arrangements for customers, incentives for reducing consumption
Management systems eg ISO 50001
Carbon reporting

9. Investment for Sustainability
Capital investment process
Business case for investment
Quality of data for investment appraisals, assembly of benefits case
Whole life costs / life cycle analysis
Internal and external investment, funding available

10. Sustainability in Major Network Rail Projects
Crossrail
Electrification schemes including London to Cardiff, the North West of England (allowing electric trains to operate between Preston and Liverpool, Manchester and Blackpool), the North Transpennine line between Manchester and York via Leeds and potentially Bedford to Sheffield

11. Culture
Present culture in the company and how it could be changed
Compare to safety culture

12. Technology & Innovation
Traction – on train metering, ‘eco-driving’, regenerative braking, opportunities to supplement with low or zero carbon technologies, sustainability / carbon benefits of electrification
RSSB research documents
Bi-mode operation, battery hybrid power, batteries, supercapacitors or flywheels fitment to diesel engines to store energy from braking
Hydrogen fuel cells
Include time frames for introduction of different technologies
Culture towards innovation

13. Overseas Railway Infrastructure Operators and Rail Groups
Sustainability credentials of overseas rail infrastructure providers eg ProRail in the Netherlands and major projects eg Hong Kong China rail express rail link
European rail bodies: EIM (www.eimrail.org) and UIC (www.uic.org)

14. Other Infrastructure Providers
For example the Highways Agency, BAA, London Underground
Examples of good practice and how these may be applicable to Network Rail
## Appendix B: Research timetable Gantt chart

<table>
<thead>
<tr>
<th>Activity</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRACTION ENERGY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define detailed research projects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meet with energy services team</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meet with internal infrastructure experts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct points heating investigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Life Cycle Analysis Module and Coursework]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FRAMEWORK STUDIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case studies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meet with Thameslink upgrade programme</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop integrated website structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Transitions to a Low Carbon Econ module]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site visits to other NR projects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GENERAL RESEARCH OUTLINE</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Initial research, continued literature review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analysis of results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapt any relevant NR docs for confidentiality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critique and interpretation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissemination of results</td>
<td></td>
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</table>

*The Gantt chart details the timeline for various research activities from October 2012 to March 2013.*
### Appendix C: Stakeholder list

<table>
<thead>
<tr>
<th>INDUSTRY AREA</th>
<th>ORGANISATIONS</th>
<th>DEPARTMENTS (NR only)</th>
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<tbody>
<tr>
<td>Network Rail</td>
<td><strong>Department</strong></td>
<td><strong>Team</strong></td>
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<tr>
<td></td>
<td>Safety and Sustainable Development</td>
<td>Sustainable Business Strategy</td>
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<td></td>
<td>Infrastructure Projects</td>
<td>Routes</td>
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<td>Strategy</td>
<td>Culture Change</td>
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<td>Asset Management</td>
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<td>Finance</td>
<td>S&amp;SD [IP]</td>
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<td></td>
<td>Network Operations</td>
<td>[Energy procurement]</td>
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<td>Government and Corporate Affairs</td>
<td>Network Strategy</td>
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<td>Sites</td>
<td>Technical Services</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Asset Information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy Services</td>
</tr>
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<td>Contracts and procurement</td>
</tr>
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<td>Information management</td>
</tr>
<tr>
<td>Train/Freight Operating Companies</td>
<td><strong>Key companies encountered so far</strong></td>
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<tr>
<td></td>
<td>First Capital Connect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First Great Western</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First Hull Trains</td>
<td></td>
</tr>
<tr>
<td></td>
<td>First TransPennine Express</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Northern Rail</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23 TOCs, 6 FOCs in total</td>
<td></td>
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<td></td>
<td>Association of Train Operating Companies (ATOC)</td>
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<td>Energy provider</td>
<td>EDF Energy</td>
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<td>External contractors</td>
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<td>Academic</td>
<td>Supervisors</td>
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<td>Scientific journals</td>
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<td></td>
<td>Rail Research UK Association</td>
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<tr>
<td></td>
<td>University Transport Studies Group (UTSG)</td>
<td></td>
</tr>
<tr>
<td>Governance</td>
<td>Department for Transport (DfT)</td>
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</tr>
<tr>
<td></td>
<td>Rail Safety and Standards Board (RSSB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Office of Rail Regulation (ORR)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Department for Energy and Climate Change (DECC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport Scotland</td>
<td></td>
</tr>
<tr>
<td>Campaigners/NGOs</td>
<td>Sustrans</td>
<td></td>
</tr>
<tr>
<td>Consultancies</td>
<td>Atkins</td>
<td></td>
</tr>
</tbody>
</table>
References


Davis, S. (2012). “Logistics at the core (Corporate Sustainability Report 2011)”. UPS, Atlanta


Sharpe, J., V. Ramdas, A. Stevens and J. Weekley (2013). Technology Futures - A horizon scan of transport technologies, Transport Research Laboratory.


6-monthly EngD Progress Report
2: April 2013 – September 2013

Rupert Zierler

(URN: 6248587)

Integrating sustainability frameworks within Network Rail’s business practices

Academic Supervisors: Dr Walter Wehrmeyer
Dr Jhuma Sadhukhan

Industrial Supervisors: Kent Farrell
Michael Goodfellow-Smith*
Iain Groark*
Executive Summary

This progress report covers the period April – September 2013, and provides a detailed project plan for all subsequent periods, for research into integration of sustainability management frameworks within Network Rail, focusing on infrastructure energy use.

Progress towards deliverables

Nearly all activity-related goals set in the previous report have been achieved. All academic projects have been completed successfully.

Progress against research questions defined in the previous report has also been satisfactory. However, a robust delivery structure for the findings from these is needed over the next 6-month period, particularly for a current piece of interview-led research.

In brief, devolved Route management structures at Network Rail have the potential to encourage improved energy management through innovation. However, improved sustainability-led communication structures are required to enable this, as devolution was enacted for other purposes. Policy changes to increase the rate of sustainable technological innovation should not necessarily be aimed directly at the technologies themselves, but to change the internal economic drivers behind them, potentially moving beyond the use of the Public Performance Measure as it is today.

A new structure of delivering outputs to Network Rail on a more regular basis will be established over the next 6 months. Emerging themes for the next stage of research include:

- Influencing behaviour-change in the field of infrastructure energy
- The importance of information flow to sustainable development in large businesses

Interview research

A series of semi-structured interviews and discussions is being performed, to determine the extent of a perceived gap between attitudes and behaviours relating to sustainable development within the management structure of Network Rail.
Results from these interviews will test a number of hypotheses regarding energy-related technological innovations. These relate to communication structures between Routes, geographical factors, cost barriers, and whether this gap is similar to those experienced in other large businesses, industries, and among the general public, or whether railway-specific factors are dominant.

The aim is to deliver a report on findings from these interviews by the end of December 2013. Initial explorations suggest that communication structures relating to sustainability innovations require development, and support a wider academic discourse regarding the flow of information within large businesses to support sustainable development.

**Infrastructure energy project involvement**

Several initial meetings have been held with various parts of Asset Management Services (who oversee infrastructure maintenance and upgrades) and Network Operations (who typically oversee monitoring processes), at both Central and Route levels.

General progress in engaging with these has been satisfactory, with the caveat that this needs to deepen with a select few. These include analysis of potential points heater savings from new control systems, material analysis relating to conductor rail energy applications, and the reporting structures of traction energy losses and greenhouse gas emissions from infrastructure.

**Project plan**

A delivery structure for the key findings from this research has been laid out towards the end of this report, based on progress under the various research themes.

A change of industrial supervisor unexpectedly took place within a week of submission of this report. Therefore, some of this plan is subject to change over the initial few weeks of the next reporting period, details of which will be included with the next report.
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Glossary

AMR    - Automatic Meter Reader
AMS    - Asset Management Services (division of Network Rail)
EPSRC  - Engineering and Physical Sciences Research Council
ESTA   - Electricity Supply Tariff Area
NR     - Network Rail
ORR    - Office of Rail Regulation
PPM    - Public Performance Measure; the percentage of trains running on schedule per day.
RAM (E & P) - Route Asset Manager (Electricity and Power)
SBS    - Sustainable Business Strategy team
TOC    - Train Operating Company
UIC    - International Union of Railways (global consortium, with the stated aim “to promote rail transport at world level and meet the challenges of mobility and sustainable development.”)
1. Introduction

This progress report discusses all major activities for the period April – September 2013. A detailed research project plan is laid out, including intended delivery dates for research question outcomes, towards the end of this report.

Section 2 measures progress against objectives set in the previous report. This progress is stated in terms of both whether research questions have been satisfactorily answered, and more general goals specific to the previous six months, such as deadlines and conferences. Exploration of the research questions identifies how these may change for the coming 6-month period.

Section 3 briefly outlines work completed for the purpose of taught modules, and includes a discussion of the outcomes of the 2013 EngD conference in Guildford.

Section 4 discusses an ongoing piece of interview-based research revolving around the management of infrastructure energy at Network Rail. This is supported by a short literature review.

Section 5 discusses the current level of integration with Asset Management-led projects in support of this research. This section also describes how involvements are intended to develop.

Section 6 outlines actions and objectives, both for the next 6 months and the remainder of the EngD research project, including a detailed project plan and Gantt chart of intended delivery dates.

Section 7 provides brief comments on overall progress.
Change of supervisor – Impacts on Project Plan

As of 24 September 2013, industrial supervisor Michael Goodfellow-Smith has resigned from his post at Network Rail. Iain Groark, Head of Sustainable Business Strategy, is taking over as second industrial supervisor for the foreseeable future. As a result, parts of the proposed project plan are subject to confirmation, and are likely to change shortly after the submission of this report. Any subsequent alterations made will be discussed in the next 6-month report, and an update will be provided to academic supervisors prior to this.
2. Progress towards deliverables

This section initially covers progress against activity-related goals set in the previous report (2.1). However, most of this section outlines progress as measured against answering research questions from the earlier report (2.2), and discusses new questions which have arisen as a result of this exploration (2.3).

2.1 Progress against goals

A summary table of progress measured against activity-related goals set in the previous report is provided in Table 1. Green indicates completion, yellow indicates an ongoing status which is not behind schedule, red indicates ongoing but behind schedule, and blue indicates an incomplete status but no further relevance to this research.

The only goal defined in the previous report which has not seen sufficient engagement has been investigation of Crossrail and Thameslink Upgrade programmes, which have their own significant sustainable development operations. Although communication with these projects has been less than ideal, it is not thought that this shortcoming represents a major threat to the outcomes of this research.

Development of the internal web page was under the ownership of Michael Goodfellow-Smith. Responsibility for this has shifted since the previous report, and he has resigned from his post at Network Rail. Links to key environmental legislation information are now in place (a 'legal register'), as required for compliance purposes. However, no further developments to this are anticipated for the foreseeable future.
<table>
<thead>
<tr>
<th>Goals</th>
<th>Status</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish more regular contact with the energy services team</td>
<td>In progress</td>
<td>Have made several initial contacts. However, there are some concerns regarding level of engagement with individual projects. Discussed in section 5.</td>
</tr>
<tr>
<td>Investigate Thameslink Programme and Crossrail as potential case studies</td>
<td>Behind schedule</td>
<td>Have only met with Thameslink representatives briefly, and have not yet met anyone from Crossrail. This has lowered in priority following initial meetings with other projects, but is felt to be an important area for investigation as examples of good practice.</td>
</tr>
<tr>
<td>Prepare for EngD conference</td>
<td>Completed</td>
<td>EngD conference completed. Content of presentation satisfactory, but improvement of delivery style required.</td>
</tr>
<tr>
<td>Develop research plans with energy services</td>
<td>In progress</td>
<td>Some concerns regarding level of engagement with individual projects. Discussed in section 5.</td>
</tr>
<tr>
<td>Continue to develop website</td>
<td>No longer applicable</td>
<td>Corporate Register environmental database in place. On hold.</td>
</tr>
<tr>
<td>Support SBS team where possible</td>
<td>In progress / ongoing</td>
<td>Ongoing. Full participation in team meetings and development of strategy.</td>
</tr>
<tr>
<td>Identify possible areas of business for social research</td>
<td>Completed</td>
<td>Have developed an interview structure for deployment among energy-related functions. See section 4.</td>
</tr>
<tr>
<td>Identify at least one technological infrastructure innovation for an LCA study</td>
<td>Completed</td>
<td>Aluminium/Stainless Steel Cap conductor rail deployment, or benefits of reduced complexity of traction energy supply.</td>
</tr>
<tr>
<td>Complete all necessary coursework and adapt for Network Rail accordingly</td>
<td>Completed</td>
<td>All coursework completed on schedule, and summarised for colleagues.</td>
</tr>
</tbody>
</table>
2.2 Progress against research questions

Progress has primarily been achieved through a combination of literature review, informal discussions, and semi-structured interviews. Most supporting information in answering these questions is qualitative at present, being based on 1-to-1 discussions with Network Rail staff or scientific articles. The aim for the next 6 month period is to support this with quantitative information and analysis.

The question numbers (listed in brackets) refer to the original question numbering given in the previous report. These numbers are to help maintain records of outcomes over the course of this EngD research. They are listed in order of their categorisation in the previous report, and so are not directly in numerical order.

Quantitative data on several aspects of infrastructure energy use is not consistently available at present. Metering, smart-metering, and by-asset sub-metering projects are underway across Network Rail, under the umbrella of the Automatic Meter Reader (AMR) programme, but some of these are not likely to be completed until a relatively late stage in the EngD programme.

*** Update, 30 September 2013 ***
Delivery of the AMR installation programme has recently been brought forward, with the aim of completion at the end of 2014. This creates the opportunity for additional analysis of energy use before the completion of this EngD research, although this may still be too late in the course to allow some comparative year-on-year reflections.
2.2.1 [Question 1] Do new devolved Route structures in Network Rail encourage or discourage energy-related innovation?

Network Rail has recently devolved several functions to control of geographically-organised Routes. Breaking down operations to a regional level potentially aligns with localisation aims internationally and via the UK Localism Act 2011, and supports niche sustainability innovations, as described by multi-level perspective development models (see Geels, 2002, and 2012 for application to transport). However, Route devolution was not necessarily implemented to achieve sustainable development goals. This research question pursues whether devolution supports sustainable development, and current internal NR attitudes regarding this.

Criticism has previously been levelled at the previous financial structure of Network Rail. Jupe (2009) discusses how the key beneficiaries of its funding have, in the past, been capital markets, financial institutions and contractors.

The positives or negatives of competition within railway services are not clear. Exploration of competition in railway markets suggests that this leads to improvements in the frequency of services, although this particular study investigated wholly-owned lines (i.e. track and train) (Lalive and Schmutzler, 2008). However, an earlier study suggests that internal competition introduced to former rail monopolies leads to reduced economies of scale, and hence increasing costs (Jensen, 1998).

These studies have all investigated the financial performance of devolution and competition within railways, rather than in terms of environmental performance or social benefits. Through scientific literature alone, it is not therefore known whether internalised competition between Routes at Network Rail, i.e. within the same company, will have a similar effect, nor whether this will impact on energy efficiency.

Initial discussions with Route Asset Managers (RAMs), and observations from the interviews mentioned in section 4 suggest that competition in sustainability and energy performance is not directly supported by the new Route structure. The Public Performance Measure (PPM) is the primary driver behind infrastructure improvements, sustainable or otherwise. This measures the percentage of trains delayed more than 5 minutes, or cancelled outright, and is recorded on a per-day basis. Any of these
delays traceable to an infrastructure-related fault are the responsibility of Network Rail, even if this was caused by external action (such as cable theft or unforeseen weather conditions).

The devolution process itself is felt by many to have been to more closely align infrastructure operation with activities and geographical layout of Train Operating Company (TOC) franchises, rather than as a means of encouraging competition frameworks between Routes. It seems that the effect of devolution on sustainable development objectives has been to introduce another level of hierarchical detachment through reporting to central management, rather than to encourage a competitive network of peers.

Whilst the responsibilities of the Routes are being adjusted and defined, and the communication processes between them are being set-up and refined, innovations in any one Route are not easily communicated to the others, or to Central functions. There is also a risk that introducing competition at Route level will lead to consistent disparities between them in terms of sustainable development performance. For example, a hypothetical Route with high environmental performance may take a continued lead on improvements, to the extent that less high-performing Routes look to them for guidance rather than seeking out their own, original sustainable innovations. In an ordinary marketplace, the incentive to achieve this would be gaining an advantage over peers. However, as the Routes are still part of the same overarching organisation, and are all geographically unique, a competition model is not as likely to generate as many benefits for generating sustainable innovations.

The supply of electricity for traction power is divided into Electricity Supply Tariff Areas, or ‘ESTAs’. These are divided into several areas for AC overhead supplies, one large ESTA for the DC 3rd rail network in Wessex, Southern and Kent Routes, and another for the Merseyrail DC 3rd rail system. These do not match the boundaries of the Routes, introducing a further complexity into the determination of traction electricity saving calculations.

This question will remain open over the coming months, although initial observations have been made, as discussed above. To align with the objectives of the SBS team, this will be broadened to include observation of the encouragement of sustainable development-related competition, in addition to the current energy focus. However, initial findings suggest that shifts in communication structures have slowed the rate of energy- and
sustainability-related innovation, possibly driven by focus on cost and PPM. A possible solution to overcoming these issues could be to integrate a sustainable innovation-related communications regime with the already-robust safety reporting mechanism, and the forthcoming sustainability management computer system (see section 4.1.2).

The current estimated date for final delivery of a report on this question is December 2013 (see project plan, section 6).

2.2.2 [Question 5] What is the potential for establishing cooperation frameworks between Network Rail, National Grid, and energy suppliers, to achieve carbon emission reduction and sustainability objectives?

The scale of Network Rail’s operations leads to impacts on the national electricity supply grid that are non-trivial. Railways tend to operate during times of peak energy demand, as shown in Figure 1. Therefore, increases in rail travel are likely to require an increase in electricity production capacity in order to accommodate the accompanying peak demand. This compares unfavourably with developing infrastructure for electric road vehicles, due to the flexibility of their recharging times, despite rail requiring less electrical energy overall, as described by Grenier and Page (2012) for a light rail scheme. Battery-powered trains offer the same recharging flexibility as cars, but these are still in the early stages of development, and a dominant recharging technology has not yet emerged (Molyneux, Bird et al. 2010). Cooperation with TOCs to ensure their development would need a long-term agreement, but the timescales of franchise ownership at present do not facilitate this, and are unlikely to change in the near future (McLoughlin 2013).
EDF Energy has been contracted as Network Rail’s traction electricity provider for the period 2013-2023, supplying electricity from largely nuclear power stations (Parry-Jones 2013). This theoretically reduces the carbon intensity of Network Rail’s electricity use. However, Network Rail purchases approximately 1% of all electricity generated in the UK (Parry-Jones 2013), and this proportion is likely to increase as route electrification becomes more widespread. Therefore the impact of rail on overall power availability for homes and industries is non-trivial, and justifying the continuation of railway operation to external governance bodies is likely to require demonstration of efforts to increase energy efficiency. However, as most of this power is used by the trains themselves, Network Rail’s ability to affect electricity consumption will be reliant on the strength of communication frameworks with TOCs and FOCs.

The physical origin of electricity supplies to Network Rail are complex and diverse, partly due to the two separate traction electrification systems used on Britain’s railways. Although EDF Energy provides all traction power, infrastructure energy is supplied by several providers. This not only increases the complexity of GHG emissions calculations, but the number of stakeholders involved in any potential cooperation framework.

Points heater power supplies are often shared with other lineside infrastructure. This includes collections of other points heaters, signalling systems, lighting, level crossing equipment and several other systems. As individual heaters are not, as yet, sub-metered, the precise amounts of
energy they consume are not known, and are categorised as a percentage of the power consumed at the point of supply. As a result, the accuracy of greenhouse gas emission calculations is reduced. Given the geographical spread of NR’s operations, the fuel mix of electricity at any particular supply point is not likely to directly match that of the disclosed percentages stated by any of the suppliers involved (for example EDF Energy, 2013), or the UK government’s disclosure data table for UK averages, DECC 2013).

Internal communication structures for carbon emission reduction and sustainable development need to be established or improved, before extensive cooperation between with external stakeholders can be conducted with maximum effectiveness. For the purpose of this EngD research, a greater focus on NR’s internal communication structure is needed, before recommendations can be formulated regarding external cooperation. This topic may be returned-to at a later date, if this investigation yields recommendations as to how internal communication can be improved.

It is proposed that an output paper from this research question be produced for distribution at Network Rail. Details of this are to be discussed in October 2013.

2.2.3 [Question 6] What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?

Many foreign railway infrastructure operators are not limited to infrastructure alone; most operate at least a proportion of trains running on their lines as well. European directive 91/440 requires railway infrastructure operators to allow open-access operators to run on their lines, at least in part. However, implementation of this varies from country to country, with differing proportions of their networks franchised out to non-state-owned companies. Therefore management-based recommendations relating to sustainable development practices would need to be adapted heavily before implementing on UK railways.

The Train Operating Company (TOC) franchising system in the UK has introduced significant complexity into the application of not only energy-saving technologies on-board trains, but measurement of their energy use.
Network Rail and members of SBS team are hosting a UIC conference on Sustainable Land Management on 1-2 October 2013. In addition to Land Management topics, the conference is being used as a feedback forum to assist development of NR’s sustainability strategy. It is hoped that this will provide opportunities to form links with railway infrastructure providers in other countries in support of this EngD.

Due to the sheer diversity of international railway infrastructure operators, it is felt that this question should remain open throughout the duration of this EngD research. Although establishing communications with other infrastructure operators should always be of interest, this question is not output-focused at present, but rather supports discussion in others.

It is proposed that areas of specific interest or gaps in knowledge within the SBS team relating to international railway operators’ practices should be identified as soon as possible. This will support supplying an output of interest to managers at Network Rail.

2.2.4 [Question 7] Can rail act as a market leader for sustainability across all transport modes?

Current ‘market leaders’ in terms of transport appear to be operators focused around a single city, and particularly Hong Kong’s MTR corporation (Walder 2012), as discussed in the previous report. Similarly, sustainability discourse in transport research fields currently focuses on reducing the environmental impacts of travel in and around cities (reviews include Li 2011, or (May, Page et al. 2008), and efforts to link transport with urban planning (see Dulal, Brodnig et al. 2011). Beyond transport, cities themselves have been identified as key to achieving global sustainability goals, given that they house an increasing percentage of the world’s population, and bring with them economies of scale for sustainable planning (McCormick, Anderberg et al. 2013).

Network Rail Routes, rather than focusing on individual cities, tend to align along major strategic links (as shown in Figure 2). For example, London North Eastern and London North Western are principally based along East- and West Coast Main Lines respectively. However, some Routes contain multiple cities with heavily-developed metropolitan transport
networks (i.e. those with an extensive metro/tram system or dedicated Passenger Transport Executive), whilst London is divided among all Routes apart from Wales and Scotland. Whilst some TOCs operating on Network Rail infrastructure are city-oriented (such as LOROL’s London Overground, or Merseyrail in Liverpool), many cover more diverse geography (such as Northern Rail), or provide inter-city travel (such as Virgin Trains).

The current franchising structure for train operators is not flexible enough to re-orient services towards serving major metropolitan areas, and as a result may have difficulty in driving any discourse towards urban sustainability. There would be no single ‘market leader’ for railways in general within the UK, as TOCs have to compete with the performance of other operators before even considering the impacts on other modes.

Figure 2 - Network Rail devolved Routes, showing major metropolitan transport networks superimposed by the author (original image copyright Network Rail, adapted by the author).
A sustainable transport system requires multiple travel options working in concert, with a particular emphasis on reducing carbon emissions associated with car use. Therefore, it appears that no single mode should ‘lead the market’ per se, and it is not helpful from a research point-of-view to perceive rail as being in competition with other modes in this context. There is a wealth of research covering the encouragement of modal shift towards rail (for example Cuenot, Fulton et al. 2012). However, the current debate surrounding the environmental benefits of rail compared to other modes (as discussed by Federici, Ulgiati et al. 2009) suggests that cooperation between modes based on the needs of the traveller should be focused on, rather than competition.

Rail should instead provide a firm backbone to a varied and accessible transport system, with gaps in rail’s coverage supplied by other modes, as discussed by Reis, Fabian Meier et al. (2013). A review of research into supporting the economic case for rail in a sustainable transport system was provided in the previous 6-month report.

Although the phrasing of this question has been deemed unhelpful to the course of this research, it has highlighted an ongoing need for revisiting and reflecting on research from the earlier literature review. This is particularly true given the previous 6 months’ focus on specific infrastructure technologies, rather than the wider economic context of rail in the UK. Production of an output paper for wider Network Rail use based on this earlier research is proposed for discussion with supervisors at the earliest opportunity.
2.2.5 [Question 2] **What are the most effective methods available to Network Rail for reducing infrastructure energy use, and how strong are the economic, social and environmental cases for these?**

Improvement of the control systems for points heaters are seen to be a key method of reducing unnecessary or unintended energy consumption by the central Energy Services department. These heaters are used to prevent points from freezing together in adverse weather conditions, and to prevent build-ups of snow which may otherwise jam the mechanism. Currently, most heaters are activated via a thermostatic system based on the surrounding air temperature. Faults have occasionally led to points heaters being left on at times of year when they are not needed, only being discovered at subsequent, non-real-time meter readings.

However, there is some scepticism towards the intended remote-control-and-monitoring system among Route Electricity and Power specialists, as it felt that there are issues with the system’s reliability. The Public Performance Measure (PPM) is seen as the key method by which performance of Routes is judged. Therefore, any measures which are believed to potentially impact negatively upon this are viewed with caution.

Conductor rail heating (see Figure 3) is used to prevent electrical pick-up ‘shoes’ on DC 3rd rail electric trains from sticking to the rail in freezing conditions. It is a relatively new technology, compared to points heating, as the system was not required for older, less electronically complicated ‘slam-door’ stock, and therefore trackside installations have not generally reached the end of their lifespan.

Conductor rail heating is not differentiated from points heating when assessing their energy use, which introduces complications when calculating likely energy savings, as described for points heaters in section 2.2.2. However, the potential technology changes for these are slightly different, focusing on changing application of power after activation, rather than improving parameter information used by the control system. Current heaters run at a constant power rating, and are supplied by two feeds with 3 wires each. A possible solution is to fit a control system which provides an initial ‘burst’ of power from both sets of wires, and then tails off with a ‘maintenance’ supply from one set. An alternative is to fit a newer ‘self-regulating’ system, which adjusts Wattage based on temperature.
However, these require new training and expertise in order to maintain them, as well as having some other technical issues to overcome.

Figure 3 - Mock-up of a conductor rail heating system at Network Rail, with cladding to prevent heat loss. Photograph by the author, May 2013.

Changes in conductor rail materials also offer a potential method of reducing electricity consumption for traction power. This would primarily be achieved through use of an aluminium rail with a stainless steel cap, to replace the predominantly steel rails in use today, some of which are nearing the end of their planned life.

Although this research intends to focus on power used for infrastructure, this particular application blurs the line somewhat between infrastructure and traction power. It also blurs the business case as to whom would benefit most from the upgrade. TOCs are likely to benefit most immediately from a reduced power draw, but the direct cost of power purchase to NR would be reduced under regimes of increased metering detail and accuracy.

As pointed out by Guthrie and Parker (1989) and Adams and Frost (2008), industries most closely associated with adverse environmental impact have extensive histories of reporting environmental information. The perception of rail as an environmentally sustainable form of transport in recent years may have directed attention away from ensuring that this was the case. This perception may be driven by the fact that the post-war shift from steam- to ‘cleaner’ diesel and electric power preceded the rapid developments in environmentalism and modern sustainability dialogues in
the early 1970s. Railways also represent a very small proportion of total greenhouse gas emissions from UK transport (DfT 2011), reinforcing policy focus elsewhere. The adoption of sustainable principles by railway operators, despite their long industrial history must therefore be driven by experience from other industries.

Leitner, Wehrmeyer et al. (2010) point out that the most effective regulatory instruments in driving sustainable innovations are not necessarily those aimed at technological developments. Fundamental changes need to take place at the higher policy- and economic levels, in order to make the longest-term sustainable changes to business practices (see Figure 4). This call is duplicated for integration of sustainability within general engineering practices by Rosen (2013). At Network Rail, this could apply to a shift away from using PPM as the primary means by which the performance of sustainable infrastructure upgrades are judged; other, more environmentally-related KPIs should raise in importance, not least energy use levels or carbon emissions.
Completion of metering installation projects is likely to help determine the effectiveness of individual energy efficiency technologies, as data on a per-asset level is currently incomplete and based on estimates at the point of supply.

It is proposed that separate analyses should be performed to first analyse the actual and potential efficiency savings relating to track heater control systems, and second for a life-cycle-oriented study of the environmental benefits of new conductor rail materials. These should be revisited periodically throughout the course of this research, to check that expectations have been met, and implications for NR’s sustainability frameworks.
2.2.6 [Question 8] How strong is the business case for energy saving/efficiency technologies at Network Rail?

Two major stumbling blocks to business cases for sustainability in large corporations have been identified by Salzmann, Ionescu-somers et al. (2005). The first of these is the complexity of developing this business case, owing to the number of parameters that need to be included in its development. The second is referred to as the ‘materiality’, whereby business cases for sustainability are limited to the

As mentioned above in 0, the complexity of installing energy monitoring equipment and on-train energy saving technologies across the whole of the UK rail industry is increased by the TOC franchising structure. Installation of monitoring equipment on infrastructure may alter the amount of energy billed for the purpose of traction, and vice versa.

Replacement of any track-related asset is subject to:

- Age, and stage in intended life-cycle
- State of repair of the asset
- Availability of track for maintenance work (particularly on busy lines)
- Cost of replacement (particularly if being replaced before the intended end-of-life phase)
- Safety implications of continued use of the asset

The cost of replacing any equipment to achieve increased energy efficiency requires that the energy savings outweigh the cost of replacement prematurely. Many pieces of trackside equipment have a planned lifespan of approximately 25-30 years. Therefore, some equipment installed in recent years, but before energy efficiency became a major issue would not be economically replaceable. However, opportunities for installation of energy-efficient equipment are likely to be frequent in coming years, owing to ex-British Rail equipment reaching end-of-life, and general underinvestment in infrastructure under Railtrack (1994-2002).

Metering and AMR installation projects are likely to help determine the success of the business case for energy efficiency technologies through increased information availability. However, as these are currently
incomplete, the possible energy savings of these technologies are likely to be underestimated, as approximate figures will need to be used for these, and for carbon emission estimates.

This research question was felt to be similar to Question 2, in terms of likely outputs. Therefore, outputs from this question will be merged with Question 2, and the ‘effectiveness’ mentioned there will cover whether a particular method is financially viable, as well as technically feasible and environmentally sound. This merging has also taken place due to the issue raised by (Salzmann, Ionescu-somers et al. 2005); eco-efficiency and ‘no-brainer’ efficiency savings are relatively easily-grasped by large businesses, whereas the benefits of less tangible, long-term management-oriented practices are not. Therefore, the emergent questions surrounding behavioural influence and information flow (see 2.3, below) should increase in priority.
2.3 New emergent questions

Pursuit of the research questions outlined in 2.2 has identified several issues relating to the uptake of sustainable principles and actions at Network Rail. These are to be addressed through two new supporting research questions, defined below.

These new questions have been incorporated in the project plan, in addition to alterations to the older or continuous questions (outlined in section 6). Again, delivery of these is subject to confirmation following the shift in supervision structure.

2.3.1 [Question 10] What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on Network Rail’s infrastructure?

Establishing methods of influencing the behaviour of large businesses is a mature but incomplete area of research. A recent report from Corporate Culture investigated corporate and organisational priorities, motivations, challenges and strategies to achieve sustainable behaviour change, through interviews at a senior level of several businesses (Kemp and Drummond 2013). This topic is often the subject of discussion in the business sections of periodicals (for example, Drummond 2013).

As discussed for Question 2 (see 2.2.5), sustainable innovations need to be driven at the economic and policy levels, in order to achieve the most long-lasting benefits (Leitner, Wehrmeyer et al. 2010). At Network Rail, the possibility that PPM should not be used as the only means of judging the performance of infrastructure upgrades in all instances requires exploration. Alternative measures could potentially include carbon emission levels, energy-use valuations or a biodiversity impact values-based assessment system, as suggested by Wallace (2012).
2.3.2 [Question 11] **To what extent are gaps in information flow acting as a barrier to sustainable development at Network Rail, and what measures could overcome them?**

Development of sustainability Key Performance Indicators (KPIs) has highlighted areas where greater levels of sustainability-related information is required, before performance can be measured. An example of this need relates to the precision of metering data for NR’s various assets, as discussed in sections 2.2.5 and 2.2.6. Discussion of NR’s energy management has highlighted a disparity between the ownership and application of information. One section of the business may be responsible for collecting and reporting raw data, but not for developing solutions to issues raised by analysis of it. This may be due to the large size of the company, as monitoring any aspect of an organisation of this size is a full-time occupation.

Information availability was found to be a key barrier to uptake of public transport services in earlier research by the author (Zierler 2010). The quality of sustainability reports are also often judged on the amount and transparency of information communicated publicly (Global Reporting Initiative 2011), and the robustness of their KPI provision (Adams and Frost 2008). Given these and other personal observations of information flow acting as a barrier to achieving sustainability, this question has been formulated.
3 Course-related work

This brief section discusses the contribution of taught modules and other activities with the University of Surrey to the progress of this research over the last 6 months.

3.1 Life Cycle Assessment

This course gave a comprehensive introduction to ‘GaBi’ Life Cycle Assessment software. It is not yet clear how these skills will be transferred to the outcomes of this EngD research, as the feasibility of a detailed environmental Life Cycle Assessment alongside this research is currently in question. This was raised at the most recent supervisor meeting, and it is intended that inclusion of some form of less-detailed assessment exercise will be discussed at a separate meeting with academic supervisors in November 2013.

Insight into the process of performing a detailed Life Cycle Assessment has developed an appreciation for the difficulties of performing such in-depth analysis. It also raises questions as to whether one can be conducted within Network Rail in the near future for any single type of asset, given the complexity of asset ownership, control mechanisms, diversity of equipment models, and the constant flux of repair and replacement.

3.2 Transitions to a Low Carbon Energy Economy

This module taught how to consider changes towards low carbon practices as a transition pathway, rather than as a disruptive individual change. The most effective technique was a role-playing exercise, where carbon-related issues for a hypothetical train manufacturer were identified, and various stages of a transition to sustainable operations were planned. This supports research conducted for Question 2 (2.2.5), suggesting that technological changes can feed into a wider transition process for an organisation. Post-module coursework for this module also contributed greatly to answering other research questions discussed in section 2.2.
3.3 **Leading Self and Your Key Relationships**

These skills were applied in the preparation of the project plan for this report; the breakdown of activities in terms of research question content is based on the Vision-Outcome-Performance-Process methodology recommended by this course, as well as recommendations from academic supervisors. This course also developed skills used to conduct the interview programme discussed in section 4, such as identifying levels of rapport and how to best pursue less tangible topics like beliefs and attitudes in conversation (as opposed to raw facts).

3.4 **EngD Conference, 4-5 June 2013**

The key output for this conference was not a poster presentation, as anticipated in the previous report. Instead, a 15-minute presentation focused on Stakeholders and Impacts of the research was produced, aimed at the EPSRC research body, in line with the similarly altered theme of the conference.

Feedback indicated that the content of the presentation was good in terms of content and structure, use of visual aids, and adaptation for the target audience. Areas in distinct need of improvement were primarily delivery-related, namely audibility, levels of eye contact, and timekeeping. A key shortcoming in preparation was the short amount of time spent rehearsing, which was shortened in favour of making alterations to the presentation slides. These issues will be addressed for future presentations, although the EngD conference itself may have a different format in subsequent years.

A selection of slides from this presentation has been used to introduce the purpose of this research, at some initial meetings with various NR staff. However, this is being reviewed due to its length, and a shorter summary document will be produced within the next few weeks.
4 Social Research – Energy Interviews

The following literature review and rationale provides background information and scientific justification for a piece of interview-based research into the embedding of sustainable energy management practices within Network Rail, as proposed in the previous report. The need to establish sustainable energy management systems is described. Then the current state of sustainability management at Network Rail as a whole is discussed. The precedent for analysing the gap between attitudes and behaviours regarding sustainable development is then investigated in detail. Hypotheses are then provided for testing based on the review. A brief description of the methodology, sampling method, and initial results are then provided.

4.1 Literature Review

4.1.1 The need for sustainable energy management systems

In addition to the need to reduce carbon emissions, energy use by large-scale industry will need to lower significantly, in order to continue meeting domestic demand. Moriarty and Honnery (2012) discuss how all energy sources contribute at least a little to climate change effects, and these effects scale with use. The amount of energy produced is therefore likely to decrease, to satisfy visions of a secure (and clean) energy future (as discussed by Sadorsky, 2011). Therefore energy use will likely need to be managed by large infrastructure operators in order to support this, particularly if electric vehicles start competing for supply (Grenier and Page 2012).

Dey, LaGuardia et al. (2011) make a number of recommendations for logistics companies for improving the sustainability of their operations. Among these is a need to set measurable carbon goals. This is call is duplicated by Delina (2012), who states:
“…a well-defined mission enables an institution to reach its objectives more effectively and to significantly achieve the overall integration and coordination of its [energy efficiency] activities”

Although Network Rail is not a logistics company in the complete sense of the term, many operations are comparable between the two, particularly regarding tracking of supply chains, as are their functional operational units (i.e. distance travelled per cargo delivered and delay minutes). Therefore it seems reasonable to assume that this statement holds true for infrastructure operators too.

Carrying out research into Network Rail’s likely future pathway to delivering a sustainable railway could aid in scenario development for the UK economy. Some work has already been done into the socio-technical implications of different infrastructure responses to future natural hazards (Siracar, Sage et al. 2013). Armstrong and Preston (2011) specifically investigate scenarios for UK railways’ economic role in different energy supply scenarios, but do not look at how rail will structure its own energy security under these regimes.

4.1.2 Forthcoming Network Rail sustainability management

A new sustainability management reporting system, to monitor progress against selected sustainable development KPIs is in the late stages of development at Network Rail. Monitoring the after-effects, diffusion and early use of this system would support research into the effects of green information management systems, as recommended by (Meacham, Toms et al. 2013). As this is intended to be a flexible system, recommendations from this research could be used to support future developments to this system, and integration of specifically energy-related management subsystems. This is particularly pertinent, given the current programmes of metering installation (as of September 2013), and the intention to increase the robustness of Network Rail’s asset information.

(Sealy, Wehrmeyer et al. 2010) recommend that sustainability management systems should be defined in terms of stakeholder relevance. The requirements of external stakeholders for NR are relatively well-defined, in terms of ORR regulations, other laws and compliance, staff unions, government requirements, and interest groups like Passenger...
Focus. However, application to internal stakeholders remains incomplete; detailed understanding of the practical requirements of specific technologies at various of development is incomplete. Tactical interventions and investigations have been carried out by the SBS team to resolve this, but gaps in understanding remain, particularly at Route level. This programme of interviews aims to meet this requirement, through observation and potentially classification of sustainability issues most relevant to infrastructure energy applications.

4.1.3 The Attitude-Behaviour gap

There are several known opportunities for development of understanding regarding the sustainability attitude behaviour gap, and for developing recommendations to overcome this. The gap between sustainable or pro-environmental attitudes and behaviours (sometimes referred to as the value-action gap), has been explored extensively in recent years. However, the results of these studies are often highly-specific to the population segment (Hards 2012) or industry (Pesonen, Josko et al. 2013) upon which they were conducted. In a transport context, this gap has been investigated in relation to adoption of sustainable travel behaviours in the UK (Prillwitz and Barr 2011).

Major differences between sustainable values and actions are known to still exist across many businesses. Maleviti, Mulugetta et al. (2012) investigate how hotel managers view the application of energy efficiency measures to their facilities, albeit for buildings rather than infrastructure. They find that hoteliers are most likely to apply technologies that are easy to install, such as energy-saving lights. A lack of information on a variety of energy-saving technologies and renewable energy supplies also hindered deployment of more advanced technologies, alongside a feeling that specific legislation should be applied to encourage hoteliers further. Other studies of specific businesses and industries come to similar conclusions in their respective contexts (for example, Rosen 2013), and attempt categorisation of attitude groups (Anable 2005). It should be ascertained whether these themes of quick-fix technology application, lack of information on energy-saving alternatives, and desire for supporting legislation persist within Network Rail.
Various studies of the attitude behaviour gap around personal energy consumption among the general public have been performed. (Valkila and Saari 2013) have investigated this gap among Finnish residential communities, finding that geographical location is of significance when considering the extent of peoples’ concern over energy issues. This may be reflected in the varying priority levels that different NR Routes give to addressing these issues. Gadenne, Sharma et al. (2011) corroborate several previous studies finding that cost is a major barrier to acting upon pro-environmental attitudes among the general public, with any perception of a premium charge for environmental benefits reducing the likelihood of purchase. Identifying the extent to which geographical factors play a part in sustainable decision-making, and whether perception of premium costs for environmental benefits have an effect on Route asset policies could then guide steps to promote thinking on sustainable energy use issues, or to encourage the spread of ideas between Routes.

Jeswani, Wehrmeyer et al. (2008) investigate the attitude-behaviour gap at the whole-corporation level, but not directly at the departmental or managerial level, regarding corporate responses to climate change. They identify a continuum of response levels; ‘indifferent’, ‘beginner’, ‘emerging’, and ‘active’. Identifying a similar continuum for the environmental and energy performance of NR Routes may assist in developing a framework for encouraging competition and innovation in various aspects of sustainability.

Based on the first few meetings with various asset managers and engineers, attitudes towards sustainable development within Network Rail’s managerial structure seem fairly positive. However, they are faced with many operational constraints, which may take precedence over environmental performance. These include the Public Performance Measure, levels of reliability, and maintenance access, in addition to general uncertainty over implementing new technologies, particularly software-based solutions which may appear to them as something of a ‘black box’.
4.1.3 Conclusions

There is scientific justification, given current gaps in knowledge relating to infrastructure sustainability management, for carrying out a piece of interview-led research into the environmental and sustainability-related attitude-behaviour gap at Network Rail.

A set of research questions have been developed, based on the review above, specifically for this research project. These will be used as a basis for guiding the interviews, and for the subsequent breakdown of analysis. These are:

- Is sustainability already embedded in any of NR’s asset development practices?
- How integral is energy use in developing the business cases for NR projects?
- What are the barriers to SD integration and the adoption of energy use as an assessment tool in NR?
- What is the current attitude of Network Rail staff towards making energy efficiency improvements?

Some further sub-questions have been used in personal guidance notes for interview delivery, but these are omitted here for clarity.

This interview process will feed primarily into answering research questions 1 (see 2.2.1) 2 (2.2.5), 10 (2.3.1), and 11 (2.3.2), as discussed in the respective sections, and has already yielded some preliminary results (see section 4.4, below).

4.1 Methodology

Although these discussions will have a highly informal structure, these sessions will henceforth be described as ‘interviews’, to differentiate them from other discussions mentioned elsewhere in this report.

A semi-structured method similar to this has been used recently in a European railway context, to develop recommendations for a climate change adaptation methodology (Lindgren, Jonsson et al. 2009). This
particular study conducted interviews with those in the ‘Head Office’ of the Swedish Rail Administration, implying that participants were of a higher rank than those intended for this research. The Swedish system of railway management is fairly similar to that in the UK, so the parallel use of this interview technique is justified. However, this has not been applied at a Route-equivalent level before in a railway context, to the knowledge of the author. This structure will allow for exploration of topics not anticipated by this research, and personal experiences of those involved relating to infrastructure energy.

Based on the wider research review provided in section 2, the following hypotheses have been formulated:

- The environmental attitudes and energy performance of the various Routes, central management, and key infrastructure projects are all at disparate stages in their adoption of energy-saving and sustainability measures
- The gap between sustainable development attitudes and behaviours reflects that in other large businesses and industries
- Sustainable practices have already been embedded at Route level, but have not been identified as such, owing to the PPM-related focus governing their activities
- Extrinsic geographical factors, such as local weather patterns or altitude, play a part in determining the extent to which Routes pursue energy saving practices or asset policies.
- Perception of a premium on energy saving technologies acts as a barrier to their adoption at a Route level in Network Rail

These hypotheses will be assessed qualitatively, using a framework similar to that used by Lindgren, Jonsson et al. (2009). This breaks responses down into general awareness, responsibility, climate-related threats, vulnerabilities, consequences and adaptation measures.

The aim is to reach the final conclusions of this discussion programme before the end of 2013. A definitive guide to the outcomes of these interviews will be produced at this time. However, information from these are already informing the next stage in research, helping to identify the next stages of individual project involvement (discussed in section 5).
4.2 Interviewee selection

Targeted individuals include Engineers, Analysts, and Managers below the level of Director, working on infrastructure energy projects within AMS and Network Operations (not limited to those chosen for direct involvement with the researcher). Of particular interest are the Route Asset Managers for Electricity and Power, known as RAM (E&P). These have direct control over technologies implemented on specific Routes, and testing schemes for new equipment.

The selection of candidates for these discussions was conducted via a combination of:

- Exploring internal organisational charts
- Recommendations by industrial supervisors
- Recommendations by previous participants

4.3 Initial/Pilot Results

These guidelines have formed the basis for a series of meetings with engineers and managers in Asset Management Services, Network Operations, Route-based functions, and potentially within the Infrastructure Projects function.

Several managers and engineers have recognised the need for specific carbon- or energy use-related targets, in order to drive reductions in GHG emissions and electricity use, preferably set by the business. However, some have suggested that if such targets were to be set, these would be adopted by the Office of Rail Regulation (ORR), as official regulatory targets as well, possibly having an impact on finances going forward.

There are some contrasting opinions surrounding this. Some managers feel that ‘leading’ the regulator in establishing carbon targets would reduce the severity of such regulation, and enable a greater level of control over these in future. Others feel that the ORR would not adopt any energy-related regulation without prior provocation, and so setting targets should be avoided. The specifics of this require further exploration. However, there is some indication that this is increasing hesitancy toward adopting specific carbon- and energy-related targets.
5 Network Rail Project involvement

This section outlines the specific infrastructure improvement and development projects within AMS and Network Operations which have been approached to support this research. These activities directly support the delivery of the research questions outlined in sections 2.2.1, 2.2.2, 2.2.5, and 2.2.6. The rationale for pursuing involvement with these has been outlined throughout section 2.

The primary aim of involving this EngD research with specific Asset Management and Network Operations projects is to assess the potential for energy savings at Network Rail, compared with actual achievement. The goals are to identify the organisational barriers to sustainable development in infrastructure energy use, in turn providing insight into such barriers for other large, devolved organisations. These goals are in the process of being achieved, by:

- Identifying as many Network Rail projects as possible which have an impact on infrastructure energy use, and their priority to NR
- Engaging with a selection of these, to provide them with environmental impact information and support their communication of any environmental benefits they may provide
- Resulting identification of the potential best-case energy savings by Network Rail, to better understand the gap between this and actual achievements in this area.

5.1 Project stakeholders

This section outlines progress with each energy infrastructure project in terms of engagement levels.

5.1.1 Points heaters and control systems

As discussed in the previous report, points heaters have been identified as a priority intervention for reducing infrastructure energy use. However, contact relating to these has primarily been through the ‘Carbon Input into the CP5 Delivery Plan’ reporting team, rather than through those directly delivering the infrastructure. Heater energy use data has been supplied by this team, and an analysis will be completed following leave in October.
5.1.2 Conductor rail heaters

This was raised as a topic of interest by a Route Asset Manager during an extended meeting. A subsequent meeting with the manager in charge of their development provided technical background and some issues with implementation (discussed in section 2.2.5). Follow-up meetings have been planned, but cancelled over the course of September. It is planned to re-engage with this topic during November, as conductor rail materials, traction energy losses and assisting with the carbon input into the CP5 delivery plan have previously taken priority.

5.1.3 Conductor rail materials

The provision of aluminium/stainless steel-capped rails is currently subject to discussion with potential suppliers. One supplier was met with separately in August in support of the interview programme, to provide an external perspective. However, subsequent attempts at contact with both the NR Engineers involved and the supplier have not been successful.

The aim of engagement here is to conduct an environmental life-cycle-based analysis of the potential benefits of using these rails. However, if further information from the supplier is unavailable, this will need to be reconsidered. Information on energy savings here could then feed in to traction energy losses reporting, as aluminium rails are likely to have different loss properties, owing to conductivity differences with steel.

5.1.4 Traction energy losses reporting

Attending these meetings has provided information on the structure of electricity supply at Network Rail. Several changes to the management of traction energy supply are being proposed, particularly boundary changes to Electricity Supply Tariff Areas, which have implication for monitoring of infrastructure energy. As this reporting process emerged from an ORR requirement, it has also provided insight into the regulatory pressures acting on NR, and highlighted a company-wide desire to 'lead' the regulator on environmental issues. Some members of this team have also attended interviews. The intention is to continue attendance at these, and
to pursue track site visits to improve understanding on how losses are measured.

*** Update, 30 September 2013 ***
It has been suggested that future reports should contain an analysis of the environmental impacts of losses, and benefits of any improvements. Details of this are to be discussed in the November team meeting.

5.1.5 Intelligent infrastructure

Members of this team have previously provided data regarding point heater energy use, and an exploratory exercise was carried out to estimate potential carbon emissions savings of new control systems. However, continued attempts to meet with the head of the Remote Condition Monitoring team have been unsuccessful. The intention is to redress this through provision of outputs relating to points heater analysis (see section 5.1.1).

5.2 Overall progress

Generally, initial meetings with all of these projects or teams have been positive, and suggested collaborative work in future. However, involvement with some of these has remained peripheral, and identification of specific data for environmental analysis has not been forthcoming, with the notable recent exception of points heating data.

There has also been one meeting with an Innovation Support manager, who has provided useful background information on innovation methodologies. It is proposed to discuss joint involvement with the other EngD researcher in the SBS team, regarding the diffusion of sustainable innovations in climate change adaptation, alongside energy-related topics.

Table 2 provides a summary of current engagement levels with various projects, and measures to improve these as discussed at the most recent all-supervisor meeting. Green indicates strong recent progress with identified methods of further engagement with the project. Yellow indicates strong initial meetings with those involved with projects, but a shortage of follow-up activities, or recent difficulties with communication. Red indicates priority areas for re-addressing topics, where a need for
communication is known, but replies have not been forthcoming, or requests for information have not been fulfilled.

Table 2 – Asset Management project engagement levels

<table>
<thead>
<tr>
<th>Project</th>
<th>Progress</th>
<th>Possible resolving actions (immediate)</th>
</tr>
</thead>
</table>
| Intelligent infrastructure (overseeing metering-related projects) | Have previously provided GHG emission calculations, but few recent replies. | 1. Meeting with Tony Brennan (project manager), to discuss progress of AMR installation project  
2. Re-contact John Smith (manager in Network Operations), regarding potential outputs of interest to the Intelligent Infrastructure team |
| Points heating (analysis of currently-available energy data) | Good recent progress            | 1. Analyse data on energy suppliers provided by Andrew Vickers (analyst of points heating data).  
2. Identify information of interest to CP5 Delivery Plan development. |
| Points heating control systems             | No in-depth involvement, despite being favoured by Energy Services | 1. Re-assess involvement following analysis of currently-available data  
2. Discuss feasibility of systems with further RAMs |
| Conductor rail heating                     | High initial interest, but little follow-up | 1. Meet Cliff Elsey (RAM) to discuss SBS ‘team triangle’ policy statement.  
2. Re-contact Mark Ellerby (engineer related to this project) |
| Conductor rail materials                   | Met external supplier, but progress stalled recently | 1. Re-contact Richard Allen (engineering lead on this project).  
2. Assess current supplier status, and contact new ones or previous interviewee as appropriate |
| Carbon/energy input into CP5 delivery plan | Good recent progress - has aided other areas | 1. Continue attending meetings with delivery team.  
2. Establish delivery programme for analysis |
| Traction energy losses reporting           | Meeting availability has been lower than anticipated. | 1. Continue attending meetings when available.  
2. Re-contact group regarding interview participation |
| Interviews - sustainable energy management | Interview material now well-prepared, but low recent response rate | 1. Send further email invitations, and follow-up with telephone calls.  
2. Schedule future interviews further in advance.  
3. Incorporate earlier informal meeting notes into current research.  
4. Seek methods of limiting impacts of interviewee availability on research. |
| [Innovation support]                       | Asset Management projects have been prioritised | 1. Discuss joint involvement with other members of Sustainable Business Strategy team.  
2. Discuss possible output delivery with Innovation Support team. |
To aid future engagement levels, a summarised 1-page briefing on the aims of my research is to be produced. This is to be supplied alongside any future invitations to discussions in support of this research. Previously, adapted slides from the EngD conference in June have been used as a briefing, but it was felt there were too many of these to deliver the message concisely without a speaker present.

Management of these projects for the purpose of this research has been grouped under 3 headings, which will provide a basis for part of the next 6-month report. Key NR stakeholders and research question impacts are summarised below:

**Points heaters and control systems**

Key NR stakeholders:

- Energy Services (central department within AMS)
- Intelligent Infrastructure team
- ‘Carbon input into CP5 delivery plan’ team (cross-departmental, including Sustainable Business Strategy members)

Involvement here will primarily feed into answering Questions 2 and 5, identifying the most effective options available to reduce the environmental impacts of track heater use. There are also implications for Question 11, reflecting upon communication of metering data for these, and how this may be affecting the delivery of other projects.

**Conductor rails and heating systems**

Key NR stakeholders:

- Route – Kent (Asset Managers and Engineers)
- Electricity and Power assets

This is primarily aimed at supporting question 2, i.e. determining the sustainability benefits of these projects. However, as this project is primarily being pursued by a particular Route, this will help to determine
the role that devolution has played in encouraging sustainable innovation (Question 1), and subsequently whether current decision-making processes support uptake of sustainable technologies (Question 11)

**Energy management – losses and metering**

Key NR stakeholders:

- Traction losses reporting team (within Energy Services)
- Automatic Meter Reader delivery project
- Sustainable Business Strategy team

In addition to aiding identification of energy use reduction methods (Question 1) Involvements in this category will investigate the flow of (metering) information between internal stakeholders, supporting Question 11. The effects on decision-making that wider meter installation bring about will also support Question 10.

### 5.3 General reflections on involvement

The coming 6-month period marks the transition from initial reviewing and exploration, to one where outputs are structured in detail, and delivery of these to stakeholders beyond the immediate SBS team and academic supervisors commence more fully. This is intended to demonstrate the value of this EngD research to stakeholders within Network Rail, and hence to increase exposure of the findings.
6. Actions

This section first outlines a list of specific activity-related goals, as discussed in previous sections. A summary of the research questions which will form the basis of the next report is then included. Finally, a detailed project plan timetable is displayed in fold-out Gantt charts.

6.1 Activity-related actions

The following activity-related goals are listed in order of intended completion date:

- Support delivery of UIC Sustainable Land Management Conference, 1-2 October
- Confirm details of delivery plan with new industrial supervisor in October
- Continue interviews until approximately 20 completed, integrating findings from previous exploratory meetings.
- Produce report based on exploratory interview programme, for Network Rail stakeholders (December)
- Produce report on infrastructure energy applications for Network Rail stakeholders before submission of next report (February-March)
- Attend taught modules (November and March), complete all necessary coursework and adapt for Network Rail accordingly

The following goals represent ongoing considerations for the duration of this research:

- Continue to evolve research questions as new information becomes available
- Provide report output based on research question content to supervisors and SBS team.
- Provide ongoing support to general SBS team functions and policy development
6.2 Research questions review

The questions listed below represent those which will guide research over the coming 6 months, and will provide the basis for the structure of the next 6-month report. The rationale and evolution processes of these questions are discussed in section 2.

- [Question 1] Do new devolved Route structures in Network Rail encourage energy-related innovation, and sustainable development through competition or cooperation?

- [Question 2] What are the most effective methods available to Network Rail for reducing infrastructure energy use, and how strong are the economic, social and environmental, and business cases for these?

- [Question 5] What is the potential for cooperation frameworks between Network Rail, National Grid, and energy suppliers, to achieve carbon emission reduction and sustainability objectives?

- [Question 6] What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?

NEW QUESTIONS

- [Question 10] What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on railway infrastructure?

- [Question 11] To what extent are gaps in information flow acting as a barrier to sustainable development at Network Rail, and what measures could overcome them?
6.3 Project Management Plan

Fold-out pages 44-45 provide detailed Gantt charts outlining the project plan for the duration of this EngD research. These divide activities by the research questions they support, and are based on decisions outlined in all previous sections.

Delivery points have been designed to tessellate with future 6-month report and dissertation deadlines, with as few clashes as possible.

The greatest level of detail for this plan has been provided for the next 12 months (i.e. October 2013 – September 2014). This is to allow leeway for future research question evolution and exploration, as has happened for this report.

Some aspects of this plan may change, due to the recent unexpected change of industrial supervisors. Specifics of the delivery plan will be discussed as soon as possible, but unfortunately this could not be completed before the submission deadline for this report, due to the timing of events. Delivery dates are therefore assumed to be approximate, but have been laid out as something approaching a final proposal. An update on this will be provided to supervisors at the earliest available opportunity.

Research questions answered in the literature review for the April 2013 report, or merged with other questions for the coming period (as detailed in section 2) have been omitted from the chart for clarity.
<table>
<thead>
<tr>
<th>Research Question</th>
<th>Activity</th>
<th>2012</th>
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**Gantt chart - Detailed research outline, page 1 of 2**

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### Research Questions

1. Do new devolved Route business structures in Network Rail encourage or discourage energy-related innovation?

2. What is the potential for cooperation frameworks between Network Rail, National Grid, TOCs, and energy suppliers, to achieve GHS emission reduction and sustainability aims?

3. What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?

4. What are the most effective methods available to Network Rail for reducing infrastructure and other energy uses, and how strong are the economic, social and environmental cases for these?

5. What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on Network Rail’s infrastructure?

6. To what extent are gaps in information flow acting as a barrier to sustainable development at Network Rail, and what measures could overcome them?

7. Do new devolved Route business structures in Network Rail encourage or discourage energy-related innovation?

8. What is the potential for cooperation frameworks between Network Rail, National Grid, TOCs, and energy suppliers, to achieve GHS emission reduction and sustainability aims?

9. What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?

10. What are the most effective methods available to Network Rail for reducing infrastructure and other energy uses, and how strong are the economic, social and environmental cases for these?

11. What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on Network Rail’s infrastructure?

### Future Research Questions Development

- Sustainability framework recommendation development
- Prepare 1-page summary research briefing

### Interview Research

- Planning
- Piloting
- Main interviews
- Collating and coding
- Analysis of results
- Write-up

### General Research Outline

- University taught modules (and coursework)
- Initial and continued literature review
- 6-month report, thesis, and dissertation writing

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**Gantt chart - Detailed research outline, page 2 of 2**

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<th>2016</th>
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<tr>
<td></td>
<td>Interview research (see details below)</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
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<tr>
<td></td>
<td>Discuss EngD innovation collaboration</td>
<td>Jul</td>
<td>Aug</td>
<td>Sep</td>
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<td>Oct</td>
<td>Nov</td>
<td>Dec</td>
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<td>Final delivery - Interview report</td>
<td>Jan</td>
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<td></td>
<td>Return to topic after AMR delivery</td>
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<td>Aug</td>
<td>Sep</td>
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<td></td>
<td>Pursue meetings with train operators</td>
<td>Oct</td>
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<td></td>
<td>Follow-up communications</td>
<td>Oct</td>
<td>Nov</td>
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<td></td>
<td>Establish gaps in knowledge at NR</td>
<td>Jan</td>
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<td></td>
<td>Investigate international conferences</td>
<td>Apr</td>
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<td></td>
<td>Literature review</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
</tr>
</tbody>
</table>
7. Concluding remarks

The unfortunate departure of one industrial supervisor has highlighted the need for a more structured delivery plan. Although the previous ‘hands-off’ approach allowed greater exploration of scientific- and sustainability literature and themes, it had been previously arranged that such a delivery plan would be agreed upon in preparation for this report. However, this will now need to be reorganised, in order to accommodate the requirements of the new supervisor, and the effects on the Project Plan are undeniable. It is hoped that this will be resolved quickly, following a short period of pre-organised leave in October.

Aside from this issue, all supervision has been more than satisfactory, and very forthcoming when minor issues have needed resolving. In general, the course is proceeding well, and understanding of the sheer breadth of sustainability as applied to railways has developed strongly. The coming six months are crucial to the successful outcome of this research, as the veracity of this first major Project Plan will be tested through the levels of engagement achieved with Network Rail projects.

Word Count

Executive summary: 528

Main body: 10,130

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References


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6-monthly EngD Progress Report

3: October 2013 – March 2014

Rupert Zierler

(URN: 6248587)

Integrating sustainability frameworks within Network Rail’s business practices –

The attitude-behaviour gap and infrastructure energy efficiency

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Executive Summary

This progress report covers all EngD research conducted during the period October 2013 – March 2014.

This research aims to address the gap between pro-environmental attitudes and behaviours, with respect to the management of energy-consuming infrastructure at Network Rail.

Progress towards deliverables

Most activity-related targets for the past six months have been achieved, with the exception of some actions relating to development of a Network Rail energy strategy. This has been redressed by redirecting focus towards completion of the Interview research project, and additional study of social-psychological theories in preparation for other projects.

Generally, this 6-month period has seen a major shift in the emphasis of research, from summarising technological approaches to energy efficiency, to investigation of achieving the same ends through behavioural change.

Interview research outcomes

A series of interviews with managers of infrastructure energy applications was completed in late 2013. A draft report on this has been prepared, and is in the process of being adapted for journal publication.

A complete summary of conclusions and recommendations is provided in this report, along with implications for publication and likely journals for submission.

As anticipated, attitudes towards energy-efficient technologies and the environment in general were broadly positive. However, their adoption was inhibited by factors including uncertainty towards the reliability of new technology, conflicts of interest regarding their business cases, a desire for increased central leadership on environmental issues (despite recent devolution of other business functions), and the absence of specific energy efficiency goals from the current suite of performance measures.
**Energy scenario development**

The second main phase of research (alongside the social/interview component) will consist of a series of energy use scenarios. These will compare the relative energy efficiency benefits of potential:

- Behaviour-change interventions and patterns
- Solely technological approaches to energy efficiency

With the Interview research nearing completion, in-depth planning of this phase will take place from May onwards.

Some methodological considerations are discussed, highlighting previous research into prediction of energy use patterns, based on a brief review of literature on similar research projects.

**Actions for the next 6 months**

The following actions have been prioritised for the next 6-month period:

- Completion of 2-year dissertation
- Publication of journal article based on Interview research
- Detailed planning of Energy Scenario modelling project
- Attend Tyndall PhD conference (April), EngD conference (June), and BEHAVE conference (September)

Most projects relating to primary research will commence in May, owing to a large number of coursework commitments in April (along with the Tyndall PhD conference).

In addition, further social research involving Network Rail’s graduate scheme intake is to be explored, developed, and carried out alongside a training session to be delivered in August by the Sustainable Business Strategy team.

A detailed project plan chart for the next 12 months is included in the main report, along with a summary research framework.
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Glossary

EMS - Environmental Management System
JCR - Journal Citation Reports (journal impact rating listings)
LEAP - Long-range Energy Alternative Planning software
NR - Network Rail
SBS - Sustainable Business Strategy team (Network Rail)
1. Introduction

This progress report discusses all major activities for the period April – September 2013. This has seen the completion of one phase of Interview-led research, and the initiation of the second phase, based on energy use scenario development.

Section 2 discusses progress against both specific actions, and research questions set out in the previous report. The latter of these includes some conclusions reached by the Interview research programme, as well as discussion of relevant literature not already covered in the main report.

Section 3 outlines course-related work that took place over the reporting period.

Section 4 discusses how the Interview research is to be communicated, both within Network Rail (NR) and in the scientific literature.

Section 5 discusses energy scenario development, intended as the next major phase of this research project. A few important journal papers are outlined, as well as issues relating to tying this together with the earlier socio-psychological research elements.

Section 6 lays out the series of actions scheduled or likely to take place over the next reporting period, and the research questions which will guide these.

Section 7 gives some final personal reflections on overall progress so far, as well as possibilities for the following 6 months.
2. Progress towards deliverables

Section 2.1 outlines progress against specific goals set in the previous report.

Section 2.2 discusses progress with relation to the research questions discussed in previous reports, and suggests some developments of these to reflect changes in focus over the past 6 months.

Section 2.3 introduces new research questions, which provide the central basis for Energy Scenario development, and for possible additional behavioural research.

Section 2.4 provides details of some additional actions which have supported this research, but were not discussed in the previous report.

2.1 Activity-related goals

Overall, the activities outlined in the previous report have been completed satisfactorily, although some have been postponed due to a combination of increased focus on Interview research, and issues detaining project stakeholders.

2.1.1 Support delivery of UIC land management conference

The feedback forum provided useful information for the Sustainable Business Strategy (SBS) team’s methods of interaction within NR.

This conference did not assist directly with research aims as much as previously expected, and did not provide any lasting links with external organisations. This was partly due to the land management and vegetation focuses of the event. However, the overall increase in team engagement has provided additional outlets for communicating outcomes of this research within NR.
2.1.2 Confirm details of delivery plan

The head of the SBS team, with whom this action was to be coordinated, has been temporarily seconded to a separate team handling work related to the recent severe weather events on parts of the network. As a result, coordination and delivery of work relating to the future NR Energy Strategy is likely to be delayed. This is not expected to be a major setback, as coursework was always scheduled to predominate during the March-April period.

2.1.3 Continue interviews

The initial target of 20 interviewees was met in November, allowing the write-up process to begin. Details of these interviewees are kept confidential, but an outline is provided in the draft report.

Information from meetings has been added to the original body of data gathered prior to December, bringing the total number of participants to 23. It is not yet clear whether this information will be added to the intended paper prior to submission for two reasons. First, although the data from the new interviews is not apparently contradictory to those collected earlier, the main report was written without this information, and adaptation time may increase as a result. Secondly, adding these would increase the period over which the interviews were conducted significantly, raising issues with comparison of the information gathered.

2.1.4 Produce interview report

The first draft of this report was completed in early January and submitted for feedback from academic and industrial supervisors. This feedback was broadly positive, and supervisors’ recommendations for alterations were implemented.

The ‘Writing for Publication and Public Engagement’ session at Surrey University highlighted the need to adapt the report’s content for specific journals. The initial report was not originally written with a specific journal in
mind, so changes are in the process of being made, in addition to those recommended by supervisors. This is discussed more fully in section 6.

2.1.5 Produce report on infrastructure energy applications for NR stakeholders

This goal has been postponed due to the extreme weather events over the Christmas and New Year period. The intention here was to present this material to the Head of Sustainable Business Strategy (SBS) with a view to presenting this elsewhere in the business, but actions to mitigate weather impacts have delayed this. Time has instead been focused on the Interview report project, developing understanding of social psychological theories, and other minor tasks as needed.

2.1.6 Attend taught modules

All modules during this period were completed, and all coursework submitted prior to respective deadlines.

In addition to the compulsory modules, the optional ‘Psychology of Sustainable Development’ was also attended. Details relating to taught modules are covered in section 3.

2.1.7 Evolve research questions

It was agreed that the key contribution of this research towards a future NR Energy Strategy would be towards elements relating to behaviour change. The other two principal elements of this will be looking at Supply (such as grid mix, ‘in-house’ renewable energy sources and general security), and Demand (use of low-energy technologies).

This plan for a more strategic focus, in combination with the socio-psychological focus of the research to date, has led to agreement with supervisors regarding the overriding structure of this EngD programme. Instead of focusing on a few energy-efficient technologies and their technical capabilities, potential energy scenarios will take a more generalised approach for all future technology-led energy use reductions. This will then be compared with a scenario based on behaviour-change led energy
practices, which will be based on the interviews and some future socio-psychological components to the study (discussed later in the report).

The full impact of this shift on the body of research questions is discussed in section 4.

2.1.8 Provide report output based on research question content to supervisors and SBS team

A brief summary of content from the Interview research report was produced and discussed with supervisors within the SBS team. This raised some potential issues relating to presentation style, when delivering information on this project to the rest of the business.

Short summaries of coursework content were also produced for the most relevant reflective essays and exercises. It is intended to continue this practice with output from the forthcoming modules, particularly that from Psychology of Sustainable Development.

2.1.9 Provide ongoing support to SBS team

A series of meetings were held in early 2014 regarding integration with the Business Culture Change team at Network Rail, building a sustainability programme with a similar structure to NR’s previous safety culture change development. Support was given in the identification of key stakeholders, and meetings to determine the precise aims of the programme. This is due to continue over the next few months, although some meetings have been missed to attend lecture courses.

It was recently announced that the SBS team would be delivering a training session to Network Rail’s 2014 engineering graduate intake. Meetings with those delivering the training scheme highlighted opportunities within the programme for conducting social-psychological research. Details of this are discussed more fully in section 6.
Table 4 - Progress summary for Activities. Green indicates completion as expected; Red indicates a goal is currently behind schedule

<table>
<thead>
<tr>
<th>Goals</th>
<th>Status</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support delivery of UIC land management conference</td>
<td>Completed</td>
<td>Completed, but no significant outcomes for wider research project.</td>
</tr>
<tr>
<td>Confirm details of research delivery plan</td>
<td>On hold</td>
<td>Work towards NR Energy Strategy delayed by recent weather events</td>
</tr>
<tr>
<td>Continue interviews</td>
<td>Completed</td>
<td>Satisfactory number of interviews completed. Others will be added to dataset, but may be omitted from final journal paper.</td>
</tr>
<tr>
<td>Produce interview report</td>
<td>Completed</td>
<td>First draft completed. Minor progress has been made towards journal submission.</td>
</tr>
<tr>
<td>Produce report on infrastructure energy applications for NR stakeholders</td>
<td>On hold</td>
<td>Work towards NR Energy Strategy delayed by recent weather events</td>
</tr>
<tr>
<td>Attend taught modules</td>
<td>Completed</td>
<td>All attended successfully, and all coursework completed on schedule.</td>
</tr>
<tr>
<td>Evolve research questions</td>
<td>Completed</td>
<td>Discussed in section 4 of this report.</td>
</tr>
<tr>
<td>Provide report output based on research question content to supervisors and SBS team</td>
<td>Completed</td>
<td>Summary document completed and discussed. Application of this information to Energy Strategy currently delayed.</td>
</tr>
<tr>
<td>Provide ongoing support to SBS team</td>
<td>In progress / ongoing</td>
<td>Continued to provide input at SBS team meetings, and general in-office support to industrial supervisors.</td>
</tr>
</tbody>
</table>
2.2 Research question progress

Overall, progress towards addressing these questions has been promising, largely supported by the completion of the semi-structured interview programme and subsequent report.

Some of the proposals made in this section of the previous report relating to outputs have been reassessed and rationalised at subsequent supervisor meetings. This has largely been due to the increased focus on the Interview research, and the resulting shift in overall emphasis from technical analysis to behavioural interests and policy studies.

The remainder of this section discusses how each of these questions has been addressed by the Interview research project or other activities. Where appropriate, additional literature (not currently included in the Interview report) is discussed to support this.

A visual summary of research question progress is provided in Table 6.

[1] Do new devolved Route structures in Network Rail encourage energy-related innovation, and sustainable development through competition or cooperation?

The Interview research programme identified that the effects of Route devolution were not perceived as being particularly influential on infrastructure energy use. Identification of opportunities for efficiency improvements was perceived to have been made easier by the new Route structure. However, steps towards implementing these improvements were not felt to have made any progress as a result of the devolution process. This suggests that the ‘bedding-in’ period for the new Route organisation structure was still taking place at the time of the interviews.

The Interview programme also highlighted that the expectation was for energy management goals to come from the Central functions of NR, rather than to be developed separately by the Routes. This implies that behavioural approaches to energy efficiency will need clear and obvious support from other parts of the business. This reflects the findings of Paillé and Boiral (2013) who identify the importance of perceived organisational support.
These findings also reflect those of Christina et al (2013), who identify that the structural context of an organisation has a greater impact on energy-related behaviours than personal values or beliefs. They also create a theoretical framework based on Value-Belief-Norm theory, designed to assess energy management performance in organisations (Table 5). Although this paper investigates building energy use, the implications are likely to hold for infrastructure energy, as the management structures involved are reasonably similar.

Table 5 - After Christina et al (2014). Value-Belief-Norm theoretical framework for the workplace.

<table>
<thead>
<tr>
<th>Organisational environmental values</th>
<th>Beliefs</th>
<th>Norms</th>
<th>Behaviours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>Supervisory commitment</td>
<td>Sense of incorporation of pro-environmental behaviour in workplace</td>
<td>High performance of energy-related tasks</td>
</tr>
<tr>
<td>Internal</td>
<td>Performance management, Task strategy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This question will continue to be pursued, given the apparent importance of company structure to pro-environmental performance. However, the act of devolution itself may not be as influential on pro-environmental outcomes as believed at the outset of this EngD programme.

[2] What are the most effective methods available to Network Rail for reducing infrastructure energy use, and how strong are the economic, social, environmental, and business cases for these?

The infrastructure technologies with the most significant likely energy usage reductions have been discussed in the previous progress report. These were identified at meetings with senior managers in the NR’s Energy Services department. The principal high-impact technological approaches for infrastructure applications are:
- Points heater control technologies
- Conductor rail heater improvements
- Conductor rail material changes
- Addressing losses from traction supply (overhead line and 3rd rail)

Due to the increased research emphasis on policy and behaviour change, additional technological applications with significant future impacts on energy efficiency have not been identified at this stage.

Therefore the question is no longer which technologies will deliver the greatest benefit, but how these benefits will compare with those of possible behaviour change-based approaches to NR’s energy management. This has been captured by a new research question [13] discussed in section 2.3, which will guide the development of Energy Scenarios.

[5] What is the potential for cooperation frameworks between Network Rail, National Grid, and energy suppliers, to achieve carbon emission reduction and sustainability objectives?

The previous progress report proposed an output paper based on this question. However, discussions with supervisors led to an increased focus on the Interview research project, which has placed this question effectively ‘on hold’.

Given the recent energy supplier deals discussed in previous reports, it has been considered more relevant to concentrate on factors influencing internal NR stakeholders for the time being. This is also to address calls from psychological literature to specifically address workplace production-related behaviours (Uzzell & Räthzel, 2009), rather than necessarily to influence external stakeholders.

This question may be addressed in greater detail in subsequent reports, but there are no specific outputs related to this question scheduled for the next 6 months.

[6] What lessons can be learnt from foreign rail infrastructure operators about sustainability integration?
Framing this as a separate research question is no longer considered useful to the overall research programme. Although of interest to Network Rail, the phrasing of the question is too general to provide a basis for specific research programmes. Literature review for both coursework and research has uncovered examples of sustainability reports (e.g. Pepy, 2011), research and policy on technical infrastructure applications (RSSB, 2009) (e.g. Jackson, 2009; SAN Railway Systems, 2009) and scientific articles (e.g. Åkerman, 2011; Chang & Kendall, 2011; Chester & Arpad, 2010; Mikhail Chester and Arpad, 2012) based on foreign examples. Future reports will not therefore cover this question, as it is implicit in all others.

[10] What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on railway infrastructure?

The Interview research programme identified which psychological barriers to energy-efficient behaviour affect NR employees, but not necessarily how they can be overcome. Hence, a review of social-psychological literature has revealed several potential methods by which employees can be encouraged to adopt these behaviours. However, caution must be exercised when trying to implement too many pro-environmental goals at the same time.

As discussed earlier, research by Paillé & Boiral (2013) reveals how ‘perceived organisational support’ is positively related to ‘organisational citizenship behaviour for the environment’ (e.g. biodiversity offsetting). This could be through issuing of environmental performance targets, or funding specifically for environmental impact mitigation. This suggests that energy efficiency could be encouraged by communicating how much NR’s energy use affects the surrounding environment, and the social energy security impacts of NR’s increasing energy requirements. This needs to be treated with caution, however, as there is a need for further research into the effectiveness of encouraging pro-environmental behaviour using ‘spillover’ from concern for other environmental issues (Murtagh, Gatersleben, & Uzzell, 2012).

(Paillé & Mejía-Morelos, 2014) demonstrate that employee commitment to a given organisation acts as a mediator to this sense of organisational support and pro-environmental behaviour. Psychological contract breaches reduce this sense of support. In the case of Network Rail, this may represent the...
desire for leadership from central functions on environmental issues. Here, the management of electrical equipment is associated with ensuring the smooth operation of the railway, rather than necessarily identification of high energy consumption problems.

Slow adoption of energy-efficient technologies could also be symptomatic of a more general resistance to change. Although looking at travel behaviours, (Murtagh et al, 2012) identify self-identity threat as a possible source of this resistance. In the case of NR energy managers, this is manifested as an infringement of role identity, such as stated by one interview participant:

“Give an engineer a target, and they’ll meet it, but don’t expect them to develop the targets themselves.”

In a separate paper, Murtagh et al (2013) also identify that although setting explicitly energy-related targets may be beneficial to a business, motivations other than energy reduction are likely to be needed to encourage more effective energy behaviour changes. The need to reduce energy use needs to be framed in more tangible, asset-specific terms, such as “turning lights off” or “using heaters less” in order for these actions to be performed.

However, Christina et al (2013) identify that energy-related task performance is negatively affected by multiple-goal conflicts, such as meeting increasing customer requirements whilst saving additional energy. Setting energy-related delivery goals must therefore be incorporated carefully into existing employee incentive schemes to avoid conflicts. Responsibility for energy-related goals may require delegation to individuals who are dedicated specifically to that task, rather than needing to meet all NR’s performance requirements at once.

Zhang, Wang, & Zhou (2013) also point out that, although personal norms are a major influence on whether employees perform energy-efficient behaviours, these are negatively moderated by the organisational energy-saving ‘climate’ (i.e. company-set goals). This implies that schemes to address managers’ energy-efficient practices should not take a heavy-handed approach, and ‘drown out’ the normative influences encouraging pro-environmental behaviour acting on individuals from outside the workplace. Their study investigated in-office activities, but may also hold true for production-related activities such as infrastructure management.

In summary, the Interview programme uncovered the existing (perceived) barriers to achieve infrastructure energy efficiency, which corroborates
current psychological research into workplace pro-environmental behaviour. Although this supported the overall process of answering this research question, the behavioural influences on energy efficiency (and pro-environmental behaviour in general) are revealed as being far more complex in the scientific literature. Methods of influencing internal stakeholders should be revealed by further behavioural research, a component of which is intended to take place with Network Rail’s graduate intake. This is discussed more fully in section 6.1.5.

[11] To what extent are gaps in information flow acting as a barrier to sustainable development at Network Rail, and what measures could overcome them?

This question was originally intended to focus on the energy flow relating specifically to data transfer within NR. Information flow was not identified as a major barrier to achieving energy efficiency among the interview participants – ownership of asset information had a clear structure, and communication frameworks between Route Asset Managers had become regularised by the time of the Interviews.

Several participants did identify that more energy efficiency schemes were more likely to take place following the completion of metering- and sub-metering programmes. However, implementation of these is already scheduled to take place within the timescale of this EngD programme, so addressing this need should not be considered a primary concern for research purposes.

The more influential information flow is therefore more likely to be related to training on sustainability, pro-environmental behaviour and energy efficiency issues. Greaves et al (2013) investigate the influence of personal beliefs on specific office-related activities, including switching off computers, use of video conferencing instead of travel, and recycling waste. Although these activities are valuable in reducing energy use, they do not necessarily represent the primary activity of a given business in the field of manufacturing, or more appropriately, infrastructure operation.

Greaves et al (2013) also demonstrated the potential validity of the Theory of Planned Behaviour in predicting energy-saving actions in the workplace. This theory has a similar structure to Triandis’ Theory of Interpersonal
Behaviour (see Triandis, 1977), which was used as the basis for mapping Interview responses.

Attempts to address this question will therefore focus more on training-related information, rather than transfer of raw energy data between managers or departments, due to the more wide-reaching implications for encouraging behaviour change.
Table 6 - Progress summary for research questions. Green indicates a completed question; Yellow indicates work is ongoing, but satisfactory to this point.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Progress</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Some results, but ongoing</td>
<td>Route devolution was not considered a primary source of concern for interview participants, but organisation of energy-efficiency interventions may have been affected</td>
</tr>
<tr>
<td>2</td>
<td>Completed</td>
<td>Technological methods of reducing energy use have been identified. How effective these are, compared to behavioural approaches now needs to be determined</td>
</tr>
<tr>
<td>5</td>
<td>Ongoing</td>
<td>Relationships between NR and energy stakeholders are likely to develop further as more complex energy management control systems come into operation.</td>
</tr>
<tr>
<td>6</td>
<td>[Closed]</td>
<td>This question was considered to be implicit to all others, and no longer requires a separate stated question</td>
</tr>
<tr>
<td>10</td>
<td>Ongoing</td>
<td>Interview research suggests a lack of incentives for pursuing energy-efficiency objectives, and a desire for increased leadership from the centre of the organisation</td>
</tr>
<tr>
<td>11</td>
<td>Some results, but ongoing</td>
<td>Although not raised as a major issue in the Interview research programme with respect to internal data transfer, there is a possibility that a lack of sustainability training could be preventing wider awareness of energy use issues.</td>
</tr>
</tbody>
</table>
2.3 New emergent questions

The research questions covered in the previous section have guided the development of the Interview research, and the decision to design energy use scenarios in support of NR’s energy strategy. However, some new questions have been devised to more closely represent the outputs of these two key projects.

- [12] What are the comparative benefits of behaviour change strategies, or technological solutions for achieving energy efficiency and other sustainable development aims?

This question frames the forthcoming development of energy scenarios. Comparing the two approaches will highlight which is the most cost-effective. It is likely that some combination of both approaches will be the optimal result, but this question is intended to reveal which pathway should receive the greater emphasis within NR.

- [13] Is Triandis’ Theory of Interpersonal Behaviour a useful predictor of energy management behaviour at Network Rail, and what are the implications for influencing energy-efficient behaviour?

Most current research into the workplace pro-environmental value-action/attitude-behaviour gap focuses on office- (Murtagh et al, 2013) or travel-related activities (Lo et al, 2013). As a result, the application of social psychological theories such as the Theory of Planned Behaviour, Value-Belief-Norm and others in a business practice context has not yet been thoroughly tested. This question is intended to frame this requirement, and serve as a basis for later social research components of this research, such as investigation of NR’s graduate intake (as discussed in section 6.1.5).
2.4 Additional activities

2.4.1 EngD conference, 17-18 June 2014

The first 500-word abstract for the 2014 EngD conference has been submitted (see Appendix 1). The chosen stream is 'Academic contribution to knowledge and adding to the “big picture”', selected for two reasons. Firstly, the ‘Business application’ (as represented by the other main conference stream) is likely to be strategy development-based, and therefore highly specific to Network Rail, whose funding and governance structure is not widely replicated worldwide. Secondly, the need for cross-disciplinary research into energy behaviour change in business practices is widely acknowledged in scientific literature (e.g. Murtagh et al., 2013). Feedback on the initial abstract had not been delivered at the time of report submission; the final format of the presentation is yet to be determined by the organisers.

2.4.2 Tyndall PhD conference, 23-25 April 2014

The Tyndall PhD conference is a climate change-oriented event for current doctoral researchers, taking place at the University of Manchester in 2014. A 300-word abstract was submitted (see Appendix 2), under the themes of Energy & Emissions, and Governance and Behaviour (others included Water & Land, and Cities & Coasts). This will take the form of a poster presentation, although a 5-minute presentation was applied for.

2.4.3 BEHAVE conference, 3-4 September 2014

An abstract was also submitted to the BEHAVE conference (3rd European conference on Behaviour and Energy Efficiency), due to take place in September 2014. It is not known at this time whether the submission was successful. The high admission costs may also prove prohibitive to attendance at later conferences, when this research is likely to be at a more complete stage, and more appropriate for presentation.
3. Course-related work

All or part of the following lecture courses took place during the previous six months. Some salient points for the main body of research which were raised by these are discussed.

3.1 Corporate Environmental and Social Responsibility

Coursework for this module discussed the role of ‘choice editing’ for managing sustainable consumption patterns. A particular point of interest raised here was the importance of government legislation in encouraging the adoption of pro-environmental technologies. Bocken and Allwood (2012) highlight how this is the case for some businesses in the consumer goods industry.

The structure of Bocken & Allwood’s paper also provided guidance for the forthcoming Interview paper, as it was based around a similar series of semi-structured interviews, in a business context. Their approach to coding interview responses influenced the design of the Interview response table. Although this addressed approaches to influence consumer choices rather than managerial ones, a similar framework could be constructed to identify methods of influencing these as well.

3.2 Environmental Auditing and Management Systems

This module was valuable in understanding the activities of the rest of the SBS team, which has been addressing requirements of an Environmental Management System parallel to this research programme. Research on this project has not so far had any involvement with the environmental auditing process, and is not likely to. However, the development of ISO50001 Energy Management System standards was also discussed, and the audit processes are likely to be very similarly structured. Any future NR Energy Strategy will need to guide the design of Energy Management Systems which conform to these standards, if audit-based accreditation is to be achieved, and should therefore consider all aspects required.
The post-module assessment for this module was still in progress at the time of submission, and pre-module marks were not yet available; details of this coursework will be discussed in a later report.

### 3.3 Psychology of Sustainable Development

Psychology of Sustainable Development is anticipated to be important for the completion of initial social research stage, particularly as the author has not previously attended any form of formal psychology training.

This module highlighted the importance of distinguishing between the ‘value-action’ gap and the ‘attitude-behaviour’ gap. Up to this point, the two terms had been used interchangeably. The Interview research categorised participant responses by attitudes towards specific business activities, rather than overarching discussions of sustainability values (although these were occasionally touched upon). This being the case, the Interview research will hence be referred to as an attitude-behaviour gap study.

The post-module exercise is likely to be highly useful, as one exercise is to critically evaluate evidence for the attitude-behaviour gap for pro-environmental behaviours. This will also aid with creation of a further research project among Network Rail’s graduate intake (see section 6.1.6). Although taking place within this reporting period, the course is scheduled to take place the week immediately prior to submission. Coursework from this module will therefore be covered in a subsequent report.
4. Interview research communication

A key output from this reporting period was the production of a draft report based on semi-structured interview-led research, carried out over the period May-November 2013. This report is currently being modified for journal publication. In addition, input from the Psychology of Sustainable Development module is expected to benefit the writing style.

This section provides a summary of the Interview research. Key findings from the interview process are re-summarised here. The way in which this research ties in with the wider project is then discussed, in terms of communicating within the business, and the approach taken to publication. How this will tie in with the intended Scenario Development project is discussed in section 5.

4.1 Summary of findings

The following section is taken from the ‘Conclusions’ section of the draft Interview report:

Effects of devolution

Route devolution at NR has the potential to drive innovation in energy efficiency. However, in order to achieve this, targets and incentives relating to energy use need to be set, by either Central business functions or the Regulator. The effects of devolution on Network Rail’s approach to energy efficiency have been relatively low-impact, positive or negative, reflecting the fact that this was not a direct goal of devolving responsibility. However, although localisation of management improves the ability to identify problems, it has not, as yet, delivered solutions in this area. In fact, there is a possibility that devolution may be a hindrance, given the continued need to deliver against particular performance measurements, and a desire for improved central management leadership.

Barriers to implementing energy efficiency

The importance of the PPM among those interviewed highlights the effectiveness of business incentives, but its current dominance occasionally obstructs pursuit of innovative technologies, often due to the increasing volume of traffic over NR.
metals. This would reflect the recommendation of Leitner et al (Leitner, Wehrmeyer, & France, 2010) that policy instruments need to reflect the desired goals to encourage innovation in the right areas. Linear assets do not apparently differ from buildings, other businesses, or personal everyday energy use in this respect. Assuming that competition is a driver for innovation, establishing these policy instruments would enable Routes to compete against one another for increasing efficiency of their assets.

Use of PPM has enabled Network Rail to move on from the previous profit-oriented governance model of Railtrack, which led to the degrading of infrastructure in favour of cost savings, negative impact on the perception of rail’s value to the public, and major safety failures culminating in the Hatfield rail crash of 2002. PPM is seen by participants to have refocused Network Rail’s purpose as improving the social value of rail through the inherent convenience of reducing delay minutes, alongside the economic benefits brought by reducing journey times and improvements to UK productivity (Chen & Hall, 2011).

However, this research suggests that working towards PPM targets has also led to a heightened sense of caution towards environmentally-innovative technologies and practices, and a tendency to improve incrementally on existing ideas rather than develop new ones. This is coupled with a corporate memory of desperate emergency repairs and closures in the post-Railtrack years, and a recent drive to embed a pro-safety culture change, and a programme of reducing government investment, to instil a highly risk-averse culture across all aspects of the business. Whilst this is highly desirable from a safety point of view in the short term, this encourages technological lock-in, hinders demand-side energy-related innovation, and increases exposure to long-term energy security risks. In terms of encouraging pro-environmental behaviour change, this could also reflect the desire to “get one’s own house in order” before dealing with externalities such as environmental effects, despite the overall higher-than-anticipated environmental awareness of those interviewed.

Recommendations from the report were then as listed below:

- PPM needs to be re-evaluated as a performance measure for some aspects of the business, particularly those which impact most strongly on greenhouse gas emissions or energy use, and accompanied by goals and incentives explicitly related to energy efficiency.
• However, this is not a recommendation to completely cease the use of PPM as a driver for the business as a whole, owing to the social benefits brought by improved services, and the improvements to NR’s public perception to date.

• Peer communication with the specific objective of improving energy efficiency, should be established at the asset manager level for trackside infrastructure, both within NR and with key external stakeholders.

• Clearer guidance from central NR functions regarding energy efficiency aims and requirements are required. This should ideally be accompanied by additional training schemes, and acquisition of new skillsets or expertise relating to renewable energy generation.

• No improvements to energy efficiency should come at the expense of safe operation of the railway or excessive disruption to service.

In addition, Paillé & Mejía-Morelos (2014) explicitly calls for research combining social exchange theory, the Theory of Planned Behaviour and Value-Belief-Norm theory in an organisational context. This supports the rationale for the response-mapping methodology used in the Interview research report. Although the interview data were instead mapped to Triandis’ Theory of Interpersonal Behaviour, this retains similarities to the Theory of Planned Behaviour, and has been recommended as a method of analysing energy behaviours to the UK Government (Chatterton, 2011).

4.2 Communicating results to Network Rail

Following the completion of the first report draft, attempts were made to contact a small number of the original interview participants, to conduct a consultation exercise on the results. The aim of this was to confirm that the results were representative of their original statements, and to address the feasibility of some of the recommendations. However, none were available to meet prior to the submission of this report. This is probably partially due to the increased demands on all asset managers following the recent severe weather events affecting parts of the network.

Although this is not a major setback in terms of publication requirements, this would address potential issues with communicating the findings within NR, which are, at present, subject solely to progress with energy strategy.
development. As progress with this has been delayed, establishing other communication routes within the business through this consultation process would boost the value of this research to NR in the meantime.

4.3 Pathway to publication

The journals discussed below have been selected for potential submission. At the time of report submission, initial enquiries regarding material relevance had been made *Energy Policy*, *Environment and Behavior*, and the *Journal of Cleaner Production*. Impact ratings are given for each, and all are in the top quartile of their respective journal categories with a few exceptions (according to ISI Web of Knowledge, 2014). Factors influencing journal submission are summarised in Table 7, along with additional journals worth consideration in case of submission difficulties to the others.

*Energy Policy* accepts papers on a wide variety of topics related to energy use in both consumer- and organisational contexts. This is the primary candidate for article submission at the time of this report, mainly due to the broad variety of topics accepted.

*Environment and Behaviour* is in the second quartile of both Environment and Social Psychology categories. However, this journal features several pieces of qualitative environmental psychology research. This will be considered as an alternative submission target, if responses from *Energy Policy* or the *Journal of Cleaner Production* are not forthcoming.

The *Journal of Cleaner Production* featured an article by Bocken & Allwood (2012), which very closely reflected the structure of this Interview research (discussed in section 3). Other material in this journal tends to focus on manufacturing processes, but it is believed that this Interview research may have relevance for management of energy in large organisations. This will be considered an alternative submission target, pending a positive response to email enquiries.

The *Journal of Environmental Psychology* tends to focus on outputs from empirical, quantitative studies, rather than qualitative or thematic analysis. This may still be considered as a possible outlet for the intended research into Network Rail’s graduate intake at a later stage, but requires further empirical data (ideally from a questionnaire survey) before a full submission can be considered.
Table 7 - Journal information, reviewed to support article submission, listed alphabetically. Priority journals for submission are highlighted in italic font.

<table>
<thead>
<tr>
<th>Journal</th>
<th>Impact factor</th>
<th>Top quartile?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Policy</td>
<td>2.743</td>
<td>YES</td>
<td>Accepts articles on broad variety of energy topics. <strong>TOP PRIORITY for article submission</strong></td>
</tr>
<tr>
<td>Environment and Behavior</td>
<td>1.282</td>
<td>NO</td>
<td>Secondary target for article submission, as Interview research is similar to most of its content</td>
</tr>
<tr>
<td>Journal of Cleaner Production</td>
<td>3.398</td>
<td>YES</td>
<td>A secondary target – research similar to the Interview programme has previously been accepted</td>
</tr>
<tr>
<td>Journal of Environmental Economics and</td>
<td>1.969</td>
<td>YES</td>
<td>Accepts articles on a wide variety of environmental topics, but economic focus may not suit behavioural content</td>
</tr>
<tr>
<td>Management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Journal of Environmental Psychology</td>
<td>2.549</td>
<td>YES</td>
<td><strong>Priority for later article submission, pending results of later research projects</strong></td>
</tr>
<tr>
<td>Review of Environmental Economics and Policy</td>
<td>3.273</td>
<td>YES</td>
<td>Focuses on review articles. May be considered for submission later in the EngD programme, following additional behavioural research.</td>
</tr>
<tr>
<td>Transportation Research Part D: Transport</td>
<td>1.291</td>
<td>NO</td>
<td>Focuses on transport studies, but may be appropriate given the implications of this research for infrastructure operators.</td>
</tr>
</tbody>
</table>
5. Energy scenario development

Section (5.1) discusses the academic- and business literature which validates the need for scenario development, and methodological approaches used for predicting energy use elsewhere.

Section (5.2) then discusses how these could apply to energy scenario development for Network Rail infrastructure, with reference to possible influences on each scenario.

5.1 Literature review

Maleviti, Mulugetta, & Wehrmeyer (2012) model future energy use scenarios for the Greek Hotel sector. These, like the intended outputs from this research, use input from interviews with managers to determine likely patterns of energy use. Howlett et al (2011) also put forward that governmental energy legislation on its own is not sufficient to bring about significant changes in energy use. Although researching the hotel sector, this methodology could be transferred to an infrastructure context relatively easily; discussion points from the Interview research closely resemble those mentioned by hotel managers, such as the dominance of other (financial) performance measures.

The research referred to in these articles made use of the freely-available Long-range Energy Alternative Planning (LEAP) software. This was explored as a possible method of generating scenario data for the next phase of research, due to its use by Maleviti et al and its open source availability for students. However, the freely-available data provided with the software is based on energy mixes from outside the UK; new data would need to be inputted by hand. As a result of this, most future projection work is likely to use Microsoft Excel as the main modelling tool.

Oh, Wehrmeyer, & Mulugetta (2010) use a log mean Divisia index to determine the likely future growth of carbon dioxide emissions in South Korea, based on energy use statistics from recent years. It is unclear whether Network Rail’s recent energy use patterns can be used in this way for three main reasons. Firstly, there have been significant increases in electrification coverage since the 1980s, which introduce dramatic shifts in energy use. Secondly, electrification of the Great Western Main Line and
other routes will have a similar effect, but are likely to utilise some different technologies from the outset (such as infrastructure to cope with regenerative braking systems). Finally, the electrical throughput associated with modern rolling stock are much higher, and require their own specific infrastructure energy technologies (such as conductor rail heating) to accommodate their use; it is unclear how these are likely to change in the near future.

Zhang, Siebers, & Aickelin (2012) identify residential energy consumer archetypes based on their energy use patterns. Identification of management archetypes could also benefit scenario development. In the case of NR, these archetypes could be divided by department, infrastructure asset type, organisational Route or demographics of the managers themselves, along age, gender or experience lines, for example.

Several theoretical frameworks for predicting energy use are therefore known to exist. Further exploration is required to determine which of these are most appropriate for appraising NR’s energy-related operations.

### 5.2 Methodology

#### 5.2.1 General approach

The central methodology used will reflect that used by (Maleviti 2010). Initial social research from the Interview programme and other components will lead to development of a behaviour change-led energy scenario, whilst more traditional projection methods will determine the output of a technological solution-led scenario.

In addition to a figure for overall electrical energy use, these scenarios will produce likely pathways for the energy intensity of NR’s service provision. This implies use of a functional unit based on electrical energy, combined with a measure of service levels, such as passenger-km or freight-tonne-km. This will be determined in a later supervisor meeting.

The overall approach is summarised in Figure 5, (page 33).
5.2.2 Behaviour change-led scenario

One or more scenarios will incorporate inferences from the Interview report and later behavioural research projects (such as the intended investigation of this year’s graduate intake, see section 6.1.6), to predict energy use and intensity levels resulting from the rollout of a behaviour change-led energy strategy. The likely impact levels of several possible interventions would be based on this information, alongside information from external psychological studies. These modelled interventions could be based on:

- Awareness-raising campaigns
- General increased availability of metering information
- Driver behaviour training (of Network Rail-owned rail vehicles)
- Increased support for energy-related innovation schemes

Estimates of improvements to environmental performance brought by implementing an Environmental Management System will be influenced through determination of the relationship between policy attainment and environmental performance at NR, as suggested by Wehrmeyer (2011).

Senbel, Ngo, & Blair (2014) outline a possible competition-led methodology for addressing personal energy use. This could potentially serve as a driver for innovation in discrete settings, such as station buildings or depots, although how this would transfer to a linear infrastructure setting is less clear.

5.2.3 Technology-led scenario

There is also planned to be a scenario based on the absence of these behavioural interventions, based on a situation where Network Rail relies solely on technological solutions. However, the precise details of where behaviour change ends and technology begins is yet to be discussed. For example, Vidmar (2012) also discusses a review methodology for management of energy efficiency in industrial settings. The implications of this method for energy use could be considered as part of the behaviour-change led scenario, but could also be seen as a mechanistic approach to the problem, focused on technology rather than influencing attitudes. Similarly, automated energy management systems could be considered as a technological solution, or a function of the energy behaviour of the programmer of the devices.
Figure 5 - Current scenario structure, including elements common to both intended scenarios
6. Actions

All actions discussed here are summarised on the main project plan (Figure 7). The diagrams also map how the actions discussed here will deliver on the guiding research questions.

6.1 Activity-related actions

6.1.1 Two-year Dissertation

This is due for submission at the end of this reporting period. This will need to be completed in the following stages, with the main write-up occurring in August-September.

- Attend all university run preparation sessions
- Approve dissertation plan with all supervisors
- Obtain feedback on draft versions from all supervisors
- Submit dissertation

6.1.2 Conferences

The conference presentations listed below are scheduled to take place over the next 6 month period.

- EngD conference
  - Complete 1000-word abstract
  - Complete poster/slides presentation material as required
  - Deliver presentation (17-18 June 2014)

- Tyndall PhD conference
  - Produce poster presentation materials and send to organisers
  - Deliver presentation (23-25 April 2014)

- BEHAVE conference
  - Await response from conference organisers
  - Prepare material as needed
6.1.3 Taught modules

Attend the following taught modules, complete all necessary coursework and adapt for Network Rail accordingly:

- Environmental Auditing and Management Systems
- Psychology of Sustainable Development
- Environmental Law

6.1.4 Interview research publication

A primary goal for the next six months is to submit the Interview research piece to an academic journal. The aim is to complete this before the end of June 2014, and will be carried out in the following stages:

- Select journal based on responses from initial enquiries
- Adapt content of original Draft interview report to requirements of specific journal(s)
- Submit for publication

6.1.5 Continue consultation efforts regarding interview research

This is to overcome the shortage of responses encountered prior to submission of this report. This is intended to confirm the validity of findings within the business.

Meetings are likely to be obstructed to a degree by course attendance until the end of April. However, attempts will be made to arrange consultations for April and May. It is hoped that any major work relating to the extreme weather events of early 2014 will be resolved by this point, increasing managers’ availability.

6.1.6 NR graduate induction research

The SBS team is scheduled to do deliver a training session on sustainable development issues for the NR 2014 graduate intake. This project has only recently been identified as a possible source of research data, so details have not been finalised at this point.
The precise details of how this will be conducted are yet to be confirmed with those in charge of the induction process, and are dependent on the eventual sample size. So far, involvement has only been secured with the Engineering graduate segment, although the idea of delivering a similar session with the general management intake is being pursued. In the case of the former, then the research would take a qualitative approach once, probably involving the observation of workshop activities on the day of delivery, and ideally some follow-up activities such as diary-keeping on their experiences sustainable development-related issues. If the full intake is involved, quantitative questionnaire-led research could be implemented; this is the preferred scenario, as it allows this research to take a more rigorous mixed-method approach, which has benefited previous research into railway station use by the author (Zierler, 2010).

The likely course of action is summarised by the following list of procedures:

- Discuss details of research activity with those responsible for the training session.
- Produce sustainable development training presentation and workshop materials
- Analyse outputs of workshops
- Produce questionnaire if required
6.2 Research questions review

The questions listed below represent those which will guide research over the coming 6 months, and will provide the basis for the structure of the next 6-month report.

- [Question 1] Do new devolved Route structures in Network Rail encourage energy-related innovation, and sustainable development through competition or cooperation?

- [Question 5] What is the potential for cooperation frameworks between Network Rail, National Grid, and energy suppliers, to achieve carbon emission reduction and sustainability objectives?

- [Question 10] What can be done to influence decision-making toward adopting sustainable, low-energy alternative technologies on railway infrastructure?

- [Question 11] To what extent are gaps in information flow acting as a barrier to sustainable development at Network Rail, and what measures could overcome them?

NEW QUESTIONS

- [Question 12] What are the comparative benefits of behaviour change strategies, in contrast to technological solutions for achieving energy efficiency and other sustainable development aims?

- [Question 13] Is Triandis’ Theory of Interpersonal Behaviour a useful predictor of energy management behaviour at Network Rail, and what are the implications for influencing energy-efficient behaviour?


6.3 Updated project management plan (2014-15)

In contrast to the previous report, this project management plan focuses on the requirements of the next 6-12 months, rather than the whole remaining EngD course. This is to allow flexibility, reflecting the fact that aspects of the NR Graduate research project are still to be determined, as are details of energy scenario development. The structure is also activity-oriented, rather than aligned to the research questions themselves, although the relevance of these to each activity has been mapped on the table.

The main features of the plan are:
- Interview report writing and publication
- Graduate induction-related research
- Preparation for the 2-year dissertation
- Early stages of energy use scenario development
- Other key academic events occurring parallel to the main research

Figure 6 - Current research framework
Network Rail, University of Surrey

Figure 7 - Research plan Gantt chart. This plan covers details of activities taking place for the coming 12 months. A complete research plan for the whole EngD programme is provided in the previous progress report.
7. Concluding remarks

This 6-month period has seen a marked shift in the emphasis of research, largely due to the outcome of the semi-structured interviews, and identification of a behaviour change knowledge gap within the business.

The Interview research in particular has progressed well, largely due to the completion of the first report draft. Progress has been slightly slower since completion of this, during the editing and improvement process. However, this has been to accommodate aspects of journal writing which were not fully realised prior to the 'Writing for Publication and Public Engagement' course. These included identifying writing styles of different journals, choosing journals based on content requirements. Some of this period was also dedicated to improving understanding of social-psychological theories, which have proven invaluable during the write-up process.

The period from March-April 2014 has placed an unusually strong emphasis on course-related work, owing in part to the voluntary attendance of 'Psychology of Sustainable Development'. This will mean that significant progress with general research aims may be delayed until May 2014. However, the necessity of attending the Psychology course cannot be overstated, in order to confirm that the previous Interview research is robust, to ensure that future social research elements are prepared to the highest standards, and that these elements are combined successfully with energy scenario projection.

Delays with arranging an additional industrial supervisor have not proved to be as obstructive as first thought.

The main emphases of the next 6-month period will be (in no particular order):

- Conferences
  - Tyndall PhD conference (April)
  - EngD conference (June)
  - BEHAVE conference (September)
- NR graduate training
  - Preparation
  - Presentation (August)
  - Analysis and write-up
- Academic module attendance
- Journal Interview paper submission
- 2-year dissertation write-up

The 2-year dissertation will take up a large segment of this reporting period. It is therefore vital that paper submission takes place as soon as possible, ideally before August.

The likely attendance of at least two conferences during this time, and the submission of journal articles will signify a major leap forward in terms of communicating findings from this research beyond Network Rail.

Word Count: 8,207
(Pages 7-41, excluding content of figure images)
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ISI Web of Knowledge. (2014). Journal Citation Reports. Retrieved 2014-03-29 (URL unavailable – uses University of Surrey secure login)


SAN Railway Systems. (2009). Switch Point Heating, System Blue Point (catalogue)


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Appendices

Appendix 1 – EngD conference abstract

Title: Embedding energy efficiency within Network Rail: the attitude-behaviour gap and implications for infrastructure energy use

Theme: Academic contribution to knowledge and adding to the “big picture”

Investigating reasons for the gaps between pro-environmental values, attitudes, and their eventual real-world behaviours, is a growing area of psychological research. Studies in this field to date have looked at travel, consumer product choices, and actions within the home or office. However, few studies have attempted to link the attitude-behaviour gap with an organisation’s key operations, such as manufacturing processes or logistics.

To address this need, a series of exploratory semi-structured interviews were undertaken with managers and specialists relating to electrical railway infrastructure at Network Rail, on the broad topic of energy efficiency. These were then analysed qualitatively using a coarse thematic analysis, to both confirm the existence of the gap in this case, and to identify potential barriers to energy-efficient behaviour adoption. These themes were then mapped onto Triandis’ theory of interpersonal behaviour as various forms of attitude, behaviour, and external factors and norms. This allowed information to be presented clearly for use within Network Rail, and facilitated further discussions with managers within the business.

This study differentiated from previous value-action gap research in three main respects. Firstly, an effort was made to link organisational behaviours and determinants for the principal operations of a business, whereas previous research has looked at domestic or in-office activity at small scales. Secondly, there has been little or no research to date on the attitude-behaviour gap in the context of infrastructure-operating organisations. Finally, the decision was made to focus on mid-level- rather than high-end managers or the entirety of a business, as this has been recommended for research by recent scientific literature.

As anticipated, attitudes towards energy-efficient technologies (and sustainable development in general) were broadly positive. However, their adoption was inhibited by uncertainty towards the reliability of new technology, conflicts of interest regarding their economic business cases, a desire for increased central leadership on
environmental issues (despite recent regional devolution of some business functions), and the absence of specific energy efficiency goals from the current suite of performance measures. The dominance of economic norms and other external controls highlights possible difficulties for future applications of these social-psychological methodologies in an infrastructure context.

Possible shortcomings with the methodology arise when considering that these are based on exploratory interviews conducted without auditory recording equipment. However this significantly reduces the resources required to conduct such a study, and reduces the likelihood of revealing information sensitive to a company’s operations externally. It also offers a potential method of communicating social-psychological research to energy managers with greater ease.

This interview-based research is intended as the first part of a cross-disciplinary study. This will involve further social research among Network Rail’s graduate intake, and culminate in the development of energy-use scenarios. The latter of these is intended to identify the relative benefits of adopting energy behaviour change strategies, compared with purely infrastructural solutions. The key business impact from this research will be supporting the delivery of a future Network Rail infrastructure energy strategy.

[Submitted March 2014]
Appendix 2 – Tyndall/BEHAVE conference abstract

Title: Embedding energy efficiency frameworks and pro-environmental behaviour into Network Rail’s business practices

Theme: Energy & Emissions / Governance & Behaviour

Network Rail seeks to increase the efficiency of all its energy-consuming assets, including energy used in buildings and operational infrastructure. A component of this includes encouraging behavioural change at all managerial levels. There is also a need to increase the rate of uptake of energy-efficient technologies and small-scale renewable generation. This study supports these efforts through investigation of the pro-environmental value-action gap relating to improving the energy efficiency of railway infrastructure. This gap has been studied elsewhere for day-to-day actions in the home\(^1\) or office\(^2\), consumer behaviour\(^3\), or travel choices\(^4\), but research has so far tended to avoid investigating the management of the principal operations of a given business.

A series of exploratory semi-structured interviews was conducted with managers of electrical railway infrastructure. Results from this were subjected to a form of thematic analysis, and responses were mapped to appropriate social-psychological theories, to both confirm the presence of the gap, and to identify specific aspects.

As anticipated, attitudes towards energy-efficient technologies (and sustainable development in general) were broadly positive. However, their adoption was inhibited by factors including uncertainty towards the reliability of new technology, conflicts of interest regarding their business cases, a desire for increased central leadership on environmental issues (despite recent devolution of other business functions), and the absence of specific energy efficiency goals from the current suite of performance measures.

This research is the first component of a wider study into the effects of behaviour change on energy use for linear infrastructure, to provide a component of future studies.

\(^1\) Valkila & Saari (2013), Attitude–behaviour gap in energy issues: Case study of three different Finnish residential areas
\(^2\) Greaves, Zibarras & Stride (2013), Attitude–behaviour gap in energy issues: Case study of three different Finnish residential areas
\(^3\) e.g. Axsen & Kurani (2013), Developing sustainability-oriented values; Insights from households in a trial of plug-in hybrid electric vehicles
\(^4\) Lo, van Breukelen, Peters & Kok (2013), Proenvironmental travel behaviour among office workers: A qualitative study of individual and organizational determinants
Network Rail energy strategies. The second phase is intended to develop energy use scenarios for railway infrastructure applications, examining the relative environmental, social, and economic benefits of Behaviour Change- or Technology-focused approaches to energy efficiency.

[Submitted March 2014]
2-year dissertation

EngD: Sustainability for Engineering and Energy Systems

24-Month Dissertation, October 2014 *(updated with corrections, March 2015)*

Rupert James Larman Zierler

(URN: 6248587)

‘Embedding energy efficiency behaviour frameworks within Network Rail’s business practices:

The attitude-behaviour gap and infrastructure energy efficiency’

Academic Supervisors: Dr Walter Wehrmeyer

Dr Jhuma Sadhukhan

Industrial Supervisors*: Kent Farrell¹

Amelia Woodley²

Andrew Stiles²

1. October 2012 – September 2014
2. September 2014 onwards

Word count (excluding Acknowledgements and References): 9,987
Executive Summary

Background

This Dissertation outlines research undertaken at Network Rail (NR) on energy efficiency and behaviour change, investigating the gap between attitudes and eventual behaviours among managers of energy-intensive railway infrastructure, in terms of the adoption of energy-efficient technologies at NR.

Given the existing level of engineering expertise at NR in developing technical approaches to increasing energy efficiency, the concept of behaviour change currently receives comparatively little attention. Existing research into organisational energy efficiency barriers is thought to overestimate the importance of capital costs, and downplay the influence of individuals’ attitudes.

Goal

The central goal of this EngD research project is to develop tools to support wider adoption of energy-efficient behaviours at NR, with particular regard to infrastructure technology adoption by mid-level operations managers. This is intended to focus on the management of large-scale electrical infrastructure, to complement other potential NR-led behavioural interventions for general appliance use in offices, stations and maintenance depots.

Research Questions

The main research questions to support this goal are:

1. What challenges and barriers arise when embedding pro-energy-efficiency behaviour change frameworks within a major infrastructure operator?
2. Which of the identified barriers have the most significantly negative impacts on adoption of energy-efficient technologies and management behaviours?
2-year Dissertation

3. What are the predictions for NR’s future electricity use, under different energy behaviour culture change scenarios?

**Objectives and Papers**

To address the above questions, the research process has been split into three main objective phases, with differing but complementary methodologies. Each objective stage is to be accompanied by submission of a scientific journal paper:

I. Semi-structured interviews with managers of energy infrastructure

   - *(Awaiting supervisor approval)* ‘An exploratory qualitative assessment of the value-action gap for the energy efficiency of railway infrastructure’.

II. Questionnaire surveys with a wider sample of NR staff, to confirm the earlier qualitative findings and establish their levels of significance

   - *(Proposed)*. Working title: ‘The attitude-behaviour gap and energy-efficient management decisions: survey within a major infrastructure provider’

III. An agent-based model of technology adoption processes to produce an energy strategy support tool, based on quantitative data from the questionnaire phase

   - *(Proposed – stretch objective)* Working title: ‘Agent-based modelling of organisational energy management behaviours’

**Methodology**

The three phases follow a pathway of inductive qualitative exploration, deductive empirical confirmation, and forecast modelling of implications, respectively. Delivery of the pilot- and main questionnaires is to be coordinated through multiple existing company-wide survey deployment mechanisms. This mixed-method approach also reflects existing methodological frameworks for study of energy-efficient behaviours.

**Output Contributions**

Interviews have already suggested the existence of a gap between what are largely pro-environmental attitudes, and technology adoption-related behaviours, and identified potential barriers which could explain this. Additional contributions to knowledge from this project are intended to include:

- More detailed understanding of the barriers to energy efficiency at a middle management or operational level, around large-scale ‘production’-oriented technology adoption
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- Application of the Theory of Interpersonal Behaviour in the context of energy behaviours, responding to calls for greater integration of organisational studies with wider behavioural theories
- A case study investigation of organisational pro-environmental behaviour within the little-researched context of a major infrastructure provider
- Testing the applicability of agent-based modelling techniques for predicting production-oriented technology adoption behaviours in organisations.
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Glossary

ABG - Attitude-Behaviour Gap
CP4 - Network Rail Control Period 4 (2009-2014)
CP5 - Network Rail Control Period 5 (2014-2019)
FOC - Freight (train) Operating Company
LNE - London North Eastern
LNW - London North Western
NAM - Norm Activation Model (Schwartz, 1977)
NR - Network Rail
SBS - Sustainable Business Strategy team (NR)
SME - Small-Medium-sized Enterprises
SPSS - Social science statistical data analysis software
TIB - Theory of Interpersonal Behaviour (Triandis, 1977)
TOC - Train Operating Company
TPB - Theory of Planned Behaviour (Ajzen, 1991)
1. Introduction

This Dissertation outlines research undertaken on energy efficiency and behaviour change, investigating the gap between attitudes and eventual behaviours among managers of energy-intensive railway infrastructure, in terms of the adoption of energy-efficient technologies at Network Rail.

Work was undertaken at NR facilities based with their Sustainable Business Strategy (SBS) team, in collaboration with the University of Surrey. This research project began in September 2012, and is currently expected to complete in September 2016.

The original task of “embedding sustainability frameworks” suggested a variety of possible topics and approaches. Early on, the decision was made to focus on energy-related issues, specifically electricity use. This was to address a specialism gap within the SBS team. There are also currently plans to develop a Network Rail Energy Strategy, divided into Supply, Demand, and Behavioural Change approaches. It was agreed at an early stage that this project would contribute to the latter of these categories to coordinate with the author’s previous social research experience.

1.1. Prioritising energy and behaviour change

NR is currently seeking to reduce its electricity consumption, in order to lower costs, reduce vulnerability to energy supply security, and to curtail the environmental impact of its carbon dioxide emissions. Early discussions with managers of specific energy-saving projects highlighted the possible existence of several barriers to wider adoption of the technologies they dealt with. The literature review suggested that research into industrial barriers to pro-environmental activities was fairly widespread. However, other studies rarely looked at large-scale production decisions (as opposed to small-scale appliance use). Neoclassical economic approaches taken by the majority tend to overstate the importance of capital costs, and under-represent the influence of individuals’ attitudes on energy behaviours. Those which do take a more behavioural approach tend to be qualitative in nature, and establish highly contextual sets of barriers without drawing upon existing general psychological theories. Additionally, there
appears to be a shortage of behavioural case studies within major transport infrastructure operators.

These initial observations established a central goal:

- Provide tools to support greater adoption of energy-efficient behaviours at NR, particularly in an energy infrastructure management context.

To achieve this, and address the points raised above, the following main research questions were formulated, as a means of supporting internal strategy development, and developing information support tools for energy-related decision makers:

1. What challenges and barriers arise when embedding pro-energy-efficiency behaviour change frameworks within a major infrastructure operator?
2. Which of the identified barriers have the most significantly negative impacts on adoption of energy management behaviours?
3. What are the predictions for NR's future electricity use, under different energy behaviour culture change scenarios?

To address these questions, the research process has been split into three distinct phases, with complementary methodologies:

I. Semi-structured interviews with managers of energy infrastructure
II. Questionnaire surveys with a wider sample of NR staff, to confirm the earlier qualitative findings and establish their levels of significance
III. An agent-based model of energy-efficient technology adoption processes to produce an energy strategy support tool, based on data from the questionnaires

Full details of ties between research questions and phases are provided in the Methodology (section 3). So far, the first phase is nearing completion, with a journal paper awaiting final approval prior to submission.
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This manager-centred research is intended to complement a proposed series (beyond this project) of energy behaviour change interventions in NR-managed buildings, stations, maintenance depots, and offices.

1.2. Document structure

Section 2 provides the main review of literature. First, the reasons for addressing NR’s infrastructure energy use in particular are established. Secondly, the dominance of economics-led research into organisational energy efficiency barriers is discussed, highlighting possible reasons for pursuing a psychological approach instead. Thirdly, examples of existing behaviour-led approaches to investigating organisational energy efficiency are examined, in organisational and other settings. Finally, general theories of pro-environmental behaviour are discussed, along with reasons for selecting Triandis’ (1977) Theory of Interpersonal Behaviour as a basis for surveys and models.

Section 3 lays out the existing and intended methodology for the three main research phases.

Section 4 provides an overview of results from the initial interview phase, and the implications of these for later phases.

Section 5 outlines goals and supporting objectives to achieve completion of the research questions, assesses risks to completion for various stages of the project, and provides a detailed timetable for the remainder of this programme.

Section 6 provides concluding statements and an appraisal of course progress to date.
2. Literature Review

2.1. Network Rail

To understand the challenges that NR faces with respect to energy efficiency (research question 1), it is important to first establish the current scope of NR’s operations with respect to energy use. NR is the single largest purchaser of electricity in the UK, accounting for nearly 1% of all UK demand, or approximately 3.2TWh/year in 2013 (Higgins, 2013). A large proportion of this is sold on to Train/Freight Operating Companies (TOCs/FOCs) as electricity for train traction power, but non-traction applications still account for more than 537GWh per year. NR energy efficiency measures are subsequently likely to have a high impact on the UK’s overall electricity demand. Security and availability of energy supply are seen as a major determinant of rail’s future strategic transport role in strategic foresighting exercises (Armstrong, 2011), highlighting the need for demand-side energy interventions to negate potential shocks to supply.

Regulatory drivers are thought to have already influenced decline in NR’s energy consumption. Chief among these are the UK government target to reduce greenhouse gas emissions by 80% on 1990 levels by 2050 (DECC, 2008), and the EU 2008 Climate and Energy Package’s aim for 20% reduction in primary energy consumption by 2020. NR also aims to reduce carbon dioxide equivalent emissions arising from non-traction consumption by 11% over the period 2014-19 (known as CP5), having narrowly missed a 20% reduction target over the period 2009-14 (CP4), a significant proportion of which was achieved by switching energy provider. ‘Scope 2’ emissions, resulting from electricity consumption represents the most significant proportion of NR’s greenhouse gas emissions (Figure 8). This reduction in target impact suggests that the rate of emissions reductions brought about by regulatory influence is slowing, in turn highlighting the need for additional environmental impact reduction measures.
Figure 8 – NR carbon-dioxide-equivalent emissions, 2013/14 (based on internal NR data)

Of the non-traction electricity, nearly 37% is used for applications on the railway infrastructure itself, as indicated by Figure 9. Although energy consumption in managed stations is also significant, all trackside technologies viewed together represent the largest single portion of direct electricity consumption by NR. This in turn suggests that addressing energy efficiency measures for these would have the highest impact. Offices and signal boxes were also undergoing a series of relocations and closures. The managers of electrical trackside infrastructure were selected for closer scrutiny on these bases.
These carbon- and energy reduction aims sit alongside reopening rail routes (e.g. Waverley line from Edinburgh), upgrading capacity on existing ones (e.g. Thameslink Upgrade programme), spreading electrification (e.g. Great Western Main Line) and steadily-increasing rail use by passengers and freight (DfT, 2013). Curtailing electricity consumption poses the greatest opportunity for carbon emission reductions, yet the volume and intensity of equipment used is set to increase. Energy use reduction may lie in non-technical solutions, such as addressing the technology adoption behaviours of operational-level managers.

User demands on the UK electricity grid are increasing, and likely to increase as a result of widespread energy demand electrification, without demand-side interventions.
(Barton et al, 2013). Peak train travel times coincide with peak grid demand, exacerbating this problem (see Figure 10). Although the majority of consumption impacts will originate from traction electricity, infrastructure energy use will reflect this pattern in the form of transformer losses, and increased prioritisation of track heater use.

Figure 10 – UK national electricity demand (based on National Grid average half-hourly usage data, Jul-Dec 2012) superimposed by the author against UK daily rail travel index (from Melbourne, 2011).

Several technological opportunities for reducing railway infrastructure energy use exist. Three of the more widespread examples are:

- Points heating, control systems and usage prioritisation regimes
- Alternative conductor rail heating technologies and heater positioning
- Redesigning distribution networks to reduce traction electricity transmission losses

Other more localised improvements include new designs for tunnel water pumps, new types of traction gel dispenser (for reducing train wheel-spin), and digital control telecommunications equipment. Given the scale of NR’s operations, and the long lifespan of most railway equipment, individual decisions to implement energy efficiency improvements here will have further-reaching consequences than the small-scale energy behaviours favoured in behavioural literature (discussed in 2.3).
NR has recently devolved management responsibilities, including infrastructure energy management to eight regionally-organised 'Routes' (see Figure 11). The effects of these changes on energy efficiency are unlikely to have manifested yet, given that commentaries on the economic effects of rail privatisation in the mid-1990s are still emerging (e.g. Li, 2014; Preston & Robins, 2013; McCartney, 2012). However, it is thought that the aggregate effect of several recent changes to the railway industry may have affected managers' prioritisation of energy efficiency, in favour of addressing safety and train punctuality.

Changes to NR’s organisational structure have been announced following its recent reclassification as a public body (Topham, 2014). Energy use behaviour change is recognised by the UK government as a key area for research and intervention, as outlined by Revell (2012), and evinced by other recent reports to government (e.g. McVicar, 2012). The resulting closer governmental ties seem likely to increase pressure for adoption of behaviour change measures.
Conclusions

Despite traction power representing the majority of electricity use by UK railways, the large and increasing scale of NR’s infrastructure energy use is sufficiently large to warrant the application of more widespread energy efficiency measures. The reducing scope of NR’s operational carbon dioxide emission targets suggests that additional measures are required, if NR’s emissions are to reflect reductions due to take place elsewhere in the UK. The pressure to do so is likely to increase in the current policy climate.

Initial discussions with managers of energy-intensive infrastructure pointed out that the uptake of energy-efficient technologies was slower than originally anticipated. This suggested the possible presence of organisational or behavioural barriers, as the
positive economic benefits of reducing energy costs seem relatively straightforward. This raises the further research question:

1a. What are the potential behavioural barriers to adoption of energy-efficient technologies at NR?

The next two sections discuss some previous observations of organisational energy efficiency barriers, from economic and behavioural perspectives respectively.
2.2. Energy efficiency – economic perspective

To further identify barriers to energy efficient behaviours and their significance (research questions 1 & 2), it is also necessary to look at barriers occurring in other industries. The first, key observation is that in-depth studies of these barriers in major transport operators have not, to the author’s knowledge, been carried out within available scientific literature.

Increasing the energy efficiency of a company’s operations, at first glance, seems to have few drawbacks; reducing energy consumption also lowers costs, and often the complexity of supply infrastructure. Yet the ‘energy efficiency paradox’, or slow corporate adoption of efficient technologies despite seemingly-strong economic cases, is still a commonly-observed phenomenon (e.g. DeCanio, 1998; Kounetas & Tsekouras, 2008; Martin, 2012).

Sorrell et al (2000; 2004; 2011) provide a commonly referred-to taxonomy of organisational barriers to energy efficiency. The validity of framing ‘barriers’ to energy efficiency at all has been questioned, due to the possible supposition that rational choices in favour of energy efficiency will be made once they are removed (Shove, 1998). However, the author shares the position taken by Banks (2012); the term ‘barrier’ is used here in reference to “a feature of the socio-technical landscape which influences the diffusion of an energy efficient technology or practice”. Defining a set of discrete barriers is thought to be an approachable method of presenting findings to those unfamiliar with energy behaviours.

Sorrell et al’s barriers are categorised as imperfect information, hidden costs, risk (technical or financial), access to capital, split incentives, and bounded rationality. These barriers have been tested on numerous occasions, most often finding that initial capital costs are the most significant factor (e.g. Trianni & Cagno, 2012). Venmans (2014) reaffirms this, also pointing out that relatively few scientific papers have investigated efficiency in energy-intensive industries, supporting the case for investigating barriers at NR. The significance of capital costs is corroborated by energy efficiency studies that don’t use Sorrell et al’s framework (e.g. Kaplowitz et al, 2012). Capital costs are also significant barriers for other pro-environmental energy technology adoption, such as small-scale renewable generation (Balcombe et al, 2013).
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However, Fleiter et al (2012) found that higher prioritisation of other investments was almost as important as initial capital costs in SMEs, whilst Thollander et al (2007) found them to be more important. Rohdin et al (2007) find that barriers in larger companies are more commonly related to risk, decision-making, and prioritisation of energy management than with capital costs. Supporting this, Cagno & Trianni (2014) found that low managerial prioritisation of energy efficiency, lack of interest, and a lack of internal communication of energy issues were more significant barriers. Trianni et al (2013) observed that prioritisation of investment, as well as the potential effects of disruption and poor (new) equipment performance were dominant in energy-intensive foundries. Nagesha & Balachandra (2006) also independently identified 'behavioural and personal' barriers as being of equal importance with capital cost. The conflicting evidence around the importance of capital costs, and the recurring significance of management prioritisation raises the possibility of further behavioural, rather than economic causes for the energy efficiency paradox.

Closer inspection shows that Sorrell et al (2000) may have underestimated the significance of barriers falling outside the realm of neoclassical economics (what they call 'behavioural' and 'management theory' barriers). Their original list was narrowed-down based on a limited selection of industrial and higher-education case studies; this may have unfairly oriented the focus of organisational energy efficiency discourse away from non-economic influences by subsequent authors.

Taken together, these papers point at a glossing-over of socio-technical and social-psychological obstacles to energy efficiency from the dominant economic viewpoint. Whilst economic considerations are not to be ignored, economics alone cannot explain levels of investment in energy efficiency projects, as DeCanio (1998) points out, promoting the case for further examinations of these other types of organisational barrier.

Conclusions

Referring to research question 1, barriers to energy efficiency have been widely investigated, and a common set of these (after Sorrell et al, 2000) has risen to prominence. However, this dominant economic viewpoint does not embody the entire spread of observed barriers, and seems to be oversimplifying socio-technical or social-psychological influences on organisational energy behaviours. Additionally, Schleich & Gruber (2008) put forward that quasi-public organisations experience greater numbers
of barriers, whilst energy-intensive companies experience fewer. NR fits into both categories, but it is not clear which of these scenarios predominates.

It is proposed that at an individual level, the technology adoption behaviours of those managers at the middle, operational level will have the greatest influence on pro-energy-efficiency technology diffusion, due to their more direct control over the technologies mentioned in 2.1. This raises the further research question:

1b. What are individual operational-level managers’ attitudes towards energy-efficient technology adoption?

In relation to question 2, it is unclear whether capital costs or other economic factors are the most significant barrier to energy-efficient technology adoption. This viewpoint is corroborated by Sorrell et al (2011) who state that the significance of costs is generally over-determined, and interacts with other undetermined factors; managers’ attitudes to technology adoption could be one of these.

To support this proposition, the next section compares previous behavioural approaches to understanding individuals’ pro-environmental and energy-efficiency behaviours with the economic viewpoint, and discusses some examples of these in organisational contexts.
2.3. Energy efficiency – behavioural perspective

In seemingly oblivious parallel to the ‘energy efficiency paradox’, differences between what people say and do with respect to pro-environmental behaviours in settings beyond organisations are often framed as the ‘attitude-behaviour’ (or ‘value-action’) gap (ABG). Blake (1999) coined this term to describe how a lack of pro-environmental behaviour is not always a result of a lack of information on pro-environmental options, but can result from a range of other cognitive barriers. The ABG has been observed in several different contexts, including a general observation of pro-environmental behaviours lagging awareness among European citizens (Pirani & Secondi, 2011).

Whitmarsh (2009) found that individuals make distinctions between actions to mitigate climate change, and actions to conserve energy, potentially reducing the ABG’s applicability to energy behaviours. However, observations of energy conservation behaviours seem largely to reflect general pro-environmental examples. Observations of the ABG in relation to energy behaviours include appliance use in the home (e.g. Valkila & Saari, 2013; Abrahamse 2005), consumer purchasing choices in relation to energy-efficient products (e.g. Gadenne et al, 2011), and travel behaviours or choice of transport mode (e.g. Murtagh, 2012). Most of the behaviours studied are small-scale and apply only to the individuals being studied, having little immediate effect on others. However, papers often look at the social normative influences which lead people to think they should adopt particular behaviours (e.g. Onwezen et al, 2013).

Behavioural barrier discourse on reasons for the ABG reflects that in the field of economics. Kollmuss & Agyeman (2002) propose a model framework to explain the existence of the ABG, despite acknowledging that doing so might not be ‘feasible nor useful’. Their paper was criticised for taking an overly ‘instrumentalist’ approach, seeking to define the problem of addressing pro-environmental behaviour as being easily-predictable, and for the complexity of the model’s linkages (O’Donoghue & Lotz-Sisitka 2002). This reflects Shove’s (1998) argument against the definition of economic barriers (see 2.2). The complexity of developing a new theory specifically for pro-environmental behaviours may be counterproductive, given the widespread availability of more general theories around behaviour adoption (see 2.4, below).

As with non-organisational studies, most organisational psychological energy-efficiency studies focus on widespread-but-small-scale energy consumption activities. Reflecting the non-organisational examples, these include use of office equipment such as computers (Dixon, 2014; Greaves et al, 2013; Murtagh et al, 2013), and travel behaviour among commuters (Lo et al, 2013). However, unlike with economics-led studies, business decisions relating to adoption of energy-efficient technologies relating to ‘production’-related activities have not often been investigated from this
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perspective. In the case of NR, ‘production’ would relate to the operation of railway infrastructure. Studies of social normative influences on employee pro-environmental are rare, and tend to be framed as originating from ‘the organisation’, rather than their peers (e.g. Boiral & Paillé, 2012), suggesting that these need further exploration.

Some observations suggesting the presence of the ABG can also be made from qualitative studies relating to energy efficiency from beyond the neoclassical economic corpus (of which there are many more than described here). Pesonen et al (2013) frame their study of a swimming hall around the concept of the ABG, observing that despite pro-environmental attitudes among the majority of staff, reductions in water temperature and application of efficient technologies were not taking place. Maleviti et al (2012) conducted interviews with hotel energy managers, finding that their customers’ environmental concerns were driving pro-environmental attitudes among them, but a lack of information on energy-efficient options was felt to hinder their adoption. In addition, improvements to the energy efficiency of equipment were thought to be the most important contribution that engineers could make in terms of general sustainability (Rosen, 2013).

Conclusions

There appear to be at least as wide a variety of behavioural barriers to energy efficiency as economic ones, highlighting the need for contextual, qualitative investigation of these when looking at new settings. This justifies an interview-led approach to answering research question 1. Similarities between the two discourses suggests that behaviour-oriented studies could be just as effective at identifying barriers, but these have not been applied as widely for looking at production-oriented technology adoption.

As Darnton et al (2006) point out, a shortage of links have been drawn between observed managerial attitudes, behavioural influences, and generalised social-psychological theories of pro-environmental behaviour. Lo et al (2012) also review that current studies lack integration between organisational and individual determinants in their analysis, promoting more thorough use of existing research when designing qualitative studies (as conducted by Lo, 2011 for a variety of small-scale energy behaviours). Both of these factors could be addressed by testing existing theories of individuals’ behaviour in an organisational context, as is planned here.
To identify the relative importance of individual barriers from a social-psychological perspective (thereby answering research question 2), it was chosen to use an existing theoretical framework. This is to counter the proliferation of theoretical constructs resulting from qualitative observations of pro-environmental behaviour, and the calls for closer links between organisational energy behaviours and existing theories.

There are several available theories for describing and predicting individual pro-environmental behaviour, as reviewed by Jackson (2005) for consumer behaviours, and Darnton et al (2006) regarding implementation of behaviour change policies. The following four theories were selected based on their recurrence in available scientific and policy literature.

**Norm Activation Model (NAM):**

Schwartz (1977) developed this model in an attempt to describe altruistic and pro-social behaviours. It is thought that this is probably the least applicable of the four main theories discussed here, due to the known effects of external constraints on the applicability of this theory (Jackson, 2005), and differences in the way people perceive climate change and energy efficiency respectively (Whitmarsh, 2009). Zhang et al (2013) used the NAM to investigate employee energy-saving behaviour in Chinese companies, but simplified the external constraints to a general organisational ‘energy saving climate’, rather than a more-detailed set of influences. Steg et al (2014) also points out that the NAM is better-suited to situations where normative, rather than gain goals are the focus of changing a particular behaviour. As the latter of these are more likely to apply in an organisational setting, this theory was not selected.
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Value-Belief-Norm Theory (VBN):

Unlike the other theories discussed below, this theory was developed specifically for modelling the adoption process for pro-environmental behaviours (Stern, 2000). Personal values are thought to drive beliefs around specific behaviours, which in turn lead to personal norms and a sense of obligation to act pro-environmentally.

Christina et al (2014) based the structure of interviews with staff at a major retailer on VBN, but found that personal values were overridden by those of the organisation. They propose an alternate version of VBN to account for this, taking into account the adverse effects of employees needing to pursue multiple goals (as proposed by Cheng et al, 2007). However, the need for changes highlights shortcomings for using the VBN in organisational contexts. Furthermore, Andersson et al (2005) also suggest that VBN theory is only partially supported in a corporate context, because of employees' overriding concerns for their salary and lifestyle. Stern (2000) also states that this theory has more predictive powers for behaviours “that are not strongly constrained by context or personal capabilities”, leading this theory to be dismissed for the purposes of this project.

Theory of Planned Behaviour (TPB):

This theory was developed as an extension of the earlier Theory of Reasoned Action (Ajzen, 1991), introducing the concept of perceived behavioural control to account for instances where individuals perceive that they have limited influence over their otherwise assumedly-rational actions. This is perhaps the most commonly-used theory for exploring pro-environmental- and energy-efficient behaviours (Jackson, 2005). Greaves et al (2013) and Lo (2011) both apply the TPB in an organisational setting, finding that it can be used to explain antecedents of small-scale pro-environmental and energy-efficient behaviours.

Widespread testing of the TPB in other contexts has taken place despite acknowledgement that it does not adequately take into account habitual behaviours or normative influences (Shove, 1998; Jackson, 2005). The only direct comparison of explanatory power between multiple theories suggests that the TPB is roughly equal or less than the Theory of Interpersonal Behaviour (TIB) (and significantly better than the NAM), albeit in the context of travel mode choice (Bamberg & Schmidt, 2003). These factors together suggest that further research should focus on testing the validity of other theories.
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*Theory of Interpersonal Behaviour (TIB):*

The TIB is one of the more complex behavioural models available, addressing the shortcomings of the TPB by addressing the influences of habits, and factors external to the individual (Triandis, 1977) (see Figure 12). Jackson (2005) points out that Triandis’ TIB is less commonly used than both the TPB and NAM, particularly for pro-environmental behaviours, despite its aforementioned greater potential explanatory power, and its combined rational- and emotional approach. The TIB also very closely resembles the model framework proposed by Huijts et al (2012) for sustainable energy technology acceptance; levels of personal acceptance could be a factor in the adoption of efficient technologies by managers within NR.

This theory is currently favoured by reviews for the UK Department for Energy and Climate Change (Revell, 2012; Chatterton, 2011), and is generally gaining more widespread recognition due to its comprehensive selection of behavioural influences (e.g. Prager, 2012). The shortage of journal papers on organisational pro-environmental behaviour based on this theory is therefore surprising, and bolsters the need for testing the TIB’s validity as a basis for policy. NR’s reclassification as a public body increases this need.
Conclusions

Of the theories explored, testing the TIB in an organisational energy efficiency context represents the greatest opportunity for an original contribution to knowledge. It is recognised as needing more extensive testing and application, despite being thought to have greater explanatory power than other theories (Bamberg & Schmidt, 2003; Darnton 2008). Selecting this theory may also ease communication of findings in the UK, due to its current favour in policy literature.

Use of the TIB to identify the significance of different barriers (research question 2) will require empirical testing of its theoretical linkages. This leads to the supporting question:

2a. Is the hypothesised gap between energy-efficient attitudes and behaviours supported by empirical observations within NR?

As Triandis (1977) and Darnton (2008) acknowledge, behavioural models do not represent the actual thought processes taking place in individuals’ heads prior to taking action, but are tools for organising our understanding of behaviours. With this in mind, a natural progression of such a tool would be to test its predictive capabilities. Given the individual-oriented structure of the TIB, and its framing of interactions between them as normative and habitual influences, an agent-based modelling approach is believed to be both appropriate for this purpose, and relatively little-tested in the field of organisational behaviours. This is the intended scenario development method for answering research question 3, discussed further in section 3.3.
3. Methodology

This project is intended to consist of three main phases, consisting of inductive exploration, deductive questioning, and modelling of hypothesised effects, respectively:

1. Interviews with managers and engineers working with energy-intensive railway infrastructure applications

2. Questionnaire surveys around employee energy-related attitudes and behaviours

3. Agent-based modelling to forecast NR’s future energy use, based on outputs from the previous two stages.

These phases are designed to align approximately to research questions 1, 2 and 3 respectively, as outlined in Table 8 at the end of section 3. These also reflect the three aspects (‘Material culture’, ‘Cognitive norms’, and ‘Energy practices’) of the ‘Energy Cultures’ framework proposed by Stephenson et al (2010), enabling possible later comparison with other research. The interview phase is nearing completion. The survey stage is currently undergoing detailed planning. Parameters and data requirements for the modelling stage are to be defined during development of the survey questionnaire.

3.1. Phase I – Interviews

Interviews with managers, engineers, analysts and specialists in the field of electrical trackside support infrastructure took place between July-November 2013. These followed a semi-structured format, allowing freedom to explore previously-overlooked topics. Field notes then formed the basis for a thematic analysis. This process broadly followed an exploratory ‘grounded theory’ approach (Glaser & Strauss, 1967). Notes from previous meetings served as guidelines for structuring note-taking in the first interviews, which in turn iteratively informed later interviews. Thematic analysis was then applied to notes taken during and after the interviews. Sections of notes and annotations were transcribed to Microsoft Excel tables and sorted accordingly. Similar
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techniques have previously been used to investigate energy use in the home (e.g. Mirosa, 2013), but have not been observed for organisational situations.

The structure of Triandis’ (1977) TIB was chosen as a framework for mapping topics highlighted for the thematic analysis, as discussed in the literature review (section 2.4). This phase did not empirically test any of the linkages suggested by the TIB; the theoretical construct was simply used as a means of theme-sorting, to serve as a guide for the later phases.

A full description of this process is provided in section 4, along with results.

Publication plan

A journal paper is in the process of submission to the Journal of Cleaner Production, awaiting final publication approval from supervisors at the time of going to press. This was selected for the journal’s high impact factor, and previous acceptance of similar qualitative studies (e.g. Zilahy, 2004).

3.2. Phase II – Questionnaire survey

Although the interview phase raised a number of potential barriers to energy efficiency, numerical attitude data is needed to determine which of these has the most significant effect on energy management behaviours. It is also planned to test whether the causal linkages suggested by the TIB hold true in the case of NR, using chi-square tests and Cronbach’s alpha.

Data collection is planned to be based on self-report questionnaire surveys. It is unlikely that the final survey design will focus solely on managers of energy infrastructure, as with the initial interviews. Wider information on more general environmental attitudes and values at NR is of interest to the SBS team for a variety of purposes, and will allow for comparison with earlier studies of demographic influences of environmental (Wehrmeyer & McNeil, 2000) and energy-related (Mills & Schleich, 2012) attitudes. Information on energy managers’ attitudes (to answer research
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question 2) will be sampled from this broader dataset. This questionnaire would be based on a 5-point Likert scale structure. This is partly to aid participant understanding, as per the recommendations of Oppenheim (1998) and following experiences of confusion or misuse of 7-point- and continuous response scales in previous work by the author (Zierler, 2010). The exact set of statements to test is to be determined, but is likely to reflect the structure of the themes identified during phase I.

Mechanisms for delivering questionnaire surveys are already established at NR. Plans for deployment of questionnaires are currently being pursued through two main, non-mutually-exclusive pathways:

- Improving and upgrading an existing survey, recently deployed by the semi-autonomous Network Rail (High Speed) division
- Creating and deploying a new survey with the assistance of NR’s Business Change function

NR (High Speed)'s survey in early 2014 investigated general environmental attitudes across their staff profile, conducted solely at their own facilities. Basing a survey on this existing framework is likely to require modification, to capture more detailed information on energy attitudes specifically. Whether their framework is adopted or not, data from this survey could provide supporting information. An initial discussion with their delivery team is scheduled for October 2014.

Precise dates for the main phase of survey delivery will not be finalised until after completion of the pilot. See Figure 6, section 5 for an outline of estimated delivery dates.

Data from this survey will be analysed using various statistical techniques available in ‘SPSS’ software. Additionally, secondary data analysis from other pre-existing NR staff surveys will be used in support of the original survey. The ‘Your Voice’ company-wide employee satisfaction survey covered themes relating to the influence of company devolution and pace of change, which also emerged in this project during phase I. The next survey is due to take place in May 2015. Access to the earlier 2013 dataset was being negotiated at the time of going to press.
Publication plan

Publication of survey analysis will be sought in empirical psychological journals. The *Journal of Environmental Psychology* is the favoured recipient, to reflect this project’s use of the TIB construct, the number of energy behaviour studies already published in this journal for other contexts (e.g. Greaves, 2013; Norton, 2014; Paillé, 2013; Paillé, 2014). *Energy Policy* is also under consideration for the latter reason (e.g. Gadenne, 2011; Rohdin, 2007). The working title for this paper is ‘The attitude-behaviour gap and energy-efficient management decisions: survey within a major infrastructure provider’.

3.3. Phase III – Modelling and scenario development

The cross-sectional snapshot of energy attitudes and behaviours from phase I is planned to be extended with a predictive tool to justify the potential benefits of behavioural interventions. Development of an agent-based model is proposed as an innovative method of supporting behaviour change policies, addressing the call for wider incorporation of social influence into energy behaviour studies (Axsen et al, 2013), and the possibility that peers have a stronger influence on energy behaviours than personal attitudes (Senbel et al, 2014). Two scenarios are planned, where either:

- The current rate of efficient technology adoption holds, and no major behavioural interventions are made, or
- Business structural changes, new performance measures, or cultural interventions influence energy managers in improving efficiency

In an energy efficiency context, agent-based modelling has previously been applied to measure policy effects of a ban on incandescent lightbulbs (Chappin & Afman, 2013), the effects of office temperature and other climatic factors on building energy use (Lee & Malkawi, 2014), and UK domestic energy use scenarios (Natarajan et al, 2011). Additionally, this technique has been used to model levels of satisfaction with management of infrastructure assets (Osman, 2012).

The final categories of ‘agent’ have yet to be determined. However, these may include ‘external stakeholders’, ‘trackside assets’, ‘infrastructure energy managers’, and ‘other
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NR staff. The latter two of these are planned to be structured around the TIB. Parameters will be defined based on inputs from the surveys in phase II.

Software options for the agent-based model are the open-source ‘Netlogo’ and ‘RePast’ packages. Being open-source eliminates the need for additional expenditure, and is designed for ease-of-use for those without a background in programming. This could not only simplify the creation process, but also allow for easy understanding by subsequent users (further supported by its graphical interface), if the developed model is retained within NR.

Publication plan

Journal publication of this phase is proposed as a ‘stretch’ objective, dependent on the robustness of data collected during phase II. The working title for this is ‘Agent-based modelling of organisational energy management behaviours’. *Energy Policy* is the main target journal, due to previous publication of agent-based modelling research on behaviour change policy initiatives (e.g. Lee et al, 2014).
Table 8 - Linking activities with research questions

<table>
<thead>
<tr>
<th>Research questions</th>
<th>Phase I: Interviews</th>
<th>Phase II: Energy attitude and behaviour</th>
<th>Phase III: Agent-based modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 What challenges arise when embedding pro-energy-efficiency behaviour change</td>
<td>Literature review: Range and effectiveness of available scientific approaches, e.g.</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
</tr>
<tr>
<td>frameworks within a major infrastructure operator?</td>
<td>psychological, management oriented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a What are the potential behavioural barriers to adoption of energy efficient</td>
<td>Literature review: Examples from other pro-environmental behaviour research, in other</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
</tr>
<tr>
<td>technologies at NR?</td>
<td>industries and settings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b What role do individual operational-level managers’ attitudes play in</td>
<td>Literature review: Observations of emergent attitude-behaviour gaps around pro-environmental actions</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
</tr>
<tr>
<td>determining energy-efficient technology adoption?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Which of the identified barriers have the most significant negative impacts on</td>
<td>Literature review: Examples from other pro-environmental behaviour research, in other</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
</tr>
<tr>
<td>adoption of energy-efficient technologies?</td>
<td>industries and settings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a Is the hypothesised gap between energy-efficient attitudes and behaviours</td>
<td>Literature review: Supporting information from other internal NR questionnaires</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
<td>Epistemology: Data Gathering method; Data Analysis Method</td>
</tr>
<tr>
<td>supported by empirical observations within NR?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 What are the predictions for NR’s future electricity use, under different energy</td>
<td>Literature review: Previous applications of agent-based modelling techniques</td>
<td>Analytical, economic forecasting (based on questionnaire)</td>
<td>Application of Likert scale parameters</td>
</tr>
<tr>
<td>behaviour culture change scenarios?</td>
<td></td>
<td>Application of Likert scale parameters</td>
<td>“Netlogo” or “RePast” for model; MS Excel for testing of elements</td>
</tr>
<tr>
<td>3a (Purely technology-oriented scenario) - What is the baseline prediction for</td>
<td>Literature review: Network Rail’s energy use trends; upcoming major projects</td>
<td>Questionnaire, 5-point Likert scales; stratified sampling by NR business function</td>
<td></td>
</tr>
<tr>
<td>energy use without major behavioural interventions?</td>
<td></td>
<td>Questionnaire, 5-point Likert scales; stratified sampling by NR business function</td>
<td></td>
</tr>
<tr>
<td>3b (Behaviour culture change scenario) - What are the likely effects of extensive</td>
<td>Literature review: Effects of behaviour change interventions, both external examples</td>
<td>Questionnaire, 5-point Likert scales; stratified sampling by NR business function</td>
<td>Assess potential impacts via manipulation of survey parameters in model</td>
</tr>
<tr>
<td>energy behaviour interventions on electricity use?</td>
<td>and potential internal NR pilots in other settings (e.g. offices, stations)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Results summary

4.1. Structure of results

This section outlines the results of the interviews conducted during phase I. A journal research paper reporting on these is shortly to be submitted to the *Journal of Cleaner Production*. Details of interview procedures are provided in the methodology (section 3.1).

Interviews took place July-November 2013. There were 22 interviews in total, with managers, engineers, analysts and specialists, lasting between 1-2 hours. 7 of these were based with NR’s devolved Routes, with the remaining 15 centrally- or variably-located. Interviews were recorded using written notes, taken during and immediately after each session.

Handwritten notes were then subjected to thematic analysis, using iterative memo-based techniques in a series of grid templates in Microsoft Excel. Qualitative analysis software such as NVivo was not required due to the relatively small volume of notes, as compared to full transcripts. Themes were initially chosen based on existing literature, and later refined with recurring points from the interviews themselves. In addition, individual statements were assigned a ‘positive’, ‘neutral’, or ‘negative’ tag, in an attempt to capture the ‘affect’ (or ‘emotional’) aspect of the TIB. These tags were based on the following criteria:

Statements were categorised as positive if:

- Behaviours were perceived as being supportive of delivering energy efficiency
- Pursuit of pro-environmental aims were perceived to align with delivering other performance improvements
- An external factor had an overall positive impact on energy efficiency of infrastructure

Statements were categorised as neutral if:

- A theme was discussed as contextual information, but no opinions were expressed regarding energy efficiency effects
- Attitudes expressed in relation to a theme were balanced
Statements were categorised as negative if:

- Behaviours were perceived as being detrimental to energy efficiency
- Pursuing pro-energy-efficiency aims were thought to conflict strongly with improving performance in other areas
- An external factor was perceived as having overwhelmingly negative impacts on infrastructure energy efficiency.

### 4.2. Discussion and conclusions

Table 9 at the end of this section outlines the results of this thematic analysis. The left-hand columns demonstrate the categorisation of themes according to the structure of Triandis’ TIB (see Figure 5 in section 2.3).

In response to research question 1, four main barriers emerged from these interviews, identified by their relatively high proportion of ‘negative’ responses. Numbers refer to the thematic categories provided in Table 2:

A. Low perceived self-efficacy regarding both managers’ influence on energy-related business decisions, and the ability to adapt the current railway network for new energy-efficient technologies (3, 11, 26).

B. An emergent investor-user dilemma resulting from the current segmentation of the rail industry in the UK; benefits from energy efficiency improvements by NR were thought to largely be received by external stakeholders, rather than NR themselves (24, 25 as a possible mediating factor).

C. The perceived low accuracy of available energy use data, obstructing the quantification of energy-saving benefits for new technology projects (2, 18).

D. Very high levels of caution towards implementation of new technologies, due to perceived impacts on safety and company performance, possibly resulting from a shortage of energy-related performance measures (3, 17, 19, 20).

These findings align with some aspects of neoclassical economic observations from management- and production-oriented studies of barriers to energy efficiency in large organisations (e.g. Schleich & Gruber, 2008; Schleich, 2009; Zilahy, 2004). Points B, C & D correspond with ‘split incentives’, ‘imperfect information’ and ‘risk’ barrier categories respectively, as identified by Sorrell et al’s (2011) review of energy
efficiency barriers. Self-efficacy (A), while not aligning to Sorrell’s taxonomy, reflects Montalvo Corral’s (2003) findings that firms’ perceived control over innovation affects their adoption of cleaner technologies.

In addition, the current suite of performance measures used by NR was widely acknowledged as a strongly-influential factor governing most business decisions (14, 20). Some participants were quick to note the absence of any directly energy-efficiency- or pro-environmental measures, as a cause of slow technology uptake. The Public Performance Measure (PPM), a measure of trains arriving within 5 minutes of their scheduled time, was mentioned particularly regularly. This perception of technical risk was thought to have been heightened by the impact of a recent widespread pro-safety culture programme and related performance measures. This exacerbates the splitting of incentives, and could be a source of lower perceived organisational support on energy issues (determined as a trigger for pro-environmental behaviour by Paillé & Boiral, 2013).

Meanwhile, pro-environmental attitudes broadly resembled those from other organisational studies where participants acknowledged energy efficiency as “the right thing to do” (e.g. Kaplowitz et al, 2012), exemplified by the positive responses in themes 1, 8, 9 & 15. Participants also felt that information on efficient alternatives to current technologies was readily available (1, 13). Taking all observations of attitudes and behavioural barriers into account, this proposes the existence of an ABG in the context of NR.

Alignment of these findings with previous organisational psychological studies is reflected in the structure of the thematic categories; influential papers for each theme are provided in the ‘Theoretical Background’ column of Table 2.

### 4.3. Implications for later phases

Parameters for the questionnaire survey and agent-based model will need to be based around testing the four main theoretical barriers listed above, and the other themes raised during the interviews. Survey questions are planned to be based on the themes described in Table 2. Significance of the five barriers mentioned above will be tested by grouping together results from the relevant themes (as outlined by the numbering system).
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A possible difficulty arises when considering that ‘perceived self-efficacy’, observed qualitatively as one of the potentially more influential barriers, is a construct from the TPB, not the TIB. However, this can be accounted for using the moderating influence of ‘facilitating conditions’ within the TIB; most controls on an individual manager’s behaviour in an organisational context are likely to originate externally to the managers themselves, given the generally pro-environmental attitudes observed during the interview phase.

Additionally, the role of habits is thought to be outweighed by the influence of other normative factors in the case of NR, as only one theme category was identified as aligning directly with ‘habit’. Habit is a key feature of the TIB which sets it apart from other behavioural models, calling into question the validity of using it in this context. However, habits are thought to take hold due to social normative influences (Darnton, 2008, after Lewin, 1951), and as a result it is difficult to distinguish between the two. Questions on habitual influences beyond those observed during phase I may be added to phase II’s questionnaire to compensate.
# Table 9 - Interview responses summary

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Theme</th>
<th>Theoretical background - influential papers</th>
<th>Number of mentions per theme</th>
<th>Total Mentions</th>
<th>Positive</th>
<th>Neutral</th>
<th>Negative</th>
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<td>Atitudes</td>
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<tr>
<td></td>
<td>Social Factor</td>
<td>Norm</td>
<td>Influence of external stakeholders, or potential for interaction</td>
<td>Kollmuss &amp; Agyeman (2002) [External influences]</td>
<td>14</td>
<td>4</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Social Factor</td>
<td>Norm</td>
<td>Corporate inertia - resistance of behaviour change</td>
<td>Huijts et al (2014)</td>
<td>11</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Social Factor</td>
<td>External</td>
<td>Internal communication on energy conservation issues</td>
<td>Paillé &amp; Boiral (2013)</td>
<td>9</td>
<td>0</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

Colour-coding:
- Positive-context statements
- Neutral-context statements
- Negative-context statements
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5. Future outline

This section provides the main details of- and timetable for the proposed research programme from October 2014 – September 2016.

5.1. Goals and objectives

As discussed in the methodology (section 3), having completed the qualitative interview research, two main activity goals, and subsets of objectives remain for this research project:

- **(Phase II) Development and delivery of a questionnaire survey to test hypotheses raised during the interview phase**
  - Complete a pilot questionnaire survey before end of March 2015
  - Complete main survey period before end of July 2015
  - Produce a journal research paper based on the questionnaire survey (in *J Env Psych* or *Energy Policy*)

- **(Phase III) Behavioural agent-based modelling based on the results of the survey.**
  - Produce an agent-based model of energy use behaviour, and projections of energy used based on the likely effects of behaviour change interventions
  - Use models to make internal recommendations for NR’s management of energy-intensive infrastructure.
  - **[Stretch objective]** – Produce a journal research paper based on the agent-based model (ideally in *Energy Policy*)

These sit alongside the standard coursework- and portfolio-related objectives of the EngD course.

A summary timetable for delivery of these objectives (and other course activities) is provided in a fold-out Gantt chart at the end of this section (Figure 13, page 39).
5.2. Managing risks

As the questionnaire survey- and modelling processes are independent of other activities taking place within NR, delays caused external projects are thought to be negligible.

The author is due to commence a period of jury service on 23 February 2015. Although scheduled to last for two weeks, this may last significantly longer. Contingencies are to be discussed with questionnaire delivery stakeholders once questionnaire plans are completed.

Beyond this point, the greatest uncertainties arise from overlap between the survey research and the behavioural modelling phase. A framework for the agent-based model will need to be developed concurrently with the survey, but conversely, model parameter definition cannot be finalised until completion of the questionnaires. Successful development of the agent-based model also depends on the robustness of results at the survey stage.

Overall, none of these risks endanger completion of the project outright. Those which exist are more likely to postpone, rather than cancel planned activities. As a way of maintaining timetable flexibility, production of an external journal paper on the agent-based modelling phase is considered a ‘stretch’ objective, although the model results will be included in the final portfolio in any event.

All main risks to project delivery and recommendations to overcome these are outlined in Table 10, overleaf.
Table 10 - Risks to project delivery

<table>
<thead>
<tr>
<th>Risk</th>
<th>Severity</th>
<th>Likelihood</th>
<th>Overall</th>
<th>Steps to mitigate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redrafting of journal articles (all phases):</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Consult academic supervisors extensively before submission.</td>
</tr>
<tr>
<td>Journals may require significant changes to submitted papers, reducing time for other parts of project.</td>
<td></td>
<td></td>
<td></td>
<td>Submit papers before commencement of thesis.</td>
</tr>
<tr>
<td>Other parts of the business may not be interested in distributing survey.</td>
<td></td>
<td></td>
<td></td>
<td>Use secondary analysis of other internal surveys as a backup tool.</td>
</tr>
<tr>
<td>Low survey response rate:</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Length of questionnaire to be kept to a functional minimum, to avoid infringing on participants’ time.</td>
</tr>
<tr>
<td>May not receive sufficient responses to be able to calculate significance of behavioural factors.</td>
<td></td>
<td></td>
<td></td>
<td>Coordinate with business change team to ensure widespread delivery.</td>
</tr>
<tr>
<td>Need to re-pilot surveys:</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Ensure language used is easy-to-understand by proof-reading with SBS team colleagues.</td>
</tr>
<tr>
<td>Initial pilot survey may reveal flaws in methodology. Time to re-pilot may infringe on delivery of other work.</td>
<td></td>
<td></td>
<td></td>
<td>Leave flexible time periods in project plan.</td>
</tr>
<tr>
<td>Overrun of survey prevents model development</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Commence work on model structure before main survey data collection period.</td>
</tr>
<tr>
<td>Logistical complications with survey delivery may not leave sufficient time to complete agent-based model.</td>
<td></td>
<td></td>
<td></td>
<td>(Continued overleaf)</td>
</tr>
</tbody>
</table>
### Table 3 (continued from previous page)

<table>
<thead>
<tr>
<th>Risk</th>
<th>Severity</th>
<th>Likelihood</th>
<th>Overall</th>
<th>Steps to mitigate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agent-based modelling overrun:</strong>&lt;br&gt;Software may not be adequate for task. Model may not be representative of real-world examples.</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Trial multiple software packages during questionnaire planning phase, to test ease-of-use and functional capabilities.</td>
</tr>
<tr>
<td><strong>Jury service:</strong>&lt;br&gt;Due to take place week commencing 23 February 2015.</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Allow time clearance following scheduled service to allow for overrun. Make contingency plans for deferring commencement date of main survey. Brief supervisors and SBS team colleagues of distribution details for questionnaires in absentia if necessary.</td>
</tr>
</tbody>
</table>
Figure 13 – Research timeline chart

<table>
<thead>
<tr>
<th>Activity</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENERGY ATTITUDE SURVEY RESEARCH</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engage with Your Voice and HS1 env. attitude survey teams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define parameters for survey testing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey scoping and planning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot survey</td>
<td></td>
<td></td>
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<tr>
<td>Main survey period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyse results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft journal article</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finalise for publication; submit to journal</td>
<td></td>
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</tbody>
</table>

**ENERGY USE SCENARIO DEVELOPMENT** | | | |
| Define parameters | | | |
| Gather relevant asset energy data | | | |
| Develop agent-based modelling skills | | | |
| Test models | | | |
| Calculate scenario forecasts | | | |
| Analyse results | | | |
| Draft journal article | | | |
| Finalise for publication; submit to journal | | | |

**THESIS WRITE-UP** | | | |
| Develop structure with supervisors | | | |
| Communication Management course (thesis training) | | | |
| Convert existing journal papers to new thesis chapters | | | |
| First draft | | | |
| Main draft | | | |
| Proof-reading and final corrections | | | |
| Printing | | | |

**OTHER ACTIVITIES** | | | |
| Known conferences | | | |
| University taught modules and coursework | | | |
| [Continued literature review] | | | |
| 6-month report and thesis-writing | | | |
| Viva Voce examinations - approximate dates | | | |

**Intended programme (colours alternate for clarity)**
- Green shades
- Pale green - Allowances for omission / additional activity
- Orange - Known activity, approximate date
- Red - Intended key delivery dates
- Grey - Known leave dates

**Known conferences**
- PRRUKA conference - Kings Place, London
- EngD conference - University of Surrey, Guildford

**Known activity, approximate date**
- Module - Ecological Economics
- Module - PRINCE2 Project Management
- Module - Integrated Assessment
- Module - Communication Management

**Intended key delivery dates**

**Allowances for omission / additional activity**

**Known leave dates**

**NOTE:** The timeline chart provides a visual representation of the research activities over a 2-year period, with specific dates and key milestones highlighted for each activity. The chart is designed to help in planning and monitoring progress throughout the dissertation process.
6. Overall outlook

Phase I of this project is now nearing completion, pending submission approval for the first journal paper. In addition to the production of a journal article, phase I has provided a framework for recording any further discussions with relevant stakeholders. Information from this has already been presented internally at NR and for multiple conferences.

The collection of empirical behaviour data is now critical to the completion of this project, the submission of further papers, and development of the agent-based model. This represents the most significant remaining challenge, due to uncertainties inherent in the questionnaire data collection process, discussed in section 5.

Findings from this research will contribute to the Behaviour Change component of a forthcoming NR Energy Strategy. The delivery dates for this are to be confirmed, but expected to lie within the timescale of this research project.

In terms of meeting more direct course requirements:

- One refereed journal publication is in the process of submission to a journal with a top-quartile impact factor.
- All necessary taught modules have been attended and coursework submitted successfully, marks currently averaging 68.5%.
- All 6-monthly reports have been submitted on schedule.
- Presentations have been given at internal EngD conferences, with strongly positive feedback for the 2014 event.
- Other conference presentations have included a poster at the Tyndall Climate Change Centre PhD conference (23-25 April 2014), and a poster or presentation is scheduled at the Rail Research UK Association conference (5 November 2014).

A change of industrial supervisors has recently occurred, owing to a change of job role of the previous supervisor. This change is not believed to have caused any significant difficulties. The plans outlined in this dissertation were agreed with both outgoing and incoming supervisors in early September 2014.
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It is currently thought that all main objectives can be sufficiently met within the allotted time for completion for this course.

To conclude, the planned research activities aim to fulfil the gaps in knowledge identified by the literature review in the following ways:

- More detailed understanding of the barriers to energy efficiency at a middle management or operational level, around large-scale 'production'-oriented technology adoption
- Application of the Theory of Interpersonal Behaviour in the context of energy behaviours, responding to calls for greater integration of organisational studies and wider behavioural theories
- A case study investigation of organisational pro-environmental behaviours within the little-researched context of a major infrastructure provider
- Testing the applicability of agent-based modelling techniques for predicting production-oriented technology adoption behaviours in organisations.

Acknowledgements

Thanks to Dr Walter Wehrmeyer and Dr Jhuma Sadhukhan for their extensive feedback on earlier drafts of this dissertation, and for comprehensive teaching and support over the last two years. Much gratitude is also due to Amelia Woodley and Andrew Stiles for a smooth supervision handover in recent weeks. Finally, many thanks to Kent Farrell for introducing me to so many people, and for helping to narrow down the research topic. I wish him the best of luck in his new role working alongside HS2.
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Addendum – Corrections, March 2015

This section provides clarifications and addresses points raised at the 2-year Confirmation Viva examination on 16 January 2015. This subsumes an earlier version submitted on 2 February 2015. Each of these points is listed under the numbered headings. Some additional references and abbreviations are provided at the end; any not listed here are available in the original report.

1. Problem Statement and Aim – provide a clear statement of these

Problem statement:

Network Rail’s carbon emissions are not reducing as quickly as anticipated, having missed its own reduction targets for the period 2009-2014 (‘CP4’). Current company sustainability targets have also been criticised as being unambitious and unclear (Balch, 2013). As part of the solution to this for future periods (CP5 onwards), the necessity of addressing energy use behaviour change has been recognised in internal documentation, but the exact behavioural interventions required to achieve this have not.

It is proposed here that the personal energy attitudes of mid-level managers with direct responsibility for energy-intensive technologies could exert a major influence on energy behaviours in a Network Rail context. Previous research has suggested the importance of managers in pro-environmental decision making (Hemingway & Maclagan, 2004), but only limited empirical testing to this end has taken place to date (e.g. Papagiannakis & Lioukas, 2012). Aim 1 (below) is intended to investigate this.

Current research into attitudinal energy influences in the wider literature tends to focus largely on consumer or household practices. Economic organisational studies of energy efficiency barriers draw similar conclusions to behavioural studies of consumers, but individuals’ behaviours within organisations are often overlooked, despite behavioural paradoxes common to both settings (as discussed in the main literature review) Sorrell (2015) recommends a more nuanced approach to energy efficiency in all settings, taking greater account of social psychological approaches. Aim 2 (below) seeks to address this.

The Office of Rail Regulation (ORR) also raised several concerns over carbon emissions reporting (Arup, 2013). Points they raised included:

- Current emission baseline forecasts do not take into account any potential reduction strategies or behaviour change
2-year Dissertation

- Assumed reductions in the carbon intensity of the UK electricity supply grid were not accurate or reliable

As the single largest purchaser of electricity in the UK, quantification of the benefits of energy behaviour change programmes (Aim 3) would address the first point directly, and by doing so reduce reliance on grid-based emissions reduction to achieve NR’s carbon reduction aims.

**Aims:**

To address the problems discussed above, the overriding aims of this research are to:

1. Investigate the role of managers' personal attitudes in the adoption of large-scale energy-saving technologies, and the behaviours associated with their management.
2. Evaluate possible differences between energy efficiency barriers in organisational- and consumer settings.
3. Quantify the potential benefits of energy use behaviour change interventions

To this end, the three phases discussed in the main report align with each of these aims respectively, with interviews as a baseline study, the questionnaires as an empirical test, and the planned modelling phase as an output tool for industry.

2. *Define more clearly the meaning of the term ‘behaviour’ in this report*

The term “behaviour”, for the purposes of this report, is defined as “ways of thinking and acting on practices and technology changes”, in line with the definition used by the Energy Cultures Framework (Stephenson et al, 2010; Stephenson, 2012). The practices in question revolve around the use and management of large-scale heating devices, electronic equipment and other trackside assets, as mentioned in section 2.1 of the dissertation.

Additionally, “Habit”, in the context of this research, refers to counter-intentional habits, where a routine behaviour is reinforced by short-term gains (as discussed in Jackson, 2005, referring to Verplanken and Faes, 1999). One such practice, as suggested by an interview participant, could be continuing maintenance of large, mechanically-complex tunnel pumping systems, despite knowledge of cheaper, more advanced/efficient alternatives, because of the effects on transport disruption and impact on other company performance measures.

This definition is an extension of Habit as ‘procedural rationality’ (Simon, 1957). The Verplanken and Faes definition was considered the most applicable in the NR case, to distinguish the negative effects brought by the habits mentioned during the interview, and to reflect that the decision context (sustainable energy use) is one which is rapidly changing, reducing the effectiveness of habitual behaviour.
3. **Clearly list/present the actors involved in your system(s) and, as a suggestion, include a diagram of their interactions**

The managers interviewed were selected from two main areas of Network Rail’s organisational structure (see Figure 14, page iii). The first interviews took place with representatives from Energy Services, a subdivision of Asset Management Services (AMS). This body managed network-wide implementation of technical upgrades and replacements, handled energy supply issues, and monitored energy use. Decisions made here would have national-scale implications for energy use. In terms of the Energy Cultures Framework, AMS acts mostly as the oversight for ‘Energy Practices’, but would influence ‘Material Culture’ in terms of handling funding for the biggest changes. Participants were initially selected by the researcher using company organisation charts, in particular Route Asset Managers for Electricity and Plant. As the exploratory process continued, some later participants were contacted based on their involvement with specific projects, namely those associated with track heating technologies.

Later interviews took place with managers from Network Operations, which manages day-to-day maintenance and operation of the technologies being looked at here. Route Asset Managers in this business function would have an influence on heater control regimes, small-scale upgrades and replacement of equipment at a Route level. This was also the business function with the most frequent interaction with TOCs/FOCs (train operators). Senior Engineers involved with technology projects in this area would also have some influence on their eventual adoption. In relation to the Energy Cultures Framework, this function is related to the day-to-day ‘Norms’ of running a railway, meeting expected operational targets, and with the greatest responsibility for safety, perhaps with some localised influence on ‘Energy Practices’ (such as with the tunnel pump example, discussed under point 2).

Additionally, two participants originated from the infrastructure metering upgrade project (ongoing) within the ‘Infrastructure Projects’ function, which conducts major one-off enhancements and construction projects. Although this function doesn’t typically handle day-to-day management of energy use, this particular project had close ties with- and expertise drawn from Asset Management Services and Network Operations. Determining the business cases for such projects is probably the most ‘Material Culture’-influenced process encountered among interviewees.
However, since completion of the interviews, some major changes have occurred to this organisational structure (see Figure 15, below). Functions of the former Energy Services have been divided between the new ‘Digital Railway’ (dedicated to speeding-up implementation of ERTMS and other computerised systems) and ‘Safety, Technical & Engineering’ (absorbing AMS, now integrated with safety management and small-medium-scale upgrade engineering projects). This change is not thought to have had any impacts on the roles of managers or job reductions (only one interviewee has since left the business), but is altering some of their team structures and reporting hierarchies. If ABM is conducted toward the end of this research, taking point 6 of this response into consideration, these changes will affect the agent-interaction structure of the model.

---

5 As opposed to ‘Infrastructure Projects’, responsible for large-scale developments such as new lines, major electrification schemes etc.
4. Consideration should be given to keeping the theme of the material-energy culture ‘alive’ in the report in parallel with the TIB e.g. could use the Energy Cultures Framework

The Energy Cultures Framework has been integrated as part of this report’s definition of ‘behaviour’ (See corrections made under point 2, above), and in defining categories of interviewee (see point 3). Figure 16 shows how this research programme sits within their framework, as mentioned briefly in section 3 of the original report.

Figure 16 - Energy Cultures Framework applied to this research programme. Normal text refers to research activities, italic text to systemic behavioural influences.
5. **Clarify how the Hypotheses emerged from Stage 1 of the analysis**

Two sets of parallel hypotheses have emerged from the interview phase. Firstly, four key barriers emerged during the interview phase following consolidation of linked themes across attitude, behaviour, and external factor categories. These are provided in section 4.2 of the main dissertation report, and recounted briefly below:

A. Low perceived self-efficacy of managers around energy-related business decisions
B. Investor-user dilemma between NR (investor in railway infrastructure) and train operators (the primary users)
C. Low perceived availability of energy data
D. Low acceptance of new technologies (potentially due to heightened caution over safety)

These lead to four main testable hypotheses, respectively:

- Perceived self-efficacy among managers is positively-related to energy-efficient behaviours at NR
- Perceived conflicts of interest between NR and train operators regarding who receives the greatest benefit are negatively-related to energy-efficient behaviours at NR
- Perceived availability of energy data is positively-related to energy-efficient behaviours at NR
- Acceptance of energy-efficient technologies is positively-related to energy-efficient behaviours at NR

The second main finding was that the emergent interview themes aligned very closely with different aspects of the Theory of Interpersonal Behaviour (TIB), as discussed in the main report, and outlined in Table 2 within that document. This suggests that the TIB framework could be used for a second, parallel set of hypothesis tests, based on questions phrased around the observed themes from the interview phase. The overall structure of these hypotheses is provided in Figure 17, and the linkages therein suggest the following hypotheses for testing:

- Attitudes towards energy saving are positively related to the intention to save energy at Network Rail
- Social factors (norms, roles, and self-concepts) are positively related to intention to save energy at Network Rail
- Participants with strongly-held personal feelings about humanity’s (negative) effects on the environment have higher levels of intention to pursue energy efficiency measures at Network Rail
- Existing embedded habits have a negative relationship with intention to save energy at Network Rail
- The intention to save energy is positively related to energy saving behaviours at Network Rail
- The prevailing facilitating conditions have a moderating effect on the relationship between intention to save energy and eventual energy saving behaviours undertaken at Network Rail
Some examples of how the intended survey questions have been mapped to themes arising from the interviews, consolidated barriers A-D, the Theory of Interpersonal Behaviour, and barriers from a paper by Schleich (2009) is provided in Table 11 (the full set is omitted for brevity, and because some questions still need final approval by distributors). This allows for hypothesis testing using multiple lines of enquiry, rather than relying on one theoretical framework alone. This could also be extended to map the other behavioural theories discussed in the report (e.g. the Theory of Planned Behaviour), without necessarily adding further questions to the survey. The topics, phrasing and number of Likert scale questions (approximately 30) arose from the themes observed during the interview phase, with some minor modifications to improve questionnaire clarity.

![Diagram of questionnaire hypotheses, & structure of manager 'agents']

Figure 17 - Hypothesis-testing structure, based on Triandis' TIB.

Some other models were considered earlier. Kollmuss & Agyeman’s (2002) proposed model of pro-environmental behaviour was thought inappropriate for two reasons; the linkages between the various factors were not made clear, and due to Whitmarsh’s (2009) findings regarding the divergence of actions to save energy and actions to mitigate climate change. Other general behavioural theories, such as VBN, the Norm Activation Model and TPB did not include the role of habit in decision-making processes. Meanwhile, expanded versions of the Technology Acceptance Model (Davis, 1989; Venkatesh & Davis, 2000) increasingly resemble these general behavioural models, again without considering the role of habits.
Table 11 – Sample questionnaire Likert-scale test statements

<table>
<thead>
<tr>
<th>Q. No.</th>
<th>Question/statement wording</th>
<th>Model component (see tab 2)</th>
<th>Section of questionnaire (core/energy manager)</th>
<th>TIB Hypothesis relevance</th>
<th>Theme relevance [see Table 2 in main report]</th>
<th>Mapped to Phase 1 barriers [see section 4.2 in main report]</th>
<th>Mapped to Schleich (2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Information I need for my role is readily available to me</td>
<td>Evaluation</td>
<td>Core</td>
<td>H1</td>
<td>2</td>
<td>C</td>
<td>Bounded rationality, imperfect information</td>
</tr>
<tr>
<td>6</td>
<td>Saving energy in general is easy for my part of Network Rail to achieve</td>
<td>Belief</td>
<td>Core</td>
<td>H1</td>
<td>9</td>
<td>-</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>12</td>
<td>New technologies tend to have beneficial impacts on safety</td>
<td>Evaluation</td>
<td>Manager</td>
<td>H1</td>
<td>12</td>
<td>A</td>
<td>[Split Incentives?]</td>
</tr>
<tr>
<td>15</td>
<td>Other parts of Network Rail are quick to adopt new technologies</td>
<td>Norm</td>
<td>Core</td>
<td>H2</td>
<td>26</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>21</td>
<td>I plan to use less electricity in my place of work in future</td>
<td>Intention</td>
<td>Core</td>
<td>H1, H2, H4, H5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>Network Rail has few problems with adopting new technologies</td>
<td>Behaviour</td>
<td>Core</td>
<td>H5, H6</td>
<td>17</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>24</td>
<td>New energy-efficient technologies have generally worked reliably</td>
<td>Behaviour</td>
<td>Manager</td>
<td>H5, H6</td>
<td>13, 19</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>28</td>
<td>I am happy with the way Network Rail handles environmental issues</td>
<td>Affect</td>
<td>Core</td>
<td>H3</td>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
6. **Advisory comment regarding the use/implementation of the ABM – if early exploration of the ABM approach indicates that it is unlikely to be fruitful, then keep the opportunities to apply other approaches in mind/under review.**

It is intended that training for the ABM phase will take place during the survey data collection process. This will be the point at which the ultimate practicality of ABM is determined. A brief business case is also being prepared for the 30-month EngD report.

The fall-back position for this is to perform a comparative analysis of the validity of different behavioural theories in an organisational context. This has been prepared for by mapping multiple theoretical frameworks to each question in the survey, as shown in Table 1 (the Theory of Planned Behaviour has also been mapped in this way). This direct comparison has only occasionally been carried out in the past (e.g. Bamberg & Schmidt, 2003 for the TPB, TIB and NAM), and is thought to offer a robust alternative avenue for original research.

**References**

**ABBREVIATIONS:**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABM</td>
<td>Agent-Based Modelling</td>
</tr>
<tr>
<td>AMS</td>
<td>Asset Management Services (Network Rail department)</td>
</tr>
<tr>
<td>ERTMS</td>
<td>European Railway Traffic Management System</td>
</tr>
</tbody>
</table>

**PUBLICATIONS:**


**Introduction**

This research aims to investigate the pro-environmental attitude-behaviour gap within a major organisation, in the context of energy efficiency for railway infrastructure.

Previous studies of this gap within businesses have largely focused on common, everyday behaviours in office or residential settings, or travel choices, as opposed to production-oriented management practices, and none (to date) have done this within a major infrastructure operator. This is intended to be the first component of a wider study into the impacts of energy efficient behaviours, culminating in the development of energy use scenarios based on behavioural observations (see below for plan).

This research is being undertaken as part of an EngD in Sustainability for Engineering & Energy Systems with the University of Surrey’s Centre for Environmental Strategy and Network Rail, running 2012-2016.

---

**Research plan**

- Graduate scheme social research project
- Current infrastructure energy audit
- Energy use scenario modelling
- Business as usual (business-as-usual) scenario
- Research plan
- Technology-led scenario
- Other research projects
- Behaviour change led scenario

---

**Results so far**

- Motivational among the perceived barriers to implementation of energy-efficient practices were:
  - Uncertainty towards the reliability of new technology
  - Conflicts of interest regarding who receives benefits from investment
  - Difficulty in communicating unified energy efficiency approaches among asset-level managers due to size of company and geographical diversity
  - Lack of visibility of company energy efficiency goals, and a perceived need for centralised leadership
  - Need for more accurate data before proceeding with efficiency projects (to help quantify their benefits)

---

**Methodology**

A series of semi-structured interviews were carried out with 12 managers of electrical energy for infrastructure at Network Rail. This took a ‘Grounded Theory’ approach (Glaser, 1965), using outline questions based on experiences relating to energy management and organisational structure. A thematic analysis was applied to notes taken during the interviews, coding responses into categories based on respondents’ attitudes, subsequent behaviours, and normative pressures.

These were then mapped to ‘Talanta’ Theory of Interpersonal Behaviour (see below). This particular behavioural theory was chosen because:

- Attitudes can be broken down into those with basic categorical realisation, and ‘weak-tangible personal beliefs and values
- The capacity for including facilitating conditions as a behavioural influence

---

**References**

The various social components will feed into development of a series of energy use scenarios:

- Where energy efficiency improvements are primary business technology
- Where improvements are led by behaviour change initiatives and altered management practices
- Business-as-usual (current practices carried on indefinitely)

These scenarios will investigate both the total infrastructure electrical energy use, and the intensity of this use per service unit, probably passenger km or freight tonnes.

---

**Next phase – Energy scenario development**

The spread of decentralisation across the network will then undergo ‘scenarios’ testing through ‘gaming’ tool, and起草 of supporting ‘roadmap’

---

**Acknowledgments**

Many thanks to Rupert Zierler and to Jhuma Sadhukhan for their academic supervision, support and guidance.

I would also like to thank Kent Farrell at Network Rail, particularly for helping me navigate my way around the company and amongst the interviewees.

Finally, thanks to my PhD supervisor, for being a great egg.
Integrating sustainability frameworks within Network Rail’s business practices –

The attitude-behaviour gap and infrastructure energy efficiency

Word count (main body): 6,284

Academic Supervisors: Dr Walter Wehrmeyer
Dr Jhuma Sadhukhan

Industrial Supervisors: Andrew Stiles
Roan Willmore*

* Temporary
This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant or influential these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3). A set of barriers has now been established, in the context of an energy-efficiency ‘value-action gap’; their relative significance is due to be tested over the coming six months.

This progress report covers all EngD research conducted during the period October 2014 – March 2015, and updates an earlier project plan for the 6 months leading to September 2015.

Progress towards deliverables

Overall, progress has been satisfactory, despite some disruptions over this period, relating to supervisor change and external delays.

The first phase of research (interviews with energy managers) is nearing completion, pending peer review of the first submitted journal paper.

The second phase (energy attitude questionnaire survey) is now underway, following the completed design of an energy use attitude survey, to be known as ‘Our Energy’ within Network Rail.

The third phase (agent-based modelling) has also been initiated, with development of an intellectual case for using the technique to predict energy use at Network Rail.

Questionnaire planning and design
A questionnaire has been developed to answer the second research question, based on the outputs of the first. Questions are mapped to themes emerging from the interview research phase, behavioural theories, and barriers to energy efficiency observed in literature. Multiple versions of this questionnaire have been developed, for targeting both managers, and Network Rail staff in general. Both questionnaires were undergoing pilots with supervisory teams (Sustainable Business Strategy and Business Change) at the time of going to press.

**Business case for Agent-Based Modelling (ABM)**

Scientific literature around previous applications of ABM is reviewed. This follows on from a recommendation from the upgrade viva examination in January 2015. This review establishes that the technique chosen (ABM based on parameters from an attitude survey) has been used in the past in other contexts. Additionally, although models of organisations, and of spreading pro-environmental behaviours already exist, combination of the two is rare, especially in the realm of energy use. This review suggests that use of ABM is feasible for the third phase of this project, but will be dependent on good-quality input data from the questionnaire survey.

**Actions for the next 6 months**

The following main actions are planned for April – September 2015:

- Distribution of questionnaire survey
- Analysis of survey results using SPSS
- Attend ISIE conference (July), EngD conference (early September), and Rail Human Factors conference or CRR conference (mid-September)

In addition, software training for the third research phase and a taught module will take place. Full details are provided on a project plan chart in the main report.
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## Glossary

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<th>Description</th>
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<tr>
<td>ABM</td>
<td>Agent-Based Modelling</td>
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<tr>
<td>APM</td>
<td>Association for Project Management</td>
</tr>
<tr>
<td>BECC</td>
<td>Behaviour, Energy and Climate Change (conference)</td>
</tr>
<tr>
<td>CRR</td>
<td>Corporate Responsibility Research (conference)</td>
</tr>
<tr>
<td>CSR</td>
<td>Corporate Social Responsibility</td>
</tr>
<tr>
<td>HS1</td>
<td>‘High Speed 1’ rail link from St Pancras International to the Channel Tunnel</td>
</tr>
<tr>
<td>IEMA</td>
<td>Institute of Environmental Management and Assessment</td>
</tr>
<tr>
<td>ISIE</td>
<td>International Society for Industrial Ecology</td>
</tr>
<tr>
<td>NR</td>
<td>Network Rail</td>
</tr>
<tr>
<td>PRINCE2</td>
<td>PROjects IN Controlled Environments 2 (project management)</td>
</tr>
<tr>
<td>RRUKA</td>
<td>Rail Research United Kingdom Association</td>
</tr>
<tr>
<td>RSSB</td>
<td>Rail Safety and Standards Board</td>
</tr>
<tr>
<td>SBS</td>
<td>Sustainable Business Strategy (Network Rail team)</td>
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<td>SEES</td>
<td>Sustainability for Engineering and Energy Systems (doctorate centre)</td>
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<tr>
<td>SPSS</td>
<td>Statistics software package</td>
</tr>
<tr>
<td>TIB</td>
<td>Theory of Interpersonal Behaviour (Triandis, 1977)</td>
</tr>
<tr>
<td>TPB</td>
<td>Theory of Planned Behaviour (Ajzen, 1991)</td>
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</table>
1. Introduction

This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3). A set of barriers has now been established, in the context of an energy-efficiency 'value-action gap'; their relative significance is due to be tested over the coming six months.

This progress report reviews all research activities for the period 1 October 2014 – 31 March 2015. The main activities from this period have been the completion of the 2-year ‘upgrade’ viva process, submission of the first journal paper, and development of an energy attitude questionnaire for distribution among Network Rail (NR) staff.

Section 2 outlines progress towards goals and deliverables set in the 24-month dissertation, and relates these to both overarching research questions and key research phases.

Section 3 briefly goes through EngD course-related commitments during this 6-month period, particularly around feedback from the dissertation viva examination.

Section 4 discusses the questionnaire design process, going through hypothesis formulation, question development, and data management.

Section 5 provides an intellectual case for using Agent-Based Modelling (ABM), as the need for this was raised as part of the viva examination process.

Section 6 provides a list of actions for the next 6-month period (1 April – 30 September 2015), particularly around survey distribution and conference attendance, and a revised research timeline Gantt chart.

Section 7 provides a brief statement on project progress as a whole.
Appendices 1-4 provide conference abstracts submitted during the preceding period. Appendix 5 contains the current main, paper version of the energy attitude questionnaire. Finally, appendix 6 provides the research paper on the Interview phase of this project, as submitted to the Journal of Cleaner Production in February.
2. Progress towards deliverables

Overall, progress has been satisfactory, compared to the research project plan laid out in the 2-year dissertation. However, some actions have taken longer than expected. This is traceable to three main factors:

- A further change in industrial supervisor took place at the end of February 2015. Whilst one supervisor remained in place, this impeded the setting-up of plans for questionnaire development. Contact with this particular supervisor
- The viva examination process, scheduled to take place in November 2014, was delayed until January 2015, with the Corrections process running into February. Time allotted for implementing feedback recommendations was therefore also delayed
- A previous industrial supervisor recommended that clearance was sought for publication of the Interview research paper (discussed below). The communications process for this took longer than expected, and was eventually deemed unnecessary by NR Communications, despite the paper being ready for journal submission in 2014.

The remainder of this section discusses each major deliverable planned for this 6-month period. These are given in order of their listing in the project plan from the 2-year dissertation.

2.1. Interview research paper

A paper on the Interview phase of this research project was submitted to the Journal of Cleaner Production in February 2015. This was entitled: “A qualitative assessment of the value-action gap for energy efficiency of railway infrastructure”. This is currently under review, with no available estimates on a completion date. The content of this paper has been discussed in previous reports and the 2-year dissertation, and so is not repeated here.

The submitted version is attached as Appendix 6 of this report. Please note that this is not the final, accepted version, and is not yet published.
2.2. Engage with other internal NR survey teams

Network Rail High Speed (referred to as HS1), a subsidiary of NR, performed an environmental attitude survey across their whole organisation. It was felt that cooperation with the operators of that survey might serve to inform the content of this research project, and avoid duplication of effort. However, the content of the HS1 survey was not considered detailed enough to transfer to this research project. Questions in this survey sought mostly ‘Yes/No’ answers, rather than richer Likert-scale questions. Some questions were also ‘double-barrelled’, making it difficult to decipher respondents’ thoughts on particular environmental topics. The majority of questions were also focused on recycling and waste management, rather than energy use.

However, their survey was notable for the tailoring of questions for specific teams. This recommendation has been carried forward to the Our Energy survey, through development of two parallel questionnaires for energy managers, and general staff. Further details are available in section 4 of this report.

Adding energy-related questions to NR’s employee satisfaction survey ‘Your Voice’ was also briefly considered. However, the team responsible for the survey decided against this, due to the (already large) size of the existing questionnaire and a desire for consistency between survey years at present (as the survey itself is relatively new). A further Your Voice survey is currently scheduled for May 2015 – this may be interrogated for additional information, as the date will be closer to that of data collection for the Our Energy Survey.

Despite this, the Your Voice survey supported the development of the Our Energy survey in two key ways. Firstly, the set of demographic data collected will mirror that of Your Voice, i.e. gender, age, NR business unit, pay band, length of service, and whether the respondent works full- or part-time, works a shift pattern, or has any subordinate staff. This will allow improved communication of results within NR, and possibly enable correlation of employee satisfaction with energy attitudes for specific departments within NR. Secondly, stakeholders involved in the Your Voice distribution process are being consulted regarding assistance with distributing Our Energy as well, particularly with respect to survey software resources.

Engagement with these teams will continue throughout the remainder of this project, but will no longer be treated as a separate action.
2.3. Define parameters for survey testing

This action involved interpreting the findings of the Interview phase, developing hypothesis tests for the Questionnaire phase, and engaging with NR managers to determine additional questionnaire content. Details relating to questionnaire design are provided in section 4.

In brief, interpretation of the Interviews provided topics for the survey questions, and a set of 5 barriers for testing, based on thematic analysis. Two parallel sets of hypothesis tests were proposed, based on the aforementioned barriers, and the structure of the Theory of Interpersonal Behaviour (TIB) respectively. Discussion with managers highlighted some possible open-answer questions, and 11 energy-related behaviours to measure. Demographic parameters were selected based on the content of Your Voice, to provide compatibility of results for any potential (additional) cross-analysis of the two surveys.

This action is now considered closed, and is omitted from the revised project plan in Figure 24, section 6.

2.4. Pilot survey

At the time of going to press, questionnaires were being piloted with the Business Change and Sustainable Business Strategy (SBS) teams. Business Change are testing the Manager questionnaires, whereas SBS are testing the more general Employee version (see section 4 for details of content).

This action is not yet closed, despite being scheduled as such in the 2-year dissertation. However, actions are in place to resolve this as soon as possible, and project deadlines are not endangered (see section 6.1.1). A revised timetable is provided in the project plan (see section 6).
2.5. Additional actions

2.5.1. RRUKA conference, 5 November 2014

The annual RRUKA conference took place at Kings Place in London. This annual conference covers a broad range of railway research, such as passenger flow at stations, civil engineering issues and the management of trains. The researcher presented a poster, entitled ‘All Change Please! – Embedding Behaviour Change into Network Rail’s Business Practices’. The poster content was based on the outcome of the Interview research phase. It was felt that the poster did not receive a great deal of exposure, due to a shortage of allotted poster viewing time on the day of the conference.

The abstract used for this conference is available in Appendix 1, and a scaled-down version of the poster is included in Appendix 7.

2.5.2. APM Project Management course

A two-day APM Foundation course in project management was also taken during this period, achieving a mark of 95%. This was taken after completion of the 2-year dissertation, so lessons learnt here could not be applied to the main project plan. However, techniques from this could be applied later during the Modelling phase, particularly critical path analysis during code development.

2.6. Research question progress

Progress discussed under points 2.1 – 2.5 has been mapped to this project’s main research questions and Phases in Table 12, on the fold-out overleaf. Proposed actions covered in the table are discussed in section 6.

In summary, research questions 1, 1a & 1b will be confirmed as completed, once the Journal of Cleaner Production paper is accepted. These questions have formed the basis for development of the planned survey (see section 4).
Questions 2 & 2a have seen progress over the last 6-months in terms of development of detailed hypotheses, and finalising the answering methodology. These questions will see more significant progress over the next 6 months, following questionnaire distribution and analysis. Answers to these questions will be covered by the output research papers at the end of that process.

Questions 3, 3a & 3b are planned to see some initial progress in the coming months, particularly in defining the scenarios to be tested by ABM. Progress in recent months has largely been determining the feasibility of the chosen processes for answering these questions (see section 5). However, answering this question is largely dependent on the outcomes of questions 2 & 2a.
### Table 12 - Progress against research questions laid out in 2-year dissertation.

<table>
<thead>
<tr>
<th>Research questions</th>
<th>Phase I: Interviews</th>
<th>Phase II: Energy attitude and behaviour questionnaire</th>
<th>Phase III: Agent-based modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 What challenges arise when embedding pro-energy-efficiency behaviour change frameworks within a major infrastructure operator?</td>
<td>Content reviewed as part of 'upgrade' viva examination. Paper submitted to Journal of Cleaner Production.</td>
<td>Research phase nearing completion, pending review of submitted paper.</td>
<td>Redraft journal paper if required. Revisit material for conference presentations.</td>
</tr>
<tr>
<td>1a What role do individual operational-level managers' attitudes play in determining energy-efficient technology adoption?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b What are the potential behavioural barriers to adoption of energy efficient technologies at NR?</td>
<td>Observed barriers used as basis for questionnaire Likert-test statements.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Which of the identified barriers have the most significant negative impacts on adoption of energy management behaviours?</td>
<td>Analyse open-answer questions in questionnaire (thematic analysis) as supporting evidence for Interview Phase.</td>
<td>Hypothesis tests formalised and revised following viva examination. Questionnaire content developed with supervisors. Produced multiple survey versions and formats. Commencing pilot study.</td>
<td>Continue piloting. Review and adapt questionnaire as necessary. Produce detailed distribution plan. Begin main distribution period. Present initial findings at conferences.</td>
</tr>
<tr>
<td>2a Is the hypothesised gap between energy-efficient attitudes and behaviours supported by empirical observations within NR?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 What are the predictions for NR’s future electricity use, under different energy behaviour culture change scenarios?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a (Purely technology-oriented scenario) - What is the baseline prediction for energy use without major behavioural interventions?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>(Behaviour culture change scenario) - What are the likely effects of extensive energy behaviour interventions on electricity use?</td>
<td>Hypothesis tests formalised and revised following viva examination.</td>
<td>Begin training in ABM software. Develop dummy data to test modelling structure as needed.</td>
</tr>
</tbody>
</table>
3. Course-related work

3.1. Viva examination

The ‘upgrade’ viva examination took place on 16 January 2015. This was originally planned for November 2014, but delays were incurred whilst searching for an external examiner.

Overall, examiners were satisfied with the overall research approach taken. No major changes to the planned research phases were proposed. However, it was suggested that use of ABM, as a relatively untested methodology in this field, could be riskier than anticipated (see below).

Examiners commented on the extraordinarily large number of industrial supervisor changes which had taken place since the beginning of the programme. They acknowledged that this was likely to have caused disruption to delivery of the research project.

A set of six minor corrections were requested by the examiners. The first version of these was sent in February 2015. Some further clarifications were requested later that month, and further revisions were submitted in March. These are attached to the 2-year dissertation, and so are not included here.

Their points revolved around clarifying the problem statement, aim, definition of behaviour used by the report, and how the hypotheses to be tested by the questionnaires arose from the Interview research phase. A clearer list of actors and stakeholders was also required; this has been incorporated into the case for ABM (see section 5).

One recommendation was to align the outputs of this research with the Energy Cultures Framework, developed by Stephenson et al (2010). This will be referred to in future project outputs, including conference presentations, internal NR communications, and journal papers. The alignment of the research project to-date is described in full in the Corrections document.
It was also recommended that a contingency plan for additional research be put in place, in case ABM proves impractical in terms of code implementation (although this currently seems feasible, as discussed in section 5). Further interrogation of questionnaire data is proposed as an alternative. In addition to hypothesis tests around the TIB and Interview barriers respectively, a comparison of multiple theoretical frameworks can also be conducted. Bamberg & Schmidt (2003) performed a similar comparison to that proposed, albeit in the context of travel behaviours. Subsequently, the Theory of Planned Behaviour (TPB) (Ajzen, 1991) has also been mapped to the main questionnaire content in order to achieve this. See section 4 of this report for further details.

3.2. Taught modules

3.2.1. Ecological Economics

This module covered some basics of economics, such as Net Present Value calculations, and deeper discussions of the role of economics on the planet, particularly debating the relationship between prosperity and growth. Some of the economic techniques learnt here could be used to enhance Modelling phase outputs, enabling possible comparison of behaviour change initiatives with more conventional economic incentives. Coursework comprised one reflective essay, and one loosely-defined quantitative economic exercise. Although options relating to energy behaviour change were explored for the quantitative exercise, the output from this assignment did not relate to the overall research project in the end, owing to a shortage of relevant available price elasticity data.

3.2.2. PRINCE2 Project Management

This variant of project management focused more on the management of stakeholders within a project, than the technically-focused APM course mentioned in section 2.5.2. Techniques learnt here will be applied during the Questionnaire phase, to ensure that a large population sample is reached. Configuration management processes will also be used to ensure consistency of questions asked to different groups, and to track which individuals are responding to various versions of the questionnaire.

3.2.3. Module mark overview
Overall, progress with module coursework has been good; marks have been steadily climbing since the start of the project. However, some of the more recent modules have taken longer to complete than scheduled-for (notably Environmental Law and Ecological Economics), causing minor delays with short-term project milestones set during supervisor meetings.

Sufficient modules have now been completed to allow for Associate membership of the Institute of Environmental Management and Assessment (IEMA). A brief summary of all coursework marks to date is provided in Table 13.

<table>
<thead>
<tr>
<th>Table 13 – Coursework marks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>Mark (%)</td>
</tr>
<tr>
<td>Social Research Methods</td>
<td>60</td>
</tr>
<tr>
<td>Environmental Science and Society</td>
<td>62</td>
</tr>
<tr>
<td>Foundations of Sustainable Development</td>
<td>70</td>
</tr>
<tr>
<td>Life Cycle Thinking</td>
<td>59</td>
</tr>
<tr>
<td>Sustainable Development Applications</td>
<td>70</td>
</tr>
<tr>
<td>Life Cycle Assessment</td>
<td>73</td>
</tr>
<tr>
<td>Transitions to a Low Carbon Energy Economy</td>
<td>74</td>
</tr>
<tr>
<td>Corporate Social and Environmental Responsibility</td>
<td>63</td>
</tr>
<tr>
<td>Environmental Auditing and Management Systems</td>
<td>69</td>
</tr>
<tr>
<td>Psychology of Sustainable Development</td>
<td>73</td>
</tr>
<tr>
<td>Environmental Law</td>
<td>80</td>
</tr>
<tr>
<td>Ecological Economics</td>
<td>76</td>
</tr>
<tr>
<td>PRINCE2 Project Management</td>
<td>81</td>
</tr>
<tr>
<td>Integrated Assessment (May 2015)</td>
<td>n/a</td>
</tr>
<tr>
<td>Communications Management (late 2015)</td>
<td>n/a</td>
</tr>
<tr>
<td>OVERALL (up to PRINCE2 module):</td>
<td>70</td>
</tr>
</tbody>
</table>
4. Questionnaire design

One key product of this 6-month period has been the design of the energy attitude survey, for the Questionnaire phase of this research project. The working title for this survey is currently ‘Our Energy’. This questionnaire was developed over several sessions with supervisors, following consultation with the NR Energy Services department. This section first describes the hypotheses to be tested by the survey, then provides a description of how questions were developed, and ends by describing how the survey will be distributed, monitored and managed.

4.1. Hypotheses

Hypothesis tests are required to determine the significance of possible barriers to energy-efficient behaviour at NR. Details of the process by which these hypotheses were developed is covered in the dissertation Corrections document.

Due to the closeness-of-fit of the Interview phase’s emergent themes with the TIB, it is proposed that this theoretical framework be tested using questionnaire data.

The TIB hypotheses are as follows (null hypotheses are omitted here for brevity):

1. Attitudes towards energy saving are positively related to the intention to save energy at Network Rail
2. Social factors (norms, roles, and self-concepts) are positively related to intention to save energy at Network Rail
3. Participants with strongly-held personal feelings about humanity’s (negative) effects on the environment have higher levels of intention to pursue energy efficiency measures at Network Rail
4. Existing embedded habits have a negative relationship with intention to save energy at Network Rail
5. The intention to save energy is positively related to energy saving behaviours at Network Rail
6. The prevailing facilitating conditions have a moderating effect on the relationship between intention to save energy and eventual energy saving behaviours undertaken at Network Rail.

The structure of these hypotheses is provided in Figure 18.

Figure 18 - TIB hypothesis structure.

The second set of hypotheses revolves around the 4 ‘main’ barriers emerging from the Interview phase, as discussed in the dissertation Corrections document (henceforth referred to as ‘Interview barriers’). A fifth hypothesis has been added to reflect the possibility of multiple goal conflict (see also Cheng et al, 2007) which is discussed in the submitted journal paper (see Appendix 6). These hypotheses are listed below:

A. Perceived self-efficacy among managers is positively-related to energy-efficient behaviours at NR
B. Perceived conflicts of interest between NR and train operators regarding who receives the greatest benefit are negatively-related to energy-efficient behaviours at NR
C. Perceived availability of energy data is positively-related to energy-efficient behaviours at NR
D. Acceptance of energy-efficient technologies is positively-related to energy-efficient behaviours at NR
E. Perceived conflicts between multiple performance goals are negatively-related to energy-efficient behaviours at NR

4.2. Question development

As discussed above, the questionnaire is designed to test several parameters in parallel. This entailed inclusion of enough questions to sufficiently answer multiple hypotheses. However, the survey also needed to be kept as brief as possible, to avoid infringing on participants’ time, and to ensure collection of a larger number of completed questionnaires.

Questions were initially developed around the themes emerging from the Interview phase, and components of the TIB (which had already been mapped to the themes), enabling fulfilment of hypothesis tests 1-6. The question-mapping process is outlined in Table 14; ‘Interview theme relevance’ refers to the numbering of themes in the Interview research paper (see Appendix 6, Table 2)

Most questions were later mapped to one of the 5 Interview barriers, enabling testing of their corresponding hypotheses (A-E). Questions were also mapped to the oft-quoted taxonomy of barriers developed by Sorrell et al (2000), and model components of the TPB. Other behavioural models were considered for mapping, but these did not fit with as many survey questions as the others (particularly Value-Belief-Norm and Norm Activation models). The structure of the TPB is provided in Figure 19 for reference.

The current order of questions is based on a randomised number order, which will now remain fixed across all versions. This is intended to prevent questions on similar topics from being answered in rapid succession.
Figure 19 - TPB structure (Ajzen, 1991).
### Table 14 - Mapping survey questions to theoretical frameworks (continued overleaf)

<table>
<thead>
<tr>
<th>Q. no.</th>
<th>TIB model component</th>
<th>TPB model component</th>
<th>Survey Version</th>
<th>Interview theme relevance</th>
<th>Interview barrier relevance</th>
<th>Barriers from Sorrell et al, 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evaluation</td>
<td>Perceived behavioural control</td>
<td>General</td>
<td>21</td>
<td>C</td>
<td>Imperfect information</td>
</tr>
<tr>
<td>2</td>
<td>Evaluation</td>
<td>Attitude toward behaviour</td>
<td>Manager</td>
<td>16</td>
<td>E</td>
<td>Risk and uncertainty, [Split incentives?]</td>
</tr>
<tr>
<td>3</td>
<td>Affect</td>
<td>Attitude toward behaviour</td>
<td>General</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Norm</td>
<td>Subjective Norm</td>
<td>General</td>
<td>26</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>5</td>
<td>Affect</td>
<td>Normative belief</td>
<td>General</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Intention</td>
<td>Behavioural intention</td>
<td>General</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Habits</td>
<td>Subjective Norm</td>
<td>General</td>
<td>26</td>
<td>B, D</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Evaluation</td>
<td>Control belief</td>
<td>General</td>
<td>2, 21</td>
<td>C</td>
<td>Bounded rationality, imperfect information</td>
</tr>
<tr>
<td>9</td>
<td>Belief</td>
<td>Perceived behavioural control</td>
<td>General</td>
<td>11</td>
<td>B</td>
<td>[Access to capital?]</td>
</tr>
<tr>
<td>10</td>
<td>Behaviour</td>
<td>Behaviour</td>
<td>General</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Belief</td>
<td>Normative belief</td>
<td>Manager</td>
<td>12</td>
<td>B, (A?)</td>
<td>n/a, [Split incentives?]</td>
</tr>
<tr>
<td>12</td>
<td>Belief</td>
<td>Normative belief</td>
<td>General</td>
<td>13</td>
<td>B</td>
<td>Risk and uncertainty, [Split Incentives?]</td>
</tr>
<tr>
<td>13</td>
<td>Behaviour</td>
<td>Normative belief</td>
<td>General</td>
<td>17</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>14</td>
<td>Belief</td>
<td>Attitude toward behaviour</td>
<td>Manager</td>
<td>3</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Belief</td>
<td>Attitude toward behaviour</td>
<td>General</td>
<td>9</td>
<td>B</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>16</td>
<td>Evaluation</td>
<td>Behavioural belief</td>
<td>General</td>
<td>5</td>
<td></td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>17</td>
<td>Intention</td>
<td>Behavioural intention</td>
<td>General</td>
<td>n/a</td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>18</td>
<td>Affect</td>
<td>Subjective Norm</td>
<td>General</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Evaluation</td>
<td>Behavioural belief</td>
<td>General</td>
<td>1, 4</td>
<td></td>
<td>Hidden costs</td>
</tr>
<tr>
<td>20</td>
<td>Behaviour</td>
<td>Attitude toward behaviour</td>
<td>Manager</td>
<td>20</td>
<td>D</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>21</td>
<td>Behaviour</td>
<td>Behaviour</td>
<td>General</td>
<td>10</td>
<td></td>
<td>Risk and uncertainty, [Bounded rationality?]</td>
</tr>
</tbody>
</table>
A set of questions on specific energy-related behaviours was also developed, following discussions with NR Energy Services and an external energy behaviour change consultant. These questions are referred to under “How regularly do you do the following things?” in the questionnaire (see Appendix 5). Despite the Interview phase’s focus on infrastructure energy use, some questions on in-office behaviours (such as lighting and computer use) are included. This is to expand the potential audience for the survey, and to align with some energy behaviour interventions proposed for NR by the same external consultant. Three open-answer questions were also included on this basis.

Demographic questions were determined following consultation with the NR Your Voice survey team (as mentioned in section 2.2).
4.3. Versions and configuration management

An Excel spreadsheet has been developed for use as a configuration management database. This lists the names and version numbers of all questionnaires produced, with whom they have been distributed, and distribution dates for relevant links or documents.

Two types of questionnaire are being prepared. One is aimed at managers of energy assets, particularly trackside infrastructure, buildings and depots (given the prefix code ‘M’). The second is aimed at the general NR employee population. The general questionnaire is a shortened version of the managerial one, omitting some questions relating to management processes (given the prefix code ‘P’).

The Interview phase focused on managers of electrical infrastructure-based assets. Hence, thematic analysis produced themes most relevant to these managers. However, after reviewing organisation charts, it became clear that a larger sample of individuals would be required in order to perform the statistical tests necessary to (dis)prove the hypotheses, than were available among the manager population.

Energy behaviour change in the wider business (not just among infrastructure managers is also currently being pursued by NR. A report by an external consultant suggested three key target areas for behavioural interventions, namely stations, depots, and offices. Modifying the questionnaire for a general population sample will aid development and implementation of these projects.

It is possible that further types of questionnaire will be developed to gather more detailed information on specific sections of NR, as with the HS1 survey (discussed in section 2.2). This is dependent on later consultation with recipient stakeholders, and any energy-related interests they may have.

Each questionnaire is currently written in 3 formats, as a Microsoft Word document, and online questionnaires on SurveyMonkey and MoboSurvey platforms. The latter two allow exports as Microsoft Excel files, but the former will require manual data entry into a separate Excel spreadsheet. All text is the same across all versions, as is the page arrangement, to prevent any unintentional skewing of data. The Word document version is included in Appendix 5 of this report.
5. The case for Agent-Based Modelling

A key recommendation from the viva examination was the need to justify the use of ABM as a means of answering the final research question, and to assess its feasibility. This section discusses the need for such a model within NR, previous uses of the technique in available research literature, and justification for the particular combined methodology proposed by this project.

5.1. Introduction

Network Rail has a target for 11% reduction in total greenhouse gas emissions by 2019. A significant proportion of this (approximately 21% of this reduction) is proposed to be achieved through behaviour change programmes. Whilst a scoping exercise has highlighted some possibilities for what these interventions could entail, it is not currently clear which of these should be prioritised, and where they would have the greatest impact on the rest of the business.

Agent-Based Modelling (ABM) offers a potential method for determining where and with whom these interventions may have the best effect, and resulting impacts on greenhouse gas emissions and costs.

5.2. Previous applications of ABM

ABM has been used in several contexts related to this research project, namely technology diffusion, energy policy, environmental issues, and asset management. This technique is more commonly applied to consumer behaviours relating to adoption/purchase of more efficient technologies. Chappin & Afman (2013) looked at the impacts of phasing out incandescent lightbulbs by modelling consumers. Lee & Malkawi (2014) model occupant behaviours relating to heating use in buildings. Natarajan et al (2011) review models of UK domestic carbon emissions, highlighting both the importance of considering habitual behaviours, and the difficulty in incorporating the wider socio-economic environment into these models.
Lee, Yao and Coker (2014) model the impacts of current UK policies on domestic energy reduction. This study showed that implementing a policy suggested by more generalised economic models could have unforeseen negative consequences, but only used a basic economic decision-making model for household agents. Gerst et al (2013) model the impacts of international climate policy based on interactions between negotiators. This suggests that modelling energy managers, who negotiate and define their own targets and objectives on a regular basis could also improve predictions of energy use.

Osman (2012) presents a case for using ABM in an infrastructure asset management context. Although this study looks at management of the condition of assets, it points out some key shortcomings of non-ABM modelling techniques. The interaction of users and decision-makers with these assets are not adequately captured, the diversity of stakeholders involved with asset management is not represented, and feedback on the attitudes of those managing the system is not taken into account.

Diffusion dynamics for new innovations are known to be influenced by the structural configuration of social influence networks (e.g. Delre et al, 2010). Heterogeneity of individuals (e.g. differing attitudes towards energy use and environmental matters) also influences the rate of change towards new technologies or practices (e.g. Andrews & DeVault, 2009). ABM accounts for both of these factors, whereas larger-scale economic models assume homogeneity across the whole of a business, industry or sector. ABM has been used for modelling intra-organisational interactions previously (as summarised by Chang & Harrington, in Tesfatsion & Judd, 2006).

Additionally, most earlier studies found using this questionnaire-ABM methodology use the TPB as a basis (e.g. Schwarz 2009), whereas a sizeable amount of recent UK policy literature has focused on use of the TIB for behaviour change programmes (Revell, 2012; Chatterton, 2011; Darnton, 2008). This highlights a gap in empirical support for UK policy, which this research has an opportunity to fill, especially in the context of NR’s recent reclassification as a public body.

5.3. Methodology justification

A series of papers by Sopha et al (2013, 2011, 2010) used a similar modelling methodology to that intended for this project. Their study looked at technological diffusion of environmentally-friendly heating systems through peer networks. Agents’ behavioural parameters (i.e. whether they adopted certain types of heater) were determined using a questionnaire survey, mapped to the TPB. The
intention to use different types of heating system was then calculated as a function of attitudes, personal norms, and social influence.

Their questionnaire results also revealed that a large proportion of respondents followed habitual practices in terms of which heater types they used, in a divergent group from those who determined their heater choice in a manner consistent with the TPB. The Theory of Interpersonal Behaviour (TIB) incorporates habit as one of its main influences, which would eliminate the need for analysing this project’s population sample in separate tranches, as done by Sopha et al (2010). This reinforces the case for using the TIB as an analysis tool during this project overall.

The key difference between Sopha et al’s work and the NR research would be in the distribution of agents. Their 2013 paper used a purely geographical model of Norway as a basis, with agents communicating based on various configurations, as illustrated by Figure 20.

The NR model would need to incorporate both geographical and hierarchical structures in order to accurately portray agents’ communication patterns; the former to represent interactions between Routes and physical locations on the railway, and the latter to mimic management structures and peer groups of employees.

The employee agents would be modelled using similar equations to those used by Sopha et al (2013) (see equations 1-4 in their paper), adapted to use weightings attached to attitudes, social factors, affect, and habits instead of the TPB-related factors in their paper. Agent parameters would be determined using results from the questionnaire survey, either using direct results, or a set of randomly-created agents with the same distribution of characteristics.
Following the broad framework of Smajgl et al (2011) provided in Figure 21, an agent modelling structure for NR is proposed in Figure 22.

Figure 21 - Generalised ABM parameterisation framework (Smajgl et al, 2011)

Figure 22 - Proposed model framework for ABM using the TIB for Network Rail
One key difference between the NR research and Sopha et al (2013, 2011, 2010) is that the agents are (currently) intended to be modelled hierarchically, rather than based on physical geography. Translating the three different kinds of topology shown in Figure 20 to the organisation structure could mean:

- **Spatial topology** – employees are only able to directly influence direct reports or superiors
- **Random topology** – employees can theoretically communicate with anyone in the business
- **Small-world topology** – employees typically communicate with those closest in the company hierarchy, but have some contacts in various parts of the business

In the experience of the author, the third of these is most applicable to the NR example. Staff typically communicate most frequently with those in their team or department, but may have contacts with entirely different departments occasionally (e.g. an electricity & plant manager has frequent contact with engineers that work in their Route, but may occasionally contact Human Resources around staffing issues). Figure 23 suggests a proposed hierarchical structure for incorporation into the models. A ‘small-world’ modelling topology would focus mainly on hierarchical links, with occasional (functionally semi-random) links with people in other teams or departments (not illustrated on the diagram). For Network Operations in particular, a slightly larger of links are likely to be forged between parallel teams working across different Routes, but not as many as close colleagues from the same Route. This topology is similar to that recommend by Chang & Harrington (2006) for representing interactions among members of an organisational hierarchy.
Proposed hierarchical communication model structure (Work in progress)

Figure 23 – Proposed ABM modelling structure

5.4. Summary

Agent-Based Modelling appears both applicable and feasible to study the effectiveness of behaviour change programmes at Network Rail. There exists a gap in research regarding use of behavioural models other than the Theory of Planned Behaviour, in order to support current UK policy recommendations. ABM has been used often enough in similar (but not identical) contexts to recommend it as a tool for assessing railway infrastructure operators. The individuality of NR staff, and the diverse reporting structures within suggest that only ABM can adequately accommodate all influences acting on individuals, particularly energy-related managers. Finally, and importantly for the completion of this research project within planned timescales, techniques already exist for linking empirical observations with behavioural theory, and to use this link to produce agents which are representative of the populations observed.
6. Actions, April-September 2015

Some minor revisions have been made to the research timeline laid out in the 2-year dissertation, to reflect progress to-date.

The revised research timeline is laid out on a pull-out page at the end of this section (Figure 24).

6.1. Research plan actions

6.1.1. Pilot survey

The ongoing questionnaire pilots need to be completed before full-scale distribution can take place. Two pilots are currently under way; one with the Sustainable Business Strategy team, and another with the Business Change team at NR. A further pilot may be undertaken with a small subset of NR Energy Services staff shortly thereafter.

A review of comments on these initial pilots will take place in early April 2015. SPSS data entry will be tested using a set of dummy data, based on research into energy behaviour archetypes observed among household consumers (Zhang et al, 2012). This will be developed by the researcher and supervisors, also during April 2015.

6.1.2. Main survey distribution

Following the piloting process, the main questionnaire distribution period can commence.

A detailed survey distribution plan is planned to be developed for the next scheduled EngD supervisor meeting (early May 2015). Distribution is intended to commence shortly thereafter, once the Integrated Assessment taught module is completed (i.e. late May 2015).
The precise length of this distribution period is still to be determined. However, this is currently intended to be completed no later than the end of September 2015. Conducting this stage within a 4 month (maximum) window is intended to ensure that data is as concurrent as possible, and to reduce the chance of major changes at NR affecting peoples’ attitudes.

6.1.3. Data analysis

Analysis of questionnaire data is proposed to take place at three main points:

- First round of preliminary results, for presentation at the ISIE conference
- Second round of preliminary results, for presentation at the EngD and CRR conferences
- Final results, for a planned journal paper, and for use in the Modelling research phase.

Provided that all data can be gathered by this point, it is hoped that the EngD/CRR conference analysis will be the Final analysis as well.

It has been recommended that the researcher attends a refresher course in the use of SPSS, to support this stage. This is planned to take place with the University, but dates were not available prior to this report.

6.1.4. Produce survey research paper

Once survey data have been analysed, a scientific journal paper is to be produced. As discussed in the dissertation, either the Journal of Environmental Psychology, or Energy Policy are currently favoured as potential recipients. Alternatives include the Journal of Environmental Economics and Management, Environmental Innovation and Societal Transitions, and Environment and Behavior. All
of these journals have previously accepted papers on similar topics. The decision will be finalised once the final amount of survey data can be safely estimated.

Publication of this paper is intended to take place shortly after submission of the next 6-month report, shortly before the BECC conference.

### 6.1.5. Learn ABM programming skills

ABM programming skills need to be learnt by the researcher in order to carry out research Phase III. It is proposed that training should take place at some time during the questionnaire collection process, whilst data is coming in, but before sufficient data have been collected for the final analysis.

Whilst specific courses have not yet been identified, it is anticipated that some basics can be learned from literature and online resources. Finding training courses will be a priority towards the middle of the next reporting period.

### 6.2. Courses

‘Integrated Assessment’ is the only taught course module scheduled for the coming 6 months, taking place 11-15 May. Content of particular interest to this research project includes ‘understanding theoretical approaches to decision support’, which may inform development of a decision support tool based on project outputs.

### 6.3. Conferences

Attendance at 3-4 conferences is planned for this 6-month period, with preparation for another in October 2015. These are outlined below, along with budgetary considerations.
6.3.1. ISIE conference, Guildford, 6-10 July 2015

An abstract sent to the International Society for Industrial Ecology (ISIE) conference, hosted by the University of Surrey has been accepted for an oral presentation. This has been entered in their ‘Social Sciences Methods and Theories in the Service of Industrial Ecology’ theme. The presentation will therefore focus on use of the TIB, the interview thematic analysis process, and early insights from the questionnaire survey. The researcher has also volunteered for steward duties during the conference, eliminating any attendance fees. The abstract for this conference is provided in Appendix 2.

6.3.2. EngD conference, Guildford, 9-10 September 2015

The annual SEES EngD conference was announced shortly before submission of this report. No further details regarding content requirements had been released, so no abstract has been included here. The 2014 conference was especially successful from the researcher’s point of view; an oral presentation was given, and grouped with a discussion panel of researchers in similar fields, i.e. behaviour change toward sustainable production and consumption. Audience feedback was largely positive, although some there was some room for improvement in the level of presenter eye contact. It is hoped that a similar panel activity will take place this year.

6.3.3. Rail Human Factors conference, London, 14-17 September 2015

This conference, run by RSSB, is mostly focused on ergonomics and safety issues, but features a ‘sustainable railways’ theme, suitable for submission of the material covered by this research. An abstract for this conference has been submitted recently, currently awaiting approval (available in Appendix 3).

6.3.4. CRR Research conference, Marseille, 16-18 September 2015
This conference is intended to focus on the role of the corporate sector in providing solutions to climate change, and the fundamental level of responsibility that should be placed on them for doing so. The abstract for this conference is due by 13 May 2015, and will be written and submitted nearer that date. The submission will be aimed at their themes ‘CSR and organisational behaviour’, ‘Tensions, conflicts and paradoxes in CSR’, and ‘CSR and sustainability strategy’.

Due to the known overlap in dates between these two conferences, it is likely that only one will be attended. The CRR conference is currently preferred, due to lower fees, and the fact that railway stakeholders can be reached via the annual RRUKA conference, whereas the CRR event will reach a new audience. The possibility of fees being waived at the Rail Human Factors conference (due to NR being a major industry partner) is currently being investigated.

6.3.5. Behaviour Energy and Climate Change (BECC) conference, Sacramento, 18-21 October 2015

This conference is dedicated to human behaviour and decision-making in relation to reducing carbon emissions and energy use; this is perhaps the most directly-aligned conference found to-date in relation to the content of this research project. An abstract for this conference is due to be submitted shortly after this report, for which the current draft is provided in Appendix 4. This will be submitted under the theme of ‘Social norms and culture change’, for the ‘issue sector’ of transportation.

6.3.6. Conference Budgeting

This period will see the first use of the £2,000 EngD conference budget. If looking at the two preferred conferences (CRR and BECC), fees, hotel and transport costs are currently estimated to be near this total. Efforts will need to be made to ensure that the budget is not exceeded. This will be fully determined if and when abstracts are accepted for the respective conferences. A summary of likely conference costs is given in Table 15.
Table 15 - Conference budget estimates

<table>
<thead>
<tr>
<th>Event</th>
<th>Location</th>
<th>Fees</th>
<th>Fees (£)</th>
<th>Likely travel costs</th>
<th>Likely hotel costs</th>
<th>Total costs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Rail Human Factors)</td>
<td>London</td>
<td>£650</td>
<td>£650</td>
<td>None</td>
<td>None</td>
<td>£650</td>
<td>Volunteering reduces fees to £450, but has limited places</td>
</tr>
<tr>
<td>ISIE</td>
<td>Guildford</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Travel and hotel expenses covered by NR</td>
</tr>
<tr>
<td>SEES EngD</td>
<td>Guildford</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>CRR</td>
<td>Marseille</td>
<td>€250</td>
<td>~£200</td>
<td>£100-200</td>
<td>£250-350</td>
<td>£550-750</td>
<td>Price increases to €300 after 30 June. Travel may be claimable via NR.</td>
</tr>
<tr>
<td>BECC</td>
<td>Sacramento</td>
<td>$495</td>
<td>~£340</td>
<td>£600-800</td>
<td>£400-500</td>
<td>£1340-1640</td>
<td>Full rate increases fees to $695 (£465.65). Scholarship reduces fees to $100 (£67), but has limited places.</td>
</tr>
<tr>
<td>Total (CRR+BECC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£1890-2390</td>
<td></td>
</tr>
</tbody>
</table>

6.4. Risks

Table 16 (overleaf) provides a revised risk register, based on those emerging from the 2-year dissertation.

The only additions to this register since the dissertation relate to the aforementioned conference clashes and budgeting.

A further point relating to jury service has been closed (the period of service did not overrun). A request for temporary withdrawal over this period has been accepted, and the final thesis deadline has been extended by two weeks.

The contingency plan to perform comparative analysis of different behavioural theories has lessened the potential impacts of any overrun during the questionnaire collection phase.
### Table 16 - Risk Register

<table>
<thead>
<tr>
<th>Risk</th>
<th>Events in last 6 months</th>
<th>Severity</th>
<th>Likelihood</th>
<th>Overall</th>
<th>Changes / mitigation steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement to redraft journal articles</td>
<td>Article submitted to Journal of Cleaner Production, but no response as yet.</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>No change. Redrafting of articles will take immediate priority over ABM training should the need arise.</td>
</tr>
<tr>
<td>Low stakeholder buy-in for survey delivery</td>
<td>Secondary analysis of other internal surveys not possible due to lack of depth of data. However, there has been interest from various parties regarding the content of the survey.</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>No change overall. Questionnaire collection will take place in staggered stages with separate teams; no need for all surveys to be sent at once.</td>
</tr>
<tr>
<td>Low survey response rate</td>
<td>None</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>No change</td>
</tr>
<tr>
<td>Need to re-pilot surveys</td>
<td>Initial piloting taking place at time of going to press</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>No change</td>
</tr>
<tr>
<td>Overrun of survey preventing model development</td>
<td>Contingency plan has been developed in case of unsuitability of ABM, i.e. comparison of different behavioural frameworks (TPB etc.)</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Severity reduced from high → medium</td>
</tr>
<tr>
<td>Agent-based modelling overrun</td>
<td>Remains a possibility, but see point above regarding contingency plan.</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>No change</td>
</tr>
<tr>
<td>Jury service</td>
<td>Planned period of jury service (23 Feb – 6 Mar) did not overrun.</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Risk closed</td>
</tr>
<tr>
<td>[NEW] Conference clashes</td>
<td>Attendance at Rail Human Factors conference may be obstructed by CRR conference. EngD conference may also take place at a similar time.</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>RSSB Rail Human Factors conference takes lower priority. EngD conference organisers have been contacted</td>
</tr>
<tr>
<td>[NEW] Conference budget shortage</td>
<td>Attendance at CRR and BECC conferences may run over £2,000 conference budget</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Approach NR for transport funding to Marseille conference. Apply for scholarship award for BECC conference. (ISIE conference costs already mitigated by volunteering as steward)</td>
</tr>
</tbody>
</table>
### Research timeline

| Activity                                      | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| **ENERGY ATTITUDE SURVEY RESEARCH**          |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Pilot survey                                  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Main survey period                            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Analyse results                               |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Prepare conference materials                 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Draft journal article                         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Finalise for publication; submit to journal  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **ENERGY USE SCENARIO DEVELOPMENT**          |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Gather relevant asset energy data            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Develop agent-based modelling skills         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Test models                                   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Calculate scenario forecasts                  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Analyse results                               |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Draft journal article                         |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Finalise for publication; submit to journal  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **THESIS WRITE-UP**                           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Develop structure with supervisors           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Convert existing journal papers to new thesis chapters |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| First draft                                   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Main draft                                    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Proof-reading and final corrections           |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Printing                                      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **OTHER ACTIVITIES**                          |     | 1   | 2   | 3   | 4   | 5   | 6   | 7   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Known conferences                            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| University taught modules and coursework     | 1   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| (Continued literature review)                |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 6-month report and thesis-writing             |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Viva Voce examinations - approximate date    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

**Legend**

- Green shades: Intended programme (colours alternate for clarity)
- Pale green: Allowances for overrun / additional activity
- Orange: Known activity, approximate date
- Red: Intended key delivery dates
- Grey: Known leave dates

- 1 Module - Integrated Assessment
- 2 ISIE conference - University of Surrey, Guildford
- 3 EngD conference - University of Surrey, Guildford (estimated dates)
- 4 CRR Conference - Marseille / Rail Human Factors conference - London
- 5 RRUKA conference - Kings Place, London (estimated date)
- 6 RRUKA conference - Kings Place, London (estimated date)
- 7 Module - Communication Management (estimated date)

Figure 24 – Project plan Gantt chart
7. Concluding remarks

Overall, progress has been satisfactory. However, there needs to be a small increase in pace to meet the deliverable dates originally proposed in the 2-year dissertation.

The coming 6 months will prove most challenging in two main respects. Firstly, a large amount of questionnaire data needs to be gathered, to complete the second phase of research, and to prepare for the third (i.e. ABM or comparative studies).

Secondly, this is likely to be the busiest period in terms of conference attendance and preparation throughout the whole programme, especially if all submitted abstracts are accepted.

October 2014 – March 2015 has been the most disrupted period to date, with a combination of supervisor changes, examination delays and the interruption caused by jury service. However, the outlook for the next 6-month period is optimistic, with clear plans laid for piloting and distribution of the energy attitudes survey. The questionnaire distribution process will need to take top priority for April-July.

**WORD COUNT (Main body, pages 7-36, excluding figures and tables):**

6,284
References


Appendices

Appendix 1 – RRUKA conference (5 November 2014) abstract

TITLE:

Embedding energy efficiency within Network Rail: the attitude-behaviour gap and implications for infrastructure energy use

Investigating reasons for the gaps between organisations’ pro-environmental values, attitudes, and their eventual real-world behaviours, is a growing area of psychological research. However, few studies have attempted to link this ‘attitude-behaviour’ gap with key operations, such as manufacturing processes or technology adoption, rather than day-to-day office behaviours.

To address this, a series of exploratory semi-structured interviews were undertaken with managers and specialists relating to electrical railway infrastructure at Network Rail, on the broad topic of energy efficiency. Thematic analysis was used on interview data, to both confirm the existence of the gap, and to identify potential barriers to energy-efficient behaviour adoption.

Attitudes towards energy-efficient technologies (and sustainable development in general) were broadly positive. However, their adoption was inhibited by, among other things, uncertainty towards the reliability of new technology, conflicts of interest regarding their economic business cases, and the absence of specific energy efficiency goals from the current suite of performance measures.

This research is intended as the first part of a cross-disciplinary study, culminating in the development of energy-use scenarios. This is intended to identify the relative benefits of adopting energy behaviour change strategies, compared with relying entirely on technical innovation, to inform future energy efficiency policies.
Appendix 2 – ISIE conference (7-10 July 2015) abstract

**Title:** Managerial attitudes to energy efficiency – Testing the Theory of Interpersonal Behaviour

**Authors:** Rupert Zierler, Walter Wehrmeyer, Jhuma Sadhukhan, Andrew Stiles, Amelia Woodley

**Topics:**

2.2 – Governance of Sustainable Consumption and Production
2.3 – Sustainable Business Models and Value Networks
3.3 – Scenarios for Decoupling Economic Growth and Resource Use
7.1 – Social Sciences Methods and Theories in the Service of IE
7.3 – Social Sciences Perspectives on IE
12 – Policy Analysis: Intervention and Planning

Organisational barriers to energy efficiency, are gradually becoming better-understood, with the roles of risk, hidden costs, divergent incentives and other factors having been repeatedly identified. However, studies to date have focused on production facilities and office settings, or have looked at cross-industry commonalities. This research proposes that energy management of linear infrastructure corridors, and railways in particular, faces obstacles to efficiency which have not been revealed elsewhere, due in part to their sprawling geographical footprint. Their industrial-ecological structure appears drastically different, whilst providing strategic support for all other industries. Structural management differences could be compounded by the quasi-public structure of railway infrastructure operations in the UK (and in other parts of the world), compared to the more commonly-researched field of private enterprise.

Discourses on energy behaviours in personal, and organisational contexts remain largely separate; the organisational energy efficiency gap is often discussed in terms of largely economic influences,
whereas the pro-environmental ‘value-action’ gap is more often related to attitudes, habits and social norms. It is also proposed that organisational barriers can be described in terms of more generalised social-psychological theories.

This project aims to test whether infrastructural barriers to energy efficiency differ from those experienced in other industries, using self-report questionnaires around attitudes, behaviours and the other factors mentioned above. This builds on an earlier series of interviews and discussions with managers of energy-intensive trackside infrastructure, which used thematic analysis to identify what these barriers might consist of. The questionnaire structure tests the various linkages which make up the Theory of Interpersonal Behaviour (Triandis, 1977), with reference to recurring barriers raised during the interviews and elsewhere in scientific literature.

This research is being conducted as part of an EngD qualification in Sustainability for Engineering and Energy Systems, with the University of Surrey and Network Rail.

The work is intended to support targeted behavioural interventions at stations, depots, and among the aforementioned trackside infrastructure managers at Network Rail facilities. Observations could then also aid in forecasting the energy-related benefits of proposed behaviour change programmes. Ensuring efficient management of transport energy infrastructure is vital, given the current rapid spread of railway electrification, re-opening of old lines, and development of new high-speed routes across the globe.
Appendix 3 – Rail Human Factors conference (14-17 September 2015) abstract

Rail Human Factors 2015 Conference Abstract

Title: Energy attitudes and behaviours at Network Rail – testing potential barriers to energy efficiency

Authors: Rupert Zierler, Walter Wehrmeyer, Jhuma Sadhukhan, Andrew Stiles

Organisational barriers to energy efficiency, in particular risk adversity, hidden costs, divergent incentives have been repeatedly identified. However, studies into these barriers in recent years have focused on manufacturing production processes, small-scale energy use in office buildings, or have looked at cross-industry commonalities. It is proposed that energy management of railways, being arranged in long, linear corridors across a broad spectrum of geographies, faces its own unique set of barriers. Similarly, conditions in stations and depots are unlikely to mirror those in factories and offices. Differences in energy management could also arise from the quasi-public structure of railway infrastructure operations in the UK.

Studies into energy use behaviours in consumer- and organisational contexts remain largely separate. Organisational energy efficiency gaps are discussed in terms of largely economic influences, whereas the ‘value-action’ gap for pro-environmental behaviours is expressed in terms of attitudes, social normative influences and habitual behaviours. This research therefore also proposes that organisational barriers could be described in terms of social-psychological theories from the wider behavioural literature.

This project aims to test whether infrastructural barriers to energy efficiency differ from those experienced in other industries. To achieve this, self-report questionnaires are used to investigate attitudes, behaviours, social and emotional influences, as a large-scale case study within a major infrastructure provider (i.e. Network Rail). These questionnaires were developed from a series of interviews and discussions with managers of energy-intensive trackside infrastructure. Thematic
analysis of these interviews led to a set of baseline barriers to energy-efficient behaviours for hypothesis testing. Themes were also mapped to the Theory of Interpersonal Behaviour (Triandis, 1977), to allow this to be tested in parallel as an explanatory model utilising the same set of questionnaire data.

The findings are intended to support proposed energy-saving behavioural interventions at stations, depots, and for trackside infrastructure managers at Network Rail facilities. The two key outputs for the railway are planned to be a snapshot of attitudes towards energy use within the company, and a tool for managing behaviour change activities, supporting both identifications of target areas and subsequent business case development. This also contributes to the growing body of knowledge around how managers influence energy efficiency behaviours in organisations, drawing hitherto neglected parallels with consumer pro-environmental behaviours.

This research is being carried out as part of an EPSRC-funded Engineering Doctorate (EngD) in Sustainability for Engineering and Energy Systems, with the University of Surrey and Network Rail.
Appendix 4 – Behaviour, Energy and Climate Change conference (18-21 October 2015) abstract

Title: Changing Track: Barriers to Energy Efficiency in Rail Infrastructure Operators

Research areas:

- Organizations and management (preferred)
- Social norms and culture change

Sector:

- Transportation

Research into barriers to energy efficiency in organizations is gradually maturing, with common features emerging, such as hidden costs and risk adversity. However, studies into these barriers have focused on manufacturing production processes or smaller-scale office activities. This research proposes that barriers to energy efficiency for infrastructure operators, and railways in particular, differ from those experienced in other industries. Studies into energy use behaviours in consumer- and organisational contexts also remain largely separate. Organizational energy efficiency gaps are discussed in terms of largely economic influences, whereas the ‘value-action’ gap for pro-environmental behaviours is expressed in terms of attitudes, social normative influences and habitual behaviours. This research also proposes that organizational barriers can be observed through the lens of more general behavioural theory.

To investigate these proposals, self-report questionnaires will be used to investigate attitudes, behaviours, social and emotional influences, in a large-scale case study within a major UK rail infrastructure provider. Questionnaires were developed from earlier pathfinding interviews with managers of highly energy-consumptive trackside infrastructure, with questions mapped to several commonly-used behavioural theories, and energy efficiency barriers observed in other industries. These theoretical frameworks can then be tested in parallel using the same questionnaire data.

The findings are intended to support proposed energy-saving behavioural interventions at stations, depots, some offices, and for trackside infrastructure managers. This research is being carried out as part of an EPSRC-funded Engineering Doctorate (EngD) in Sustainability for Engineering and Energy Systems, with the University of Surrey and Network Rail.
Appendix 5 – Our Energy Survey, Manager version (pilot) (reference code: M – 0.1)

Main content provided overleaf (pages 46-51)

Note:

The general Employee/Public version of this questionnaire is omitted for brevity. Content is largely similar, but omits questions 2, 11, 14, 20 & 28 in the first section, and 8-10 in the second section.

SurveyMonkey and MoboSurvey editions of this questionnaire share exactly the same phrasing and pagination.
OUR ENERGY survey

Thank you for choosing to take part in Network Rail’s OUR ENERGY survey.

This survey intends to find out how you think about energy use in your role at Network Rail, and how you believe that the rest of the company deals with energy issues.

“Energy use” refers to the use of electricity, in your station, depot, office, or on the railway itself. It can also mean other fuels used for heating or lighting.

This work is being done to help reduce Network Rail’s environmental impacts in future, particularly in relation to the amount of electricity we consume. This will also contribute to cutting-edge research into how businesses manage their energy use, supported by the University of Surrey. Results from this survey will be made available later this year.

Please indicate how much you agree with the following statements. **Tick one box per statement ONLY. If you are filling this out on a computer, you can click on the checkboxes to tick/untick them:**

<table>
<thead>
<tr>
<th>STATEMENT</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 I know who to approach to obtain information I need to help me save energy</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2 New technologies can have beneficial impacts on safety</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3 Climate change as an issue is discussed more often than is really necessary</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4 Other parts of Network Rail are quick to adopt new technologies</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5 I am happy with the way that Network Rail handles environmental issues</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6 I plan to use less electricity in my place of work in future</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>7 Current working practices take a long time to change at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>STATEMENT</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td>---------</td>
<td>-------</td>
<td>----------------</td>
</tr>
<tr>
<td>8 Information I need for my role is readily available to me</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>9 I am able to influence large-scale business decisions in my area</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>10 I have taken part in energy saving campaigns at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>11 I think that the Route management structure has been beneficial to how energy use is managed at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>12 Innovation is adequately encouraged and supported by Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>13 Network Rail has few problems with adopting new technologies</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>14 Saving energy use by trackside infrastructure is easy for Network Rail to achieve</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>15 Saving energy in general is easy for my part of Network Rail to achieve</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>16 Improving energy efficiency will reduce risks to energy supply and blackouts</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>17 I plan to use less electricity in the future at home</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>18 I can get frustrated when I see energy being wasted</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>19 Improving energy efficiency is important to reduce costs at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>20 New digital control systems have generally worked reliably</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>21 I have actively changed a behaviour following a Network Rail campaign</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>STATEMENT</td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td>---------</td>
<td>-------</td>
<td>----------------</td>
</tr>
<tr>
<td>22 I have seen campaigns to save energy at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>23 Network Rail receives the largest share of the benefits of improvement programmes, compared to Train Operators</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>24 Network Rail's energy data collection is comprehensive and detailed</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>25 The current set of performance measures have improved performance in other parts of Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>26 Network Rail should be working harder to reduce their environmental impacts</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>27 I understand the changes that the 'Digital Railway' will bring</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>28 New energy-efficient technologies have generally worked reliably</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>29 I don't think reducing NR's energy use should be a high priority</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>30 The current set of performance measures (for example, PPM, safety) have improved performance in my part of Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>31 Train Operators have a positive influence on energy efficiency</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>32 My performance is affected by conflicts between performance goals</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>33 I tend to leave equipment switched on</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>34 Network Rail could benefit from using small-scale renewable energy sources (such as solar panels)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>35 It takes too long to adapt our workforce to new technologies</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
### How regularly do you do the following things?:

<table>
<thead>
<tr>
<th>Action</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
<th>This is done automatically</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn off computer monitors when not at your desk</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Turn off lights when no-one else is left in the room</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Turn off heating when no-one else is left in the room</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Turn off other non-essential electrical equipment</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Turn things off completely, rather than to a &quot;standby&quot; mode</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Find ways of deactivating trackside equipment to reduce energy use</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Find ways of deactivating plant to reduce energy use</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Start a project because of the potential energy savings</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>[N/A]</td>
</tr>
<tr>
<td>Include energy savings as part of the business case for a project</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>[N/A]</td>
</tr>
<tr>
<td>Investigate the energy use of existing equipment</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>[N/A]</td>
</tr>
<tr>
<td>Discuss energy use in meetings</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>[N/A]</td>
</tr>
</tbody>
</table>
Now we have some short questions on how you think about energy at Network Rail

Please outline ways in which you think Network Rail could save energy:

How can Network Rail support you in saving energy?

Any other comments relating to energy use?
Finally, we need some basic information about yourself. All information will be stored anonymously by the distributor.

Please tell us your gender:

<table>
<thead>
<tr>
<th>Male</th>
<th>Female</th>
<th>Other</th>
<th>Prefer not to say</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
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</tbody>
</table>

Please tell us your approximate age, in years:

<table>
<thead>
<tr>
<th>18-24</th>
<th>25-34</th>
<th>35-44</th>
<th>45-54</th>
<th>55+</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</tr>
</tbody>
</table>

Please tell us which business unit you work for:

<table>
<thead>
<tr>
<th>Infrastructure Projects</th>
<th>Finance &amp; Human Resources</th>
<th>Digital Railway</th>
<th>Corporate Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Network Operations</td>
<td>Safety, Technical &amp; Engineering</td>
<td>Group Strategy</td>
<td>☐</td>
</tr>
</tbody>
</table>

Do you have any staff reporting directly to you?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Please tell us how long you have worked for Network Rail:

<table>
<thead>
<tr>
<th>Less than 2 years</th>
<th>2-5 years</th>
<th>6-10 years</th>
<th>11-15 years</th>
<th>More than 15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
</tr>
</tbody>
</table>

Working pattern:

<table>
<thead>
<tr>
<th>Full-time</th>
<th>Part-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
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</tbody>
</table>

Do you work a shift pattern?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Thank you for your time!
A qualitative assessment of the value-action gap for energy efficiency of railway infrastructure

Rupert Zierler, Walter Wehrmeyer, Jhuma Sadhukhan, Kent Farrell

Abstract

This paper outlines a qualitative approach to addressing energy-efficient behaviours within a major railway infrastructure operator. Network Rail is the single largest purchaser of electricity in the UK. Behaviour change is a key component of meeting EU and local carbon reduction targets, reducing costs and improving energy security. A series of semi-structured interviews was conducted among managers of trackside electrical infrastructure, to identify current practices and potential barriers to adopting energy efficiency measures. Thematic analysis reveals four key behavioural barriers affecting the adoption of energy efficient technologies for railway infrastructure, among several other points of interest. These factors did not reflect those raised in other qualitative studies of this type, suggesting the presence of unique influences on infrastructure operators which are not present in other types of organisation. These were: issues relating to self-efficacy in energy management within the organisational structure, a specific case of the investor-user dilemma, accuracy of available energy data, and acceptance of energy-efficient technologies within current performance measure frameworks.
This research suggests the presence of a gap between what are largely already pro-environmental attitudes, and eventual energy management behaviours, suggesting that barriers, rather than personal attitudes need to be addressed. Causal barriers to energy efficiency previously observed for other industries and workplaces act in different ways to those for ground transport infrastructure, and perceptions of poor reliability for energy efficient technologies play a greater role than other economic considerations.

**Key words**
Attitude-behavior gap, sustainability, energy efficiency, railway infrastructure, qualitative analysis, technology adoption,

**Abbreviations Glossary**

- **FOC** - (rail) Freight Operating Company
- **NAM** - Norm Activation Model (Schwartz,1977)
- **NHS** - (UK) National Health Service
- **NR** - Network Rail
- **PPM** - Public (train timing/delay) Performance Measure
- **TIB** - Theory of Interpersonal Behaviour (Triandis, 1977)
- **TOC** - Train Operating Company
- **TPB** - Theory of Planned Behaviour (Ajzen, 1991)
1. Introduction

Improving the efficiency of energy-intensive business activities is a critical component of the process of lowering global greenhouse gas emissions (as summarised by Deng et al, 2012). Achieving this requires a combination of technological, behavioural and legislative means (as recognised by Murtagh et al, 2012, Gatersleben et al, 2012 and many others).

Awareness of environmental- and sustainability concepts has been steadily increasing over recent decades (as acknowledged by Gadenne et al, 2011). However, the rate of corresponding changes in behaviour is still thought to be lacking (as discussed below). Despite many years of improvement, corporate approaches to energy efficiency are still occasionally found wanting (Jeswani et al, 2008).

Network Rail (NR) currently purchases approximately 1% (around 3.2 TWh per year) of all electricity produced in the UK (Higgins, 2013). A large proportion of this is sold on to Train/Freight Operating Companies (TOCs/FOCs) as traction power, but NR still directly consumes more than 500 GWh per year, for a mixture of infrastructure-based and administrative purposes (see Figure 1). Taken together, energy-intensive trackside technologies represent a large proportion of NR’s electrical energy use. NR performance is currently measured using seven corporate goals: safety, train service performance (in terms of delays to trains), system capability, relationships with customers and stakeholders, financial control, asset stewardship and business performance. None of these directly address improvements to environmental performance; this could have a negative effect on the uptake of pro-environmental technologies.

Responsibility for several NR functions, including energy-intensive assets, have been devolved to smaller, geographically-divided ‘Routes’. This presents an opportunity to investigate barriers to energy-efficient behaviour change at a time of transition which was not undertaken explicitly for pro-environmental purposes.
The purpose of this paper is to qualitatively identify whether there is a significant gap between energy-efficiency-related attitudes and behaviours, relating to the management of large-scale uses of electricity, to identify possible reasons for this in the previously-unexplored context of an infrastructure organisation. This takes an exploratory Grounded Theory-like approach, supported by a review of literature.

Figure 1 - Non-traction energy use by percentage. Light shading indicates directly infrastructure-related energy use.
1.1. The pro-environmental attitude-behaviour gap

The pro-environmental attitude-behaviour gap is the difference between individuals’ opinions, beliefs and attitudes towards adopting pro-environmental practices, and their actual rate of adoption; the gap between what they say and what they do. This gap is well-documented in psychological literature for several different contexts, and for multiple aspects of pro-environmental behaviour (Blake, 1999; Kollmuss & Agyeman, 2002).

The majority of attitude-behaviour gap studies look at individual behaviours outside the workplace. Abrahamse et al (2005) describe several instances where information-based interventions to address pro-environmental attitudes have not resulted in significant behavioural change. Most recently, Valkila & Saari (2013) demonstrated how, despite a greening of attitudes in Finland, domestic energy-use behaviours were changing more slowly than anticipated. Consumer product purchases are a frequent topic of investigation. Kovács et al (2014) compared the gaps in relation to preferences for American and Hungarian consumers. A wide body of recent behavioural literature also exists for travel behaviours, including Murtagh et al (2012) relating to decisions to use cars, and Davison et al (2014) for air travel.

Additionally, Whitmarsh (2009) points out the distinction people make between actions taken to mitigate climate change, and those taken to reduce energy use; the latter is not often considered in the same context as the former by members of the general public. This highlights a need to investigate whether this perceived separation of energy and environment is also the case in an organisational setting.
1.2. Organisational pro-environmental behaviour

Psychological studies of the attitude-behaviour gap in an organisational context have not been conducted in as much detail as those elsewhere (Paillé, 2013; Abrahamse et al, 2005). This is despite growing consensus that large organisations need to do more to address climate change and improve their social impacts (e.g. Jeswani et al, 2008).

Tudor et al (2008) investigate individual- and organisational influences on environmental behaviour in the Cornwall National Health Service (NHS), focusing on waste management in particular. They found that organisational focus, structure and culture had a strong influence on employee behaviour, which led to apathy toward activities not represented by the core business aims. The regionalised structural similarities between the NHS and NR suggest that there could be similar company-cultural influences, in turn suggesting a need for exploration of this topic. Pesonen et al (2013) look at the gap in the context of a Finnish swimming hall, discussing how attitudes among the hall’s staff are generally pro-environmental, but knowledge of environmental issues was weak, and their management of the pool did not take a pro-environmental approach, although the details of why this was the case are sketchy. This highlights a need for scientific investigation of behaviours which have an effect on environmental impacts at the same time as the corresponding attitudes.

Boiral & Paillé (2012) highlight the need for investigation of the relationship between ‘Organisational Citizenship Behaviours for the Environment’, and company strategies or external pressures. This suggests that basing any investigation of pro-environmental behaviours within organisations should be based on a behavioural theory which takes account of these, rather than looking exclusively at personal attitudes.

With both studies of general consumer- and organisational behaviours, the Norm Activation Model (NAM) (Schwartz, 1977) and Theory of Planned Behaviour (TPB) (Ajzen, 1991) are the most widely-represented frameworks used in assessments of employee behaviours within organisations. Zhang et al (2013) used the NAM to investigate the drivers of employee energy saving behaviour within organisations. Their study is limited to office-workers, and not other types of employee such as production workers, or those with responsibility for non-office-based assets. In contrast, Greaves et al (2013) base their investigation on the TPB to explore environmental intentions in a workplace setting, focusing on small-scale and travel-related pro-environmental activities, with computer deactivation as the main energy-saving measure tested.

Most studies which use one of these preferred constructs do not go into detail about other comparable theories, or the reasons for their selection, despite acknowledgement of
shortcomings or factors unexplained by these models. However, the predictive capabilities of the NAM and TPB for actual behaviour have been questioned due to their respective assumptions of individuals’ rationality in decision-making. A rare example of a direct comparison between multiple behavioural theories was conducted by Bamberg & Schmidt (2003), suggesting that a third theory, Triandis’ (1977) Theory of Interpersonal Behaviour (TIB) had greater predictive power, albeit around transport mode choice. This suggests a need to explore the validity of other models (such as those outlined in Jackson, 2005), to overcome these limitations.

1.3. Organisational energy efficiency behaviours

There have been several psychologically-oriented studies within organisations based on the effects of energy efficiency-improving interventions. As with non-organisational studies these have, again, typically focused on changing day-to-day activities in office environments (e.g. Kaplowitz et al, 2012; Lo, 2011; Zhang et al, 2013), discrete buildings (e.g. Christina et al, 2014) or addressing commuting behaviours and travel mode choice (e.g. Murtagh et al, 2012, Lo et al, 2013). These studies were conducted in similar ways to those in domestic settings, i.e. through self-report surveys, or analysis of the impact of specific energy efficiency interventions through a combination of energy use observations and questionnaires.

The energy efficiency ‘gap’ or ‘paradox’ is relatively well-established in business and industrial management literature (e.g. Martin et al, 2012); despite the relatively straightforward economic benefits of using less energy, uptake of efficient technologies is slower than could be expected. Some of these explore larger-scale industrial or manufacturing processes, as opposed to the widespread-but-small-scale examples mentioned above (e.g. Trianni et al, 2013; Cagno & Trianni, 2014). However, few studies to date have used the NAM, TPB or TIB to characterise behavioural aspects of industrial process energy efficiency management.

As Stern (2000) and Whitmarsh (2009) point out, pro-environmental behaviour change efforts need to look at environmentally-significant, rather than environmentally-convenient behaviours; looking at small-scale but widespread behaviours may be convenient to study, but the impacts of individual decisions are likely to be smaller. It is also worth challenging the assumption that more general theories of individuals’ behaviour are applicable only to these smaller-scale activities.

Maleviti et al (2012), investigated reasons for slow uptake of energy-efficient technologies in Greek hotels, finding that relevant legislation and government policy alone does not
significantly increase their use. Engagement of mid-level managers, in their case, was found to be critical to the success of energy efficiency schemes, suggesting a need to test whether this is the case in other contexts. Zilahy (2004) performed interviews regarding implementation of energy efficiency practices among Hungarian businesses producing ‘significant environmental loads’. Whilst this study identified a number of barriers to energy efficiency, and was production-oriented, none of the participants represented a transport company.

Montalvo Corral (2003) used a questionnaire-based method to assess the determinants for firms’ willingness to innovate in cleaner technologies. This looked primarily at external influences related to market pressures, and came to the conclusion that technological capabilities and perceived economic risk accounted for most of the variance. Cagno & Trianni (2014) investigated barriers to energy efficiency measures in small-medium-sized enterprises, finding that some behavioural influences were typically more significant than levels of awareness or economic hindrance. These included individuals’ prioritisation of energy efficiency, lack of objective-sharing, and a general lack of interest. The larger scale of Network Rail’s operations could raise or lower these barriers’ significance, or raise new ones resulting from increased organisational complexity. As Schleich (2008) observed:

“Organisations with public or quasi-public ownership structure (i.e. who are not profit-oriented) exhibit the most barriers and those with high energy consumption exhibit the least”

Railway infrastructure in the UK falls into both of these categories; Network Rail operates as a ‘not-for-dividend’ organisation, but purchases a significant percentage of the UK’s electricity production. This highlights a need to determine which of these factors is dominant, and the implications for energy behaviours in other ‘quasi-public’ institutions with high energy throughput. This is especially true in light of NR’s recent reclassification as a public, rather than private entity (although it should be noted this was not the case at the time of the original interviews). Venmans (2014) investigates both barriers and triggers to the adoption of energy efficiency measures in ceramic, cement and lime companies which, like NR, are energy-intensive. Venmans’ paper highlights the importance of budgetary hurdles, but also raises behavioural influences such as a perceived lack of staff time, hassle and inconvenience, and conflicts of interest; determining whether these factors are more significant in the quasi-public, not-for-dividend framework of NR, is part of the purpose of this paper.
2. Methodology

This research is based on a series of semi-structured interviews, conducted over a six-month period, no more than 2 hours each. 22 individuals took part, representing a broad mixture of roles associated with the management of infrastructure electrical assets within NR (see Table 1) for a summary of participants. 7 managers were based with the devolved Routes, whilst the rest were Centrally- or variably located within the business. The gender balance is largely male, this was representative of Network Rail staff at the time of the interviews. A loose list of questions served as a general topic guide for the interviewer, although these were rarely stated in their exact form.

<table>
<thead>
<tr>
<th>Interviewee number</th>
<th>Gender</th>
<th>Approximate interviewee job title</th>
<th>Location within business</th>
<th>Duration of interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>Project Engineer</td>
<td>Central</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>Analyst</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>Engineer</td>
<td>Route</td>
<td>1 hour</td>
</tr>
<tr>
<td>4</td>
<td>Female</td>
<td>Engineer</td>
<td>Route</td>
<td>1 hour</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>Manager</td>
<td>Route</td>
<td>2 hours</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>Manager</td>
<td>Route</td>
<td>1 hour</td>
</tr>
<tr>
<td>7</td>
<td>Male</td>
<td>Manager</td>
<td>Route</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>8</td>
<td>Female</td>
<td>Senior Manager</td>
<td>Route</td>
<td>1 hour</td>
</tr>
<tr>
<td>9</td>
<td>Male</td>
<td>Senior Manager</td>
<td>Central</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>10</td>
<td>Male</td>
<td>Specialist</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>11</td>
<td>Male</td>
<td>Specialist</td>
<td>Varies</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>12</td>
<td>Male</td>
<td>Analyst</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>13</td>
<td>Female</td>
<td>Analyst</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>14</td>
<td>Male</td>
<td>Manager</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>15</td>
<td>Male</td>
<td>Project Manager</td>
<td>Central</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>16</td>
<td>Male</td>
<td>Analyst</td>
<td>Central</td>
<td>1 hour</td>
</tr>
<tr>
<td>17</td>
<td>Male</td>
<td>Project Manager</td>
<td>Route</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>18</td>
<td>Male</td>
<td>Engineer</td>
<td>Central</td>
<td>1 hour</td>
</tr>
</tbody>
</table>
Participants were selected from mid-level operational or engineering roles relating to trackside assets, rather than at the top level or a general cross-section of the workforce. These did not include anyone directly responsible for the powering of trains (traction), except for the management of losses from transmission along electrical infrastructure. The technologies which were discussed included various forms of track heaters, track adhesion devices, conductor rails, tunnel pumping systems, and both ‘dumb’ (e.g. thermostatic) and ‘intelligent’ (centrally-controlled digital) control systems.

Previous research into perceptions of an earlier ‘Sustainability Policy’ at Network Rail had focused on Directors and senior management (Ryan, 2010). However, this also reflects calls for further research into the value-action gap discussed earlier (e.g. Lo et al, 2012). In summary, the decision to investigate at mid-level asset management was taken due to:

- Focus on roles specific to the management of energy-intensive assets
- A tendency for previous research to focus at the ‘top’ of company hierarchies, or a mixture of all employees

Information was collected in the form of written notes taken by the interviewer during each session. Critically, this did not include any direct transcription of audio recordings, as recommended the ‘Grounded Theory’ research methodology (Glaser and Holton, 2004). This approach is also justified in terms of protecting company-sensitive information; the interviews involved divulging business practices to the researcher, rather than day-to-day behaviours as with some of the other studies mentioned. Demonstrating a lack of recording equipment was intended to encourage informal discussion, and to prevent accidental leakage of some sensitive information. Permission to take written notes was sought from participants. Additionally, this reduced the resources required to transcribe and analyse interview data.
Themes were then mapped to Triandis’ (1977) TIB, represented in Figure 2. This was not intended as a means of empirically testing the relationships described by the model, but as a means of qualitatively organising the results. This behavioural model was selected over others for the following reasons:

- Firstly, this model has recently been recommended for use by the UK’s Department for Energy and Climate Change (DECC) as a means of identifying where behaviour change interventions are needed (Chatterton, 2011)
- Secondly, the ‘interpersonal’ framing of this model was thought to better represent interactions within a large business due to its inclusion of external influences
- Thirdly, it considers the breakdown of attitudes into ‘evaluation’ and ‘belief’ categories (discussed in section 4). This was thought to be especially relevant to a business setting, as this was believed to be method of disaggregating purely business-driven
attitudes to more deeply-held individual beliefs or values developed independently of the current employer.

- Fourthly, studies of organisational behaviour using the Norm Activation Model have been largely inconclusive to-date (as reviewed by Lo, 2012), despite having value for describing non-organisational behaviour (e.g. Minton, 1997) The effects of social norms are accounted for within the Triandis model as a contributing factor.

Triandis’ model was applied in this way subsequent to the initial interview programme. Grounded Theory methodology recommends that concepts should be developed independently of existing theory. However, following a review of psychological literature, it became apparent that the emergent themes aligned best with the structure of Triandis’ model (as opposed to several others reviewed by Jackson (2005), including as the Theory of Planned Behaviour (Ajzen, 1991) or the Norm Activation Model (Schwartz, 1977)). The predictive capabilities of Triandis’ framework also compare favourably with these other theories, albeit based in the context of travel behaviours (Bamberg & Schmidt, 2003). Social interaction with co-workers has also been shown to influence the adoption of pro-environmental technologies in a consumer setting (Axsen, 2013). Applying existing theories within a Grounded Theory framework is not without precedent; Dunne (2011) discusses a similar application of existing theoretical constructs in a new context as part of this methodology. Alignment with an accepted, empirically-supported behavioural model was thought necessary, in order to facilitate creation of an energy use forecasting model (necessarily using numerical inputs) at a later stage.

The act of framing the attitude-behaviour gap as something which can be empirically measured (“blindness to the limitations of instrumental perspectives”) has been criticised for not adequately explaining the complexities associated with external influence-related factors (O’Donoghue & Lotz-Sisitka, 2002). This was addressed here by using a semi-structured interview style, avoiding reliance on pre-defined hypotheses.
3. Structure of results

Themes were then mapped to Triandis’ (1977) TIB, represented in Figure 2. This was not intended as a means of empirically testing the relationships described by the model, but as a means of qualitatively organising the results. This behavioural model was selected over others for the following reasons:

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- Secondly, the ‘interpersonal’ framing of this model was thought to better represent interactions within a large business due to its inclusion of external influences
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A summary of all responses is outlined in Table 2. This takes cues from Christina et al (2014) in provision of theoretical background for each theme, and Toth et al (2013) for the theme – sub-theme layout (organised by attitude, behaviour and external factor, in this case).
### Themes

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Theme</th>
<th>Theoretical background paper (where applicable)</th>
<th>Positive</th>
<th>Neutral/mixed</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation</td>
<td></td>
<td>Value of pursuing energy efficiency</td>
<td>Cheng et al (2007) [Multiple goal conflict]</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data accuracy / availability</td>
<td>Paillé (2013) [Perceived organisational support]</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Business cases for efficient technologies</td>
<td>Fleiter et al (2012) [Priority reduction of energy efficiency]</td>
<td>3</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ability to adapt current network</td>
<td>Ajzen (1991) [Self-efficacy]</td>
<td>2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unique local Route concerns</td>
<td>n/a</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Importance of Energy security</td>
<td>Kollmuss &amp; Agyeman (2002) [External influences]</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A particular control system development project</td>
<td>n/a</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall - Evaluation-based attitudes</td>
<td></td>
<td>15</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>Belief</td>
<td></td>
<td>Experiences of behaviour change in the business</td>
<td>Paillé et al (2013)</td>
<td>2</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Environmental risks and benefits</td>
<td>Andersson et al. (2005) [Sustainability in large organisations]</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interpretation of sustainability</td>
<td>Zhang et al (2013) [antecedents of energy-saving behaviour]</td>
<td>9</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inability to affect decisions</td>
<td>Christina et al (2014), Ajzen (1991) [self-efficacy]</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Route devolution effects on energy efficiency</td>
<td>Andersson et al. (2005)</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall - Belief-based attitudes</td>
<td></td>
<td>17</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>General</td>
<td></td>
<td>Innovation in energy efficiency - experiences</td>
<td>Huijts et al (2014) [pro-environmental technology acceptance]</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NR's Public Performance Measure - pros and cons</td>
<td>Cheng et al (2007)</td>
<td>0</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impacts on safety of new technologies</td>
<td>Huijts et al (2014)</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Opinions of renewable energy technologies</td>
<td>Huijts et al (2014)</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall - General attitudes</td>
<td></td>
<td>8</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>OVERALL - ALL ATTITUDES</td>
<td></td>
<td>40</td>
<td>71</td>
<td>19</td>
</tr>
<tr>
<td>Behaviours</td>
<td></td>
<td>Information ownership</td>
<td>Zhang et al (2013)</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metering - facilitating further business change</td>
<td>Zhang et al (2013)</td>
<td>0</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implementation of intelligent infrastructure systems</td>
<td>Zhang et al (2013)</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>External factors</td>
<td>Social factor</td>
<td>Habit (normative)</td>
<td>Norm</td>
<td>Facilitating condition</td>
<td>Overall - External factors</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>-----------------------------------</td>
<td>---------------------------------------------------------------------</td>
<td>-------------------------</td>
<td>---------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conflicts of interest with external organisations</td>
<td>Whitmarsh (2009) [sharing responsibility for climate change]</td>
<td>0 1 6</td>
<td>Influence of TOCs, or potential future interactions</td>
<td>Kollmuss &amp; Agyeman (2002) [External influences]</td>
<td>2 5 1</td>
</tr>
<tr>
<td></td>
<td>Overall - External factors</td>
<td>5 36 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Summary of themes identified, with theoretical background information.
4. Results and discussion

4.1. Attitude-related responses

4.1.1. Evaluation-based attitudes

A summary of all evaluation-based themes is provided in Figure 4.

The business case[s] for specific efficient technologies were not strongly viewed positively or negatively. The monetary benefits of energy savings were often thought to be balanced by technical issues with installation or maintenance. Improvements often needed justification in train performance-enhancing terms before they were likely to be adopted. Whilst participants often acknowledged that efficient technologies were the ‘right thing to do’, any replacement before assets’ end-of-life represented a ‘sunk cost’. There were also concerns that high-tech solutions (such as digital control systems) were being considered before low-tech options had
been implemented. One participant also suggested that dealing with trackside vandalism was of greater importance than dealing with energy efficiency. The larger number of responses on this topic was expected due to the subject matter of the discussions. Nevertheless, responses within this theme revealed the presence of uncertainty around adoption of energy efficiency measures.

Although energy use data was routinely collected, the granularity of information was not thought to be sufficient to know which assets were causing the biggest energy efficiency issues. Data accuracy/availability was the evaluation-based theme with the largest number of negative-context occurrences, suggesting that this is a source of particular frustration and a possible barrier to energy efficiency. The difficulty of quantifying energy-related benefits from activities happening ‘off-grid’ was also acknowledged, such as alternative maintenance techniques which prevented excessive use of certain assets. Schleich & Gruber (2008) also encountered a lack of consumption data as a major barrier to energy efficiency in their study of barriers the commercial and services sector, corroborating the possibility that this is a major stopping point here as well. This theme is thought to have knock-on effects among some of the others discussed below, suggesting that this could constitute a major barrier to energy-efficient behaviours.

Self-efficacy, in terms of the perceived ability for energy efficiency measures to make major differences to environmental performance, was also a key component of interviewee responses (Ability to adapt current railway network). One participant stated:

“It would be easy to adapt in a logistical sense, but all new technology, whatever it is, brings new problems, unforeseen things”

Introduction of new energy-efficient technology options were frequently associated with aspects of the current network which would not sufficiently accommodate them, as well as the need for changes in employee skill sets. This was heightened by the uncertainty over technological options discussed above.

Similarly to monetary considerations, the performance-related value of pursuing energy efficiency was not perceived as overwhelmingly positive or negative. More electrical equipment was also felt to be needed to address inefficiencies caused by train delays.

The prioritisation of more general management-related issues was exemplified by one statement in particular:
“Improving management of our assets should take a higher priority. Energy efficiency will then follow, not the other way around.”

Other participants also discussed how they thought that taking direct approaches to dealing with energy efficiency were counter-productive. Leaving a particular piece of heating equipment activated was seen as less wasteful than the recovery and maintenance costs associated with the incident it was designed to prevent, if the heater were to suddenly be needed unexpectedly (before it could be reactivated). This situation reflects other studies where energy efficiency has been deemed a low priority due to operational concerns (e.g. Schleich, 2009), and highlights a need to address links between energy efficiency and train (or company) performance in order for efficiency measures to be adopted more widely. This theme also highlights a possible goal conflict between financial aims and efforts to address environmental issues in general.

A few other evaluation themes were mentioned by a small number of participants. Improvements to control systems and automation were thought to have a potentially far greater effect on energy efficiency than updating on-site equipment. The importance of efficiency for overall energy security was mentioned, both in the context of reducing NR’s energy use to minimise supply grid impacts, and in one case, a desire to reduce reliance on national grid-based sources. However, two participants thought that this was not going to be a major problem for the foreseeable future, whilst another stated that responsibility for addressing this lay with train operators due to their higher energy impacts (see section 3.3). Finally, although the majority of technologies discussed were common across all parts of the business, a few unique local Route concerns were also raised regarding specialist equipment at specific sites, often in the context of them not receiving high priority due their specificity.
4.1.2. Belief-based attitudes

![Belief-based attitudes - number of separate mentions in interview coding.](image)

Figure 5 - Belief-based attitudes - number of separate mentions in interview coding.

A summary of all belief-based themes is provided in Figure 5.

Those interviewed displayed a relatively holistic and nuanced view of environmental aspects of sustainability (i.e. importance of pursuing environmental and sustainability-oriented aims), when compared with findings of other organisational studies (e.g. Maleviti, 2012. These typically found a lack of information on pro-environmental (or energy-efficient) technology options as a main barrier to improvements. However, this does not appear to be the case for the Network Rail example. The broader Brundtland (1987) environmental-social-economic definition of ‘Sustainability’ was also known among some respondents, although for others the word still had a mostly financial association (i.e. the ability to pay for something in perpetuity). Issues raised included land-take and biodiversity impacts, increased sensitivity to extreme weather events following railway electrification, social impacts of unsightly equipment on neighbouring communities. This suggests that an information deficit on environmental issues may not be a barrier to organisational energy efficiency in this case.
The environmental benefits of using less energy (e.g. lowered carbon dioxide emissions or material use) were generally positively-perceived, and were seen as ‘the right thing to do’ (benefit/risk assessment of energy conservation actions). There was less clarity regarding how to justify pro-environmental improvements in monetary or performance terms, due to the aforementioned shortage of energy data (see section 3.1.1). Only one participant suggested that railways should not pursue energy efficiency objectives at all. Their opinion arose due to rail’s perceived status as a sustainable option, and the sense that the responsibility for change lay with other modes of transport with higher environmental impacts (e.g. private road vehicles). Overall, participants’ responses appeared pro-environmental, and considered multiple aspects of potential environmental impacts, further suggesting that personal attitudes towards the environment are not acting as a barrier to energy efficiency in this instance.

Experiences of behaviour change efforts within the business for other purposes were largely balanced, and even slightly in favour. Network Rail has recently undergone a major programme of addressing workforce safety, supported by cultural change efforts. This has been accompanied with inclusion of specific safety performance measures which affect both the level of public subsidy and performance-related pay (discussed in section 3.3). These have also targeted very specific safety-related behaviours, through a ‘lifesaving rules’ programme. Participants also referenced how the shift from a profit-oriented structure of the predecessor organisation (Railtrack) had reduced the tendency for short-termism, what was termed a “cheap is good” period in the late 20th century. This suggests the possibility that participants could be receptive to other behaviour change programmes (i.e. for energy efficiency). Some explicitly mentioned the potential for encouraging behaviour change that would be brought by increased levels of emissions-and energy-use information. Although the knock-on effects of increasing information levels cannot necessarily be relied upon (e.g. Schleich et al, 2014), the NR safety example appears to suggest some increased level of engagement with related topics.

A small number of participants expressed scepticism regarding the (in)ability to affect macro-level business decisions around adoption of energy-efficient technologies, representing another possible example of low perceived self-efficacy (as mentioned in Error! Reference source not found.). These statements are thought to have stemmed from the large scale of the organisation, a sense that operational performance was paramount, and that political will needed to be behind any major decision before being signed off. Some participants discussed how they though government or regulatory decisions were behind the biggest behavioural shifts, rather than proactive approaches on the part of the organisation. This suggests that, for the operational-level managers investigated, a gap between attitudes and behaviours could originate from the sense that improving energy efficiency is beyond their level of control; external, normative influences may be counteracting any personal pro-environmental leanings.
A topic initially anticipated to be of importance were the possible effects of devolving responsibilities to Routes, i.e. the effects of shifting management structures. However, this was not perceived as greatly important in relation to energy efficiency by the interviewees, and was mentioned infrequently. As this major organisational change was relatively new at the time, the benefits or problems in relation to energy efficiency were not yet felt, but was generally seen as an opportunity for improvement rather than as a major potential barrier.

### 4.1.3. Combined (general) attitudes

![Figure 6 - General (combined belief and evaluation) attitudes - number of separate mentions in interview coding.](image)

A summary of combined (general) attitudes is provided in Figure 6.

Energy efficiency innovation processes represents participants’ attitudes towards the processes by which previous energy efficiency innovations were adopted, rather than specific experiences of technology deployment (discussed in section 4.2, below). All innovations
discussed were technological in nature, rather than oriented at changing employee behaviour, or were designed to automate processes which previously rely on employee behaviour. This relates to the habit of seeking technological solutions to energy efficiency problems rather than addressing behaviours associated with use of existing technologies (see section 4.3). All innovations discussed were also aimed primarily at cost savings, rather than energy use reduction as an environmental objective, highlighting the disjoint between the largely pro-environmental attitudes (discussed earlier).

The current suite of performance measures were felt to have benefitted the ability of individual managers to deliver train performance (i.e. the number of delayed trains and delay minutes) and safety improvements (current performance measures – usefulness and shortcomings). However, the technologies and practices adopted to improve against these measures were felt to be ‘quick wins’, to deal with train delay problems over the previous reporting period, rather than long-term solutions. Some technologies were known to be highly energy-consumptive, but had made significant reductions in train delays. This highlights the probable importance of performance measures in determining managerial behaviours. Inclusion of safety targets among the performance measure suite were not thought to conflict with achieving energy efficiency; a recurring suggestion was that less energy use implied less exposure to dangerous electrical contact. However, they were not thought to speed up the implementation of any innovative technology other than those directly aimed at improving safety.

Participants frequently volunteered their opinions of renewable energy technologies, both as part of wider discussions of energy, and occasionally in the context of increasing company energy security. Small-scale technologies such as solar photovoltaics or low-output wind turbines were frequently mentioned in a positive context, but mostly as a potential option for the future, rather than the present day. Their reputation-building aspects were recognised, but were not thought to be financially viable or easy to maintain. These statements reinforce the generally pro-environmental stance of managers established in sections 4.1.1 and 4.1.2.

Several interviewees discussed the integration energy-efficient technologies with present safety monitoring systems, due to their sometimes-unknown performance characteristics (impacts on safety of new technologies). This closely relates with the self-efficacy issues (discussed earlier) around adapting the current railway network to accommodate these technologies, as well as the emerging over-arching theme of technological uncertainty as a barrier. Although opinions were neither strongly positive nor negative, this highlights the perceived difficulty of integrating new technologies in the context of increased salience of safety issues and performance goals, without a concurrent increase in energy efficiency awareness and organisational goals.
4.2. Behaviour-related responses

![Graph showing descriptions of current behaviours]

*Figure 7 - Descriptions of current behaviours - number of separate mentions in interview coding.*

A summary of all behaviour-based themes is provided in Figure 7.

Discussions of experiences of new technology deployment, experiences of reliability of energy-efficient technologies, and implementation of intelligent infrastructure systems reflected one another, both in terms of relating to various forms of technology deployment, and the balance of positive- and negative-context responses. Although some technologies had encountered negligible problems or delays, there were a greater number of mentions of examples which had, particularly during testing phases. Modern, low energy electronic equipment was often discussed as being too sensitive to faults, and difficult to phase in alongside older energy-intensive systems. These complexities were mostly discussed in terms of effects on safety and other non-financial performance measures.

*Energy monitoring practices* were frequently mentioned (i.e. the use and detail of metering systems), but not in an especially positive or negative light. Improvements to the level of
detail were widely regarded as necessary to facilitate development of energy-efficient practices. Occasional examples were discussed where improvements were well under-way, but some also felt this was not being done quickly enough. One participant also felt that a major opportunity to implement energy-efficient technologies had been missed, prior to the adoption (by Train Operating Companies) of the latest generation of more energy-intensive trains. This theme relates closely to attitudes towards the availability of data in general (discussed above); this theme differentiates by referring to specific activities related to energy monitoring, rather than discussion of data availability and transparency in general. Both themes contribute to an overarching theme of a perceived need for improved information flow.

Given some of the earlier interviewees' concerns about availability, the information ownership practices of energy data were explored among later participants. There were no perceived complexities regarding data ownership among those asked, suggesting that overall communication does not represent a major barrier to energy efficiency. However, one interviewee mentioned that it wasn’t clear who was ultimately responsible for acting on this information. Given the low number of responses on this theme, it is difficult to draw conclusions. It’s possible that this lack of clarity could be indicative of a sense that responsibility for improving energy efficiency lies outside the remit of energy managers’ work, i.e. their self-efficacy in this area was felt to be low. This also relates to the importance of performance measures as a driver of decision-making.
4.3. External factor-related responses

![Descriptions of external factors](image)

Figure 8 - Descriptions of factors external to the individual - number of separate mentions in interview coding

A summary of all external factor-based themes is provided in Figure 8.

This theme covered the stated effects of *drivers and performance measures* on the business as a whole, rather than attitudes towards their effects on individuals’ work (discussed in section 3.1.3.). Train service performance, known as the Public Performance Measure (PPM) was mentioned several times as a leading driver of most infrastructure improvements (alongside financial costs). Whilst inclusion of this factor in performance-related pay was considered largely beneficial to the business, the absence of a similar goal for energy efficiency was noted by some participants. Overall, the current set of performance measures were perceived as being highly beneficial to business performance, but not necessarily to energy efficiency. This perceived value to the business could be serving as a normative influence counter to any personal pro-environmental attitudes. One early interviewee raised the possibility that, given the engineer-dominated structure of infrastructure providers, it was to be expected that most innovations that arose would be technological, rather than employee-oriented or behavioural in nature. Another explicitly mentioned that there was a natural scepticism towards behaviour-related company policies, which are perceived as less tangible. This led to exploration (in later interviews) of this as a normative influence on energy efficiency decision-making.
Some participants discussed changes in the railway industry as being relatively slow, compared to other industries, some citing examples from when railways in the UK were still nationalised (corporate inertia). Although not necessarily indicative of attitudes to energy efficiency, its recurrence suggests a normative sense that the rest of the industry is generally slow to act on new ideas. Resistance to change has previously been linked to a sense of threatened self-identity by Murtagh et al (2012). When the need for behaviour change (in their case travel mode choice) was presented as a threat to their identity as a parent or motorist, resistance to change was greater than when a problem was presented neutrally. This suggests that presenting the need for introducing energy-efficient practices as a threat to the future of a business (i.e. identity as an employee of the rail industry) may heighten resistance to further pro-environmental change. However, the receptivity to specifically-targeted behaviour change programmes may counter this more-general resistance in the Network Rail example.

‘Conflicts of interest regarding receipt of project benefits’ was the most strongly negatively-opined external factor-related theme, suggesting that it is one of the more significant barriers to energy efficient technology adoption. The external stakeholders mentioned were typically Train Operating Companies (TOCs), or occasionally suppliers. One interviewee felt that TOCs had a greater degree of responsibility for energy efficiency; a number of the technologies discussed, and some additional power supply points were added in order to accommodate the latest generation of heavier, air-conditioned trains. When the general influence of TOCs was discussed, the responses were more mixed. Although a few discussions with TOCs around energy efficiency topics had gone smoothly, others suggested that the only discussions were around ensuring enough power was provided, rather than making any alterations to the amount consumed. This reflects the corporate investor-user dilemma identified by Schleich (2009). This is more commonly associated with the slow uptake of energy efficiency improvements to rented buildings; landlords do not receive the benefits of lower energy bills unless they are covered in rental costs. In this case, the infrastructure operator could correspond to the role of landlord; TOCs pay ‘track access charges’ to NR, receiving the benefits of efficiency improvements to power transmission in the form of lower bills, whilst NR tends only to see the upgrade costs. Although most of the potential efficiency improvements discussed during the interviews had little or no impact on traction power, this problem was mentioned by more than one participant as affecting NR decision making in general, not just in an electrical context. Not only does this suggest a need for clearer performance goals in relation to energy efficiency.

Further to the theme of devolution (see section 4.1.2), the possibility of communication difficulties between Routes was explored. Although a small number of participants did relate issues with this, problems were not thought to be widespread, so this is not thought to constitute a major barrier to energy efficiency. New opportunities for peer communication...
were perceived in the recently-adopted Route structure, although one participant noted that the achievement of energy efficiency was not among the reasons for undergoing devolution.

4.4. Visualising the gap

A potential shorthand method of visualising the attitude-behaviour gap is provided in Reference source not found. This shows the average positive/negative context weightings ($W_C$) of statements in each thematic category, and the number of participants mentioning them. Horizontal positions on the chart were determined by assigning weightings to individual statements ($W_S$), ‘positive’ +1, ‘neutral’ 0, and ‘negative’ -1, summing all, and dividing by the number of statements per theme ($n$).

$$W_C = \frac{\sum n W_S}{n}$$

Equation 1

Attitude-related themes (and particularly pro-environmental beliefs) were more frequently mentioned in a positive context (i.e. the right of the diagram) than themes relating to descriptions of current behaviours or to external social controlling factors. External influences were also the most-frequently measured aspect of the guideline behavioural model (i.e. the TIB).

Similar methods have previously been used to summarise results from Likert-scale tests (Cagno & Trianni, 2014), although it is acknowledged that the 3-point method used here is less detailed. As this technique was applied retrospectively, a 5-point scale may have been unrepresentative, as it was difficult to determine whether someone was ‘slightly’ or ‘very’ positive/negative. However, it offers a potential way of visualising the gap between attitudes and behaviours (and the influence of external factors) in future, if used with an alternative quantitative approach.
5. Conclusions

When considering the themes discussed in the Results section, the most significant barriers to achieving energy efficiency have been condensed and summarised. This has been enabled by the same use of contextual coding, and matching themes from each category (attitudes, behaviours and external factors) discussed in the preceding section. These barriers are summarised as follows:

- A sense of low self-efficacy regarding both influencing business decisions on energy-efficiency issues, and the ability to adapt the current railway network to accommodate more efficient technologies
- The existence of a heightened investor-user dilemma due to the current segmentation of the rail industry in the UK, drawing the value of energy efficiency improvements for the company installing them into question.
- The availability- and level of accuracy of measurable energy use data, preventing the quantification of energy-saving benefits, which discourages adoption of known-beneficial technologies in the meantime
• Low acceptance of- or caution towards implementation of new technologies, due to perceived impacts on safety and company performance, resulting from a lack of representation of energy efficiency in the current suite of performance measures.

Parallels can be drawn with organisational barriers to energy efficiency observed in management-related literature. The barriers encountered closely reflect those discussed by Schleich & Gruber (2009) as mentioned above. However, a ‘lack of information about energy efficiency measures’ was not encountered in this instance; most interviewees were familiar with technologies which could be used to improve efficiency, although they often mentioned energy-saving measures in the same context as renewable energy technologies. This reaffirms the finding of Nemcsicsné Zsóka (2008) that environmental knowledge is not a sufficient precondition for pro-environmental organisational behaviour. Schleich & Gruber’s ‘Lack of staff time’ was also indirectly encountered; meeting train performance requirements was seen as their top priority, rather than addressing energy efficiency measures, and this was reflected in their perceptions of the economic value of addressing energy efficiency. Fleiter et al (2012) encountered similar issues around the profitability (rather than pro-environmental) aspects of energy efficiency measures reducing their priority among Small-Medium-sized Enterprises. However, in the case of NR, ‘profitability’ was instead viewed through the lens of train performance and delay minutes, rather than monetary values directly.

These findings also reflect those of Rohdin et al (2007), who carried out a similar study of barriers to energy efficiency within the Swedish Foundry industry. They encountered a sense of corporate inertia, lack of trust in information sources and the level of detail available in these. The perceived absence of detailed data in NR could also be serving as a behavioural influence, in that a lack of information is acting as a cause of bounded rationality in decision-making. Additionally in the Swedish example, their sense of risk aversion was thought to originate from economic difficulties, whereas in NR this appeared to originate from train performance issues and safety considerations, as mentioned above.

Cheng et al (2007) investigate the impact of perceived goal conflict on business performance, finding that conflict increases with perceived goal difficulty, which also has an indirect negative effect on task performance. It is possible that the wide variety of different goals already in place at Network Rail could raise a sense of conflict with any potential energy efficiency performance measures.

Taking an environmental psychology approach to energy efficiency barriers should also take into consideration the ways in which people perceive environmental issues in a domestic context; there is no reason to assume a complete disconnect between these. The findings from this paper also reflect the general difference between general eco-friendly attitudes and resulting behaviours across Europe (Pirani and Secondi, 2011). Attitudes among those interviewed were generally pro-environmental, but descriptions of associated behaviours
belied these. The design of energy-efficient behavioural interventions do not, therefore, need to address improving pro-environmental attitudes, but should instead focus on overcoming rigid organisational structures, and ways of addressing the perceived costs (monetary or otherwise) of installation. Similarly, the flow of information regarding the existence of efficient, pro-environmental technology options is relatively strong, but needs a supporting flow of data on the performance-related benefits of such options.

It is also worth considering that energy-efficient technology adoption is not limited to organisational settings. Huijts et al (2012) suggest a technology acceptance framework for consumer purchase behaviours, based on an integration of the Theory of Planned Behaviour with Norm Activation Theory and studies of hedonic motives. The structure of their framework very closely reflects that laid out by the TIB, which suggests that the theme categorisation method used in this paper reflects wider consensus on energy-related behaviour, albeit in other settings.

5.1. Study Limitations

This study has a few limitations. Use of the TIB as a guidance construct may have arbitrarily excluded some concepts from the other commonly-used behavioural models. In particular, barriers relating to self-efficacy were prevalent among the interviewees, when discussing the ability to adapt the current railway network, inability to affect wider company decisions, and as a sense of general corporate inertia. This factor forms part of the Theory of Planned Behaviour framework, but not that of the TIB, suggesting a possible shortcoming of using this as the basis for the thematic analysis. To mitigate this, self-efficacy-related statements have been captured as attitudes, as these (and evaluations in particular) are interpreted to include an element of reflection of one’s ability to carry out an action. This is thought to be appropriate, as these interviews were more general discussions of energy efficiency, than focused on specific behaviours.

This interview-led methodology has been cross-sectional, rather than a longitudinal assessment of organisational change during a transitional period. A longitudinal approach has previously been used to good effect by Wang et al (2014) for their otherwise-similar thematic analysis of green building practices. However, such approaches are usually taken before, during and after major planned company or policy transitions, none of which were taking place in tandem with this study.
5.2. Future research recommendations

As this was a qualitative study, the precise causal relationships between pro-environmental attitudes and energy efficiency-related business decisions have not been determined here, although several possibilities have been raised. The suggestions from this qualitative work need to be confirmed or otherwise through empirical testing. This could take the form of a self-report survey among a wider sample of employees. Alternatively, an intervention-led study observing the effects of feedback on energy use could be carried out (similar to Murtagh et al, 2013; Schleich et al, 2013). A specific technology, energy use intervention or group of measures will need to be chosen from the many discussed in order to achieve this.

The regulatory structure of railways in the United Kingdom is unique and complex, and therefore not representative of all international railway infrastructure operators. A comparison of behavioural influences from more than one country would allow a more generalised picture of energy efficiency management within infrastructure providers. Similarly, other forms of infrastructure provider, such as roads and highways or airports could be compared to further generalise these findings.

Further qualitative exploration of the adoption of energy-efficient technologies could be conducted by integrating the Multi-Level Perspective approach to technological transition (Geels, 2002). This is thought to be especially relevant to transport research, given observed resistances to changing travel behaviour (Whitmarsh, 2012), and made even more so for railway infrastructure by likely future increases in passenger and freight traffic (DfT 2013).

In conclusion, four barriers to decision-making in favour of- and adoption of energy-efficient technologies have been identified, relating to managerial self-efficacy, an example of the investor-user dilemma, availability of energy use data, and under-representation of energy efficiency in company performance measures. A key implication of this is that the barriers to energy efficiency in infrastructure companies are subtly different to those experienced by other types of organisation, and warrant further study, particularly in light of railway expansion and improvement in the UK.

5.3. Background to research

Research was undertaken as part of an Engineering Doctorate (EngD) in Sustainability for Engineering and Energy Systems, working with Network Rail and the Centre for Environmental Strategy, University of Surrey. This also forms part of an internal investigation into the potential benefits for energy efficiency behavioural change policies and interventions at Network Rail.

MAIN BODY WORD COUNT (including captions and tables, but not contents of figures): 325
7,843
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All Change Please! Embedding energy behaviour change into Network Rail’s business practices

Rupert Zierler1, Walter Wehrmeyer2, Jhuma Sadhukhan3, Amelia Woodley1, Andrew Stiles3

Introduction
Pursuing a reduction in electricity use is a vital component of achieving a low carbon railway. However, despite cost-related advantages of doing so, and increasingly pro-environmental attitudes, people and organisations are slow to adopt energy-efficient technologies (an “attitude-behaviour gap”). This project aims to pre-empt this at Network Rail, by identifying potential barriers and developing recommendations to overcome slow technology uptake.

This poster reviews a series of semi-structured interviews which took place late 2013 – early 2014, as part of a longer study into energy behaviours at Network Rail. The second stage is to conduct an energy and environmental attitude survey among a wider selection of staff, and the third is to develop energy use scenarios.

This research is being undertaken as part of an EngD in Sustainability for Engineering & Energy Systems with the University of Surrey and Network Rail, Sept 2010 – Sept 2016.

Results so far
The table below summarises responses recorded during the interview phase. Green, orange and red colour-coding is used to indicate when themes were mentioned in broadly positive, neutral, or negative contexts. Attitudes towards energy-efficient technologies, and sustainable development in general, were broadly positive (see themes 8, 9, 11 & 15, below). However, there were several perceived barriers to their implementation. The current suite of performance measures were also perceived as having significant, but mixed influence on the pursuit of energy efficient technologies.

In addition to informing the scoping and development of energy behaviour change programmes, these themes will provide the basis for environmental attitude survey questions, and parameters for energy use scenarios, to inform energy use strategies, and targeted awareness-raising interventions.

Some of the most significant barriers included the following:
- Uncertainty towards the reliability of new technology in general, particularly from a safety point of view (see themes 16, 17 & 19, below)
- Conflicts of interest regarding who receives benefits from investment (“investor-user dilemma”) [24]
- Low perceived self-efficacy, in terms of being able to affect large-scale business decisions [5, 15, 26, 27]
- Perceived low availability and reliability of energy use data [2, 18]

Research plan

References

Next steps – Agent Based Modelling

The interviews and attitude survey will provide the basis for a two agent-based energy use scenarios:
- Where energy efficiency improvements are technology-led, without major behavioural interventions
- Where improvements are led by behaviour-change initiatives and altered management practice.

Agent-based models simulate the interaction of individuals as part of a network, potentially allowing communications resulting from culture change programmes to be simulated in greater detail than systems-based approaches.

Appendix 7 – RRUKA conference poster (reduced scale), 5 November 2014

Methodology
A series of semi-structured interviews were conducted with managers and engineers working with trackside electrical infrastructure at Network Rail in late 2013.

A thematic analysis was applied to notes taken during the interviews, dividing responses into theme categories based on respondents’ attitudes, subsequent behaviours, and normative pressures.

These were then mapped to Trawick’s Theory of Interpersonal Behaviour (see below). This was because:
- Studies of barriers to energy efficiency in organisations rarely make links with more general theories of individuals’ behaviour.
- This theory has not been tested as often as other general theories of pro-environmental behaviour (e.g. Theory of Planned Behaviour).
- Earlier studies have tended to focus on the top echelons of an organisation or the whole workforce, rather than looking at the operational management level.

This also forms a consistent framework, to aid with the design of the forthcoming attitude survey and agent-based model.
6-monthly EngD Progress Report

6: April – September 2015

Rupert Zierler
(URN: 6248587)

Integrating sustainability frameworks within Network Rail’s business practices –

Energy management behaviours in a large infrastructure organisation

Word count (main body): 5,621

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Executive Summary

This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant or influential these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3). This period April-September 2015 has centred around deployment of a questionnaire survey, primarily to answer the second research question, whilst laying groundwork for the third.

This work is currently supporting the roll-out of an energy management programme across Network Rail’s geographically-devolved Routes. Outcomes from the self-designed, company-wide ‘Network Rail Energy Survey’ will be used to determine which behavioural interventions or campaigns will be most effective in different parts of the business, or with different employee demographics. Workshops around this are currently scheduled to take place over the coming months.

Progress towards deliverables

Most previously-planned deliverables are currently on-schedule. Major progress was made, in the delivery of the ‘Network Rail Energy Survey’. Training has also been completed which will allow completion of an agent-based model, also based on this survey data. However, a previously-rejected journal paper around research question 1 of this EngD programme needs to be re-submitted at the earliest opportunity.

Questionnaire analysis

The ‘Network Rail Energy Survey’ was successfully delivered in June-July 2015, and analysis commenced shortly thereafter. This received a high level of response, enabling all intended analysis processes to be undertaken, as well as factor- and cluster analysis to identify groups of staff with similar characteristics. Full analysis was in progress at the time of going to press. Steps have already been made toward writing a published paper through a paper presentation at the Corporate Responsibility Research Conference. However, further analysis is required to determine whether these observations hold true for smaller groups within the company, as well as for Network Rail as a whole.
**Actions for the next 6 months**

The following main actions for research are planned for October 2015 – March 2016:

- Re-submit interview analysis journal paper
- Complete analysis of the Network Rail Energy Survey
- Write, review and submit at least one research paper on survey analysis to *Energy Policy* and/or *Journal of Environmental Psychology*
- Conduct Agent-Based Modelling coding and analysis
- Commence thesis-writing process

The biggest challenge among these is finalising which existing or new behavioural framework to use for the agent-based model. Once sufficient analysis is completed, one or more of these can be chosen, and a detailed plan for the model created.
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Glossary

ABM - Agent-Based Model / Modelling
BAR - Used to refer to barriers to energy efficiency in organisations proposed by Sorrell et al (2000)
CES - Centre for Environmental Strategy
CRR - Corporate Responsibility Research (conference)
ISIE - International Society for Industrial Ecology
NR - Network Rail
RE - Research Engineer
SEES - Sustainability for Engineering and Energy Systems doctoral research centre
SPSS - Statistical software package
TIB - Theory of Interpersonal Behaviour (Triandis, 1977)
TPB - Theory of Planned Behaviour (Ajzen, 1991)
1. Introduction

This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3).

This progress report reviews all research activities for the period 1 April 2014 – 30 September 2015. The main activities from this period have been the distribution and analysis of a company-wide questionnaire survey around energy use behaviours within Network Rail.

Section 2 outlines progress towards goals and deliverables set in previous reports, and relates these to the aforementioned research questions and key research phases.

Section 3 briefly runs through EngD coursework and other training courses attended over this six-month period.

Section 4 provides details of how the Network Rail Energy Survey was undertaken, a high-level overview on early analysis findings, and implications for agent-based modelling (ABM) in support of research question 3. This covers regression/path analysis around existing behavioural theories, observations of demographic differences, factor analysis to identify new behavioural constructs, and cluster analysis to identify groups of employees with similar characteristics. Please note that these do not represent the complete or final results; analysis was ongoing at the time of going to press.

Section 5 lays out a list of actions for the next 6-month period (1 October 2015 – 31 March 2015, and a revised research timeline Gantt chart.

Section 6 contains a brief concluding statement from the researcher on overall progress.
2. Progress towards deliverables

Most activity over this 6-month period centred on finalising, piloting, launching and analysing the ‘Network Rail Energy Survey’ (referred to in the previous report as the ‘Our Energy’ survey).

The actions listed here refer to those outlined by the project plan in the previous 6-month report. ‘Additional actions’ are those which were not covered in-depth by the original plan, but represented significant time investments over the period.

2.1. Interview research paper

A paper on the Interview phase of this research programme was submitted in February 2015. Feedback from reviewers was returned in mid-April 2015. This was turned down for publication, but with several recommendations for re-working. A rewrite has been scheduled for some time, but pushed back due to unforeseen conference commitments, and concentration on delivering the Energy Survey in the most effective way possible. Rewriting has been scheduled for the week immediately following the delivery of this report, with some minor alterations already made earlier in the year.

2.2. Pilot survey

The surveys were piloted in April 2015, based on the template appended to the previous 6-month report. The Sustainable Business Strategy team (in which the RE worked) reviewed the All-Staff version, whilst the central Business Change team reviewed the Manager version. 10 responses were received for each. Input from NR’s Energy & Carbon Lead provided additional questions of interest to the company’s ‘Energy Services’ department. Several alterations were made as a result of these reviews:

- Some questions were rephrased for greater clarity
- Further questions were split into multiple topics, to avoid ‘double-barrelling’ (Ajzen, 2006)
- Extra questions were added around the efficacy of previous behavioural campaigns (not necessarily on energy use)
2.3. Main survey period, and results analysis

The main survey went ahead without any major disruption, and analysis commenced in earnest in August 2015, after some preliminary outputs for the ISIE conference (see below). These actions are covered in more detail in section 4, as this represented the most significant output over this six-month period.

2.4. Additional actions

2.4.1. International Society for Industrial Ecology (ISIE) Conference, University of Surrey, 7-10 July 2015

The ISIE conference focused on finding methods of integrating environmental concerns with economic and industrial activities. A 10-minute oral presentation was given for the ‘Social Sciences Perspectives’ track, followed by a 5-minute Q&A session. This was notably the only oral presentation given by a Surrey-based EngD researcher at the conference (although there were some poster presenters). As the presentation was given on the final day of the conference, less feedback was given than was anticipated, and the short sessions did not leave a lot of time for discussion. The researcher also acted as a session aide throughout the conference, so some additional discussion time was sacrificed in favour of these duties. The conference was, however, valuable for forging contacts with PhD (as opposed to EngD) researchers within the University of Surrey, and connections were made with doctoral researchers in similar fields from further afield.

2.4.2. Corporate Responsibility Research (CRR) Conference, KEDGE Business School, Marseille 16-18 September 2015

The CRR conference focused on sociological and psychological methods of understanding corporate responsibility in a wide variety of industries. A 20-minute oral presentation was given for the ‘Micro CSR’ track, along with a 30-minute discussion session. This conference did not feature a related publication, or published conference proceedings. However, a paper was submitted, and was subjected to a thorough but informal peer review process. This paper is provided in
Appendix 2. Several recommendations were put forward regarding any future publication of the same material. These included:

- A review of the question mapping process, including re-assignment of some questions to different theoretical constructs
- Further comparisons with earlier studies, particularly around applications of the Theory of Planned Behaviour (TPB) in workplace contexts
- Check for potential common method biases (as reviewed by Podsakoff et al, 2003) in some sections of the questionnaire

Insights were also gained from other researchers' work on pro-environmental behaviours in the workplace, particularly around demographic-related effects. One paper in particular suggested that the age of survey participants had no effect on how pro-environmental they were, on a global scale, and that any generational differences typically arise on a more local level.

2.5. Research question progress

Table 12 (overleaf) summarises how the actions discussed above relate to the research questions defined in the 2-year dissertation, and actions to come in the next 6 months.

In summary, questions 1, 1a and 1b will be considered completed once the journal paper on this subject is accepted. If publication in the *Journal of Cleaner Production* is not forthcoming, alternative journals will be sought.

Questions 2 and 2a have seen significant progress over this period, as discussed more fully in section 4 of this report. These questions will be considered completed once a paper is accepted by *Energy Policy*, the *Journal of Environmental Psychology*, or an alternative journal.

Questions 3, 3a and 3b have seen progress in terms of clarifying the variety of parameters to be incorporated into the model, largely thanks to the success of the Network Rail Energy Survey. Necessary training has also been completed. More significant progress is expected towards the end of the next reporting period, once path, factor, and cluster analysis of the survey is completed.
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</thead>
<tbody>
<tr>
<td>1. What challenges arise when embedding pro-energy-efficiency behaviour change frameworks within a major infrastructure operator?</td>
<td>Paper returned for major corrections by <em>Journal of Cleaner Production</em> reviewers. Resubmission delayed by survey collection process and conference attendance.</td>
<td>Research phase nearing completion, pending review of re-submitted paper.</td>
<td>Redraft <em>Journal of Cleaner Production</em> article immediately</td>
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<tr>
<td>1a. What role do individual operational-level managers’ attitudes play in determining energy-efficient technology adoption?</td>
<td>Analysed open-answer questions from survey, and responses to intranet news article.</td>
<td>Conduct more thorough content analysis of written responses.</td>
<td>Survey piloted, distributed, and closed out. Analysis commenced in late July, and is ongoing.</td>
<td>Planning and piloting completed. Survey data collection completed. Analysis in-progress</td>
<td>Finalise analysis of survey data. Submit journal paper.</td>
<td>TPB, TIB and BAR hypotheses reviewed – model based on results of factor analysis may be preferable.</td>
<td>Finalise choice of existing behavioural models, or new factor-analysis-determined models.</td>
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<tr>
<td>1b. What are the potential behavioural barriers to adoption of energy efficient technologies at NR?</td>
<td></td>
<td></td>
<td>Destroy research phase nearing completion, pending review of re-submitted paper.</td>
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<tr>
<td>2. Which of the identified barriers have the most significant negative impacts on adoption of energy management behaviours?</td>
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<td>2a. Is the hypothesised gap between energy-efficient attitudes and behaviours supported by empirical observations within NR?</td>
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<tr>
<td>3. What are the predictions for NR’s future electricity use, under different energy behaviour culture change scenarios?</td>
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<tr>
<td>3a. (Purely technology-oriented scenario) - What is the baseline prediction for energy use without major behavioural interventions?</td>
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<tr>
<td>3b. (Behaviour culture change scenario) - What are the likely effects of extensive energy behaviour interventions on electricity use?</td>
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</tr>
</tbody>
</table>
3. Course-related work

3.1. EngD Conference, 9-10 September 2015

The researcher submitted a poster for this conference, as requested from all third-year researchers in SEES. This covered the first steps with analysis of the Network Rail Energy Survey, as covered in section 4 of this report. A scaled-down version of this poster is provided in Appendix 5.

3.2. Taught module - Integrated Assessment

This was the only taught module during this 6-month period. The coursework from this module was not easily transferable to the research project, as it focused on the environmental impact assessment process, and a case study near a university campus. However, the module as a whole provided useful insights into the subjective nature of many non-empirical assessment methods, particularly around the social impacts of any development scheme.

3.3. Agent-Based Modelling course

A training course in ABM, run by the University of Surrey’s Centre for Research in Social Simulation (CRESS), was taken in June 2015. This taught the fundamentals of programming an ABM in open-source ‘NetLogo’ software, around a demonstration model of property prices in London. This is one of the most commonly-used modelling packages found in the academic literature (e.g. Lee et al, 2014; Yiu, 2013; Zhu, 2013), and has a high level of online community support (e.g. Macal & North, 2010). Further reasons for choosing this modelling software are discussed in the previous report. After some initial concerns around whether time for training could be found, this taught all the skills necessary to construct the intended model.
3.4. Module mark overview

A brief summary of all coursework marks to date is provided in Table 13.

Table 18 – Coursework marks

<table>
<thead>
<tr>
<th>Module</th>
<th>Mark (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Research Methods</td>
<td>60</td>
</tr>
<tr>
<td>Environmental Science and Society</td>
<td>62</td>
</tr>
<tr>
<td>Foundations of Sustainable Development</td>
<td>70</td>
</tr>
<tr>
<td>Life Cycle Thinking</td>
<td>59</td>
</tr>
<tr>
<td>Sustainable Development Applications</td>
<td>70</td>
</tr>
<tr>
<td>Life Cycle Assessment</td>
<td>73</td>
</tr>
<tr>
<td>Transitions to a Low Carbon Energy Economy</td>
<td>74</td>
</tr>
<tr>
<td>Corporate Social and Environmental Responsibility</td>
<td>63</td>
</tr>
<tr>
<td>Environmental Auditing and Management Systems</td>
<td>69</td>
</tr>
<tr>
<td>Psychology of Sustainable Development</td>
<td>73</td>
</tr>
<tr>
<td>Environmental Law</td>
<td>80</td>
</tr>
<tr>
<td>Ecological Economics</td>
<td>76</td>
</tr>
<tr>
<td>PRINCE2 Project Management</td>
<td>81</td>
</tr>
<tr>
<td>Integrated Assessment</td>
<td>75</td>
</tr>
<tr>
<td>Communications Management (late 2015)</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>OVERALL (up to Integrated Assessment):</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>
4. Survey Analysis Summary

This section presents a high-level summary on the analysis of the Network Rail Energy Survey conducted to-date, in support of research question 2. A more complete account of the analysis process is planned for future journal papers, as mentioned in the 2-year dissertation. Target journals are currently *Energy Policy*, or the *Journal of Environmental Psychology*.

4.1. Distribution and collection

As planned, two versions of the Network Rail Energy Survey were deployed. These were both distributed using the Demographix® online survey platform; no paper versions were distributed due to logistical difficulties in maintaining the confidentiality of responses.

Links to the Manager survey were distributed via email on 2 June 2015, and remained open for responses until 31 July (with two reminder emails before that date). These messages also encouraged participants to encourage non-specialists to complete the survey. This received 292 responses, out of 746 sent (39.1% response rate).

The All-Staff survey was distributed via two articles on a company intranet news service, first on 3 June, and second on 24 June. This received 582 responses across the remainder of the company’s 35,933 (as of 10 June 2015) employees.

Taken together, the two surveys represent approximately 2.4% of the total employee population in Network Rail.

*Sample representativeness*

The majority of responses were received from pay bands related to mid-level management or specialist roles (Bands 2-4, 70.1% of returned forms). This was expected, due to the Manager focus of one survey, and the means via which they were distributed (i.e. via digital devices rather than paper surveys).
There were a disproportionately large number of responses from the Safety, Technical and Engineering function. This was also expected, as a large number of roles relating to energy management are based in this department. Conversely, a dramatically smaller number of responses were received from the Network Operations function (responsible for day-to-day operation of railway infrastructure). Other demographic mixes were broadly similar to those of the company as a whole.

These factors imply that the results should be treated primarily as an observation of mid-level management behaviours, rather than as a generalised sample of NR employees. However, the large number of responses from different departments and Routes means that there is a high degree of confidence that this population is reliably represented by the results of this survey.

**4.2. Final survey details**

The final All-Staff (Manager) survey contained:

- 38 (50) ‘Agreement-scale’ questions (on a Likert 5-point agree-disagree scale) around personal attitudes
  - 16 (23) in a section on ‘Energy’
  - 9 (13) on ‘Technology’
  - 7 (8) on ‘Work’
  - 6 (6) on ‘Environment’
- 9 ‘Frequency-scale’ questions on how regularly certain energy-conserving actions were performed
- (6 ‘Frequency-scale’ questions on how regularly certain management activities were performed)
- 3 open-answer questions for qualitative analysis
- 9 sets of demographic information
  - Gender
  - Age
  - Business Function (NR department)

Each agreement-scale question was mapped to multiple theoretical frameworks. Tables 8 & 9 in the appended CRR conference paper (Appendix 2) provides full details of this mapping process.

The final version of the Manager survey is provided in Appendix 1. All questions from the All-Staff survey were also included in the Manager survey, so the All-Staff survey has been omitted to avoid unnecessary duplication.
4.3. Differences between demographics

The demographics collected by the survey were (in the order listed by the survey):

- Gender
- Age
- Business function (NR department)
- Route
- Pay band
- Whether the respondent had directly-reporting staff
- Length of service in NR
- Full- or Part-time
- Whether the respondent worked a shift pattern

Pearson’s Chi Square tests were first applied to check for significant differences in responses to each individual agreement-scale question, against each of the demographics listed above. Those tests which returned high-significance results were then checked for large differences in means between sub-groups. Finally, these results were qualitatively ‘sense-checked’, to look for meaningful trends. For example, for agreement-scale question 3 (I have previously taken part in energy-saving activities at Network Rail) the fact that longer-serving staff had taken part in more energy-saving activities could be put down to simply having been there for longer than other staff – the result is therefore perhaps particularly meaningful, despite having a high level of statistical significance. A summary of this is given in Table 19; the full matrix of results has been omitted from this report due to size, but is available on request.

‘Pay band’ appeared to have the most influence over differences in responses, followed by whether the respondent worked a ‘shift pattern’, and ‘age’. This suggests that future energy intervention campaigns should potentially decide between different behavioural intervention processes based at least partially on overall seniority, rather than gender or geographic location. However, as discussed in section 4.5, there could also be groups of employees with shared characteristics which cut across demographic boundaries.
4.4. Path/regression analysis

This section provides a brief summary of the path analysis hypothesis tests for the TIB and TPB discussed in previous reports; greater detail can be found in the working paper on this early path analysis presented to the CRR Conference, provided in Appendix 2.

To summarise, the Theory of Planned Behaviour (TPB) appears to provide the strongest model for explaining intention to save energy at Network Rail (Figure 25), compared to the Theory of Interpersonal Behaviour (TIB) (Figure 26), or a set of barriers to energy efficiency proposed by Sorrell et al (2000, 2011) (Figure 27). Of the three main constructs in this model, personal Attitudes appear to explain the most variance in responses, followed by Norms and Perceived Behavioural Control in that order. However, these results do not explain as much variance in responses as encountered elsewhere in the scientific literature (see Greaves et al, 2013).
Figure 25 - Path analysis of the Theory of Interpersonal Behaviour (Triandis, 1977) based on survey data (N = 874). *p<0.05, ***p<0.001

Figure 26 - Path analysis of the Theory of Planned Behaviour (Ajzen, 1991) based on survey data (N = 874). ***p<0.001
The low level of variance explained by the constructs from both frameworks, coupled with some uncertainty over the statistical significance of some parts of the TIB, suggests that alternative factors may be determining energy behaviours in the NR case. However, further analysis is required to examine whether the TPB or TIB frameworks hold true for specific groups of employees before they can be dismissed entirely, as the large dataset encompasses a broad variety of staff roles and locations.

4.5. Factor analysis

As discussed above, following the regression analysis process, no single theoretical framework explained a large amount of variance in the survey results. However, the large number of survey responses received enabled dimension reduction factor analysis to identify new constructs determining energy behaviours at NR.

Table 20 outlines the set of ten constructs identified by performing this process on the agreement-scale questions (i.e. ‘strongly agree’-’strongly disagree’) common to both the All-Staff and Manager surveys. This was conducted using principal component analysis, Varimax rotation and Kaiser normalisation in SPSS. A full rotated component matrix can be found in Appendix 3.
These new factors resemble some aspects of both the TPB and TIB (particularly relating to company norms and attitudes toward behaviours), with some new constructs which do not necessarily fit into either framework (such as ‘goal flexibility’). Most are specific to either ‘curtailing energy use’ or ‘adopting new technologies’, with little crossover between these two aspects of energy efficiency.

Further analysis is required to determine whether these factors are the same when analysing specific groups within the company in isolation, and whether similar factors arise when analysing the Manager survey with its attendant extra questions. It is not currently anticipated that the final factor set will differ significantly from those presented here. Note that the factors covered here differ from those covered in the CRR conference paper (see Appendix 2), which ran dimension-reduction on different question categories (i.e. ‘Energy’, ‘Technology’, ‘Work’ and ‘Environment’) separately.

### Table 20 - Factors identified by dimension reduction of all Agreement-scale questions

<table>
<thead>
<tr>
<th>No.</th>
<th>Factor name</th>
<th>Description</th>
<th>Questions with a factor loading &gt; 0.5 (see Tables 8 &amp; 9 in Appendix 2 for full question phrasing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adoption norms</td>
<td>Appraisal of company’s ability to adopt new technologies in general (not just energy-efficient ones)</td>
<td>25 26 28 29</td>
</tr>
<tr>
<td>2</td>
<td>Economic evaluation</td>
<td>Personal assessment of economics for energy efficiency</td>
<td>13 19 46 50</td>
</tr>
<tr>
<td>3</td>
<td>Goal flexibility</td>
<td>Perceived ability to fit energy saving around current performance targets</td>
<td>39 40 41</td>
</tr>
<tr>
<td>4</td>
<td>Energy intentions</td>
<td>Personal future intentions to reduce energy use</td>
<td>5 6 49 4</td>
</tr>
<tr>
<td>5</td>
<td>Energy awareness</td>
<td>Individuals' awareness of past (company) efforts to save electricity</td>
<td>3 18 7</td>
</tr>
<tr>
<td>6</td>
<td>Energy self-appraisal</td>
<td>How careful or frugal an individual thinks they are with energy</td>
<td>1 2 4 8</td>
</tr>
<tr>
<td>7</td>
<td>Technology self-appraisal</td>
<td>How readily an individual thinks they personally adopt new technologies</td>
<td>31 38 32</td>
</tr>
<tr>
<td>8</td>
<td>Energy self-efficacy</td>
<td>Perceived level of influence over one's own energy use</td>
<td>14 15 17</td>
</tr>
<tr>
<td>9</td>
<td>Technological barriers</td>
<td>Personal experiences of previous difficulties with adopting new technologies</td>
<td>30 43</td>
</tr>
<tr>
<td>10</td>
<td>Environmental norms</td>
<td>Personal appraisal of the company's approach to the environment in general (not just energy or carbon)</td>
<td>45 47</td>
</tr>
</tbody>
</table>
4.6. Cluster analysis

Once the new factors had been identified, it was chosen to investigate whether different groups of staff could be identified based on these new characteristics. This was achieved by applying a two-step cluster analysis function to factor scores (based on those in section 4.5) for each survey participant, forcing the number of clusters. Several passes were conducted, forcing between 3-10 clusters, followed by a qualitative interpretation of their implications. The 6-cluster option was chosen for the purposes of this report, although a 7-cluster alternative is being explored. Table 21 (overleaf) describes the different clusters identified, noting the highest and lowest factor scores for each.

As with the factor analysis, it is anticipated that the final choice of clusters will not be significantly different from that presented here. However, further analysis is required to determine whether these clusters are still present in NR’s various demographic sub-groups (e.g. Routes or Business Functions), before these can be said to be definitive.

The full cluster centroid table for this analysis is available in Appendix 4. A more complete cluster analysis is intended to form part of a future journal article submission.
<table>
<thead>
<tr>
<th>Cluster</th>
<th>Description</th>
<th>Factor scoring</th>
<th>Estimated % of Network Rail staff</th>
</tr>
</thead>
</table>
| “Company supporters”     | “The company’s energy record is good, but I’m not convinced of the economics for saving further energy” | HIGH: Energy self-efficacy  
LOW: Economic evaluation                      | 21% |
| “Aware and motivated”    | “I am very aware of my energy use, and have already made changes to my behaviour” | HIGH: Energy awareness  
LOW: Technological barriers                      | 19% |
| “Willing to change”      | “I recognise that I need to change, and am willing to do so”                  | HIGH: Economic evaluation  
LOW: Energy awareness                           | 16% |
| “Corporate inertia”      | “We need to save energy, but there’s no way the company’s going to change.” | HIGH: Technological barriers  
LOW: Goal flexibility                             | 15% |
| “Low self-efficacy”      | “I am generally indifferent towards energy, but I can’t make a difference anyway.” | HIGH: [Environmental norms – all scores were low]  
LOW: Energy self-efficacy                        | 19% |
| “Status quo”             | “I am able to influence my energy use, but have no intention to change.”     | HIGH: Energy self-efficacy  
LOW: Energy intentions                           | 10% |
4.7. Conclusion and plan for further analysis

Further analysis will revolve around repeating the three main analysis processes (regression, factor, and cluster analyses) with different data subsets. In particular, the differences between energy managers and specialists, and the rest of the employee population (i.e. differences between the Manager- and All-Staff survey results) are a top priority.

Whilst running these processes on the whole dataset at once has proved valuable as a ‘proving ground’, further passes are needed to arrive at a definitive set of behavioural determinants for the ABM phase. Table 22 (overleaf) provides a full listing of the current status of the intended survey analysis processes.

Additionally, content analysis using Nvivo software will be conducted, to gather further details of how employees engage with energy issues. This was originally planned to be done through manual examination, but the large number of responses would make this process difficult to achieve within current timescales.
## Table 22 - Summary of progress with survey analysis processes

<table>
<thead>
<tr>
<th>Processes</th>
<th>Completion status</th>
<th>Data subsets to test</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIB and TPB path analysis</td>
<td>Complete</td>
<td>Whole dataset</td>
<td></td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Demographic subgroups (e.g. gender, age)</td>
<td>Ignoring demographics with insignificant differences (e.g. full/part-time)</td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Cluster analysis groups (e.g. ‘company supporters’, ‘aware and motivated’)</td>
<td></td>
</tr>
<tr>
<td>Dimension-reduction factor analysis</td>
<td>Complete</td>
<td>All agreement-scale questions</td>
<td></td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Whole dataset</td>
<td>To incorporate frequency-scale questions on energy-saving activities</td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Whole dataset with revised question-mapping</td>
<td>To address feedback from CRR conference</td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td>Cluster analysis</td>
<td>Complete</td>
<td>All agreement-scale questions</td>
<td></td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Whole dataset</td>
<td>To incorporate frequency-scale questions on energy-saving activities</td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Whole dataset with revised question-mapping</td>
<td>To address feedback from CRR conference</td>
</tr>
<tr>
<td>To do</td>
<td></td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td>Qualitative content analysis</td>
<td>To do</td>
<td>Open-answer questions</td>
<td>To be conducted using Nvivo software</td>
</tr>
<tr>
<td>Path analysis for an alternative behavioural framework</td>
<td>To do</td>
<td>Whole dataset / other subsets proposed above</td>
<td>To investigate frameworks based on results of factor analysis – see section 4.8 for further details</td>
</tr>
</tbody>
</table>
4.8. **Implications for Agent-Based Modelling**

The original plan for the ABM was to base the central framework on that of the TIB, TPB, or Sorrell et al's (2000, 2011) barriers. However, as discussed earlier, analysis has revealed that the validity of these models is questionable, when considering all NR staff together. Further analysis could return favour to these existing models when considering smaller subsets of staff. However, an alternative framework should be proposed to account for these shortcomings.

**Figure 28** outlines how factors have been initially grouped into separate groups for ‘Energy’ (the curtailment of energy use), and ‘Technology’ (the adoption of new energy-efficient technologies). This is based on the observation that there was very little crossover between questions from the corresponding sections of the Network Rail Energy Survey. It seems reasonable to propose that separate frameworks for these two aspects of energy-efficient behaviours should be used. **Figure 29** proposes two possible parallel frameworks to consider when constructing the ABM. Multiple goal conflict (see Cheng et al, 2007) has been proposed as a moderator for the intention to curtail energy use, whilst Sorrell et al's barriers may have a moderating effect on intention to adopt new technologies. However, alternative arrangements of behavioural determinants, indirect effects, mediators and moderators should be analysed before deciding on a new framework layout.  

![Figure 28 - Initial grouping of factors](image-url)
Having two parallel modelling frameworks is, however, likely to increase the complexity of any ABM arising from this research. A complete modelling plan is not ready to present here, due to the complex array of framework choices still available. However, the overall structure of the agents, interaction pathways and company ‘environment’ is still planned to reflect that proposed in the previous progress report. A full plan and modelling checklist (as proposed by Macal & North, 2010), is planned for inclusion with the next progress report.
5. Actions, April-September 2015

As anticipated in earlier project plans, the coming 6 months will first focus on analysis, paper-writing, and move towards ABM once these are complete. This period will also see the first steps made towards writing the final thesis. An updated research timeline is laid out on a pull-out page at the end of this section (see Figure 30).

5.1. Research plan actions

5.1.1. Continue survey analysis

Whilst initial analysis of Network Rail’s entire body of employees as a single entity is nearing completion (as presented by the paper in Appendix 2), further analysis is required to determine whether these observations hold for department, Route and various employee demographic subgroups. See the analysis plan in section 4.7 for full details.

5.1.2. Finalise ABM design

Before programming can commence, a final design of the proposed ABM must be proposed. The majority of this framework was discussed in the previous 6-month report. However, more detailed analysis of the NR Energy Survey is required (see above) before the final choice of governing framework(s) for each agent is made. Furthermore, the number of different agent types needs to be finalised through cluster analysis (as discussed in section 4.6). This is currently expected to be completed by early January 2016.

5.1.3. Produce ABM forecasts of energy use

The coding process is scheduled to start toward the end of November 2015, once a more thorough analysis of the Network Rail Energy Survey has been completed. The completion date of the Modelling Phase is currently flexible, but estimated to be around March 2016, to allow time for the thesis-writing process.
5.1.4. Commence thesis-writing

This is scheduled to start at the beginning of 2016, once further academic papers have been produced and submitted. This will enable adaptation of their existing content for inclusion in the thesis, rather than beginning ‘from scratch’. A detailed schedule for writing, reviewing and supervision around various chapters will be proposed toward the end of 2015.

These chapters are currently anticipated to follow the following over-arching structure, but these and sub-sections will be agreed upon at a later date:

- Introduction
- Literature Review
- Phase 1 – Interviews with Energy Managers
- Phase 2 – Analysis of Network Rail Energy Survey
- Phase 3 – ABM Scenario Modelling
- Synthesis
- Conclusions

The key deliverable for this will be an outline draft, to be reviewed in April 2016 (i.e. shortly after the next report).

5.2. Courses

‘Communications Management’ is the single, final taught module remaining on this EngD programme, taking place in November 2015. No other external training is planned at this time; opportunities will be appraised as they arrive.

5.3. Conferences

No conference attendance is currently planned for the next 6 month period, and no applications are being processed. The RRUKA conference, attended in previous years, is scheduled to clash with the Communication Management course, and will not be attended this year. Conference notifications will be monitored for potential
future attendance, as the majority of the programme’s conference budget is still available.

5.4. Risks

Table 16 provides an updated risk register, based on those discussed in the previous report. A large number of risks have passed out of relevance, following successful completion of the Network Rail Energy Survey.

Although overrun during the data collection phase was largely avoided, some additional complexity in subsequent analysis processes has arisen, due to the large number of responses received. While this is a welcome development in terms of the robustness of the data gathered, some steps will need to be introduced to manage the workload effectively.
### Table 23 - Risk Register

<table>
<thead>
<tr>
<th>Risk</th>
<th>Events in last 6 months</th>
<th>Severity</th>
<th>Likelihood</th>
<th>Overall</th>
<th>Changes / mitigation steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement to redraft journal articles</td>
<td>Currently redrafting write-up of Interview phase for <em>Journal of Cleaner Production</em>. Also redrafting CRR conference paper for re-use in other journals. Completion may overrun originally-planned dates, but not severely.</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Complete rewrite as soon as possible. Complete draft papers by end of October 2015</td>
</tr>
<tr>
<td>Low stakeholder buy-in for survey delivery</td>
<td>Survey received strong publicity and was carried out without disruption</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Low survey response rate</td>
<td>Survey received a large number of responses</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Need to re-pilot surveys</td>
<td>Piloting process carried out successfully</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Overrun of survey preventing model development</td>
<td>Survey did not overrun. Analysis continuing slightly longer than planned, but still leaves time for modelling</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Agent-based modelling overrun</td>
<td>Bulk of ABM phase yet to commence. Slightly increased risk to completion due to small overrun of survey analysis phase</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Finalise choice of parameters for ABM during completion of draft survey analysis paper.</td>
</tr>
<tr>
<td>Conference clashes</td>
<td>CRR conference chosen over Rail Human Factors conference</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Conference budget shortage</td>
<td>BECC conference abstract not accepted – large proportion of budget remains, and no additional conferences planned at this time</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Risk closed</td>
</tr>
<tr>
<td>Increase in complexity of analysis processes</td>
<td>Additional analysis processes to those originally anticipated have been included in this report (e.g. content analysis of open-answer questions). This may increase the likelihood of ABM overrun (see above)</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Maintain registers of analysis processes used to date, and monitor to prevent build-up of excessive schedule</td>
</tr>
</tbody>
</table>
### Research timeline

<table>
<thead>
<tr>
<th>Activity</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENERGY ATTITUDE SURVEY RESEARCH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rewrite Journal of Cleaner Production paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyse results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft journal article on survey analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finalise for publication; submit to journal</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ENERGY USE SCENARIO DEVELOPMENT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop agent-based modelling skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Create initial model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test models</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate scenario forecasts (main model)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyse results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft journal article</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finalise for publication; submit to journal</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>THESIS WRITE-UP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop structure with supervisors</td>
<td></td>
<td>IA</td>
</tr>
<tr>
<td>Convert existing journal papers to new thesis chapters</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>First draft</td>
<td></td>
<td>L</td>
</tr>
<tr>
<td>Main draft</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Proof-reading and final corrections</td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Printing</td>
<td></td>
<td>E</td>
</tr>
<tr>
<td><strong>OTHER ACTIVITIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Known conferences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>University taught modules and coursework</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Continued literature review)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-month report and thesis-writing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viva Voce examinations - approximate date</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Green shades - Intended programme (colours alternate for clarity)
Pale green - Allowances for overrun / additional activity
Orange - Known activity, approximate date
Red - Intended key delivery dates
Grey - Known leave dates

Figure 30 - Project plan Gantt chart
6. Concluding remarks

Overall, significant progress has been made, with the completion of the Network Rail Energy Survey. For a while, this formed the ‘critical path’ in terms of data required to complete this research programme, but the outcome has surpassed personal expectations in terms of sample size. Whilst analysis of this has begun, the next six months will need to see the vast majority of this process take place, with a larger number of data combinations.

A great deal more time is now being spent out of the office, due to the need to use SPSS and NetLogo software, and the company’s internal software restrictions. This has to be balanced with the increased interest in the survey now that the collection process is complete. Internal documents on aspects of the survey analysis have already been requested, and will need to be produced in parallel with the activities outlined in this report.

In terms of supervision, it is hoped that some stability has returned, after a large number of changes over the past year. A point to note is that myself, along with another EngD researcher, are now the longest-serving members in the team which sponsors us. This has raised the challenge of making sure that the business is fully aware of the original purpose of this research, and to ensure it is used as widely as possible beyond the boundaries of the sponsoring team.

WORD COUNT (Main body, pages 8-33, excluding executive summary, references and appendices):
5,621
References


Appendices

Appendix 1 – Network Rail Energy Survey, final version

This version of the survey was distributed as an online form on 2 June 2015 to a selection of 746 managers, project managers, engineers and specialists with roles relating to large-scale electricity consumption.

The All-Staff version of the survey is not included here to avoid duplication, as all questions contained within it are also present in the Manager survey. See [TABLE] in Appendix 2 for full details.

The survey starts overleaf.
Network Rail Energy Manager Survey

[Blank space]

Dear Colleague

Thank you for choosing to take part in this survey. This survey is an extended version of a questionnaire being distributed to all employees via the Connect news service on 3 June 2015, shortly before World Environment Day - please complete only THIS version of the survey yourself. The questionnaire should take 10-15 minutes to complete.

The main purpose is to find out how you think about energy use in your role at Network Rail, how you believe that the rest of the company deals with energy, and where you think we can manage our energy more effectively and efficiently. This is being done to support future sustainable development efforts within the business around energy behaviours.

"Energy use" in this context refers to any use of electricity or other power/heat sources in any workplace setting, e.g. stations, offices, depots or at the trackside.

There are a few questions on how you think about technology and your working environment, to provide us with some background information. We also ask for a few details about yourself, but do not ask for anything traceable such as name or email address. All information will be stored anonymously.

We aim to share our findings across the company by the end of 2015. We look forward very much to your contribution!

How you think about energy

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>COMPULSORY QUESTION AVERAGE VALUES CALCULATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>I don't think about energy use very often</td>
</tr>
<tr>
<td>I think of myself as being careful with energy use</td>
</tr>
<tr>
<td>I have previously taken part in energy-saving activities at Network Rail</td>
</tr>
</tbody>
</table>

Network Rail Energy Manager Survey (Rupert Ziefer (rupert.ziefer@networkrail.co.uk))
### Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Compulsory Question</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing Network Rail’s energy use should be a high priority</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>I am responsible for the amount of energy I consume at work</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>I am able to influence the amount of energy I consume at work</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>I intend to discuss energy use more often at work in the future</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Saving electricity is easy for my Network Rail department</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>I have seen campaigns specifically around saving energy at Network Rail before today</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Saving electricity is a good way of reducing costs</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>I think that energy saving campaigns work</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Improving Network Rail’s energy efficiency would reduce risk to energy supply</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>There is sufficient expert assistance for the Routes to manage their own energy use</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>There is sufficient manpower to improve energy efficiency</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
## How you think about technology

Please indicate how much you agree with the following statements:

**COMPULSORY QUESTION**

<table>
<thead>
<tr>
<th>AVERAGE VALUES CALCULATED</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information I need for my role, on any subject, is easily available for me</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Network Rail rally adopts new technologies in general</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Other Network Rail departments are quick to adopt new technologies</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>New technologies I have used have generally worked reliably</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>It takes too long to adapt to new technologies in my Network Rail department</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Innovation in general is adequately supported across Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Learning to use new technologies is frustrating</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I look for opportunities to use technologies whenever possible</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>In the last year, I have learned how to use a new piece of technology at work</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

## How you think about work and the environment

Please indicate how much you agree with the following statements:

**COMPULSORY QUESTION**

<table>
<thead>
<tr>
<th>AVERAGE VALUES CALCULATED</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving energy use by improving track equipment is easy for Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>New technologies tend to have beneficial impacts on safety</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>It is easier to reduce energy use by traction, than to reduce energy use by infrastructure</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>It is Network Rail’s responsibility to reduce traction energy use</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
**EngD Progress Report 6**

**Apr 2015 – Sep 2015**

---

### Please indicate how much you agree with the following statements:

**Compulsory Question**

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly</th>
<th>Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I understand the changes that the ‘Digital Railway’ will bring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have actively changed any kind of behaviour following a Network Rail campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am able to influence large-scale business decisions in my Network Rail department</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The targets I work toward give me room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The targets other people have to work toward give them room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any working practices take a long time to change at Network Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My general personal performance is disrupted by conflicts between my different targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Rail receives the largest share of benefits from investment in the railway, compared to other companies (for example, Train Operators)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Energy activities**

**How regularly do you do the following things, approximately?**

**Compulsory Question**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Once per year</th>
<th>Once per month</th>
<th>Once per week</th>
<th>Every day</th>
</tr>
</thead>
</table>

---

Network Rail Energy Manager Survey (Rupert Zierler (rupert.zierler@networkrail.co.uk))
This is Does not
done apply to automatically me

Turn off computer monitors when not at your desk  ○ ○ ○ ○ ○ ○ ○ ○

Turn off lights when no-one else is left in the room  ○ ○ ○ ○ ○ ○ ○ ○

Turn off heating when no-one else is left in the room  ○ ○ ○ ○ ○ ○ ○ ○

Turn off other non-essential electrical equipment  ○ ○ ○ ○ ○ ○ ○ ○

Turn things off completely, rather than to a 'standby' mode  ○ ○ ○ ○ ○ ○ ○ ○

Find ways of deactivating trackside equipment to reduce energy use  ○ ○ ○ ○ ○ ○ ○ ○

Find ways of turning off plant equipment to reduce energy use  ○ ○ ○ ○ ○ ○ ○ ○

Discuss energy use in meetings  ○ ○ ○ ○ ○ ○ ○ ○

Leave items plugged in, even when they’ve finished charging  ○ ○ ○ ○ ○ ○ ○ ○

How often do you do the following management activities, approximately?

### COMPULSORY QUESTION

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Less than once per year</th>
<th>Once per year</th>
<th>Once per quarter</th>
<th>Once per month</th>
<th>Once per week</th>
<th>Does not apply to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start a project because of the potential energy savings</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Incorporate energy savings as part of the business case for a project</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Conduct regular monitoring of energy use</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Investigate in-depth the energy use of existing trackside equipment (e.g. track heaters, outdoor lighting)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Investigate in-depth the energy use of existing indoor office equipment (e.g. computers, building heating)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Calculate greenhouse gas or carbon emissions</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Energy opportunities

Please outline ways in which you think Network Rail could save energy

[Type your answer here]

How can Network Rail support you in saving energy?

[Type your answer here]

Any other comments relating to energy use?

[Type your answer here]

Background information

Finally, we need some basic information about yourself. All responses are anonymous and the information below is collected for analysis only.

When you have finished, please press the ‘Submit Answers’ button at the bottom of this page.

Please tell us your gender

[Please select an answer]
Male
Female
Other
Prefer not to say

Please tell us your approximate age

[Please select an answer]
18-24
25-34
35-44
45-54
55 or above

Which area of the business are you in?

Function

[Please select an answer]
**Route:**

**COMPELLATORY QUESTION**

<table>
<thead>
<tr>
<th>Please select an answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anglia</td>
</tr>
<tr>
<td>London North East &amp; East Midlands</td>
</tr>
<tr>
<td>London North West</td>
</tr>
<tr>
<td>Scotland</td>
</tr>
<tr>
<td>South East</td>
</tr>
<tr>
<td>Wales</td>
</tr>
<tr>
<td>Wessex</td>
</tr>
<tr>
<td>Western</td>
</tr>
<tr>
<td>Central functions</td>
</tr>
<tr>
<td>Not applicable</td>
</tr>
</tbody>
</table>

**Band:**

**COMPELLATORY QUESTION**

<table>
<thead>
<tr>
<th>Please select an answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Leadership Team</td>
</tr>
<tr>
<td>Band 1</td>
</tr>
<tr>
<td>Band 2</td>
</tr>
<tr>
<td>Band 3</td>
</tr>
<tr>
<td>Band 4</td>
</tr>
<tr>
<td>Band 5</td>
</tr>
<tr>
<td>Band 6</td>
</tr>
<tr>
<td>Band 7</td>
</tr>
<tr>
<td>Band 8</td>
</tr>
<tr>
<td>Ope/Signalling grades</td>
</tr>
<tr>
<td>Plant/Line Maintenance grades</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

**Do you have any staff reporting directly to you?**

**COMPELLATORY QUESTION**

<table>
<thead>
<tr>
<th>Please select an answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

**How long have you worked for Network Rail?**

**COMPELLATORY QUESTION**

<table>
<thead>
<tr>
<th>Please select an answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 2 years</td>
</tr>
<tr>
<td>2-5 years</td>
</tr>
<tr>
<td>6-10 years</td>
</tr>
<tr>
<td>11-15 years</td>
</tr>
<tr>
<td>More than 15 years</td>
</tr>
</tbody>
</table>
Do you work full-time or part-time?

COMPULSORY QUESTION

[Please select an answer]

Full-time

Part-time

Do you work a shift pattern?

COMPULSORY QUESTION

[Please select an answer]

Yes

No

[Blank space]

Thank you for completing this special version of the Network Rail Energy Survey. Please share the link below for the general employee survey with any colleagues who have not received this extended version:

http://www.demographix.com/energy2015

[Blank space]

We aim to share our findings with you before the end of 2015. In the meantime, enjoy finding out more about the environmental impacts of energy using the links below.

Find out how you can save energy at home:

http://www.energysavingtrust.org.uk/

Further information on World Environment Day:

http://www.unep.org/wed/wed2015/

A fun tool for working out your ideal low-carbon future:

http://my2050.decc.gov.uk/

[Image only]
Appendix 2 – Corporate Responsibility Research Conference abstract and paper

This was submitted on 15 August 2015 as a discussion paper for conference participants. Note this is not a published paper, as there were no published proceedings. This conference took place 16-18 September 2015. Figure and table numbers have been adjusted to reflect their position in this report.

An oral presentation on the content of this paper was also delivered at this conference, and the ISIE conference in July 2015.

This is also acting as a working paper for future submission to either Energy Policy or the Journal of Environmental Psychology, to complete the second phase of this research project.

The paper starts overleaf.
Corporate Responsibility Research Conference 2015, Marseille
Full paper submission

Title:
Energy-efficient behaviours in railway infrastructure organisations – a comparison of theoretical frameworks

Theme:
CSR and organizational behaviour

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ABSTRACT

Research questions

Railways in the UK consume 1% of the country’s electricity supply. Much of this is used to power trains, but infrastructure assets consume a significant proportion of this energy as well. With such a large footprint, increasing energy efficiency needs to take a high priority among the infrastructure operator’s corporate responsibility efforts. However, as Britain’s railways become increasingly electrified, there are limits to the reduction in consumption brought about by technological improvements alone. The behaviours of employees, and one sub-set of managers in particular, are likely to have a large impact in this area. Changing energy behaviours represents a large proportion of the organisation’s current carbon reduction targets, but the details of how to achieve this need to be finalised.

The study of barriers to energy efficiency in organisations is maturing as a field of research. Risk, clashes of incentives, hidden costs and related factors are repeatedly identified as barriers in many settings. However, research tends to focus on energy efficiency in manufacturing settings, offices, or draw cross-industry comparisons. Studies of barriers unique to transport infrastructure organisations are comparatively rare.

This project (working towards an EngD studentship with the University of Surrey) sets out to determine which behavioural barriers to energy efficiency are most significant for railway infrastructure management in the UK, assess whether employee energy behaviours reflect those of domestic consumers, and identify how where interventions are needed to reduce the energy intensity of railway infrastructure operations.

Theoretical framework

The survey compares three commonly-used theoretical frameworks in the field of energy use behaviours. The Theory of Planned Behaviour (Ajzen, 1991) and the Theory of Interpersonal Behaviour (Triandis, 1977) have been used previously to characterise pro-environmental behaviours among consumers and the travelling public, but not so often in organisational settings. Sorrell et al’s (2000) taxonomy of organisational barriers to energy efficiency have been observed in several types of firm, but rarely (if ever) among transport infrastructure operators.

Method

The significance of these theories in predicting organisational energy behaviours are tested using regression analysis on questionnaire data. A self-report survey was deployed across the company using their main intranet news service and via email. Questions are based on a Likert agree-disagree scale, with a few open-answer questions. The survey was made available to the whole organisation, with a subset of managers, engineers and specialists receiving additional questions around their decision-making processes in relation to energy-efficient technology adoption. Each question is cross-referenced to two or more of the theoretical frameworks mentioned previously.
Findings

The data from this survey enables multiple forms of analysis. Firstly, the applicability of existing behavioural theories from consumer-oriented contexts are tested in an organisational setting. Secondly, testing theoretical frameworks in parallel will enable direct comparison as to which is more effective, as has only occasionally been done in the past (e.g. Bamberg & Schmidt, 2003). The large number of responses has also enabled exploratory factor analysis to identify new behavioural constructs for this context.

The findings presented here have implications for the management of energy curtailment behaviours in infrastructure operating companies, and adds to the growing body of knowledge on organisational energy behaviours. From a theoretical perspective, this research draws parallels between divergent narratives on energy efficiency in organisational- and general consumer settings. This research is also contributing to a decision-support tool for the host organisation, for determining where different behaviour change intervention strategies should be applied within the business.
Energy-efficient behaviours in railway infrastructure organisations

1. Introduction

Railways in the UK consume 1% of the country’s electricity supply. Much of this is used to power trains, but infrastructure assets on their own still consume approximately 400 GWh/year of electricity, contributing to 326,044 tonnes of total organisational carbon dioxide-equivalent emissions annually (Network Rail, 2015). With such a large ecological footprint, increasing energy efficiency needs to take a high priority. However, as Britain’s railways become increasingly electrified, there are limits to the reduction in consumption brought about by technological improvements alone. Changing energy behaviours represents a large proportion of the UK rail industry’s current carbon reduction targets, but the details of how to achieve this are currently unclear. A clearer understanding of employee behaviours is required, in order to determine interventions designed to reduce energy consumption.

This paper sets out to determine which existing theoretical frameworks relevant to energy behaviours are most applicable for the case of UK rail infrastructure, assess whether employee energy behaviours reflect those of domestic consumers, and identify any potential alternative explanatory frameworks.

1.1. ECONOMIC PERSPECTIVE

On initial inspection, increasing the energy efficiency of a company’s operations seems to have few drawbacks; curtailing energy consumption also intuitively offers lower costs, and a reduced need for supply infrastructure. However, slow adoption of energy-efficient technologies despite the strength of the economic case for doing so is frequently observed, commonly referred to as the ‘energy-efficiency paradox’. (e.g. DeCanio, 1998; Kounetas & Tsekouras, 2008; Martin, 2012).

Sorrell et al (2000; 2004; 2011) create a taxonomy of organisational barriers to energy efficiency, referred to as imperfect information, hidden costs, risk (technical or financial), access to capital, split incentives, and bounded rationality. The significance of these barriers has been tested on numerous occasions, and their respective effects and levels of influence are often disputed. Access to capital is discussed here as an example. Some papers suggest that this factor is the most significant in adoption of energy-efficient technologies (e.g. Trianni & Cagno, 2012; Venmans, 2014). The significance of capital costs is occasionally corroborated by energy efficiency studies that don’t use alternative research frameworks (e.g. Kaplowitz et al, 2012). Elsewhere in the field of energy, access to capital is also thought to be a significant barrier to adoption of small-scale renewable generators (Balcombe et al, 2013).
However, Fleiter et al (2012) found that prioritisation of other investments was almost as important as initial capital costs in SMEs, whilst Thollander et al (2007) found these costs to be of greater importance. Rohdin et al (2007) find that barriers in larger companies are more commonly related to risk, decision-making, and prioritisation of energy management than with capital costs. Supporting this theory, Cagno & Trianni (2014) observed that low managerial prioritisation of energy efficiency, and a lack of interest and internal communication of energy issues were more significant barriers. Trianni et al (2013) observed that prioritisation of investment, as well as the potential effects of disruption and the (perceived) poor performance of new equipment were dominant factors in energy-intensive foundries. Nagesha & Balachandra (2006) also independently identified ‘behavioural and personal’ barriers as being of equal importance with capital cost.

The conflicting evidence around the importance of capital costs, and the recurring significance of management prioritisation raises the possibility of further behavioural, rather than economic causes for the energy efficiency paradox. The validity of framing ‘barriers’ to energy efficiency has been questioned, due to the assumption that rational choices in favour of energy efficiency will be made once the barriers are addressed (Shove, 1998). In response to this criticism, Banks et al (2012) attempt to redefine barriers as “a feature of the socio-technical landscape which influences the diffusion of an energy efficient technology or practice”. Sorrell et al (2000) may also have overlooked the significance of barriers falling outside the realm of economics (what they refer to as ‘behavioural’ and ‘management theory’ barriers). Their original list of barriers was determined by a limited selection of brewery, mechanical engineering and higher-education case studies; this may have prematurely focused organisational energy efficiency discourse away from non-economic factors. Nevertheless, ‘barriers’ continue to influence UK energy policy (Darnton, 2008). This suggests that the validity of ‘barriers’ as a concept needs to be investigated further, in relation to other frameworks looking at the energy efficiency paradox. These have been interpreted as the structural model proposed by Figure 31 for analysis purposes.
1.2. BEHAVIOURAL THEORY PERSPECTIVE

Several theories have been used to describe individual pro-environmental behaviour, as reviewed by Jackson (2005) for consumer behaviours, and Darnton et al (2006, 2008) with respect to UK behaviour change policies. Two of these general behavioural theories are proposed to be applicable in an organisational context; the Theory of Planned Behaviour (TPB) (Ajzen, 1991) and the Theory of Interpersonal Behaviour (TIB) (Triandis, 1977). These were selected for two reasons. Firstly, a review of literature (summarised below) revealed their previous application to organisational contexts, and the possible need for further investigation. Secondly, thematic analysis of an earlier series of interviews within the same infrastructure operator resulted in themes which closely respected aspects of these two theories.

The TPB was developed as an extension of the earlier Theory of Reasoned Action (Ajzen, 1991), introducing the concept of perceived behavioural control to account for instances where individuals perceive that they have limited influence over their otherwise assumedly-rational actions. This is perhaps the most commonly-used theory for describing pro-environmental and energy-efficient behaviours (Jackson, 2005), predominantly in the domestic sector (Abrahamse et al, 2005). Greaves et al (2013) and Lo (2011) both apply the TPB in an organisational setting, finding that it can be used to explain antecedents of small-scale pro-environmental and energy-efficient behaviours.
Widespread testing of the TPB in other contexts has taken place despite acknowledgement that it does not adequately take into account habitual behaviours or normative influences (Shove, 1998; Jackson, 2005). A rare comparison of explanatory power between multiple theories suggests that the TPB is roughly equal or less than the Theory of Interpersonal Behaviour (TIB) (and significantly better than the Norm Activation Model), albeit in the context of travel mode choice (Bamberg & Schmidt, 2003). This suggests that further research is needed to test the veracity of the TPB in organisational contexts.

The Theory of Interpersonal Behaviour (TIB) potentially addresses the shortcomings of the TPB by addressing the influences of habits, and factors external to the individual (Triandis, 1977) (see section 3 for structural diagram). Jackson (2005) points out that Triandis’ TIB is less commonly used than both the TPB and NAM, particularly for pro-environmental behaviours, despite its potential for greater explanation of model variances, and its combined rational- and emotional approach. The TIB also very closely resembles the model framework proposed by Huijts et al (2012) for sustainable energy technology acceptance, with relevance for energy-efficient technologies in particular. This theory is currently favoured by reviews on behalf of the UK government (Revell, 2012; Chatterton, 2011), and is generally gaining more widespread recognition due to its wider selection of behavioural constructs compared to the TPB (e.g. Prager, 2012). The shortage of journal papers on organisational behaviours based on this theory is therefore surprising, and reinforces the need for testing the TIB’s validity as a basis for policy.
Alternative theories applied to explain pro-environmental behaviours include the Norm Activation Model (NAM) (Schwartz, 1977), and Value-Belief Norm theory (VBN) (Stern, 2000). The NAM attempts to describe altruistic and pro-social behaviours. However, the validity of this theory can be questioned when external behavioural constraints dominate, such as with employee performance targets (Jackson, 2005). Zhang et al (2013) investigated employee energy curtailment behaviours in Chinese organisations using the NAM, but simplified external constraints as a company-specific ‘energy saving climate’, rather than a detailed set of theoretical constructs. Steg et al (2014) also points out that the NAM is better-suited to situations where normative, rather than gain goals are the focus of employee activities. As reducing costs is naturally part of managing railway infrastructure, it is not clear whether this theory is applicable in this case.

VBN theory was developed in an attempt to understand how individuals adopt pro-environmental behaviours specifically. Personal values are proposed as the drivers of behavioural beliefs, which in turn lead to personal norms and a sense of obligation to act pro-environmentally. Christina et al (2014) conducted an interview survey with staff at a major retailer based on a VBN framework, but found that personal values were overridden by those of the organisation. They propose an alternate version of VBN to overcome this, incorporating adverse effects of employees’ pursuit of multiple performance goals (as proposed by Cheng et al, 2007). However, the need for changes to this theory highlights difficulties when using the VBN in organisational contexts. Furthermore, Andersson et al (2005) also suggest that VBN theory is only partially supported in a corporate context, because of employees’ overriding concerns for their salary and lifestyle. Stern (2000) also states that this theory is more predictive of behaviours “that are not strongly constrained by context or personal
capabilities”, as with the NAM. These factors lead this theoretical framework to be dismissed for the purposes of this paper.

In summary, the three main theoretical frameworks around energy behaviour adoption being compared by this paper are the TPB (Ajzen, 1991), the TIB (Triandis, 1977), and the barriers to energy efficiency proposed by Sorrell et al (2000, 2004, 2011) henceforth referred to as BAR. The behaviour in question is the generalized curtailment of electricity use, expressed either as ‘switch-off’ measures, or adopting more-efficient technologies. The profusion of alternative theoretical frameworks also suggests that new, unique frameworks could apply in the case of infrastructure organisations.

2. Method

In order to test the desired constructs, an online questionnaire survey was developed for distribution across the infrastructure operator organisation. The main survey period occurred between 2 June and 31 July 2015. As such, the analysis presented here should be considered preliminary, but already appears to indicate some key characteristics of the dataset.

2.1. Survey development

This survey used a semi-stratified sampling method. Two versions of the survey were distributed; one addressed to any member of staff (henceforth referred to as the ‘All-Staff’ survey), and another to a selected group of senior managers, engineers, specialists and project teams thought to have greater influence over the amount of electricity consumed by the company (referred to as the ‘Manager’ survey). This was done to meet some internal requirements for the organisation. Both surveys contained compatible questions, with the Manager survey asking additional questions relevant to energy management roles.

Prior to developing the questionnaire, thematic analysis of notes from semi-structured interviews (unpublished) with the company’s energy managers suggested that the TIB framework most closely reflected employee perception of energy use. Themes raised during this process formed the basis of an initial survey design. These first versions of both surveys were piloted with two teams within the organisation, with 10 participants for each. These same participants were also consulted to refine the clarity of the questions and format as a whole.

The survey was divided into four main sections; 38 agreement-scale 5-point Likert questions around attitudes and norms, subdivided across 4 pages dedicated to ‘energy’, ‘technology’, ‘organisational structure’ and ‘environment’ (Tables 1 & 2); 9 frequency-scale Likert questions around energy-saving behaviours (Table 3); 3 open-answer questions; and 9 demographic information questions. The
Manager survey asked 12 additional agreement-scale questions, and 6 frequency-scale questions relating to pro-energy-efficiency management activities. Agreement-scale responses were ‘Strongly Agree’, ‘Agree’, ‘Neutral’, ‘Disagree’ and ‘Strongly Disagree’. Frequency scale responses were ‘Never’, ‘Once per year’, ‘Once per month’, ‘Once per week’, ‘Every day’, ‘This is done automatically’, and ‘Does not apply to me’, the latter two of which were filtered out for the purpose of this analysis. The full questionnaire can be accessed on request from the authors.

Questionnaires were constructed and distributed using the Demographix survey platform, as this had been used within the company previously, and allowed pre-developed company branding to be applied to the forms.

874 responses were received in total across both surveys. The All-Staff survey received 582 responses, all of which were included in analysis; incomplete surveys were filtered out by the software used. A response rate for this part of the survey is difficult to calculate, as the number of people who viewed it is uncertain; there were approximately 36,000 employees within the organisation at the outset of the survey, but the news article received approximately 3,000 page hits. Hyperlinks to the Manager survey were distributed via email to a targeted sample of 746 managers, engineers and specialists with responsibilities for energy use, or working on projects relating to high-consumption equipment. 292 completed responses were received, giving a response rate of 39.1% for this part of the survey.

The two surveys received responses from a broadly similar cross-section of staff, in terms of seniority level; exact data cannot be presented here to prevent breaches of confidentiality. Most responses represented people in mid-level management grades, although this also received some responses from ‘frontline’ trackside staff. As the seniority grades responding to both surveys were broadly similar, this suggests that the survey could adequately represent individuals in mid-level management, with the caveat that one third of these are in roles directly related to high-energy-consumption activities.

### 2.2. Analysis processes

All statistical analysis was conducted using IBM’s SPSS software, based on downloaded raw data. To test the validity of each TIB, TPB and BAR construct, path analysis (based on the model structures shown in Figure 31, Figure 32 and Figure 33 respectively) was conducted using multiple regression. These regressions were carried out on calculated mean scores for groups of agreement-scale questions relevant to each construct. Behaviour scores were calculated as a mean of the two means for agreement-scale questions relating directly to behaviours (see Table 24 and Table 25), and all frequency-scale questions on specific behaviours (see Table 26) respectively. Goodness-of-fit for each pair of constructs was tested by means of Pearson’s Chi-square, and Root Mean Square Error of Approximation (RMSEA), thus fulfilling part of the fit index criteria recommended by Hu & Bentler (1999).

Factor analysis was also applied to the dataset, following the initial regression analysis process. The reasons for undertaking this are more fully explained in section 3.3 below. However, the need to
carry this out emerged after analysis of the original three theoretical frameworks appeared to explain less variance than anticipated. This was conducted using Principal Component analysis in SPSS, based on Eigenvalues, rather than looking for a specified number of new constructs. All analysis used Varimax rotation, with a maximum of 25 rotations (the default maximum setting in SPSS). Missing cases were excluded pairwise.

Table 24 - Likert agreement-scale questions, showing categories and theoretical constructs mapped to each (part 1 of 2)

<table>
<thead>
<tr>
<th>No.</th>
<th>Question wording</th>
<th>Question category</th>
<th>All-staff / Manager-only?</th>
<th>TIB construct</th>
<th>TPB construct</th>
<th>BAR construct(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I don’t think about energy use very often</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Habits</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I think of myself as being careful with energy use</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Self-concept</td>
<td>Subjective Norm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I have previously taken part in energy saving activities at Network Rail</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Behaviour</td>
<td>Behaviour</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>I tend to leave equipment switched on</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Habits</td>
<td>Behaviour</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>I plan to use less electricity at home in the future</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Intention</td>
<td>Behavioural intention [Intention]</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I plan to use less electricity in my place of work in future</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Intention</td>
<td>Behavioural intention [Intention]</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I know who can give me information to help me save energy</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Perceived behavioural control Imperfect information</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>I get frustrated when I see energy being wasted</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Affect</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>I think that the Route management structure has been beneficial to how energy use is managed at Network Rail</td>
<td>Energy</td>
<td>Manager</td>
<td>Belief</td>
<td>Normative belief Split incentives</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Train Operators have a positive influence on Network Rail’s energy efficiency</td>
<td>Energy</td>
<td>Manager</td>
<td>Role</td>
<td>Normative belief Split incentives</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Network Rail’s energy data collection is highly detailed</td>
<td>Energy</td>
<td>Manager</td>
<td>Belief</td>
<td>Normative belief Imperfect information</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>New energy-efficient technologies have generally worked reliably</td>
<td>Energy</td>
<td>Manager</td>
<td>Evaluation</td>
<td>Attitude toward behaviour Risk and uncertainty</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Reducing NR’s energy use should be a high priority</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>I am responsible for the amount of energy I consume at work</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Role</td>
<td>Control belief Split incentives, bounded rationality</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>I am able to influence the amount of energy I consume at work</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Role</td>
<td>Perceived behavioural control Bounded rationality</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>I intend to discuss energy use more often at work in the future</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Intention</td>
<td>Behavioural intention [Intention]</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Saving electricity is easy for my Network Rail department</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Attitude toward behaviour Risk and uncertainty</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>I have seen campaigns specifically around saving energy at Network Rail</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Norm</td>
<td>Normative belief Imperfect information</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Saving electricity is a good way of reducing costs</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Behavioural belief Hidden costs</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>I think that energy saving campaigns work</td>
<td>Energy</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Improving Network Rail’s energy efficiency could reduce risks to energy supply</td>
<td>Energy</td>
<td>Manager</td>
<td>Evaluation</td>
<td>Behavioural belief Risk and uncertainty</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>There is sufficient expert assistance for the Routes to manage their own energy use</td>
<td>Energy</td>
<td>Manager</td>
<td>Norm</td>
<td>Control belief Hidden costs</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>There is sufficient manpower to improve energy efficiency</td>
<td>Energy</td>
<td>Manager</td>
<td>Self-concept</td>
<td>Control belief Hidden costs</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Information I need for my role, on any subject, is easily available for me</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Control belief Bounded rationality, imperfect information</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Network Rail easily adopts new technologies in general</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Behaviour</td>
<td>Normative belief Risk and uncertainty</td>
<td></td>
</tr>
</tbody>
</table>
### Table 25 - Likert agreement-scale questions, showing categories and theoretical constructs mapped to each (part 2 of 2)

<table>
<thead>
<tr>
<th>No.</th>
<th>Question wording</th>
<th>Question category</th>
<th>All-staff / Manager only?</th>
<th>TIB construct</th>
<th>TPB construct</th>
<th>BAR construct</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>Other Network Rail business units are quick to adopt new technologies</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Norm</td>
<td>Subjective Norm</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>27</td>
<td>New technologies I have used have generally worked reliably</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Attitude toward behaviour</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>28</td>
<td>It takes too long to adapt to new technologies in my Network Rail business unit</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Habits</td>
<td>Subjective Norm</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Innovation in general is adequately supported across Network Rail</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Normative belief</td>
<td>Access to capital, Split Incentives</td>
</tr>
<tr>
<td>30</td>
<td>Learning to use new technologies is frustrating</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Affect</td>
<td>Attitude toward behaviour</td>
<td>Hidden costs</td>
</tr>
<tr>
<td>31</td>
<td>I took for opportunities to use new technologies whenever possible</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Intention</td>
<td>Behavioural intention</td>
<td>[Intention]</td>
</tr>
<tr>
<td>32</td>
<td>Saving energy use by improving track equipment is easy for Network Rail</td>
<td>Technology</td>
<td>All-Staff</td>
<td>Behaviour</td>
<td>Behaviour</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>New technologies tend to have beneficial impacts on safety</td>
<td>Technology</td>
<td>Manager</td>
<td>Belief</td>
<td>Attitude toward behaviour</td>
<td>Risk and uncertainty, Split incentives</td>
</tr>
<tr>
<td>34</td>
<td>It is easier to reduce energy use by traction, than to reduce energy use by infrastructure</td>
<td>Technology</td>
<td>Manager</td>
<td>Evaluation</td>
<td>Attitude toward behaviour</td>
<td>Risk and uncertainty, Split incentives</td>
</tr>
<tr>
<td>35</td>
<td>It is Network Rail’s responsibility to reduce traction electricity use</td>
<td>Technology</td>
<td>Manager</td>
<td>Role</td>
<td>Subjective Norm</td>
<td>Split incentives</td>
</tr>
<tr>
<td>36</td>
<td>I understand the changes that the ‘Digital Railway’ will bring</td>
<td>Work</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Attitude toward behaviour</td>
<td>Risk and uncertainty</td>
</tr>
<tr>
<td>37</td>
<td>I have actively changed any kind of behaviour following a Network Rail campaign</td>
<td>Work</td>
<td>All-Staff</td>
<td>Behaviour</td>
<td>Behaviour</td>
<td>Risk and uncertainty, Bounded rationality</td>
</tr>
<tr>
<td>38</td>
<td>I am able to influence large-scale business decisions in my part of Network Rail</td>
<td>Work</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Perceived behavioural control</td>
<td>Access to capital</td>
</tr>
<tr>
<td>39</td>
<td>The targets I work toward give me scope to use less energy</td>
<td>Work</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Normative belief</td>
<td>Split incentives</td>
</tr>
<tr>
<td>40</td>
<td>The targets other people at Network Rail have to work towards give them scope to use less energy</td>
<td>Work</td>
<td>All-Staff</td>
<td>Norm</td>
<td>Subjective Norm</td>
<td>Split incentives</td>
</tr>
<tr>
<td>41</td>
<td>Any working practices take a long time to change at Network Rail</td>
<td>Work</td>
<td>All-Staff</td>
<td>Habits</td>
<td>Subjective Norm</td>
<td>Split incentives</td>
</tr>
<tr>
<td>42</td>
<td>My personal performance at work is disrupted by conflicts between targets I need to achieve</td>
<td>Work</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Control belief</td>
<td>Split incentives</td>
</tr>
<tr>
<td>43</td>
<td>Network Rail receives the largest share of the benefits from investment in the railway, compared to other companies (for example, Train Operators)</td>
<td>Work</td>
<td>Manager</td>
<td>Norm</td>
<td>Normative belief</td>
<td>Split incentives, Access to capital</td>
</tr>
<tr>
<td>44</td>
<td>Climate change as an issue is discussed more often than is really necessary</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Affect</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Network Rail should be working harder to reduce our effects on the environment</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Belief</td>
<td>Behavioural belief</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>I am happy with the way that Network Rail as a whole handles environmental issues</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Affect</td>
<td>Normative belief</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Changes I make to my energy use have a big impact on the world around me</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Self-concept</td>
<td>Behavioural belief</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>I intend to discuss environmental issues more often at work in the future</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Intention</td>
<td>Behavioural intention</td>
<td>[Intention]</td>
</tr>
<tr>
<td>49</td>
<td>Network Rail could benefit from using small-scale renewable energy sources (such as solar panels)</td>
<td>Environment</td>
<td>All-Staff</td>
<td>Evaluation</td>
<td>Attitude toward behaviour</td>
<td></td>
</tr>
</tbody>
</table>
Table 26 - Frequency-scale activity questions

<table>
<thead>
<tr>
<th>No.</th>
<th>Question &quot;How regularly do you perform the following actions?&quot;</th>
<th>All-Staff / Manager-Only?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turn off computer monitors when not at your desk</td>
<td>All-Staff</td>
</tr>
<tr>
<td>2</td>
<td>Turn off lights when no-one else is left in the room</td>
<td>All-Staff</td>
</tr>
<tr>
<td>3</td>
<td>Turn off heating when no-one else is left in the room</td>
<td>All-Staff</td>
</tr>
<tr>
<td>4</td>
<td>Turn off other non-essential electrical equipment</td>
<td>All-Staff</td>
</tr>
<tr>
<td>5</td>
<td>Turn things off completely, rather than to a &quot;standby&quot; mode</td>
<td>All-Staff</td>
</tr>
<tr>
<td>6</td>
<td>Find ways of turning off trackside equipment to reduce energy use</td>
<td>All-Staff</td>
</tr>
<tr>
<td>7</td>
<td>Find ways of turning off plant equipment to reduce energy use</td>
<td>All-Staff</td>
</tr>
<tr>
<td>8</td>
<td>Discuss energy use in meetings</td>
<td>All-Staff</td>
</tr>
<tr>
<td>9</td>
<td>Leave items plugged in, even when they've finished charging</td>
<td>All-Staff</td>
</tr>
<tr>
<td>10</td>
<td>Start a project because of the potential energy savings</td>
<td>Manager-Only</td>
</tr>
<tr>
<td>11</td>
<td>Include energy savings as part of the business case for a project</td>
<td>Manager-Only</td>
</tr>
<tr>
<td>12</td>
<td>Investigate in-depth the energy use of existing trackside equipment (e.g. track heaters, outdoor lighting)</td>
<td>Manager-Only</td>
</tr>
<tr>
<td>13</td>
<td>Investigate in-depth the energy use of existing indoor/office equipment (e.g. computers, building heating)</td>
<td>Manager-Only</td>
</tr>
<tr>
<td>14</td>
<td>Conduct regular monitoring of energy use</td>
<td>Manager-Only</td>
</tr>
<tr>
<td>15</td>
<td>Calculate greenhouse gas or carbon emissions</td>
<td>Manager-Only</td>
</tr>
</tbody>
</table>
3. Results

As mentioned previously, the results presented are preliminary, due to the recent completion date of the survey. These time constraints have precluded full path analysis for the model as a whole (e.g. a single chi-square statistic for the theoretical models as a whole). However, statistics for each stage of regression analysis are presented here. All regression analysis, significance and reliability tests are summarised in Table 27.

3.1. Regression analysis

Regression analysis reveals that, of the estimated path coefficients (B) for the TIB model, all except ‘Habit’ were statistically significant, as summarized in Figure 34. Together, Attitudes, Social Factors (Norms, perceived Roles and Self-Concepts) accounted for 28.6% of participants’ intention to curtail electricity use. These intentions in turn accounted for 18.0% of eventual energy curtailment behaviours.

All estimated path coefficients (B) for the TPB model were statistically significant, as summarized in Figure 35. Attitudes, Norms, and Perceived Behavioural Control explained 32.5% of the intention to curtail energy use, which in turn explained 30.3% of the eventual behaviours.

Of the estimated path coefficients for the BAR model, only three constructs were found to return significant results (Hidden Costs, Risk and Uncertainty, and Bounded Rationality), as summarized in Figure 36. Regression analysis suggests that all BAR constructs explained 22.8% of variance in participants’ intention to curtail electricity use, but the lack of significance for half of the antecedent constructs suggests that this figure is questionable. The effects of Intentions on energy-saving Behaviours can be considered the same as that for the TIB, as the group of survey questions used to determine these was the same for both frameworks.
Table 27 - Statistical summary of all theoretical constructs considered (N = 874)

<table>
<thead>
<tr>
<th>Theory</th>
<th>Construct</th>
<th>Regression with</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Adjusted R-square</th>
<th>Standardised coefficients</th>
<th>Coeff significance</th>
<th>Pearson’s Chi-square</th>
<th>Chi-square significance</th>
<th>df</th>
<th>RMSEA</th>
<th>Cronbach’s alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TIB</strong></td>
<td><strong>Attitudes</strong></td>
<td>Intention</td>
<td>3.295</td>
<td>0.411</td>
<td></td>
<td></td>
<td>0.233</td>
<td>&lt;0.001</td>
<td>2631.846</td>
<td>&lt;0.001</td>
<td>1332</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td>Social Factors</td>
<td>Intention</td>
<td>2.987</td>
<td>0.502</td>
<td></td>
<td></td>
<td>0.278</td>
<td>&lt;0.001</td>
<td>1981.654</td>
<td>&lt;0.001</td>
<td>990</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Affect</td>
<td>Intention</td>
<td>3.539</td>
<td>0.494</td>
<td>0.286</td>
<td></td>
<td>0.139</td>
<td>&lt;0.001</td>
<td>208.068</td>
<td>NS</td>
<td>198</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Habits</td>
<td>Intention</td>
<td>2.852</td>
<td>0.434</td>
<td></td>
<td></td>
<td>0.070</td>
<td>&lt;0.05</td>
<td>631.455</td>
<td>&lt;0.001</td>
<td>252</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>Intention</td>
<td>Behaviour</td>
<td>3.576</td>
<td>0.622</td>
<td>0.180</td>
<td></td>
<td>0.426</td>
<td>&lt;0.001</td>
<td>1792.055</td>
<td>&lt;0.001</td>
<td>1368</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Behaviour</td>
<td>n/a</td>
<td>2.966</td>
<td>0.771</td>
<td></td>
<td></td>
<td>0.640</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TPB</strong></td>
<td><strong>Attitudes</strong></td>
<td>Intention</td>
<td>3.617</td>
<td>0.427</td>
<td></td>
<td></td>
<td>0.469</td>
<td>&lt;0.001</td>
<td>2602.517</td>
<td>&lt;0.001</td>
<td>1224</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>Norms</td>
<td>Intention</td>
<td>2.933</td>
<td>0.592</td>
<td></td>
<td></td>
<td>0.122</td>
<td>&lt;0.001</td>
<td>1227.696</td>
<td>&lt;0.001</td>
<td>936</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Perceived behavioural control</td>
<td>Intention</td>
<td>2.679</td>
<td>0.497</td>
<td>0.325</td>
<td></td>
<td>0.109</td>
<td>&lt;0.001</td>
<td>1114.017</td>
<td>&lt;0.001</td>
<td>720</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>Perceived behavioural control</td>
<td>Behaviour</td>
<td>2.679</td>
<td>0.497</td>
<td></td>
<td></td>
<td>0.295</td>
<td>&lt;0.001</td>
<td>12717.173</td>
<td>&lt;0.001</td>
<td>9680</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Intention</td>
<td>Behaviour</td>
<td>3.576</td>
<td>0.622</td>
<td>0.303</td>
<td></td>
<td>0.377</td>
<td>&lt;0.001</td>
<td>5174.304</td>
<td>&lt;0.001</td>
<td>4356</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Behaviour</td>
<td>n/a</td>
<td>6.389</td>
<td>1.301</td>
<td></td>
<td></td>
<td>0.377</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BAR</strong></td>
<td>Imperfect information</td>
<td>Intention</td>
<td>2.729</td>
<td>0.782</td>
<td></td>
<td></td>
<td>0.056</td>
<td>NS</td>
<td>874.68</td>
<td>&lt;0.001</td>
<td>432</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Hidden costs</td>
<td>Intention</td>
<td>3.659</td>
<td>0.680</td>
<td></td>
<td></td>
<td>0.091</td>
<td>&lt;0.01</td>
<td>385.927</td>
<td>&lt;0.001</td>
<td>270</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>Risk and uncertainty</td>
<td>Intention</td>
<td>2.943</td>
<td>0.555</td>
<td></td>
<td></td>
<td>0.237</td>
<td>&lt;0.001</td>
<td>1386.859</td>
<td>&lt;0.001</td>
<td>684</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td>Access to capital</td>
<td>Intention</td>
<td>2.592</td>
<td>0.746</td>
<td></td>
<td></td>
<td>0.037</td>
<td>NS</td>
<td>488.908</td>
<td>&lt;0.001</td>
<td>288</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Split incentives (and appropriability)</td>
<td>Intention</td>
<td>2.904</td>
<td>0.524</td>
<td>0.228</td>
<td></td>
<td>0.011</td>
<td>NS</td>
<td>1534.16</td>
<td>&lt;0.001</td>
<td>738</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td>Bounded rationality</td>
<td>Intention</td>
<td>3.280</td>
<td>0.647</td>
<td>0.193</td>
<td></td>
<td>&lt;0.001</td>
<td>898.187</td>
<td>&lt;0.001</td>
<td>270</td>
<td>0.052</td>
<td>0.503</td>
</tr>
<tr>
<td></td>
<td>[Intention]</td>
<td>n/a</td>
<td>3.576</td>
<td>0.622</td>
<td></td>
<td></td>
<td>0.228</td>
<td></td>
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</tbody>
</table>

**df** - Degrees of Freedom  
**RMSEA** - Root Mean Square Error of Approximation  
**NS** - Not significant
Figure 34 - Path analysis of the Theory of Interpersonal Behaviour (Triandis, 1977) based on survey data (N = 874). *p<0.05, ***p<0.001

Figure 35 - Path analysis of the Theory of Planned Behaviour (Ajzen, 1991) based on survey data (N = 874). ***p<0.001
3.2. Reliability analysis

Cronbach’s alpha factors were calculated for each theoretical construct across the three frameworks (TIB, TPB, BAR), as summarised in Table 27. Most Cronbach’s alpha scores were less than the widely-recognised acceptability level of 0.7 (Santos, 1999). As noted by Greaves et al (2013), this may be acceptable for measurement of psychological constructs like those of the TIB and TPB (George & Mallery, 2003) particularly when these constructs are based on small numbers of questions, as they are here. However, this is not necessarily true of the BAR factors, as they were not developed as psychological constructs.

Only the TPB showed consistent reliability across all constructs determining intention to save energy within the organisation, with all related independent variables having a Cronbach’s alpha of 0.6 or greater (see Table 27). The TIB returned very low scores 0.6 for both ‘Affect’ (0.095) and ‘Habits’

No theoretical framework returned ‘good’ Cronbach’s alpha scores for the effects of Intention to curtail energy use on resulting energy Behaviours (0.404 for the TIB and BAR, 0.377 for the TPB), suggesting that these frameworks only explain intention to curtail electricity use, rather than the actual behaviour.
3.3. Factor analysis

Given the relatively low $R^2$ coefficients and reliability scores from the Cronbach’s alpha test, a series of factor analyses were run using SPSS’ dimension reduction function, in order to determine potential new theoretical constructs.

A minimum value of 0.5 was used for determining which questions each factor represented, following the advice of Field (2005). Factors were accepted if included significant results from 3 or more agreement-scale questions, to counteract any ‘noise’ from questions which returned loading factors between 0.3 and 0.5.

Running factor analysis across all agreement-scale questions simultaneously did not converge on any new, clear-cut factors within 25 rotations. Hence smaller groups of questions were tested in various combinations, not all of which have been covered in detail by this paper, for the sake of brevity.

The clearest results were produced when questions were grouped together as they had been on the four pages of the agreement-scale questions, i.e. by ‘energy’, ‘technology’, ‘organisational structure’ and ‘environment’. Most other factor analysis passes repeated or closely-resembled the factors found here (with a lower degree of certainty), or did not converge on new factors.

Of these, factors from the ‘energy’ and ‘technology’ categories returned the highest sampling accuracy, with Kaiser-Meyer-Olkin scores of 0.809 (ranked as ‘very good’ according to Field, 2005) and 0.706 respectively (‘good’), whilst ‘organisational structure’ and ‘environment’ factors only scored 0.670 and 0.692 (both ‘medicore’).

A total of 5 new emergent categories met all of the criteria mentioned above, with 2 potential extra categories for energy managers only, as summarised in Table 28. These were designated as ‘Curtailment Evaluation’, ‘Energy Awareness’, ‘Energy Stewardship’, ‘Self-Efficacy’, ‘Technological Norms’, ‘Goal Flexibility’ and ‘Organisational Pro-Environment Stance’. The first five of these are discussed in further detail in the next section.
Table 28- Factor analysis summary. Discarded factors are included here to account for the loading factors of those kept.

<table>
<thead>
<tr>
<th>New Factor name and interpretation</th>
<th>Decision (Keep / discard)</th>
<th>Factor category</th>
<th>Survey questions (see tables 1 &amp; 2)</th>
<th>Loading factor</th>
<th>Kaiser-Mayer-Olkin sampling accuracy</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A &quot;Curtailment Evaluation&quot; (Personal evaluation of curtailing energy use)</td>
<td>Keep</td>
<td>Energy</td>
<td>5 0.500</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>8 0.532</td>
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<td>13 0.740</td>
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<td></td>
<td>19 0.558</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>21 0.649</td>
<td></td>
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</tr>
<tr>
<td>B &quot;Energy Management capability&quot; (How ready managers feel Network Rail is for energy efficiency in terms of management practices)</td>
<td>Keep, for managers only</td>
<td>Energy</td>
<td>9 0.707</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>10 0.544</td>
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<td></td>
<td>11 0.697</td>
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<td></td>
<td></td>
<td></td>
<td>12 0.685</td>
<td></td>
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<tr>
<td>C &quot;Energy Awareness&quot; (Personal awareness of previous energy-saving campaigns and participation)</td>
<td>Keep</td>
<td>Energy</td>
<td>3 0.755</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>7 0.649</td>
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<td></td>
<td></td>
<td></td>
<td>18 0.668</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>D &quot;Energy Stewardship&quot; (Personal awareness of participants' own current energy-saving activities)</td>
<td>Keep</td>
<td>Energy</td>
<td>1 -0.576</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>2 0.668</td>
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<td></td>
<td></td>
<td></td>
<td>4 -0.708</td>
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<td></td>
<td></td>
<td></td>
<td>8 0.516</td>
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<tr>
<td>E &quot;Self-Efficacy&quot; (How much impact individuals feel they have on their own energy use at work)</td>
<td>Keep</td>
<td>Energy</td>
<td>14 0.736</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>15 0.776</td>
<td></td>
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<td></td>
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<tr>
<td>F &quot;Training Capability&quot; (Managers' assessment of current training capacity for energy-saving)</td>
<td>Keep, for managers only</td>
<td>Energy</td>
<td>5 -0.532</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>22 0.641</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>23 0.673</td>
<td></td>
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</tr>
<tr>
<td>G &quot;Technological Norms&quot; (Personal assessment of how willingly new technologies are adopted by the organisation)</td>
<td>Keep</td>
<td>Technology</td>
<td>24 0.532</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>25 0.853</td>
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<td></td>
<td>26 0.771</td>
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<td></td>
<td></td>
<td></td>
<td>28 -0.576</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H Discard (only two questions)</td>
<td>Discard (only two questions)</td>
<td>Technology</td>
<td>31 0.738</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J Discard (only two questions)</td>
<td>Discard (only two questions)</td>
<td>Technology</td>
<td>33 0.534</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K &quot;Goal Flexibility&quot; (Personal assessment of the ease of incorporating energy-saving goals)</td>
<td>Discard (low sampling accuracy)</td>
<td>Organisational structure</td>
<td>39 0.699</td>
<td>40 0.857</td>
<td>41 0.800</td>
<td>0.706 (good)</td>
</tr>
<tr>
<td>L Discard (only two questions)</td>
<td>Discard (only two questions)</td>
<td>Organisational structure</td>
<td>40 0.585</td>
<td>41 0.800</td>
<td>42 0.723</td>
<td>43 0.764</td>
</tr>
<tr>
<td>M Discard (only two questions)</td>
<td>Discard (only two questions)</td>
<td>Organisational structure</td>
<td>37 0.585</td>
<td>38 0.585</td>
<td>39 0.585</td>
<td>40 0.800</td>
</tr>
<tr>
<td>N Discard (only two questions)</td>
<td>Discard (only two questions)</td>
<td>Environment</td>
<td>45 0.607</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O &quot;Organisational pro-environment stance&quot; (Personal assessment of how well the organisation treats the energy use)</td>
<td>Discard (low sampling accuracy)</td>
<td>Environment</td>
<td>46 -0.682</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>47 0.755</td>
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</tr>
</tbody>
</table>
4. Discussion

Out of the initial theoretical frameworks considered, regression analysis suggests that the TPB accounts for the greatest amount of variance (0.325, p<0.001) in terms of ‘intention to save energy’, followed by the TIB (0.286, p<0.001) and BAR (0.211, p<0.001) respectively. However, the observed variance in Intention to curtail electricity consumption is relatively low when compared with some previous research, which can be as high as 81% (Greaves et al, 2013; Kaiser & Gutsch, 2003). This suggests that alternative sets of factors may have greater influence over employees’ intentions to save energy.

Reliability analysis also favours the TPB constructs, with an average Cronbach’s alpha of 0.643, followed by the BAR (0.551) and TIB (0.496) respectively (although alpha factors vary considerably within each theoretical framework). This posits that the TPB is the most reliable of the three original frameworks considered, in terms of determining energy-saving intentions.

However, the fact that questionable scores existed for aspects of all three frameworks suggest that none of them are ideal for explaining the Intention to curtail electricity consumption in the case of this railway infrastructure organisation. Alternative theoretical constructs therefore need to be explored within this dataset.

4.1. Factor analysis

Five potential new constructs for explaining curtailment of electricity use were arrived at using SPSS’s factor analysis function. The figures given below refer to each agreement-scale question’s respective loading factor.

‘Curtailment Evaluation’ was primarily focused around a specific set of attitudes (as defined by the TIB and TPB) relating to the organisation’s prioritization of energy efficiency. The three most prominent of these were “Reducing [the organisation’s] energy use should be a high priority” (0.740), and “Improving [the organisation’s] energy efficiency would reduce risks to energy supply” (0.649), and “Saving electricity is a good way of reducing costs” (0.558).

‘Energy Awareness’ reflected respondents’ previous participation in efforts to save energy within the organisation. The questions contributing to this factor did not align consistently with any particular construct from the original frameworks. This may be explained by evidence of previous small-scale, localized efforts to save energy, such as ‘switch-off’ stickers on computer monitors, which had been observed during the survey development process.

‘Energy Stewardship’ described a set of questions relating to how carefully participants treated their own personal energy use; “I tend to leave equipment switched on” (-0.708), and “I think of myself as being careful with energy use” (0.668). This was linked slightly less strongly with the level of salience of energy consumption; “I don’t think about energy use very often” (-0.576), and “I get frustrated when
I see energy being wasted” (0.516). This did not reflect any single construct from the other frameworks more than any other, with the possible exception of Habits (from the TIB) which contributed half of the associated questions.

‘Self-Efficacy’ reflected respondents’ perceived ability to influence the amount of energy they consume at work (q14, 0.736 and q15, 0.776), particularly in their own company department (q17, 0.567). This represented a hybrid of the TIB’s ‘Role’ and the TPB’s ‘Perceived Behavioural Control’ constructs, possibly representing how employees’ perception of their impact on the organisation’s decisions is linked to their perceived impact on their own energy use.

‘Technological Norms’ reflected the perceived ease with which the company would accept new technologies in general (in particular q25, 0.853), and the perceived differences in this between closer or more distant departments (in terms of organisational structure). This most closely reflected the Norm construct from the TPB, with one other question (q24, 0.532) relating to Perceived Behavioural Control.

Further factor analysis should be conducted with other groups of questions, before any definitive recommendations can be made regarding a possible alternative model structure. However, we can tentatively suggest that a hybrid model, based on the TPB and TIB and incorporating more-tightly-specified attitudes, norms, and a ‘self-efficacy’ factor may provide a more accurate representation of the Intention to curtail electricity consumption in this organisation.

These results have two possible implications, in terms of which factors to focus on when trying to reduce employee electricity consumption. Firstly, efforts should be made to increase the perception that others within the organisation are trying to curtail their energy use, perhaps using a comparative feedback mechanism between different stations, depots or offices, such as that studied by Dixon et al (2014). And secondly, any behavioural campaigns should focus on increasing employees’ sense of having an important impact, both on energy-saving and on the organisation’s decision-making processes. A suggestion for achieving this could be to broadcast more local energy-saving achievements via internal company news services or social media.

4.2. Study limitations

One key limitation is that this research represents a one-time cross-sectional study, rather than a longitudinal observation at a time of transition (such as that conducted for university students by Senbel et al, 2014). However, UK railway infrastructure had recently been transferred back into public sector ownership in a short space of time, and many organisational structures had been in flux until shortly before the questionnaire was distributed. As such, it was difficult to prepare for any particular organisational transition in order to observe it.

Another possible drawback to this method is the reliance on self-report data from survey respondents on specific energy behaviours, rather than direct observations. However, it would be challenging to replicate the same national scale with direct observations of individuals’ energy behaviours as achieved with this survey. It may also be difficult to track the energy use impacts of controlling large
scale equipment over large geographical distances, unlike with studies of behaviours in offices (e.g. Murtagh et al, 2013).

Methodologically, the length of the questionnaire also led to a large number of early drop-outs; 45% of participants in the All-Staff survey, and 33% from the Manager survey did not complete the form once they had started. Whilst the size of the company meant that a large number of responses still were received, this could represent a problem if the process was replicated in smaller companies using the same questionnaire.

5. Conclusions

So far, regression analysis suggests that personal attitudes have a greater impact on intention to save energy than subjective norms, in the context of a large infrastructure organisation. It also puts forward the possibility that a more personal, psychological approach to individuals’ energy behaviours within organisations may be more constructive than targeting economic barriers to energy efficiency. Further analysis of this rich dataset is required to confirm these points.

Regression analysis revealed that the TPB’s constructs fit best with the data gathered by the questionnaire, out of the three theoretical frameworks tested. However, the TPB did not account for as much variance in pro-environmental intentions as for previous organisation-based studies (Greaves et al, 2013).

Some potential new constructs arrived at through factor analysis account for a greater amount of variance in the results observed. New factors represent a hybrid of the TIB and TPB, and new constructs which could not be defined easily using the other frameworks. These related primarily to awareness of other energy-saving initiatives, and to employees’ perceived impact on their working- and physical environment.

This research represents a case study into a single (albeit large) infrastructure organisation. Two main possibilities for future research emerge. Firstly, future studies could develop a survey to test the validity of constructs suggested by this paper, either in other infrastructure operator organisations, or companies of different types. And secondly, future research could transfer other general behavioural theories (such as those discussed by Jackson, 2005) into investigation of organisational energy curtailment behaviours. The survey upon which this paper is based is already supporting delivery of behaviour-change activities across the host organisation, and guiding the development of internal communications on the subject of energy behaviours.
Acknowledgements

This research is contributing towards an Engineering Doctorate (EngD) in Sustainability for Engineering and Energy Systems with the University of Surrey, funded by the UK Engineering & Physical Sciences Research Council and Network Rail.

References


PRAGER, K. 2012. UNDERSTANDING BEHAVIOUR CHANGE - How to apply theories of behaviour change to SEWeb and related public engagement activities. *SEWeb LIFE+*. Published online: James Hutton Institute.


### Appendix 3 – Rotated component matrix for factor analysis

(SPSS output table. Factor loadings > 0.5 highlighted in yellow, > 0.4 highlighted in orange. All loadings < 0.3 have been suppressed for clarity.)

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - I don't think about energy use very often</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.543</td>
<td></td>
<td></td>
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<tr>
<td>2 - I think of myself as being careful with energy use</td>
<td></td>
<td></td>
<td></td>
<td>-.728</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3 - I have previously taken part in energy-saving activities at Network Rail</td>
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<td></td>
<td></td>
<td></td>
<td>.725</td>
<td></td>
<td></td>
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<tr>
<td>4 - I tend to leave equipment switched on</td>
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<td></td>
<td>-.702</td>
<td></td>
<td></td>
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<tr>
<td>5 - I plan to use less electricity at home in future</td>
<td></td>
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<td></td>
<td></td>
<td>.801</td>
<td></td>
<td></td>
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<tr>
<td>6 - I plan to use less electricity in my place of work in future</td>
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<td></td>
<td></td>
<td>.769</td>
<td></td>
<td></td>
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<tr>
<td>7 - I know who can give me information to help me save energy</td>
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<td></td>
<td></td>
<td>.607</td>
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<tr>
<td>8 - I get frustrated when I see energy being wasted</td>
<td>.387</td>
<td></td>
<td></td>
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<td></td>
<td>.529</td>
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<tr>
<td>13 - Reducing Network Rail's energy use should be a high priority</td>
<td>.612</td>
<td></td>
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<tr>
<td>14 - I am responsible for the amount of energy I consume at work</td>
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<td></td>
<td></td>
<td>.750</td>
<td>.761</td>
</tr>
<tr>
<td>15 - I am able to influence the amount of energy I consume at work</td>
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<td></td>
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<td></td>
<td></td>
<td>.761</td>
<td></td>
</tr>
<tr>
<td>16 - I intend to discuss energy use more often at work in the future</td>
<td>.313</td>
<td>.463</td>
<td>.306</td>
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<tr>
<td>17 - Saving electricity is easy for my Network Rail department</td>
<td>.394</td>
<td></td>
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<td>.534</td>
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<tr>
<td>18 - I have seen campaigns specifically around saving energy at Network Rail before today</td>
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<td></td>
<td></td>
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<td>.657</td>
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<tr>
<td>19 - Saving electricity is a good way of reducing costs</td>
<td>.698</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>.735</td>
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<tr>
<td>20 - I think that energy saving campaigns work</td>
<td>.384</td>
<td>.333</td>
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<td></td>
<td></td>
<td></td>
<td>.410</td>
</tr>
<tr>
<td>24 - Information I need for my role, on any subject, is easily available for me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.302</td>
<td></td>
<td></td>
<td></td>
<td>.315</td>
<td>.410</td>
</tr>
<tr>
<td>25 - Network Rail easily adopts new technologies in general</td>
<td>.788</td>
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<tr>
<td>26 - Other Network Rail departments are quick to adopt new technologies</td>
<td>.739</td>
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<td></td>
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<tr>
<td>27 - New technologies I have used have generally worked reliably</td>
<td></td>
<td>.304</td>
<td></td>
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<td></td>
<td></td>
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<td>.346</td>
</tr>
<tr>
<td>28 - It takes too long to adapt to new technologies in my Network Rail department</td>
<td>.630</td>
<td></td>
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<tr>
<td>29 - Innovation in general is adequately supported across Network Rail</td>
<td>.640</td>
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<tr>
<td>30 - Learning to use new technologies is frustrating</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>.735</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31 - I look for opportunities to use technologies whenever possible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.541</td>
<td>.325</td>
</tr>
<tr>
<td>32 - In the last year, I have learned how to use a new piece of technology at work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.686</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37 - I understand the changes that the 'Digital Railway' will bring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.427</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38 - I have actively changed any kind of behaviour following a Network Rail campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.311</td>
<td>.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39 - I am able to influence large-scale business decisions in my Network Rail department</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.511</td>
<td>.331</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 - The targets I work toward give me room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.791</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41 - The targets other people have to work towards give them room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.810</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42 - Any working practices take a long time to change at Network Rail</td>
<td>.598</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.650</td>
<td></td>
</tr>
<tr>
<td>43 - My general personal performance is disrupted by conflicts between my different targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.647</td>
<td></td>
</tr>
<tr>
<td>45 - Climate change is discussed more often than is really necessary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.349</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.363</td>
</tr>
<tr>
<td>46 - Network Rail should be working harder to reduce our effects on the environment</td>
<td>.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.560</td>
<td></td>
</tr>
<tr>
<td>47 - I am happy with the way that Network Rail handles environmental issues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.335</td>
<td>.338</td>
</tr>
<tr>
<td>48 - Changing I make to my energy use have a big impact on the world around me</td>
<td>.335</td>
<td>.338</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.522</td>
<td></td>
</tr>
<tr>
<td>49 - I intend to discuss environmental issues more often at work in the future</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.626</td>
<td></td>
</tr>
<tr>
<td>50 - Network Rail could benefit from using small-scale renewable energy (such as solar panels)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.626</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 11 iterations.
### Appendix 4 – Cluster centroids

The highest (green) and lowest (orange) factor means for each cluster are highlighted, as per Table 5 in the main report.

<table>
<thead>
<tr>
<th>Centroids</th>
<th>Cluster</th>
<th>Company supporters</th>
<th>Aware and motivated</th>
<th>Willing to change</th>
<th>Corporate inertia</th>
<th>Low self-efficacy</th>
<th>Status quo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adoption norms</td>
<td>Mean</td>
<td>0.363</td>
<td>0.110</td>
<td>-0.119</td>
<td>-0.323</td>
<td>-0.025</td>
<td>-0.259</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.844</td>
<td>0.935</td>
<td>0.954</td>
<td>1.134</td>
<td>0.967</td>
<td>1.090</td>
</tr>
<tr>
<td>Economic evaluation</td>
<td>Mean</td>
<td>-0.833</td>
<td>0.353</td>
<td>0.644</td>
<td>-0.210</td>
<td>-0.021</td>
<td>0.421</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.842</td>
<td>0.726</td>
<td>0.658</td>
<td>1.094</td>
<td>0.924</td>
<td>0.906</td>
</tr>
<tr>
<td>Goal flexibility</td>
<td>Mean</td>
<td>0.300</td>
<td>0.413</td>
<td>0.291</td>
<td>-1.244</td>
<td>0.066</td>
<td>-0.135</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.635</td>
<td>0.768</td>
<td>0.957</td>
<td>0.926</td>
<td>0.810</td>
<td>1.030</td>
</tr>
<tr>
<td>Energy intentions</td>
<td>Mean</td>
<td>0.243</td>
<td>0.308</td>
<td>0.641</td>
<td>-0.157</td>
<td>-0.287</td>
<td>-1.374</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.728</td>
<td>0.752</td>
<td>0.733</td>
<td>0.959</td>
<td>0.868</td>
<td>1.075</td>
</tr>
<tr>
<td>Energy awareness</td>
<td>Mean</td>
<td>-0.245</td>
<td>0.963</td>
<td>-0.640</td>
<td>0.421</td>
<td>-0.192</td>
<td>-0.557</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.776</td>
<td>0.762</td>
<td>0.929</td>
<td>0.895</td>
<td>0.808</td>
<td>0.803</td>
</tr>
<tr>
<td>Energy self-appraisal</td>
<td>Mean</td>
<td>0.331</td>
<td>-0.019</td>
<td>-0.406</td>
<td>0.125</td>
<td>-0.057</td>
<td>-0.100</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.816</td>
<td>0.858</td>
<td>0.899</td>
<td>0.992</td>
<td>1.125</td>
<td>1.255</td>
</tr>
<tr>
<td>Technology self-appraisal</td>
<td>Mean</td>
<td>-0.440</td>
<td>0.255</td>
<td>0.039</td>
<td>0.364</td>
<td>0.057</td>
<td>-0.267</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.891</td>
<td>0.703</td>
<td>1.035</td>
<td>0.980</td>
<td>1.023</td>
<td>1.224</td>
</tr>
<tr>
<td>Energy self-efficacy</td>
<td>Mean</td>
<td>0.438</td>
<td>0.129</td>
<td>0.265</td>
<td>0.012</td>
<td>-1.331</td>
<td>0.850</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.694</td>
<td>0.639</td>
<td>0.883</td>
<td>0.779</td>
<td>0.700</td>
<td>0.770</td>
</tr>
<tr>
<td>Technological barriers</td>
<td>Mean</td>
<td>-0.029</td>
<td>-0.205</td>
<td>0.493</td>
<td>0.550</td>
<td>-0.180</td>
<td>-0.846</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.783</td>
<td>0.919</td>
<td>0.795</td>
<td>0.983</td>
<td>1.004</td>
<td>1.048</td>
</tr>
<tr>
<td>Environmental norms</td>
<td>Mean</td>
<td>-0.113</td>
<td>0.565</td>
<td>-0.462</td>
<td>-0.335</td>
<td>0.114</td>
<td>0.208</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0.774</td>
<td>0.795</td>
<td>0.891</td>
<td>1.172</td>
<td>1.045</td>
<td>0.995</td>
</tr>
</tbody>
</table>
Energy efficiency behaviour change
A case study of behaviour frameworks at Network Rail

Introduction
Network Rail currently consumes roughly 1% of all electricity in the UK each year, and typically does so at times of peak daily demand. Electricity is also Network Rail’s largest source of greenhouse gases. Energy-efficient technology upgrades need to be supported by behavioural change interventions to meet UK regulatory targets for greenhouse gas emissions, due to the sheer scale of Network Rail’s operations.

The aims of this EngD project are to:
- Establish potential behavioural influences around energy use
- Determine their relative significance using a company-wide survey
- Forecast effects of potential behavioural interventions

This poster presents results from the recently-completed staff survey.

Method
A questionnaire survey was used to test three main theories:
- Theory of Planned Behaviour (Ajzen, 1991)
- Theory of Interpersonal Behaviour (Triandis, 1977)
- Economic barriers proposed by Sorrell et al (2000)

The questionnaire comprised 38 attitude questions, 9 on current behaviours, 3 open-answer fields, and 9 demographic attributes. Each of the attitude questions was mapped to one or more of the above theories, to enable parallel testing.

2 versions of the survey were distributed using the Demographix survey platform. One was addressed to all Network Rail staff. The second was sent to a selection of 746 managers, project managers, engineers and specialists with roles more directly related to electricity consumption. The results presented here are from questions common to both surveys.

The two main behaviours investigated were:
- Curtailment of energy use in general
- Adoption of energy-efficient technologies

Staff attitudes towards the present organisational structure and the environment in general were also addressed, to provide context.

Results
The survey received 874 responses, 582 from the All-Staff survey, 292 from Manager survey, approximately 2,4% of Network Rail’s 38,600 employees.

Results suggested that the Theory of Planned Behaviour (Figure 1) explains more variance in responses, than the Theory of Interpersonal Behaviour (Figure 2), or economic barriers proposed by Sorrell et al. (Figure 3). However, the results explained still only explained a small percentage of the variance in participants’ answers, compared to similar studies (e.g. Grawe et al., 2013). Therefore, other factors could be acting as determinants for employee energy behaviours.

Conclusions
None of the existing behavioural models tested accurately portray energy-saving behaviours at Network Rail.

Future models of organisational energy-saving behaviours should incorporate elements of the Theory of Planned Behaviour, focused around energy use and technology adoption as separate entities.

Cluster analysis identifies groups of employees with varying attitudes towards energy use in an organisational context.

Impact factors
Different groups of employees will require drastically different engagement methods. For example, the “Aware and Motivated” group do not need further information campaigns, but “Company Supporters” may be more receptive. In particular, quick gains can be made by addressing the “Willing to change” group.

Further analysis will identify which areas of the business these different groups reside in, i.e. which departments or geographic areas.

References

APPENDIX 5 – EngD conference poster, 9-10 September 2015 (reduced scale)
Integrating sustainability frameworks within Network Rail’s business practices –

Energy management behaviours in a large infrastructure organisation

Word count (main body): 6,153

Academic Supervisors: Dr Walter Wehrmeyer
Dr Richard Murphy

Industrial Supervisors: Wendi Wheeler*
Andrew Stiles

* Replacing Clive Jones, as of December 2015
Executive Summary

This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant or influential these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3). This period October 2015 – March 2016 has focused on in-depth analysis of the Network Rail Energy Survey, and subsequent production of journal papers.

This work is currently supporting the roll-out of an energy management programme across Network Rail’s geographically-devolved Routes.

Progress towards deliverables

3 academic journal papers are currently in production, based largely on the findings of the Network Rail Energy Survey.

- A qualitative paper, identifying potential drivers and barriers of energy-saving behaviours at Network Rail (also partly based on earlier interviews)
- A psychological paper, looking at the validity of existing behavioural models to the case of energy consumption behaviours at Network Rail
- A policy-oriented paper, investigating the drivers of energy-saving behaviours at Network Rail, and proposing a new behavioural model

The agent-based modelling phase has been redefined as being solely for a thesis chapter, to compensate for this increased focus on analysis of the questionnaire phase.

Analysis summary

Three principal analysis processes have been used to answer the question: “Which barriers have the most significant impacts on adoption of energy management behaviours?”

Principal component analysis of survey questions has identified several antecedent factors behind energy consumption- and technology adoption behaviours. These are:

- Social norms around technology adoption within Network Rail
- Individuals’ economic evaluation of pursuing energy efficiency
• The perceived flexibility of current performance goals to allow energy-efficient practices
• Awareness of energy-efficient options and practices
• The ease with which employees feel they can adopt energy-efficient practices and technologies
• Personal intentions to save energy

Multiple regression path analysis has determined how these factors interact, and which have the greatest influence over energy consumption and technology adoption, particularly personal evaluation of the economics of energy efficiency. A second path analysis has also found that existing general theories of pro-environmental behaviour do not necessarily hold in the case of Network Rail, contradicting existing guidance on embedding energy-efficient practices in other settings.

Finally, cluster analysis has revealed groups of employees with similar characteristics, in terms of the factors described above. The names and characteristics of these groups are presented in the report, as these may change prior to external publication.

These processes have also been used to identify the final design of an agent-based model, around the diffusion of energy-efficient innovations within the organisation. The factors listed above will form the basis for employee ‘agents’, grouped according to the results of the cluster analysis.

**Actions for the next 6 months**

The remaining 6 months of this research programme will focus on:

• Writing the final thesis
• Ensuring publication of at least one paper in a peer-reviewed journal
• Agent-based modelling for a thesis chapter only
• Preparation for presenting findings at the ‘Behave’ energy behaviour conference, University of Coimbra, September 2016.
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Glossary

ABM - Agent-Based Modelling
CES - Centre for Environmental Strategy
J Clean Prod - Journal of Cleaner Production
J Env Psych - Journal of Environmental Psychology
NR - Network Rail
RE - Research Engineer
SEES - Sustainability for Engineering and Energy Systems doctoral research centre
TIB - Theory of Interpersonal Behaviour (Triandis, 1977)
TPB - Theory of Planned Behaviour (Ajzen, 1991)
1. Introduction

This research project asks what the barriers to energy-efficient behaviours are for infrastructure operating companies (research question 1), how significant these barriers are (research question 2), and the implications for future energy use and costs at Network Rail (research question 3).

This progress report reviews all research activities for the period 1 October 2015 – 31 March 2016. Activity has largely been focused on completing analysis of the Network Rail Energy Survey, and subsequent production of journal papers.

This report does not review any further scientific- or industrial literature in detail, as with previous 6-month reports. Literature review activity is now reserved for the eponymous Thesis chapter.

Section 2 provides an overview of progress towards deliverable targets over the last 6-month period, measured against research questions arising from the 24-month dissertation. Short descriptions of the 3 journal papers currently in production are also provided.

Section 3 briefly outlines other academic work in support of the EngD qualification.

Section 4 provides a brief summary of analysis conducted over the last 6-months, discussing some of the iterative processes which led to the material presented by the aforementioned 3 journal papers. Implications for the Agent-Based Modelling (ABM) phase are also discussed.

Section 5 describes actions to be taken over the next 6 months, focusing on the writing of the final thesis, and associated scheduling risks.

Finally, section 6 gives a quick appraisal of overall progress by the researcher, and relates other impacts on the organisation resulting from this research programme.
2. Progress towards deliverables

Activities over this 6-month period have principally consisted of journal paper production, determining parameters to be used for agent-based modelling, and the commencement of the thesis-writing process.

The actions listed here refer to those outlined by the project plan in the previous 6-month report. ‘Additional actions’ are those which were not covered by the original plan, and are relevant to the outcome of this research programme.

2.1. Survey analysis & journal article production

Survey analysis has enabled production of 3 journal articles, which are currently nearing the end of production. Material from these papers will make a substantial contribution to the content of the final Thesis, with minor modifications as necessary. A supplementary description of the iterative steps taken in the production of these papers is given in section 4.

Note that the journal names mentioned here do not necessarily represent the final journal of publication. The papers are referred to by their target journal in other sections of this report.

2.1.1. Energy-saving behaviours in large organisations: Testing existing theoretical models

This paper examines the validity of two existing theories of pro-environmental behaviour in a workplace setting. Both of these theories have been receiving increased attention in recent years, and form the basis of several policy advice documents. The theory of planned behaviour (TPB) is found to be more applicable than the theory of interpersonal behaviour (TIB). However, neither theory fits entirely with observed data from the Network Rail Energy Survey.

This paper is targeted at the Journal of Environmental Psychology (Elsevier), with Environment and Behavior (SAGE publications) as a potential second candidate.
This paper was awaiting final approval from supervisors at the time this report was submitted.

2.1.2. Working title – Individuals’ energy-efficient behaviours in large organisations: A case study of a major UK infrastructure operator

This paper proposes a new model for understanding energy use behaviours in organisations, based on data from the Network Rail Energy Survey. Principal component analysis first identifies factors influencing energy use behaviours. Multiple regression path analysis produces a causal model, determining the antecedents of intentions to save energy, and of self-reported energy-saving behaviours. Finally, cluster analysis identifies key groups of employees with similar behavioural characteristics, and suggests strategies for intervening with each group, with the aim of reducing energy consumption.

This paper is intended for publication in the journal *Energy Policy* (Elsevier). A second/final draft of this is currently in production following a first round of supervisor feedback, in preparation for submission in early April.

2.1.3. Working title: Identifying barriers to energy efficiency in infrastructure operating companies

This paper reviews the semi-structured interviews which formed the majority of Phase I of this research programme, and conducts content analysis of open-answer questions from the Network Rail Energy Survey. The earlier paper submitted to the *Journal of Cleaner Production* (appended to the 30-month report, March 2015) required major revisions before publication, to the point where it was felt that a quantitative element was needed to secure publication.

This paper is currently aimed at the *Journal of Cleaner Production* (Elsevier), but alternatives include *Environment and Behavior*, or the recently-launched *Energy Research & Social Science* (Elsevier). A first draft of this paper is to be submitted for supervisor feedback shortly after the submission of this report.
2.2. **Finalise ABM design & Produce ABM forecasts of energy use**

Agent-Based Modelling has been postponed to the next 6-month period in favour of additional survey analysis and completion of related papers. It has also been decided to pursue the ABM research phase as a thesis-only exercise for two reasons. It is not thought that the development of a technology diffusion model is sufficiently innovative for production of a journal paper. Also, such a model would be difficult to calibrate in terms of the time period represented by the model (discussed below); the model could not be verified through observations within the timescale of this research programme. However, some steps have been made towards determining the structure of the final Netlogo program.

The work carried out for the *Energy Policy* paper has provided a clearer picture of how to define parameters for the agent-based model. The behavioural model and subsidiary factors which will form the basis for ABM parameters are discussed in detail in section 4.

A freely-available technology diffusion model will be used as an architectural basis for development of the energy consumption forecast model. Two main options are under consideration for adaptation:

- A technology diffusion model developed by Peter Bodo, based on duos of consumer options and their race to gain dominance in the marketplace.

This is perhaps the most promising candidate for further modification. In addition to modelling the diffusion of energy-efficient innovations, this could be used to represent competition between multiple performance goals. This model also has the advantage of separate individual, peer, and global pressures (mirroring attitudes, norms and perceived behavioural control) already in place. However, this model allows agents to move freely between one another; something which is not necessarily representative of the staff reporting structure at NR. This was also developed as a method of modelling the diffusion of technology brands in a free marketplace; the existence of regulations, legislation and company standard-setting may require further model adaptation to be representative of the situation at NR.

- An innovation model based on the Bass diffusion framework (see Bass, 2004) developed by Mallory Owen.
This has the advantage of being based on a social network, which could be used to create a hierarchical structure similar to that of NR’s management chart. However, this may prove overly simplistic, as adoption in this model is a one-way process; pressures to ‘revert’ to less energy-efficient practices would need to be incorporated.

The time steps in any such model would be difficult to define; the time taken for a pro-environmental innovation to diffuse through NR is difficult to calibrate, as there are no direct observations available for this phenomenon. However, it may be possible to calibrate based on diffusions in other spheres of NR’s operations, particularly safety. Consultation with safety staff will be arranged to ascertain the diffusion rates of recent initiatives, such as ‘Safety Hour’ (a team meeting structure initiated by central management and diffused to NR’s Routes).

These models, combined with several elements available in Netlogo’s model library will increase the anticipated rate of production for the ABM for this research programme. A further description of the parameters arising from earlier research phases is provided in section 4.4.

2.3. Commence thesis-writing

The final thesis structure has been agreed upon with all parties, and work commenced in March 2016.

The current chapter structure is as follows:

1. Introduction – establishing Network Rail historical context and need to address climate change
2. Literature Review – discussing theoretical background, from economic and behavioural perspectives
3. Methodology – summarising research methods used in chapters 4-7
4. Qualitative paper – semi-structured interviews & open-answer questions (based on J Clean Prod paper)
5. Psychology paper – Comparison of existing behavioural theories (based on J Env Psych paper)
7. Agent-Based Modelling chapter – energy consumption forecasts for NR
8. Synthesis chapter – Discussion & overall conclusions
9. Appendices
At the time this report was submitted, substantial progress had been made with the Introduction, and chapters 4, 5 & 6 by virtue of being written for external publication (see section 2.1).

The need for a methodology chapter is under review, and may be subsumed by methodology sections within proposed chapters 4-7. This is due to the wide range of analysis processes used during this research programme, and the fact that these disparate methodologies will be substantially covered within the journal paper submissions.

### 2.4. Additional actions

The researcher intends to participate at ‘Behave 2016 – 4th European Conference on Behaviour and Energy Efficiency’, taking place at the University of Coimbra, Portugal, on 8-9 September 2016.

An extended abstract is due to be sent to the organisers by 15 April 2016, under the theme of ‘End-use energy efficiency in buildings and organisations’. If accepted, a full paper will be written to accompany this. This abstract was not completed at the time of submitting this report.

Submissions are subsequently invited to be reviewed and re-submitted for a special issue of the journal *Energy Efficiency*. However, this issue’s publication lies beyond the intended completion date of this EngD programme. Observations for this paper may be incorporated into Chapter 6 of the thesis.

### 2.5. Research question progress

Table 12 (overleaf) summarises how the actions discussed above relate to the research questions defined in the 2-year dissertation, and actions to come in the next 6 months.
Questions 1, 1a and 1b

This set of questions has been revisited in recent weeks. It was felt that, due to the significant revisions required for the first J Clean Prod submission, the best solution for improvement was to present this research in parallel with open-answer question data from the NR Energy Survey. This introduces a quantitative element to the research presented, and allows points raised by the interviews to be corroborated from an additional source, increasing the robustness of the findings from both.

Questions 2 and 2a

The majority of this 6-month period has been dedicated to investigating these research questions through multiple regression path analysis, principal components analysis, and cluster analysis of the NR energy survey. The analysis for this phase is mostly complete, with the J Env Psych and Energy Policy papers nearing completion. These analyses are covered in section 4.

Questions 3, 3a and 3b

As mentioned above in section 2.2, the ABM process has postponed in favour of ensuring timely completion of papers relating to research questions 2 & 2a. However, the parameters to be used have been defined, and components of other models with potential for adaptation have also been identified. A fuller description of these parameters, and other implications for the ABM phase is provided in section 4.4.
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1a. What role do individual operational-level managers’ attitudes play in determining energy-efficient technology adoption?</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>1b. What are the potential behavioural barriers to adoption of energy efficient technologies at NR?</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. Which of the identified barriers have the most significant negative impacts on adoption of energy management behaviours?</td>
<td></td>
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</tr>
<tr>
<td>2a. Is the hypothesised gap between energy-efficient attitudes and behaviours supported by empirical observations within NR?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3. What are the predictions for NR’s future electricity use, under different energy behaviour culture change scenarios?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>3a. (Purely technology-oriented scenario) - What is the baseline prediction for energy use without major behavioural interventions?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>3b. (Behaviour culture change scenario) - What are the likely effects of extensive energy behaviour interventions on electricity use?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Course-related work

This section briefly presents work done in support of the EngD programme, not directly related to the main research programme.

A module marks table is available in the previous 6-month report; the average mark has not changed since the previous report (70% overall).

3.1. Communication management & EngD writing retreat

The Communications Management course… Although contact with external media is unlikely over the remainder of this programme, principles learned here have been applied to internal communications work for NR’s Energy Management team. Communications Management did not

Writing skills learnt during this course were applied during a writing retreat, 7-11 March 2016. This event also provided the first dedicated thesis-writing session, producing a draft introduction.

Whilst useful from a personal development perspective, it is unlikely that the principles learnt on this course will be applied to the remainder of this research programme.
4. Survey analysis supplement

This section presents a brief summary on the analysis of the Network Rail Energy Survey conducted over the last six months, in support of research question 2. Further details will be covered within the proposed *J Env Psych* and *Energy Policy* papers discussed in section 2.1.

All analysis processes involved some degree of iteration, not all of which can be presented within the space of a journal article. Therefore, this report also covers a small amount of material which will not appear in the final thesis or journal papers, particularly relating to cluster analysis.

4.1. Proposed theoretical model of organisational energy consumption behaviours

Figure 37 shows the final model of energy consumption and curtailment behaviours arrived at for the *Energy Policy* paper.

This model shows that employees’ individual economic appraisals (‘Economic Evaluation’) of the value of energy efficiency has the strongest relationship with the intention to save energy. The flexibility of performance goals (‘Goal Flexibility’), and employees’ perceived level of influence over the amount of electricity they consume (‘Energy Self-Efficacy’) have weak relationships with intentions. Energy Self-Efficacy also has a weak relationship with self-reported behaviours, although intentions have a stronger relationship with these.
The model accounted for 37.6% of variance in questionnaire responses. This is comparable to the level of variance explained by similar models (i.e. the TPB and TIB) (see Greaves et al, 2013) for pro-environmental behaviours in organisations.

Table 30 lists question items for each of the constructs given in Figure 37, in addition to ‘Technology Adoption Norms’, and ‘Energy Awareness’, which also met acceptance criteria discussed in the Energy Policy paper. Adoption Norms explained the largest level of variance in responses, and met several internal consistency criteria. However, several attempts to incorporate these factors into path analysis models resulted in very low scores for various model fit indices. Reasons for this were not certain at the time of writing this report, but could be due to participants’ cognitive separation of the processes of technology adoption, and curtailing energy use. This would be similar to the separation between pro-environmental- and energy-saving behaviours (Whitmarsh, 2009).

Please note that all factor names are not necessarily the final versions to be presented in papers or the final thesis, and are subject to change following submission of this report.
Table 30 - Question items related to constructs in proposed organisational energy behaviour model

<table>
<thead>
<tr>
<th>Factor</th>
<th>Questionnaire items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology Adoption Norms</strong></td>
<td>Network Rail easily adopts new technologies in general</td>
</tr>
<tr>
<td></td>
<td>Other Network Rail departments are quick to adopt new technologies</td>
</tr>
<tr>
<td></td>
<td>It takes too long to adapt to new technologies in my Network Rail department</td>
</tr>
<tr>
<td></td>
<td>Innovation in general is adequately supported across Network Rail</td>
</tr>
<tr>
<td></td>
<td>Any working practices take a long time to change at Network Rail</td>
</tr>
<tr>
<td><strong>Economic Evaluation</strong></td>
<td>Reducing Network Rail’s energy use should be a high priority</td>
</tr>
<tr>
<td></td>
<td>Saving electricity is a good way of reducing costs</td>
</tr>
<tr>
<td></td>
<td>Network Rail should be working harder to reduce our effects on the environment</td>
</tr>
<tr>
<td></td>
<td>Changes I make to my energy use have a big impact on the world around me</td>
</tr>
<tr>
<td></td>
<td>Network Rail could benefit from using small-scale renewable energy (such as solar panels)</td>
</tr>
<tr>
<td><strong>Goal Flexibility</strong></td>
<td>I am able to influence large-scale business decisions in my Network Rail department</td>
</tr>
<tr>
<td></td>
<td>The targets I work toward give me room to use less energy</td>
</tr>
<tr>
<td></td>
<td>The targets other people have to work towards give them room to use less energy</td>
</tr>
<tr>
<td><strong>Energy Self-Efficacy</strong></td>
<td>I am responsible for the amount of energy I consume at work</td>
</tr>
<tr>
<td></td>
<td>I am able to influence the amount of energy I consume at work</td>
</tr>
<tr>
<td></td>
<td>Saving electricity is easy for my Network Rail department</td>
</tr>
<tr>
<td><strong>Energy Awareness</strong></td>
<td>I have previously taken part in energy-saving activities at Network Rail</td>
</tr>
<tr>
<td></td>
<td>I know who can give me energy to help me save energy</td>
</tr>
<tr>
<td></td>
<td>I have seen campaigns specifically around saving energy at Network Rail before today</td>
</tr>
</tbody>
</table>
### Energy Intentions (4 items)

- I plan to use less electricity at home in future
- I plan to use less electricity at my place of work in future
- I intend to discuss energy use more often at work in future
- I intend to discuss environmental issues more often at work in future

### Behaviour (12 items)

- 3 items – agreement-scale statement questions
  - I have previously taken part in energy saving activities at Network Rail
- 9 items – questions on how frequently participants performed specific energy-saving behaviours
  - In the last year, I have learned how to use a new piece of technology at work
  - I have actively changed any kind of behaviour following a Network Rail campaign

#### 4.2. Alternative cluster analyses

The cluster analysis process outlined in the *Energy Policy* paper was subject to several iterations. The clusters discussed in the previous 6 month report (and presented to the CRR conference in September 2015) did not form the final basis for journal article materials. Those clusters were based on an aggregation of all factors produced from the principal components analysis of the whole dataset. Subsequent internal consistency analysis reduced the number of reliable factors down to the 6 antecedent presented in Table 30, as presented in the *Energy Policy* paper.

Also for the *Energy Policy* paper, participants were narrowed down from the original 874 responses, based on participants’ pay grades (‘Band’). Bands 1-4 were selected (N = 628), as these submitted the largest proportion of responses, and generally represent those in management roles or higher-ranking technical specialists. This produced 5 clusters (compared to the original 6) with markedly different characteristics. Both sets of clusters are presented in Table 31. As with factor names, please note that all cluster names are subject to changes following submission of this report.

For all cluster analyses, cases (i.e. survey responses) were reset to the same order in which they were submitted (i.e. their reference identification number). This was to ensure results were repeatable between analysis sessions, as the 2-step clustering process in SPSS is highly sensitive to initial conditions.
Table 31 - Original (left) and New (right) cluster analyses. Original clusters are based on all 874 respondents and a 10-factor model. New clusters are based on Pay Bands 1-4 and a 6-factor model.

<table>
<thead>
<tr>
<th>Original cluster</th>
<th>Description</th>
<th>New cluster</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Already There’</td>
<td>&quot;I am already good at adopting new technologies and saving energy; I have no intention to change, and don't think we have enough flexibility or tech support to do much more&quot;</td>
<td>‘Efficiency Aware’</td>
<td>I have high awareness of energy efficiency campaigns, and feel that saving energy is relatively easy for me to achieve, but I do not necessarily intend to do so.</td>
</tr>
<tr>
<td>‘Economic Skeptic’</td>
<td>“I am able to make a difference to my energy use, but I’m not convinced of the economics of doing so”</td>
<td>‘Economic Skeptic’</td>
<td>“I neither feel able nor willing to save energy, and cannot see the economic value of doing so.”</td>
</tr>
<tr>
<td>‘Technologically Frustrated’</td>
<td>“I am willing to save energy, and am convinced of the benefits, but there are some technology problems to overcome”</td>
<td>‘Barrier-Sensitive’</td>
<td>I personally intend to save energy, but feel held back by the rate at which the organisation adopts new energy-efficient technology.</td>
</tr>
<tr>
<td>‘Willing to Change’</td>
<td>“I know I’m bad at saving energy currently, but am willing to improve, and think that the company offers support to do so”</td>
<td>‘Conflicting Goals’</td>
<td>I have a very low intention to save energy in future, but feel I am capable of doing so at a personal level, particularly in economic terms.</td>
</tr>
<tr>
<td>‘Low Impact’</td>
<td>“I think the company does enough environmentally already, and although I think saving energy is good economically, I’m not sure I can make a difference”</td>
<td>‘Low Organisational Support’</td>
<td>I feel that the company is a good adopter of new technologies in general, but energy efficiency is not a valuable use of company resources.</td>
</tr>
<tr>
<td>‘Status Quo’</td>
<td>“I (and the company) are already good at saving energy, and I don’t intend to save any more, nor am I able to.”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It is interesting to note that the cluster solution based on all survey participants (N = 874) seemed to reflect different stages of the technology diffusion model (Rogers, 2010). However, the clusters identified for Bands 1-4 (N = 628) are harder to define in terms of any known market segmentation model.

Analysis was also conducted by splitting results along other demographic boundaries, including age group (18-34 and 35+), gender (male and female), and length of experience at Network Rail (0-5 years and 6-15 years). However, these all produced clusters with similar characteristics to those described in Table 31.

Results were also varied by ‘forcing’ set numbers of clusters using the same data. This was repeated for the demographic groups mentioned above. In all cases, the ‘natural’ number of clusters (i.e. the number arrived out without changing any settings in SPSS) reached the most satisfactory solution; larger cluster groupings produced very small groups with unlikely characteristics, or produced slightly nuanced versions of previously-identified clusters with only one defining difference in factor loadings. Therefore these ‘forced’ clusters were rejected in favour of the ‘natural’ number of cluster sets in every case.

4.3. Plan for further analysis

Table 22 provides a summary of progress against analysis processes identified in the 36-month report. These have been focused around answering research question 2 & 2a (see page 419).

The majority of questionnaire analysis processes identified in the previous report have been completed. The main exception is the qualitative content analysis, which was in progress at the time this report was submitted. This is mostly due to the fact that several responses were very specific to the NR setting; several technologies and systems were mentioned which only apply to NR, and additional consultation has been required to ascertain their functions. Nvivo software has sped up the process considerably, but the sheer number of responses has also proved challenging.

Some analysis processes will need to be revisited in the coming months, in order to produce a research paper for the ‘Behave’ conference. This will not affect the analysis already conducted for the Energy Policy and Journal of Environmental Psychology papers.
<table>
<thead>
<tr>
<th>Processes</th>
<th>Completion status</th>
<th>Data subsets to test</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIB and TPB path analysis</td>
<td>Complete</td>
<td>Whole dataset</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete; to revisit for</td>
<td>Demographic subgroups</td>
<td>Ignoring demographics with insignificant differences (e.g. full/part-time)</td>
</tr>
<tr>
<td></td>
<td>‘Behave’ conference paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Cluster analysis groups</td>
<td>Cluster analysis groups re-appraised in the process of writing Energy Policy paper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(e.g. ‘company supporters’, ‘aware and motivated’)</td>
<td></td>
</tr>
<tr>
<td>Dimension-reduction factor analysis</td>
<td>Complete</td>
<td>All agreement-scale questions</td>
<td></td>
</tr>
<tr>
<td>(Principal Component Analysis)</td>
<td>Complete</td>
<td>Whole dataset</td>
<td>To incorporate frequency-scale questions on energy-saving activities</td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Whole dataset with revised question-mapping</td>
<td>Questions re-mapped using feedback from CRR conference (Sept 2015) and supervisor input</td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td>Cluster analysis</td>
<td>Complete</td>
<td>All agreement-scale questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete; to revisit for</td>
<td>Whole dataset</td>
<td>Cluster analysis</td>
</tr>
<tr>
<td></td>
<td>‘Behave’ conference paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Whole dataset with revised question-mapping</td>
<td>Questions re-mapped using feedback from CRR conference (Sept 2015) and supervisor input</td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>Manager / All-Staff surveys separately</td>
<td></td>
</tr>
<tr>
<td>Qualitative content analysis</td>
<td>In progress</td>
<td>Open-answer questions</td>
<td>Analysis in progress at time of report submission</td>
</tr>
<tr>
<td>Path analysis for an alternative behavioural framework</td>
<td>Complete</td>
<td>Whole dataset / other subsets proposed above</td>
<td>Conducted for Energy Policy paper, final draft currently in preparation.</td>
</tr>
</tbody>
</table>
4.4. **Implications for Agent-Based Modelling (ABM)**

As mentioned in previous reports, the ‘agents’ in the proposed ABM will represent Network Rail employees. These will sit within the ‘environment’ of the organisation, and linked with one another based on an approximation of the company’s divisional- and hierarchical structure. The overall framework for this ABM process is provided in **Figure 38**.

![Figure 38 - Modelling framework, based on factor, path, and cluster analysis processes.](image)

The antecedent factors discussed in section 4.1 will be used as parameters for agents. The different weightings of each path (e.g. Economic Evaluation → Intention) are intended to act as multipliers between the factor loadings presented in **Table 33**. These factors are:

- Economic Evaluation
- Goal Flexibility
- Energy Self-Efficacy
- Intention
The Adoption Norms and Energy Awareness constructs may also be incorporated into the model as 'environmental' factors (i.e. one external to the agents, but present as a moderating influence), to reflect their importance as identified by the factor analysis process. An alternative would be to incorporate these as separate multipliers within each agent.

One or more sets of clusters, such as those described in section 4.2 will be used to assign different characteristics to groups of agents. Variations between groups are intended to be based on the observed differences between average factor loadings identified by cluster analysis (see Table 33).

Table 33 - Factor loadings identified by cluster analysis. Taken from the current draft of the Energy Policy paper. Red highlights indicate centroids with a positive difference higher than 0.5, whilst blue highlights indicate negative differences greater than 0.5.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1 Technological Skeptic</th>
<th>2 Efficiency-Aware</th>
<th>3 Barrier-Sensitive</th>
<th>4 Organisational Barriers</th>
<th>5 Economic Skeptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number in cluster</td>
<td>n = 131</td>
<td>n = 165</td>
<td>n = 139</td>
<td>n = 96</td>
<td>n = 97</td>
</tr>
<tr>
<td>Percentage of total sample</td>
<td>20.9%</td>
<td>26.3%</td>
<td>22.1%</td>
<td>15.3%</td>
<td>15.4%</td>
</tr>
<tr>
<td>Adoption norms</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
<tr>
<td>Economic evaluation</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
<tr>
<td>Goal Flexibility</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
<tr>
<td>Energy Intentions</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
<tr>
<td>Energy Awareness</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
<tr>
<td>Energy Self-Efficacy</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
<td>Mean St. Dev.</td>
</tr>
</tbody>
</table>
Figure 39 – Netlogo-based technology diffusion model, developed by Peter Bodo.

Figure 39 provides a screenshot of the technology diffusion Netlogo model, developed by Peter Bodo. The black area on the right represents the environment, in which agents interact with their neighbours. In this case, agents start as white arrows, prior to adopting an innovation, which turns them red or blue, depending on which of two innovations they currently favour. More than one class of initial agent would be needed for the NR model, representing the behavioural clusters discussed earlier in this section.

Agents move around within the environment; this will represent either NR as a whole, or a single department within the organisation. However, as mentioned in section 2.2, this movement may need to be restricted, to represent the company’s management structure.

These agents have a pre-determined ‘taste’ for one of the two innovations. This could be adapted to represent individual attitudes (particularly in the ‘Economic Evaluation’ category) toward energy-efficient behaviours, as determined by the NR Energy Survey.

Agents may switch innovations they have previously adopted due to pressure from peers, or ‘global’ pressures. These aspects of the model can be adapted to represent normative influence (i.e. who else has already adopted an energy-efficient

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6 The Netlogo code for this model is available at [http://ccl.northwestern.edu/netlogo/models/community/Technology%20diffusion%20ABM](http://ccl.northwestern.edu/netlogo/models/community/Technology%20diffusion%20ABM), last accessed 2016-04-01
innovation) for the former, and perceived self-efficacy (i.e. organisational support) for the latter.

Agents purchase products from ‘producers’, represented by two small icons near the middle of the environment. These could be used to represent innovation pilot schemes within the organisation, or alternatively, external suppliers developing new energy-efficient products. In either case, characteristics of a specific innovation or set of innovations will need to be defined. Options for these characteristics currently include:

- Financial cost
- Carbon savings of product
- Regulatory preference for product

In summary, the potential for development of this model is extensive, as most of the factors identified by earlier research phases map onto aspects of Bodo’s diffusion model. Nevertheless, a more diverse array of specifications for agents, the environment, and links between agents are required, to reflect the factors and clusters identified by the NR Energy Survey.
5. Actions, April – September 2016

As anticipated in earlier project plans, the coming 6 months will first focus on analysis, paper-writing, and move towards ABM once these are complete. This period will also see the first steps made towards writing the final thesis. An updated research timeline is laid out on a pull-out page at the end of this section (see Figure 40, page 435).

5.1. Research plan actions

5.1.1. Complete journal papers

Completion of the three journal papers outlined in section 2.1 is currently the top priority. The submission order will be as follows:

1. *Journal of Environmental Psychology*
2. *Energy Policy*
3. *Journal of Cleaner Production*

No explicit deadlines have been set, but submission of all papers is intended to take place by the end of May 2016 at the very latest.

5.1.2. Conduct agent-based modelling

This is currently intended to take place from May 2016 onwards (see Figure 40, page 435). The ‘review with supervisors’ stage is extended to allow flexibility for production of this model alongside other work, notably the thesis literature review. This will form the last main thesis chapter, prior to the final synthesis chapter.

The end product of this will be a model of the effects of energy-efficient technology diffusion on energy consumption within NR. As discussed in section 4.4, this is likely to be an investigation of the effects of diffusion of a single innovation or technology, rather than a generalised model of all technologies and behaviours across the organisation.
As with the research papers, the deadline for this process is currently flexible, subject to further discussion with supervisors.

5.1.3. Write thesis

Thesis-writing commenced in March 2016, and will continue over the remaining months of this research programme. The chapters which will constitute this thesis have been described in section 2.3. So far, a draft Introduction chapter has been produced, but each chapter will require at least the following:
- 1st draft
- Supervisor feedback
- Main draft
- Supervisor feedback
- Final write-up

The whole thesis will then require formatting, proof-reading, and final cross-referencing checks.

An outline schedule for this process is provided in the research timeline (page 435), but is subject to further discussion and detailed planning with supervisors.

5.2. Conferences

The researcher intends to participate at ‘Behave 2016 – 4th European Conference on Behaviour and Energy Efficiency’, taking place at the University of Coimbra, Portugal, on 8-9 September 2016.

An extended abstract is due to be sent to the organisers by 15 April 2016, under the theme of ‘End-use energy efficiency in buildings and organisations’. If accepted, a full paper will then be written, with a deadline on 3 June 2016. This abstract was in production at the time this report was written.

Submissions are also invited for review and re-submission for a special issue of the journal Energy Efficiency. However, this issue’s publication lies beyond the intended completion date of this EngD programme. Observations for this paper may be incorporated into Chapter 6 of the thesis.
5.3. Risks

Table 34 provides an updated risk register, based on those discussed in the previous report.

The most substantial timetable shifts are likely to arise from requirements for corrections to journal articles following review. Some flexibility has been built into the research timeline for the next 6 months to account for this. The format of each paper has been closely matched to that of other papers in the respective target journals (particularly the *J Env Psych* paper).

The repurposing of the ABM phase as a thesis-only exercise has also allowed for greater flexibility in the research timetable. This removes one external review stage which would otherwise delay completion of the thesis chapter.

Table 34 - Risk register

<table>
<thead>
<tr>
<th>Risk</th>
<th>Events in last 6 months</th>
<th>Severity</th>
<th>Likelihood</th>
<th>Overall</th>
<th>Changes / mitigation steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirement to redraft journal articles</td>
<td>3 papers being submitted in parallel</td>
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<td>High</td>
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<td>Maintain flexibility in writing schedule to allow for paper rewrites. Ensure initial paper drafts follow recommended format of target journal.</td>
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<td>Use externally-developed model as a framework for model architecture. Write up ABM process as a thesis chapter only.</td>
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<td>Register of analysis processes enabled has aided version control and provided tracking of analysis processes necessary for different papers.</td>
<td>Low</td>
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<td>Low</td>
<td>Maintain analysis process register during ABM, and production of Behave conference paper.</td>
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## Research timeline

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**Figure 40 – Research timeline.**

- Green shades - Intended programme (colours alternate for clarity)
- Pale green - Allowances for overrun / additional activity
- Orange - Known activity, approximate date
- Red - Intended key delivery dates
- Grey - Known leave dates

| 1 | EngD conference, University of Surrey |
| 2 | BEHAVE conference, University of Coimbra, Portugal |
6. Concluding remarks

The re-prioritisation of writing journal articles over agent-based modelling reflects the requirement to publish a peer-reviewed journal article. However, the agent-based modelling process is likely to be much simpler than originally anticipated, thanks to the availability of externally-developed models. It is unlikely that a peer-reviewed article on agent-based modelling will be produced within the timescale of this EngD programme. However, this process is likely to provide useful insights for the Thesis, and for internal use by NR.

This research project has provided justification for a series of energy engagement workshops within NR’s regional ‘Route’ subdivisions. These took place in the latter half of 2015, with support from the researcher. A series of company intranet communications have also been developed with the assistance of the researcher.

A secondary impact of this research programme has been increased interest in social research methods in other Network Rail business units. The researcher has been involved in the development of a further questionnaire survey on the topic of ‘Safety by Design’ (i.e. ensuring engineering projects are safe for all stakeholders, including those involved in construction). This has drawn on survey design recommendations (Francis et al, 2004) for the Theory of Planned Behaviour (Ajzen, 1991) in a similar manner to the NR Energy Survey, with 36 question items mapped to constructs from the TPB and Safety by Design principles defined by Gambatese et al (2005) shown in Figure 41.
Figure 41 - Design for safety concept, after Gambatese et al, 2005.

The ‘critical path’ for the research programme now rests on the acceptance of the academic journal papers described in section 2.1. Overall completion of the research programme is currently estimated to be on schedule for the end of September, with sufficient flexibility in the proposed timetable to ensure this is achieved.

As a concluding note, the researcher wishes to thank all involved with supervising this research programme over the years, from both the industrial and academic spheres. Network Rail has seen some major changes over the years, and their help has been invaluable to ensure that this programme has achieved both scientific- and organisational aims, whilst raising awareness around the issue of energy consumption and raising the profile of social science as an organisational tool.

WORD COUNT (Main body, pages 6-31):
6,153


References


ATTITUDES TOWARDS ENERGY EFFICIENCY – A COMPARISON OF ENERGY MANAGEMENT SPECIALISTS AND OTHER EMPLOYEES

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Keywords: Instructions, Energy efficiency, Behaviour, Coimbra

Abstract

Studies of attitudes to energy efficiency in organisations have tended to focus on economic barriers, rather than drawing on the large body of research into individuals’ energy behaviours in domestic settings. This paper presents a case study of the differences in attitudes between energy specialists and the rest of the staff population in a large infrastructure management organisation in the UK. A principal components analysis of data from two surveys identifies five main antecedent factors driving employee attitudes towards energy efficiency. Cluster analysis based on these factors is then conducted, classifying six groups with different attitudes towards energy efficiency in the workplace. The differences between energy-specialist staff and the general employee population have a higher ratio than differences observed for other demographic characteristics. Age, gender, pay grade, having directly reporting staff and years of experience also introduce significant, but less pronounced variations. The results point to a need for the resolution of conflicts between energy efficiency goals and other performance pressures, particularly the need for explicit consumption reduction targets, to encourage energy-efficient behaviour.
1. INTRODUCTION
Railways consume 1% of all electricity generated in the UK [1]. The morning and evening peak travel periods coincide with daily peaks in energy consumption [2]. The UK’s operator of main line railway infrastructure is under regulatory pressure to reduce greenhouse gas emissions 11% between 2014-2019 [3]. The organisation under observation has internally recognised that employee behaviour change can contribute; attitudes, contextual norms, and perceptions of organisational support of its employees need to be understood, to formulate effective intervention strategies. However, no formal energy consumption reduction targets had been set at the time of this study, and these were not part of the suite of performance measures used to assess employee performance.

Economics-based research has investigated the ‘energy-efficiency paradox’, or the low adoption rates of energy efficiency measures despite their financial and environmental benefits [4-6]. Under this paradigm, the energy-efficiency paradox is commonly treated as having arisen from a series of discrete barriers originating from sources primarily related to information provision or financial benefit (e.g. [7, 8]). However, more recent research has pointed out that behavioural barriers are likely to play a larger part [9, 10], highlighting a need to re-examine organisational energy consumption in light of individuals’ behavioural preferences.

Meanwhile, in the fields of sociology and psychology, the ‘attitude-behaviour gap’ or ‘value-action gap’ has been identified as a factor explaining weak pro-environmental behaviour individually (e.g. [11-13]). Other sociological and psychological studies in organisational examine the gap using models of interacting attitudes, norms, and other social factors at the individual level (e.g. [14]). This wealth of behavioural research suggests that factors other than economic barriers or a shortage of information provision may be driving the shortfall in energy-efficient technology adoption across various industries.

Previous papers on energy-related behaviours in organisations have tended to focus on offices (e.g. [15, 16]) or a limited number of buildings (e.g. [17]). Others have compared high-level comparisons of energy management styles across whole sectors (e.g. [5]), often with only one respondent per surveyed company (e.g. [18]). Wide-reaching case studies within single large organisations are rare.

Observations of differences in attitudes and behaviours between managers with explicit energy-related responsibilities, and the general employee population are, oddly, hard to find. Wehrmeyer & McNeil [19] identify that employees’ attitudes to environmental issues are not homogeneous, but can be classified according to spectra of eco- vs. techno-centrism, and preference for centralisation vs. individualism.

This paper sets out to test whether different suites of antecedent factors govern the intentions and behaviours of energy-related management staff, and a general employee population, in terms of approaches to energy efficiency in the workplace. This paper also sets out to test whether similar attitudinal groupings of employees can be identified, with an eye toward developing pro-energy-efficiency behavioural intervention strategies.

2. METHOD
This paper takes a two-stage approach to determining differences between energy management specialists and the general employee population regarding attitudes, norms and self-efficacy towards energy use and efficiency.

Firstly, a principal components analysis (PCA) was applied to responses to a questionnaire survey to both types of employees of a major railway infrastructure operator in the UK, framed around the topic of “Energy: What do you think?”
Secondly, factors identified by the PCA were subjected to two-step cluster analysis, to identify subsets of employees with similar attitudes towards energy efficiency, and thereby compare energy specialists and non-specialists based on their membership of these groups. This two-part methodology has previously been applied in several settings to examine determinants of pro-environmental behaviours (e.g. [20-22]). All analysis was conducted using IBM SPSS version 22.

2.1. Survey design and distribution

Survey questions were designed to map to three main inputs: an earlier series of semi-structured interviews with asset managers at the organisation in question, the Theory of Interpersonal Behaviour [23], and the Theory of Planned Behaviour [24]. A full description of the survey questions can be found in Table 3 at the end of this paper. The Demographix® platform was used to distribute the survey, as this allowed organisational branding to be applied to the survey forms. This was intended to encourage participation, as interviewees thought that external surveys were likely to be ignored. Questions were arranged into three main groups when presented online, themed around ‘Energy’, ‘Technology’, and ‘Working Environment’ (which included questions about organisational pressures and environmental impacts).

Two slightly different versions of the survey were distributed. The first was sent to 743 energy-related management, engineering, and specialist staff via two emails (1 invitation and 1 reminder). Participants were identified using organisation charts with the management group recruited from the following sections: the organisation’s energy management department, asset managers responsible for electrical equipment and plant, managers of projects associated with electrical equipment or railway electrification, environmental specialists, and engineers with electrical or electronic competencies. This is referred to throughout as the ‘Manager’ survey.

The second survey was a shortened version of the Manager survey, made available to the rest of the organisation’s approximately 36,000 employees and promoted via two articles on their intranet news service. This survey removed questions relating to energy management-specific topics, thought not to be within the knowledge of the general employee population.

Agreement-scale question responses were scored on a 5-point Likert scale ranging from ‘Strongly Disagree’ (value 1) to ‘Strongly Agree’ (value 5). 50 such questions were presented in the Manager survey, and 38 in the All-Staff survey. The comparison between the two groups is based on the same questions in either survey.

2.2. Principal Component Analysis (PCA)

Rotated PCA was carried out on the 38 questions common to both the Manager and All-Staff surveys. It should be noted that Principal Axis Factoring is an alternative method of performing this process, although the difference is primarily in the underlying mathematics and generally considered a minor difference. For most projects, PCA and Principal Axis Factoring yield very similar results, as it did here. However, the interpretation of the results, using different matrix rotations in PCA, was found to be somewhat easier.

Items with factor loadings greater than 0.4 were considered when determining that factor’s qualitative characteristics; the phrasings of the corresponding questions were used to interpret the meaning of each factor respectively. Other papers have used 0.5 as a minimum for this purpose (e.g. [19]). These newly-identified factors were then tested for internal consistency using Cronbach’s Alpha tests. Factors scoring higher than 0.6 (as recommended by [25]) on this scale were selected for inclusion in the cluster analysis process. Selection for this
process also required a minimum of 3 item factor loadings of 0.45 or greater (similar to [21]), although in practice this was superseded by the Alpha scores. This process was repeated for the two surveys separately, and on random subsets of the data to ensure that these factors were not erroneously influenced by one small part of the survey population.

2.3. Cluster Analysis
SPSS’ two-step cluster analysis process was applied to the selected factors, with the aim of identifying groups who can be engaged in energy-saving interventions in different ways. Cases (i.e. questionnaire results from different participants) were sorted by source (i.e. the version of the questionnaire) and then by the order in which they were received by the system, to ensure repeatability of results. This process was repeated for the two survey datasets separately, and then with randomised ordering of cases to ensure that the clusters generated were not artefacts of the order in which forms were received. The validity of the cluster sets were also checked using the silhouette measure of cohesion and separation provided in SPSS.

3. RESULTS
Firstly the characteristics of the questionnaire samples are presented. Secondly, a description of the PCA process is provided, focusing on an interpretation of the resulting factors. Finally, the results of the cluster analysis process are presented, discussing how the distribution of these differed across the two surveys.

3.1. Survey distribution and sample characteristics
The Manager survey (i.e. the energy specialist sample) received 292 fully-completed forms whilst the All-Staff survey returned 582 completed forms, for a total sample size of N = 874. The All-Staff survey largely received responses from staff in similar pay grades to those targeted by the Manager survey, despite not being directly targeted at that particular group. This may have been due to the online distribution method chosen being favoured by that group. We can therefore say that this data is more representative of staff in mid-level managerial, administrative, engineering or specialist roles, rather than ‘frontline’ employees involved with maintenance or day-to-day operations or all employees in the organisation per se.

In terms of other demographics, females represented 18.6% of responses (compared to approximately 15% of the organisation’s population). The organisation’s Operations division was markedly under-represented (43.6% compared to 70.7% for the whole organisation), whilst the Projects, Strategy, and Health & Safety departments were somewhat over-represented. Beyond that, responses were broadly representative of the organisation as a whole in terms of age group, geographical location, and the number of years worked within the firm.

3.2. PCA
Table 1 presents the results of the PCA process for the whole dataset. 10 factors were identified, the interpretation of which is described below. Together, these factors explained 54.7% of variance across responses. This level of explained variance is similar to other studies of this type for pro-environmental behaviours in other settings [19, 22, 26]. PCAs of the population subsets tested produced broadly similar results, with small variations in factor loadings.

The first 5 factors, recurring across all data subsets tested consistently met the selection
criteria outlined in section 2.2, explaining 32.1% of variance in responses between them.

‘Adoption Norms’ describes participants’ perceptions of how easily the organisation adopts new innovations and working practices.

‘Economic Evaluation’ is a measure of individuals’ attitudes towards the level of prioritisation energy efficiency should receive, in terms of financial costs and benefits to the environment.

‘Goal Flexibility’ describes individuals’ perceived ability to fit energy efficiency goals around other performance targets, and the level of influence they can exert over large-scale business decisions.

‘Energy Intentions’ describes personal intentions to curtail energy consumption, and discuss energy efficiency and environmental issues more often in future.

‘Energy Awareness’ focuses on participants’ awareness of previous energy-saving efforts within the organisation, and knowledge of how they can access information on the subject.

‘Energy Self-Appraisal’ represents individuals’ appraisal of their own day-to-day energy consumption, and their emotional response to the subject.

‘Technology Self-Appraisal’ represents individuals’ appraisal of how easily they personally adopt new technologies, and their receptiveness to behavioural intervention campaigns on this subject.

‘Energy Self-Efficacy’ describes how responsible people feel for their own energy consumption within the organisation, both individually and as part of an organisational department.

‘Technology Barriers’ links responses to two questions: the level of frustration experienced when using new technologies, and the level of disruption to work caused by conflicts between performance goals, implying that the deployment process can prove frustrating to individuals.

‘Environmental Norms’ links personal satisfaction with the way that the organisation handles environmental issues, with the general availability of information across the organisation.

3.3. Cluster analysis

6 clusters were generated, the characteristics of which are summarised in Table 2. The Low Organisational Support cluster is defined by a general willingness to save energy and the perceived flexibility of doing so within current performance goals, but a perception that the organisation is slow to adopt new technologies and does not generally pursue energy-saving campaigns.

The Economic Sceptic group is characterised by average scores across most factors, except for a very low Economic Evaluation score, suggesting that the financial value of energy savings are most important to this group.

In contrast, those defined as having Conflicting Goals had high Economic Evaluation scores, but very low Goal Flexibility, indicating that a personal preference for pursuing energy efficiency is perceived as being obstructed by (or at least contradictory to) current organisational performance goals in other areas. This represented the largest single group of employees, at 24.7% of the sample.

Personally Motivated employees are optimistic ‘champions’ who perceive no particular barriers to personally pursuing energy efficiency, and are particularly confident that the organisation is already very good at adopting energy-efficiency measures and innovations in general.

The Low Technology Support group were acutely aware of previous organisation-led
efforts to save energy, and scored highly for Economic Evaluation, Goal Flexibility and Energy Intentions, but had low Adoption Norms scores, implying a perceived norm that other parts of the organisation would not support energy efficiency improvements. Employees with Low Personal Priority had a moderately high score for Goal Flexibility, but a very low score for Energy Intentions. This could be indicative of a general personal indifference towards reduce energy consumption, despite having the flexibility to do so.

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<td>.686</td>
<td>.522</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>37</td>
<td>.427</td>
<td>.372</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>.549</td>
<td>.514</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Self-Efficacy</td>
<td>14</td>
<td>.750</td>
<td>.649</td>
<td>.597</td>
<td>4.51</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>.761</td>
<td>.672</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>.534</td>
<td>.581</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology Barriers</td>
<td>30</td>
<td>.735</td>
<td>.609</td>
<td>.365</td>
<td>4.37</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>43</td>
<td>.650</td>
<td>.555</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Norms</td>
<td>24</td>
<td>.410</td>
<td>.495</td>
<td>.384</td>
<td>4.13</td>
<td>54.7</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>.647</td>
<td>.586</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>.560</td>
<td>.493</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 – Factors generated by the PCA process
Table 2 – Clusters, as defined by PCA-generated factors. Numbers indicate differences from mean centroid value.

<table>
<thead>
<tr>
<th>Clusters - differences from mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Organisational Support</td>
<td>-0.663</td>
<td>-0.217</td>
<td>-0.166</td>
<td>1.197</td>
<td>-0.590</td>
<td>-0.100</td>
<td></td>
</tr>
<tr>
<td>Economic Sceptic</td>
<td>0.444</td>
<td>-1.565</td>
<td>0.413</td>
<td>0.071</td>
<td>0.309</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td>Conflicting Goals</td>
<td>0.557</td>
<td>0.191</td>
<td>-1.061</td>
<td>0.219</td>
<td>0.478</td>
<td>0.400</td>
<td></td>
</tr>
<tr>
<td>Personally Motivated</td>
<td>0.735</td>
<td>0.176</td>
<td>0.039</td>
<td>0.306</td>
<td>0.282</td>
<td>-1.589</td>
<td></td>
</tr>
<tr>
<td>Low Technology Support</td>
<td>-1.196</td>
<td>-0.036</td>
<td>-0.103</td>
<td>-0.044</td>
<td>1.286</td>
<td>-0.061</td>
<td></td>
</tr>
<tr>
<td>Low Personal Priority</td>
<td>N</td>
<td>100</td>
<td>128</td>
<td>216</td>
<td>181</td>
<td>126</td>
<td>123</td>
</tr>
<tr>
<td>% of sample</td>
<td>11.4%</td>
<td>14.6%</td>
<td>24.7%</td>
<td>20.7%</td>
<td>14.4%</td>
<td>14.1%</td>
<td>100%</td>
</tr>
</tbody>
</table>

3.4. Relating clusters to demographics

This paper has noted where differences in cluster membership exceeded 5%, expressed as a proportion of the total sample population size. Cluster membership was significantly related to whether the respondent was an energy specialist or a general employee (p < 0.001). Energy specialists were more prevalent among the Economic Sceptic (11%) and Low Technology Support (11%) clusters. Meanwhile, the general staff population were far more likely to belong to the Conflicting Goals cluster (14%), whilst being only slightly more prevalent than specialists in the other clusters (2-4%)

In terms of other demographic characteristics, membership of clusters was significantly related to gender, age, pay grade, years of experience in the organisation, and whether the respondent had any direct reports (i.e. subordinate staff). Geographical location and organisational department did not exhibit statistically significant relationships.

Cluster membership did not vary greatly between genders. Females were slightly more prevalent in the Personally Motivated (5%) and Low Personal Priority (6%) groups, whilst males were very slightly more prevalent across all other clusters.

Cluster membership also did not vary greatly across age groups. Younger employees (18-34 years old) were slightly more prevalent in the Low Organisational Support cluster (6%), whilst older (35+) staff were slightly more likely to perceive Low Technology Support (8%). Differences in attitudes between pay grades were more pronounced. Higher pay grades (the top 3 tiers) were somewhat more likely to belong to the Economic Sceptic (12%) and Low Technology Support (10%) groups. Lower pay grades were more likely to be Personally Motivated (10%) whilst experiencing more Conflicting Goals (7%) and Low Organisational Support (5%).

Staff with more than five years of experience at the organisation were slightly more prevalent in the Low Technology Support cluster (7%), whilst those with less than five years’ experience were more common in the Low Organisational Support (6%) and Personally Motivated (5%) groups.

Employees with direct reports were more common among the Economic Sceptic (6%) and Low Technology Support (13%) clusters, whilst those without subordinates were more prevalent among the Conflicting Goals (9%) and Personally Motivated (8%) groups. This reflects the differences observed between energy specialists and non-specialists.
4. DISCUSSION

Firstly, the implications of the newly generated factors are discussed, in terms of their relationship with existing theories of pro-environmental behaviour. Secondly, these clusters are summarised in terms of their demographic characteristics, highlighting the strong differences between energy specialists and the general employee sample. Finally, the implications of the identified clusters are discussed, in terms of employee engagement techniques for reducing energy consumption in infrastructure operators or other large organisations.

4.1. Relationship with other behavioural theories

None of the identified factors directly matched the construct mapping of the Theories of Planned [23] or Interpersonal [24] Behaviour used when designing the survey, with the exception of ‘Energy Intentions’. Our results therefore suggest that neither of these theories are directly supported as frameworks for understanding energy behaviours in organisations. However, the factors generated by the PCA process suggest a few similarities with Ajzen’s theory, focusing on specific workplace practices for each of that theory’s constructs. Attitudes are reflected in ‘Economic Evaluation’, Subjective Norms in (technology) ‘Adoption Norms’, and Perceived Behavioural Control bears some similarity to ‘Goal Flexibility’. This highlights that existing theories of individual consumer behaviour may be applicable, and therefore engagement strategies designed for consumers may also have positive effects on organisational energy efficiency. However, further research is needed to ascertain the level of influence that Ajzen’s factors have over decisions in organisational settings (building on [14]).

4.2. Differences between energy specialists and employees in general

The largest observed statistically-significant variations in cluster membership across demographic groups were between those of the Manager and All-Staff samples. This suggests that the attitudes of energy specialists regarding energy use behaviours do not reflect those of the wider employee population. This raises the possibility that cross-sector surveys of barriers to organisational energy efficiency, often answered by energy specialists within the companies to which they are distributed, may not accurately reflect the attitudes of the majority of staff in these organisations.

The higher proportion of energy specialists in the Economic Sceptic cluster highlights a possible behavioural source for the energy efficiency paradox. This, combined with a perceived low level of efficient technology implementation, could represent a general pessimism toward the rate of progress in terms of reducing the firm’s energy consumption, as a result of trying to obtain capital for energy efficiency improvement projects. Meanwhile, energy specialists also appear to underestimate the perceived importance placed on meeting other performance goals by other employees. In our case study, the presence of a non-binding goal (in terms of staff performance measurement) aimed at reducing greenhouse gas emissions was not sufficient to drive employee behaviour change toward reducing energy consumption. This indicates that a clearer performance goal aimed at reducing energy consumption may be required, to improve the visibility of energy consumption as an issue on equal footing with other financial or regulatory targets.

4.3. Implications for employee engagement strategies

The comparatively large size of the Conflicting Goals group corroborates earlier research suggesting that performance goals are a major concern for many employees, when
attempting to implement what many perceive as nebulous, secondary aims around energy efficiency [27]. These findings also corroborate the economically-oriented research suggesting that perceptions of the economic value and technological feasibility of energy efficiency need to be the key topics of employee engagement to achieve energy-efficient behaviours in the workplace [8, 28]. Clearer presentation of energy consumption information alongside other performance-related or regulatory targets is could help achieve this; in our case study, daily performance against other targets was displayed electronically throughout their facilities, suggesting this would be fairly easy to deploy.

The fact that the Personally Motivated group is common among younger, less-experienced employees is encouraging for driving future reductions in electricity consumption. This suggests that junior staff may be more willing to initiate projects aimed at saving energy, and that gentle awareness-raising campaigns within organisations would probably be most effective if targeted at this group. This is countered to an extent by the even spread of the Low Personal Priority cluster across all demographics; it is not clear whether this group have a low intention to save further energy because they feel they have already done all that they can, or that they simply are not interested, suggesting a topic for further research.

It should be noted, however, that no single demographic category was dominated outright by any single identified cluster. A similar survey to that presented here could assist managers with selecting a more personalised approach to encouraging energy savings in localised teams, rather than relying on assumptions based on demographic characteristics.

5. CONCLUSIONS

The factors presented in this paper suggest that encouraging energy-efficient behaviours in organisations should take a different approach to methods recommended for domestic, individual or consumer contexts. Cluster analysis has identified six key groups to consider when organisations develop their own internal energy engagement strategies. The attitudes of energy specialists are observed to differ significantly from those of the wider employee population, suggesting that questionnaire responses in cross-industry surveys do not necessarily accurately represent the attitudes of individuals in the companies they represent.

Two suggestions for future research arise. A similar questionnaire could be used to determine whether the same antecedent factors or attitude categorisation clusters arise in other organisations. Alternatively, a new survey could be designed and distributed to test the new factors generated by the PCA specifically, rather than have them emerge from a survey designed to test other behavioural frameworks, as presented here. This could apply structural equation modelling to test how these factors determine energy consumption behaviours, as has frequently been done for other theories of pro-environmental behaviour in other settings [14, 29].

None of the observations presented here detract from the overall need to address energy efficiency behaviours in organisational settings. The findings presented here offer an opportunity for large organisations to tailor their energy use engagement strategies, and highlight the need for energy specialists to promote and deploy clear energy performance goals across their respective firms.

Research for this paper was conducted as part of an EngD in Sustainability for Engineering and Energy Systems with the University of Surrey, with the support of Network Rail and the Engineering & Physical Sciences Research Council (EPSRC).
Table 3 – Questionnaire items from the two surveys. Items in grey were included only in the Manager survey, and are not analysed by this paper, but are provided here for transparency.

<table>
<thead>
<tr>
<th>No.</th>
<th>Question phrasing</th>
<th>No.</th>
<th>Question phrasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I don’t think about energy use very often</td>
<td>26</td>
<td>Other [organisation] departments are quick to adopt new technologies</td>
</tr>
<tr>
<td>2</td>
<td>I think of myself as being careful with energy use</td>
<td>27</td>
<td>New technologies I have used have generally worked reliably</td>
</tr>
<tr>
<td>3</td>
<td>I have previously taken part in energy-saving activities at [the organisation]</td>
<td>28</td>
<td>It takes too long to adapt to new technologies in my [organisation] department</td>
</tr>
<tr>
<td>4</td>
<td>I tend to leave equipment switched on</td>
<td>29</td>
<td>Innovation in general is adequately supported across [the organisation]</td>
</tr>
<tr>
<td>5</td>
<td>I plan to use less electricity at home in future</td>
<td>30</td>
<td>Learning to use new technologies is frustrating</td>
</tr>
<tr>
<td>6</td>
<td>I plan to use less electricity in my place of work in future</td>
<td>31</td>
<td>I look for opportunities to use technologies whenever possible</td>
</tr>
<tr>
<td>7</td>
<td>I know who can give me information to help me save energy</td>
<td>32</td>
<td>In the last year, I have learned how to use a new piece of technology at work</td>
</tr>
<tr>
<td>8</td>
<td>I get frustrated when I see energy being wasted</td>
<td>33</td>
<td>Saving energy use by improving track equipment is easy for [the organisation]</td>
</tr>
<tr>
<td>9</td>
<td>I think that [a geographically-devolved] management structure has been beneficial to how energy is managed at [the organisation]</td>
<td>34</td>
<td>New technologies tend to have beneficial impacts on safety</td>
</tr>
<tr>
<td>10</td>
<td>[External stakeholders] have a positive influence on [the organisation’s] energy efficiency</td>
<td>35</td>
<td>It is easier to reduce energy use by [trains], than to reduce energy use by infrastructure</td>
</tr>
<tr>
<td>11</td>
<td>[The organisation’s] energy data collection is highly detailed</td>
<td>36</td>
<td>It is [the organisation’s] responsibility to reduce traction energy use</td>
</tr>
<tr>
<td>12</td>
<td>New energy-efficient technologies have generally worked reliably</td>
<td>37</td>
<td>I understand the changes that [a particular upgrade programme] will bring</td>
</tr>
<tr>
<td>13</td>
<td>Reducing [the organisation’s] energy use should be a high priority</td>
<td>38</td>
<td>I have actively changed any kind of behaviour following a [organisation] campaign</td>
</tr>
<tr>
<td>14</td>
<td>I am responsible for the amount of energy I consume at work</td>
<td>39</td>
<td>I am able to influence large-scale business decisions in my [organisation] department</td>
</tr>
<tr>
<td>15</td>
<td>I am able to influence the amount of energy I consume at work</td>
<td>40</td>
<td>The targets I work toward give me room to use less energy</td>
</tr>
<tr>
<td>16</td>
<td>I intend to discuss energy use more often at work in the future</td>
<td>41</td>
<td>The targets other people have to work towards give them room to use less energy</td>
</tr>
<tr>
<td>17</td>
<td>Saving electricity is easy for my [organisation] department</td>
<td>42</td>
<td>Any working practices take a long time to change at [the organisation]</td>
</tr>
<tr>
<td>18</td>
<td>I have seen campaigns specifically around saving energy at [the organisation] before today</td>
<td>43</td>
<td>My general personal performance is disrupted by conflicts between my different targets</td>
</tr>
<tr>
<td>19</td>
<td>Saving electricity is a good way of reducing costs</td>
<td>44</td>
<td>[The organisation] receives the largest share of benefits from investment in the railway, compared to other companies</td>
</tr>
<tr>
<td>20</td>
<td>I think that energy saving campaigns work</td>
<td>45</td>
<td>Climate change is discussed more often than is really necessary</td>
</tr>
<tr>
<td>21</td>
<td>Improving [the organisation’s] energy efficiency would reduce risks to energy supply</td>
<td>46</td>
<td>[The organisation] should be working harder to reduce our effects on the environment</td>
</tr>
<tr>
<td>22</td>
<td>There is sufficient expert assistance for [geographically-devolved regions] to manage their own energy use</td>
<td>47</td>
<td>I am happy with the way that [the organisation] handles environmental issues</td>
</tr>
<tr>
<td>23</td>
<td>There is sufficient manpower to improve energy efficiency</td>
<td>48</td>
<td>Changes I make to my energy use have a big impact on the world around me</td>
</tr>
<tr>
<td>24</td>
<td>Information I need for my role, on any subject, is easily available for me</td>
<td>49</td>
<td>I intend to discuss environmental issues more often at work in the future</td>
</tr>
<tr>
<td>25</td>
<td>[The organisation] easily adopts new technologies in general</td>
<td>50</td>
<td>[The organisation] could benefit from using small-scale renewable energy (such as solar panels)</td>
</tr>
</tbody>
</table>
REFERENCES


The energy efficiency behaviour of individuals in large organisations: A case study of a major UK infrastructure operator

Highlights

- Individuals’ attitudes to energy use are observed in a rail infrastructure operator.
- Principal components analysis identified 10 antecedent factors driving behaviour.
- Cluster analysis identified 5 groups of staff with similar characteristics.
- A new framework for understanding energy behaviours is proposed.
- Employee engagement on energy issues should take a market segmentation approach.

Abstract

Energy consumption behaviours are gradually becoming better-understood. However, there is still a deficit in terms of knowledge of individuals’ energy-use behaviours in organisations, despite a variety of available theories. This paper addresses this need in three main stages, based on a survey among mid-level managers at a major infrastructure operator in Great Britain. Firstly, a principal components analysis is performed to identify key determinant constructs driving energy-efficient behaviours in organisations, revealing the importance of perceived benefit to the organisation and flexibility of existing performance goals and targets. Secondly, cluster analysis is undertaken, in an effort to identify differences in behavioural influences between demographic groups. These clusters highlight the heterogeneity of employee populations’ energy behaviours, demonstrating that assumptions cannot be made about these based on single responses to cross-industry surveys. Finally, a structural equation model of individuals’ energy use intentions and behaviours using the newly-identified constructs is developed, revealing some similarities with existing behavioural frameworks such as the Theory of Planned Behaviour (Ajzen, 1991). Implications for policymakers
are then discussed, in terms of encouraging individual employees’ curtailment of energy consumption in organisations through tailored engagement programmes.

**Key words**

Cluster analysis, principal components, energy behaviour, organizational attitudes, corporate sustainability, technology adoption
1. Introduction

Emissions of greenhouse gas originating from electricity production are a key contributor to climate change processes (IPCC, 2014). The UK has set a target for an 80% reduction in greenhouse gas emissions by 2050 (against 1990 levels) (Climate Change Act, 2008). Transport accounts for 21% of the country’s total greenhouse gas emissions (DECC, 2015). Management of transport infrastructure accounts for a large proportion of this consumption; railways in the UK consume 1% of the national electricity supply (over 4 TWh/year) (MacLeay et al, 2015), and the management of transport infrastructure (as opposed to operation of trains) represents approximately one eighth of this total. The railway industry in the UK is currently under regulatory pressure to reduce its financial costs (Shaw, 2016), this imposing a further need for energy efficiency programmes to be implemented. However, studies of other industries (discussed below) suggest that economic drivers alone are not necessarily sufficient to drive improvements in energy efficiency.

Management of energy consumption at the point of use is a key element in efforts to reduce greenhouse gas emissions across any organisational setting (Warren, 2014). Energy behaviours have been investigated from a wide variety of perspectives, including economics, engineering, psychology and sociology (Lopes et al, 2012). Allen & Chatterton (2013) recommend that a low carbon future should be led by greening businesses and making demand-side improvements, with an emphasis on addressing individuals’ behaviours. However, energy attitude and behaviour studies in organisational settings are far less common than those undertaken for consumers or individuals in households (Andrews & Johnson, 2016). This is despite recognition that reducing energy demand in organisational settings is likely to be more difficult than previously assumed, due to multiple overlapping non-price-related barriers (Sorrell, 2015). Some efforts have been made to overcome this by looking at retail firms (Christina et al, 2014a & 2014b) specifically, but larger organisations remain under-researched (Andrews & Johnson, 2016). This suggests a need for further case studies of energy consumption behaviours in larger businesses, to allow observations of employee energy consumption behaviours and their role in improving energy efficiency to be better-understood across a range of operational scales.

The majority of energy behaviour studies to date have focused on domestic settings (Lopes et al, 2012; Greaves et al, 2013; Boomsma et al, 2016). Energy consumption behaviours in households
often deviate from established economic decision-making theories (Zhou & Yang, 2016). However, it appears that some assumptions are currently made about the uniformity of energy consumption behaviours by individuals within organisations, whereas earlier studies of pro-environmental behaviours suggest that this is not the case (Wehrmeyer & McNeil, 2000). Qualitative analysis by Goulden & Spence (2015) also suggests that commercial organisations need to be treated as heterogeneous networks when considering individuals’ approaches to energy use. Whitmarsh (2009) also shows that attitudes toward mitigating climate change do not equate with attitudes towards of saving energy, suggesting the value of investigating energy behaviours in greater depth generally. Furthermore, Murtagh et al (2013) point out the distinction people make between home and the workplace, in terms of personal pro-environmental behaviours. This paper therefore investigates the structure of energy behaviours of individuals in a large organisation and aims to address the question of whether behavioural frameworks developed to understand consumer- or domestic behaviours can be successfully applied to organisational settings.

1.1. Economic and Engineering approaches

The reluctance of organisations to undertake energy efficiency measures despite the profitability of doing so, known as the ‘energy efficiency paradox’ is well-documented in economic literature (DeCanio, 1998; Kounetas & Tsekouras, 2008; Martin, 2012). A set of barriers to energy efficiency proposed by Sorrell et al (2000, 2004, 2011) have received repeated attention in recent years, and are commonly referred to by other authors in the field of organisational energy behaviours (e.g. Schleich & Gruber, 2008; Schleich, 2009; Fleiter et al, 2012). However, these were based on an initial case studies within three industries (Sorrell et al, 2000) (higher education, brewing and mechanical engineering), none of which share many characteristics with transport infrastructure operation. This body of research seems to largely downplay the role of behavioural influences on organisational energy efficiency. In particular, credibility and trust in information (Testa et al, 2016), and individually-held values (Papagiannakis & Lioukos, 2012) have both been found to have significant relationships with the environmental performance of organisations, contradicting the aforementioned economics-led studies. Even economically-framed studies suggest that behavioural factors may play a greater part in determining energy efficiency than originally thought (Cagno & Trianni, 2014, and that economic incentives only explain a portion of observed behaviour (Sorrell, 2015). This suggests a need for further research into behavioural influences affecting energy consumption in organisational settings. This also raises the possibility that employee performance
measures should focus on non-financial goals, if a reduction in employees’ energy consumption is to be achieved.

1.2. Psychological and Sociological approaches

General theories of individual behaviour have often previously been applied to analyse pro-environmental, energy consumption, and technology adoption attitudes and behaviours in organisations. The Theory of Planned Behaviour (TPB) (Ajzen, 1991) (following on from Ajzen & Fishbein, 1977) has often been used to characterize both pro-environmental and energy-saving behaviours. This theory assumes that individuals are rational actors, who make decisions based on a consideration of all known factors. However, debates have often arisen around the validity of particular constructs within the overall framework. The association of the ‘Subjective Norm’ construct with intentions and behaviours in particular is a subject of much debate, either seeming to exert greater (Papagiannakis & Lioukas, 2012) or lesser (Dixon et al, 2015; Tetlow et al, 2015) influence than attitudes in organisational settings. Littleford et al (2014) suggest the differences between organizational- or home settings are a defining feature of energy consumption behaviours. However, they believe that there are fewer applications of the Theory of Planned Behaviour in organisational settings than are necessary to fully understand these characteristics.

The Theory of Interpersonal Behaviour (TIB) (Triandis, 1977) shares many similarities with Ajzen’s theory, but has not been tested as often (Jackson, 2005). This theory includes a ‘Habit’ component, to account for behaviours which may be made as a result of familiarity and repetition rather than conscious decision-making. Rare comparisons with the TPB have been favourable, such as for pro-environmental travel behaviours (Bamberg & Schmidt, 2003). Again, the validity of some constituent constructs have been questioned, albeit in contexts other than energy conservation (e.g. Gagnon et al, 2003; Moody & Siponen, 2013) Despite this, The TIB is consistently raised in support literature for UK policy-makers (e.g. Darnton, 2008; Chatterton 2011). The structure of Triandis’ theory closely reflects an energy technology acceptance framework proposed by Huijts et al (2012) and later tested in Huijts et al (2014). This suggests that the TIB as a possible framework for describing the determinants of energy-efficient technology adoption.

Observations of pro-environmental behaviour in the workplace are not limited to these two frameworks. Boiral & Paillé (2012) and Paillé & Boiral (2013) find that the level of perceived organisational support is related to ‘organisational citizenship behaviours for the environment’.
Andersson et al (2005) found mixed levels of support for constructs proposed by Value-Belief-Norm theory, suggesting that this theory would require revision for application in corporate settings. The profusion of theoretical constructs offered as methods of explaining intentions and behaviours suggests that further research is needed to identify which of these may apply to organisational settings. Given that it is not clear which of these theories might apply in a large-scale organisational context, this raises the proposition that an exploratory analysis method may be used to identify whether any aspects of these existing frameworks are applicable in workplace settings.

1.3. Principal Components Analysis in energy behaviour research

Principal components analysis (PCA) if often used to identify factors influencing general pro-environmental behaviours, adoption of new (pro-environmental) technologies, and energy conservation, which we draw upon below. This technique has been applied in both consumer- and organisational settings, as described below. However, as with studies of energy behaviour in organisational settings more generally, exploratory, quantitative case studies of this type are not currently widespread in the literature.

Axsen et al (2012) used principal axis factoring (a close analogue of PCA) to compare general lifestyle practices and pro-environmental technology adoption, finding that the two groups of practices were largely independent of one another. Subsequent cluster analysis also classified groups who were either ‘green’ or ‘technology’ oriented. Similarly, Sütterlin et al (2011) applied PCA and cluster analysis to classify market segments of consumers with commonly-shared energy-saving behaviours, broadly identified as energy ‘savers’ or ‘consumers’. Barr et al (2005) also identified groups which portrayed varying degrees of environmentalism (or lack thereof). Michelsen & Madlener (2013) investigated homeowners’ decisions to adopt types of residential heating systems, identifying cost, general attitude, available grants, energy security considerations, comfort considerations and the influence of peers all played a part in this process. Again, these were broken down into those preferring the convenience of existing technologies, and those who were motivated to adopt new ones, with a third group who were aware of the consequences of energy-efficient technology adoption but experienced other barriers.

Gadenne et al (2011) used PCA to identify specific characteristics of environmental attitudes and norms relating to energy-saving behaviours for consumers. Their paper takes the additional step of testing these new factors within a TPB-based framework. Their paper recognises that the TPB does
not incorporate institutional influences on individual behaviour. However, incorporating factors determined by PCA into a path analysis framework would enable observations of whether or not these external influences play a part in determining energy-saving behaviours in organisations.

The papers mentioned above clearly indicate the heterogeneity of consumers in terms of energy consumption attitudes and behaviours. However, few papers to date have examined the heterogeneity of energy attitudes within single organisations. Wehrmeyer & McNeil (2000) identified four determinant factors behind employee environmental attitudes in their case study of a pharmaceutical company: ‘Conscientious Activism’ (actions taken in support of the environment), ‘Corporate Environmentalism’ (sharing information on a firm’s environmental choices), ‘Deep Green’ (valuing nature in its own right), and ‘Technological Omnipotence (the sense that technology will solve all problems). Considering the separation of attitudes between pro-environmental- and energy-saving attitudes in domestic settings (Whitmarsh, 2009), Wehrmeyer & McNeil’s (2000) clusters suggest that this may not be the case in the workplace, also suggesting the need for further investigation of this topic in different industries.

1.4. Method selection

In conclusion, this paper aims to address calls for further research into individual energy attitudes and behaviours in organisational settings (e.g. Andrews & Johnson, 2016). The case study presented here intends to identify potential antecedent constructs driving end-use energy consumption behaviours through PCA, and propose a new causal framework based on these new constructs through structural equation modelling. This allows comparison of antecedent factors driving behaviours in other contexts, such as those discussed in section 1.2. Cluster analysis of the new behavioural constructs then presents the case for treating employees of large organisations as a diverse array of individuals, rather than a single homogeneous group. This choice of technique allows identification of heterogeneous networks within organisations, which is thought to enable development of more-effective company policies for reducing employees’ energy consumption (Goulden & Spence, 2015).
2. **Method**

The current study was conducted in the rail infrastructure operator Network Rail plc in the UK. The overall structure of the empirical analysis process chosen was: (1) Conduct a questionnaire survey on the topic of energy-saving attitudes behaviours and make basic demographic observations; (2) Perform exploratory factor analysis of the questionnaire data to identify the driving factors behind these behaviours; (3) Cluster data based on these new factors to identify key engagement groups for policymakers; (4) Propose a new behavioural framework for the energy-saving behaviours of individuals in large organisations.

A similar methodology has been employed previously to look at pro-environmental technology adoption (Axsen et al, 2012), adoption of household heating systems (Michelsen & Madlener, 2013), energy and conservation behaviours (Sütterlin et al, 2011; Barr et al, 2005), and energy conservation behaviours among household consumers (Gadenne et al, 2011), and gender differences in workplace environmental attitudes (Wehrmeyer & McNeil, 2000).

This paper takes the additional step of applying a selection of the generated factors in a multiple regression path analysis model. This is commonly applied in the field of environmental psychology to assess frameworks relevant to pro-environmental behaviours, such as the TPB (Ajzen, 1991) and TIB (Triandis, 1977). Zhang et al (2013) used this method to test a model of energy-saving behaviour in organisations based on Norm Activation Theory (Schwartz, 1977), identifying personal norms and organisational energy-saving ‘climate’ as playing determinant roles. Studies of pro-environmental behaviours in an organisational setting have investigated firms’ willingness to adopt or develop cleaner technologies (Montalvo Corral, 2003), environmental intentions in the workplace (Greaves et al, 2013), and the relationship between managers’ attitudes and corporate environmental performance (Papagiannakis & Lioukas, 2012).

2.1. **Questionnaire survey**
This paper presents the results of an original questionnaire survey, distributed among all employees of a large infrastructure operator in the UK. The organisation’s operations consume electricity at a rate of more than 400GWh per year. However, a large proportion of this is then sold-on to clients in some of their building-based facilities, and operators making use of their infrastructure.

Survey questions were developed around topics identified by an earlier series of semi-structured interviews (not reported here). These interviews took place with a selection of mid-ranking management staff with responsibilities relating to large-scale energy consumption. Questions were also originally mapped to constructs defined by the TPB and TIB. Further questions were added at the request of the organisation’s sustainability specialists. These included questions 38 (“I have actively changed any kind of behaviour following a [organisation-led] campaign”), 50 (“[The organisation] could benefit from using small-scale renewable energy (such as solar panels”).

Forms were distributed using the Demographix® distribution platform. This allowed company branding and formatting to be used, as a means of increasing the perceived importance of the survey among employees with busy work schedules.

Five-point Likert scales were used to improve the visual presentation of the online forms, and because other similar surveys within the organization had previously used these scales. It is noted that seven-point scales have previously been identified as optimal in instances where respondents’ attitudes toward a mental construct have been refined over time (Krosnick & Presser, 2010). However, the topic of energy consumption had not previously been the subject of an internal survey within the organisation, and was not among the firm’s stated priorities (beyond a general acceptance of a need to address sustainability). Meade & Craig (2012) also point out that the reliability of five- and seven-point scales is virtually identical.

A main set of 38 questions used a 5-point agreement-scale format (and unipolar coding scheme); Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). A set of 9 further questions designed to represent a self-report measure of their current behaviours used a five-point frequency-scale format and coding scale; ‘Never’ (1), ‘Once per year’ (2), ‘Once per month’ (3), ‘Once per week’ (4) and ‘Every day’ (5). These questions are presented in Table 1. Employees were also presented with the options ‘Does not apply to me’, and ‘This is done automatically’; these were coded as missing responses for the analysis presented here. A self-report measure was chosen in order to gather data within a relatively short timescale, whilst receiving information from the broadest possible range of company departments and staff specialisms. The researchers recognise the limitations of stated-preference surveys, and discuss this in section 4.3, below. However,
classifying multiple energy behaviours as a generalised group addresses the issue of compatibility raised by Ajzen & Fishbein, 1977 (see also Karlin et al, 2015); i.e. behaviours should be treated with the same level of generalisation as their determinant constructs.

Voluntary survey entry forms were made available to all of the organisation’s (approx.) 36,000 staff via a company intranet news website. 874 responses were returned, the vast majority of which originated from mid-level management staff, based on demographic data collected on participants’ pay grades. Results from employees in management-level pay grades were selected, leaving 628 useable forms. This represents approximately 6.5% of the total population in management-level roles within the organisation. Table 2 provides a full description of the sample’s demographic characteristics.

[INSERT TABLES 1 & 2 ABOUT HERE]

Table 1 caption: Demographic characteristics of sample, with significance of relationship with cluster membership variable. NS = ‘Not Significant’.

Table 2 caption: Self-report behaviour questions, based on the frequency scale described in main text.

2.2. Principal components analysis

New explanatory factors for energy-saving behaviours were identified using rotated PCA, applied to the 38 Likert agreement-scale question items. As raised by Michelsen & Madlener (2013), this investigation process requires decisions by the researchers on the analytical procedure which may impact the outcome of the analysis. All analysis was carried out using SPSS version 22.

Having set a minimum eigenvalue of 1 for generating new factor constructs, Varimax rotation with Kaiser normalisation generated 10 new factors after 13 rotations. Beyond this initial acceptance criterion, two other criteria were used to determine the constructs’ subsequent inclusion in the later cluster- and path analysis stages. Firstly, factors were required to have 3 or more constituent items (i.e. survey questions) with factor loadings greater than 0.5, as recommended by Costello & Osborne (2005). Items with loadings greater than 0.4 are also used in calculations of internal consistency (Cronbach’s alpha) for the new factor constructs (factor loadings less than 0.3 have been suppressed for ease of presentation in this paper). Secondly, new factor constructs were required to have a
Cronbach’s alpha score of 0.6 or greater, as recommended by Hair et al (2013) and George & Mallery (2003) for exploratory research.

### 2.3. Structural equation modelling

Structural equation models were produced using SPSS AMOS version 22. Our analysis process involved placing constructs from the PCA process which met our aforementioned acceptance criteria into a variety of model configurations. In addition to the factors generated by PCA, a ‘Behaviour’ construct was produced as a mean of all frequency-scale questions outlined in Table 2.

The model configurations considered were all variations on a linear arrangement of a variety of antecedent factor combinations, leading to intentions to save energy, leading in turn to self-reported behaviours. The model presented later in this paper is the strongest result produced after several iterations following this general pattern. This raises a possible limitation of our study; models of pro-environmental behaviour can be considerably more complex (e.g. Kollmuss & Agyeman, 2002), and associations between intentions and behaviours (as summarised by Jackson, 2005). However, a number of other theories do follow this broad pattern (e.g. Ajzen, 1991; Triandis, 1977), suggesting that such an approach can yield meaningful results.

### 2.4. Cluster analysis

A cluster analysis process was conducted to determine differences between demographic groups within the infrastructure operator. This was also performed to check whether employees conformed to any existing frameworks for identifying groups within larger populations, such as those relating to technology acceptance (Beal & Bohlen, 1957), pro-environmental choices (Anable, 2005), or other observed cases of (pro-)environmental attitudes in organisational settings (Wehrmeyer & McNeil, 2000).

A two-step clustering method was selected, using a log-likelihood distance measure. The order of the cases within the dataset was reset according to serial number (i.e. the chronological order in which completed forms were returned) for every clustering pass, to ensure replicable results. Results were clustered based on the Factors selected by the preceding PCA stage.
3. Results

Firstly, the outcome of the PCA process is described, along with qualitative interpretations of the 10 attitudinal factor constructs identified. Secondly, clusters based on those factors meeting our acceptance criteria are presented, revealing that groupings based on perceptions of saving energy do not necessarily align to a 1-dimensional ‘pro-environmental/non-environmental’ scale. The demographic characteristics of these clusters are also described, suggesting only minor variations in proportions of cluster membership across all those demographics presented in Error! Reference source not found.. Finally, the results of the structural equation modelling process are outlined, presenting the causal model driving energy-savings and behaviours scoring most favourably on multiple indices of model fit.

3.1. Principal Component Analysis

Data from staff at management pay grades (N = 628) was used as a basis for determining a selection of antecedent factors driving self-reported energy consumption behaviours. Although only 17% of the sample was female, this was broadly reflective of the organisation as a whole, which was approximately 15% female at the start of the survey. In terms of organisational departments, project management- and safety specialist staff were somewhat over-represented, whilst staff responsible for day-to-day ‘frontline’ operations were somewhat under-represented. All other demographic categories were broadly representative of the managerial population. The findings of this survey may therefore be transferable to organisations with similar population characteristics, particularly other major engineering or infrastructure management firms.

10 new factors were identified using the PCA process, as discussed below. 35 of the 38 agreement-scale questions posed to survey participants aligned to one of these new factors. The questions which did not return any factor loadings greater than 0.4 were “I think that energy saving campaigns work”, “Information I need for my role, on any subject, is easily available for me”, and “New technologies I have used have generally worked reliably”. Most questions were associated with only one factor, although “Reducing [the organisation’s] energy use should be a high priority” and “Changes I make to my energy use have a big impact on the world around me” had loadings higher than 0.4 for two factors respectively.
Error! Reference source not found. outlines how questions from the survey map to each of these factors. Question numbers refer to their order in the original questionnaire. Error! Reference source not found. provides all factor eigenvalues, percentage variance explained, and the total variance explained by the factors chosen using the factor-loading and internal consistency criteria mentioned in the previous section.


Table 4 caption: Factor constructs produced by PCA - eigenvalues, and percentage variance explained.

Technology Adoption Norms (TAN) represents respondents’ impression of how easily other parts of the organisation adopt new technologies in general, and the organizational support available for necessary adaptations. Higher scores indicated a perception that the organisation was quicker to adopt new technologies. This factor was comprised of 5 items, and the Cronbach’s alpha score was acceptable (α = 0.730), leading to its acceptance for the cluster analysis process.

Benefit Evaluation (BE) represents respondents’ appraisal of the economic and environmental benefits of pursuing energy efficiency to the organisation, and supporting the spread of pro-environmental technologies. A higher score here indicated a favourable perception of the economic and environmental benefits of energy efficiency improvements within the organisation, and the level of priority these should take. This factor was comprised of 5 items, and returned Cronbach’s α = 0.674, leading to acceptance for further analysis.

Energy Intentions (EI) groups together stated intentions to save energy at work and at home, and to discuss energy and environment-related matters in future. Higher scores indicated a higher level of intention to reduce electricity consumption, and discuss the problem more often at work. There were 4 constituent items, and Cronbach’s α = 0.769, leading to acceptance for further analysis.
Goal Flexibility (GF) measures respondents’ perceived ease of fitting energy-saving goals around their existing suite of other financial and non-financial performance measures. High scores for this construct indicate that respondents find it easier to overcome goal conflicts, whilst lower scores suggest that these are acting as a personal barrier to reducing energy consumption. There were 3 items in this construct, and Cronbach’s $\alpha = 0.704$, leading to acceptance for cluster analysis.

Energy Awareness (EA) records whether respondents have come across organisation-wide energy-saving initiatives in the past, or have access to energy-saving information. Higher scores indicate a greater awareness of previous efforts to save energy and ease of access to information. There were 3 items in this construct, and Cronbach’s $\alpha = 0.645$, leading to acceptance for cluster analysis.

Energy Self-Appraisal (ESA) is a measure of how careful participants believe they are with their own energy use, and their level of emotional involvement with saving energy. Higher scores indicated that an individual perceived themselves as being more careful with energy consumption, and more likely to get frustrated when they could do nothing about it. There were 3 items in this construct, but Cronbach’s $\alpha = 0.594$, lower than the predetermined threshold. This factor was therefore not taken forward to the cluster- or path analysis phases.

Energy Self-Efficacy (ESE) represents whether participants feel responsibility for- and have an ability to influence their own energy use, with reference to how easy it would be for their own company department to do so. Higher scores indicate that an individual feels it is easier for them to reduce their energy consumption. This shares some features with ‘perceived behavioural control’ in Ajzen’s (1991) Theory of Planned Behaviour, but only for curtailing energy use—no similar factors for technology adoption emerged from this factor analysis. There were 3 items for this construct, and Cronbach’s $\alpha = 0.629$, leading to acceptance for further analysis.

Technology Awareness (TA) is a measure of how readily participants adopt new technologies, and their level of awareness regarding the organisation’s most recent technology upgrades. Higher scores are indicative of a person perceiving themselves as better at adopting new technologies. There were 4 items in this construct, but Cronbach’s $\alpha = 0.499$, leading to this factor being dropped in later analysis stages.

Technological Frustration (TF) relates difficulties with learning new technologies to conflicts between performance goals. Higher scores relate to a higher level of frustration with the organisation’s technology adoption processes. However, as there were only 2 input variables produce a factor loading $>0.5$, and Cronbach’s $\alpha = 0.352$, this was not taken forward to further analysis phases.
Environmental Norms (EN) relates to how satisfied respondents were with the organisation’s handling of environmental issues, and with the overall level of information they are able to access. However, as with Technological Barriers, only 2 input variables have a value >0.5, and Cronbach’s $\alpha = 0.283$, and so was not taken forward to further analysis phases.

Table 5 provides a summary of Cronbach’s alpha scores for the constructs described above. Based on the reasonable internal consistency of these constructs, Technology Adoption Norms, Benefit Evaluation, Energy Intentions, Goal Flexibility, Energy Awareness, and Energy Self-Efficacy were carried forward to the path- and cluster analysis processes.

Table 5 caption: Cronbach’s alpha values for newly-calculated factors.

### 3.2. Path analysis

Several alternative structural equation models based on new constructs generated by the PCA process were tested. Error! Reference source not found. provides an example of one of the models tested, but not supported by the observed data. The full suite of alternative model structures tested is omitted from this paper for clarity.

Figure 1 caption: Example of one of several causal frameworks investigated during the path analysis process.

Figure 2 caption: Final structural equation model. This produced the highest model fit indices of any model tested, based on this study’s newly-developed constructs.

The structural equation model in Error! Reference source not found. exhibited the strongest fit according to several indices, whilst including as many factors as possible identified by the exploratory analysis. Table 6 provides the correlation matrix for this model. Benefit Evaluation has a
strong positive association with Energy Intentions. Goal Flexibility has a weak positive association with Energy Intentions. Energy Self-Efficacy has a weak positive association with both Energy Intentions and energy-saving Behaviour. Energy Intentions are also seen to have a moderate positive association with Behaviour.

The validity of the model was checked against multiple standard model fit indices, as recommended by Hair et al (2013). All of the indices most-commonly observed in the literature produced scores which were strongly indicative of a good fit. Chi-square significance divided by degrees of freedom (CMIN/DF) was 0.049 (i.e. the likelihood that the model where all constructs are not associated with one another is true is less than 5%). The Root Mean Square Error of Approximation (RMSEA) was 0 (against a recommended maximum of 0.05). The Normed Fit Index (NFI) score was 1 (values greater than 0.9 indicating a good fit). The Comparative Fit Index (CFI) was 1 (values greater than 0.9 indicating a good fit). It should be noted that inclusion of the ‘Technology Adoption Norms’ construct in any of the configurations tested produced models with multiple poor fit index scores. This suggests that this factor may not be a determinant of intentions to save energy, or self-reported energy behaviours.

The model explains 35.2% of variance in Energy Intentions as a result of the three antecedent constructs, and 8.6% of variance in resulting Behaviour. This model is therefore better-suited for explaining the intention to save energy, rather than the self-reported behaviour.

It is interesting to note the similarity between the proposed structural equation model, and that of the Theory of Planned Behaviour (Ajzen, 1991) as shown in Error! Reference source not found..
TPB’s ‘Attitude’ construct is reflected in the new model by ‘Benefit Evaluation’. Evaluative attitudes are oriented towards perception of benefits to the organisation, rather than to the individual, and are comprised of both economic and environmental considerations. Similarly, ‘Perceived Behavioural Control’ is loosely represented in the new model by ‘Energy Self-Efficacy’, and has causal links with both intentions and self-reported behaviours, as proposed by the TPB. However, constructs similar to ‘Subjective Norms’ are notable by their absence. All models tested which included one or both of the two normative-style factors (Technology Adoption Norms and Energy Awareness) produced poor fit indices. This suggests that other personal normative concerns in relation to energy use could be overridden by the need to meet performance goals in this organisational setting.

Correlation of variables was checked using both Pearson and Spearman correlation techniques, to account for possible non-linear relationships between variables; both processes returned similar results. According to the classification scheme of Cohen (1988), Benefit Evaluation, Goal Flexibility and Energy Self-Efficacy all exhibit moderate correlation (i.e. $0.3 < r < 0.5$) with Energy Intentions (see Error! Reference source not found.), as demonstrated by the structural equation model. Goal Flexibility is also moderately correlated with Energy Self-Efficacy. Behaviour is only weakly correlated (i.e. $0.1 < r < 0.3$) with all other constructs.

3.3. Cluster analysis

Five clusters were identified, using the six constructs defined during the PCA process meeting the selection criteria defined in section 2.2. Factor centroids with values $> \pm 0.25$ were qualitatively classified as being defining characteristics of individuals belonging to that cluster (e.g. ‘Benefit Sceptics’ score lowest for the ‘Benefit Evaluation’ construct). These are listed below in order from the most- to least-significantly different from 0. A full list of standardised factor centroids is provided in Error! Reference source not found..

Table 7 caption: Characteristics of clusters generated by two-step process. Means and standard deviations are those relative to the centroid for each (PCA-generated) factor score.
These clusters are described in the order of emergence using the chosen clustering method. The quality of these clusters is designated as ‘Fair’, using SPSS’ silhouette measure of cohesion and separation (between 0.2-0.5, see Rousseeuw, 1987).

The relationships between demographic categories and the cluster membership variable were statistically significant for age, organisational department, pay grade, and whether the individual had any directly-reporting staff, but not for gender, or for number of years’ experience in the organisation. The descriptions for each cluster’s characteristics are as follows:

The ‘Technological Sceptic’ group (n = 131, 20.9%) is characterized by low scores for Energy Self-Efficacy, Benefit Evaluation, and Energy Intentions, and no particular high scores. This can be interpreted as a group who neither feel able nor willing to save energy, and cannot see the economic or environmental benefits to the company of doing so. Although the causal relationship between these factors is not clear from the clustering process alone, this is the only cluster which groups together both low Energy Intentions and Benefit Evaluation, suggesting this as a key defining feature for this cluster. Based on established behavioural theories (e.g. Ajzen, 1991, Triandis, 1977), it is perhaps more likely that evaluation (an aspect of attitudes) leads to intention in this case. This group had notably lower representation among the organisation’s projects department, but otherwise showed only minor variations in membership levels cross different demographic groups. None of the other demographic categories with a significant relationship to cluster membership demonstrated a 5% or greater difference between groups.

‘Efficiency-Aware’ participants (n = 165, 26.3%) scored very highly for Energy Awareness, and somewhat high for Energy Self-Efficacy, with no particularly low scores. This cluster identifies individuals with the highest awareness of energy efficiency campaigns, and those who feel that energy savings are relatively easy for them, but not necessarily those with the highest intention to do so. Of the clusters identified, this perhaps represents those with the best (perceived) access to information. Perhaps unsurprisingly, membership of this group increases with age, and higher pay bands, reflecting greater awareness of previous efforts to save energy due to a longer time in service at the organisation. This group was also most prevalent in the organisation’s health and safety department, which included teams responsible for the firm’s sustainability policies.

The ‘Barrier Sensitive’ group (n = 139, 22.1%) score highly for Benefit Evaluation, and Energy Intentions, but have low scores for Energy Awareness, Energy Self-Efficacy, Technology Adoption Norms, and Goal Flexibility. This grouping of Factors suggests a personal intention to save energy.

and a high level of support for energy efficiency measures, but may be held back by a perception that the rest of the organisation needs to adopt technologies faster, and that their personal efforts to save energy will therefore have minimal effect. Membership of this group increases among younger staff, those in lower pay bands, and among employees without subordinate staff.

The ‘Organisational Barriers’ group (*n* = 96, 46.3%) are identified by a particularly high score for Energy Self-Efficacy, and a fairly high score for Benefit Evaluation, but low scores for Energy Intentions, Energy Awareness, and Goal Flexibility. Of all the clusters, this group had the lowest overall intention to save energy in future, but the highest perceived ease of doing so at a personal level, particularly in economic terms. This suggests that this group may perceive conflicts in desired performance goals as a reason for not pursuing energy efficiency efforts within the business. This cluster showed only minor variations in membership levels across different demographic groups (i.e. all groups were proportionally represented among the cluster’s population).

Those in the ‘Benefit Sceptic’ cluster (*n* = 97, 15.4%) have high scores for Technology Adoption Norms, Energy Intentions, Energy Self-Efficacy, and Goal Flexibility, and low scores for Benefit Evaluation, and Energy Awareness. The exceptionally high score for Technology Adoption Norms suggests that this group receives the highest perceived technological support from the company, but the low Benefit Evaluation score implies that they are not necessarily in agreement that energy efficiency is a worthwhile use of company resources. As with the ‘Organisational Barriers’ cluster, this cluster also showed only minor variations in membership levels across all observed demographic groups.
4. Discussion

Firstly, the PCA-generated antecedent behavioural factors are discussed, in terms of their similarities with constructs from existing behavioural theories. Secondly, the implications of the identified clusters are discussed in relation to organisations’ policies towards encouraging curtailment of energy use in the workplace. Thirdly, limitations of the present study are outlined, focusing on the method chosen. Finally, overall implications for organisational policies arising from the present study are presented.

4.1. Principal components analysis and structural equation model

The factors identified bear many similarities with constructs proposed by the TPB (Ajzen, 1991). The similarity of the proposed model structure to that of the TPB also implies that there are some similarities between energy-saving behaviours in organisations, and those of consumers more widely. This supports the approach taken by Greaves et al (2013) in using the TPB to identify employee engagement methods for different energy behaviours, but also suggests some minor variations on the TPB’s constructs.

The constructs proposed by the present study are focused more specifically on either curtailing energy use, or adopting energy-efficient technologies; personal attitudes relate to energy use only (i.e. Benefit Evaluation), perceived behavioural control relates to technology adoption only, and Subjective Norms appear to relate to a combination of the two. These observations suggest that further investigation of the TPB and TIB in workplace settings may be warranted. It is not clear why the TIB receives more attention in UK policy literature than the TPB (e.g. Chatterton, 2011), given observations of the applicability of the TPB in a wider variety of settings. A further possibility may be that rational choice-based decision-making models are the most appropriate for individuals in organisations, rather than those (as defined by Jackson, 2005) which focus on moral and normative conduct, or social identity theory (Turner & Oakes, 1986). The relationship between constructs demonstrated by the present study’s structural equation model also contrasts with the linear model.
for pro-environmental behaviours in organisations proposed by Ruepert et al (2016). This reinforces previous observations that individual actions to save energy are not necessarily related to actions taken to reduce personal impacts on climate change (Whitmarsh, 2009).

The relationships demonstrated by the structural equation model also present some implications for company employee engagement policies around energy-saving behaviours. The relatively strong effect of Benefit Evaluation on the intention to save energy, in relation to normative influences (performance goals) and self-efficacy is consistent with more general observations of pro-environmental behaviour in organisations (Greaves et al, 2013; Lo et al, 2012). To address this, the economic value of energy efficiency measures aimed at changing behaviour need to be explicitly demonstrated to employees before they consider adopting these new behaviours. This could be achieved by sharing examples of best practice from organisations with strong track records of energy efficiency or sustainability initiatives, or raising awareness of scientific studies which have measured the amount of electricity saved by simple behavioural changes (e.g. Goodhew et al, 2015; Kaplowitz et al, 2012).

The strong scores for the various model fit indices indicate the validity of the causal relationship between the different constructs presented in the model. It is recognized that a strong model fit in a single organisational setting alone is not enough to confirm the theory presented here, and we propose that future research test this model or variations upon it in other industries. Nevertheless, this reinforces the possibility that the TPB can be adapted for application in organisational settings (as also proposed by Dixon et al, 2015).

Technology Adoption Norms (i.e. perceptions of how readily the organisation adopted new technologies) could not be included in any of the structural equation model variants tested without negatively impacting multiple indices of model fit. This may be indicative of previously-observed distinctions between energy-saving measures which require the adoption of a new technology, and those which require lifestyle changes (Aini et al, 2013), being present in organisations as well. Therefore the recommendations arising from this discussion are focused mainly on addressing lifestyle-based energy curtailment activities rather than technology adoption. However, as evinced by the cluster analysis (and discussed in section 4.2), individuals’ perceptions of technology adoption by the rest of the organisation do play a part in the perception of the efficacy of their own energy-saving actions.
The possible co-linear relationship between Goal Flexibility and Energy Self-Efficacy could arise from a perception that achieving company performance goals takes priority over achieving energy efficiency; the latter seems difficult or impossible until the former is achieved.

4.2. Cluster analysis

The existence of clusters of staff with varying characteristics supports the idea that employees of large organisations are not homogeneous, in terms of their energy-related attitudes. This heterogeneity has also been observed previously for more general pro-environmental attitudes in organisational settings (Bansal, 2003). The heterogeneity also occurs despite the survey results reflecting the views of those only in the highest pay bands within the organisation. Future research of this kind in large organisations should be aimed at identifying whether similar clusters emerge when examining data from a wider range of pay grades and experience levels, such as ‘frontline’ operational or customer-service staff.

Clusters and demographic categories were only loosely related to one another; clusters were not divided strongly between demographic subdivisions (e.g. age brackets, pay bands etc). This suggests that segmentation strategies, with the intention of creating targeted energy-reduction intervention campaigns, may be more difficult to target at specific groups within organisations, as has previously been investigated in domestic settings (Zhang et al, 2012). However, the present study highlights that individuals will respond differently to campaigns aimed at changing energy consumption behaviours, and the varying needs of the members of each cluster described in this paper should be taken into account when designing them. Whilst fostering a sense of community within organisations is known to be important for energy conservation (Dixon et al, 2015), the current study suggests that a diversity of needs and concerns within organisations should also be recognised.

Karlin et al (2015) proposed that tailored feedback on personal energy performance is essential to reduce individuals’ energy consumption. The present study builds on this by suggesting that initial engagement programmes also need to be tailored for different groups to achieve the highest levels of participation in these schemes. Again, it should be borne in mind that, given the nature of the survey responses analysed by this paper, these observations only apply to management-level staff; operational or ‘frontline’ employees may differ. Nevertheless, focusing campaigns around operational-level managers with responsibilities for facilities or small teams offers a level of tailoring
which may be more manageable within a national-scale organisation, compared with directly approaching every single employee.

Some policy recommendations can be drawn from the few demographic differences which arose. There is an age- and experience-related gap around perceptions relating to the efficacy of energy-saving actions. Older, more experienced staff (as exemplified by the Efficiency-Aware group) feel more-able to take on energy-saving actions, whilst younger managers feel more willing to do so, but feel held back by a perceived lack of support from the rest of the organisation (i.e. the Barrier-Sensitive group). Although those in senior management grades may set pro-energy-efficiency policies, junior management grades are more likely to have control over implementation of these policies on a local scale (e.g. deciding whether to discuss energy consumption at meetings). This confirms Goulden & Spence’s (2015) observations regarding the importance of Facilities Managers in the spreading of energy-efficient organisational practices. Therefore any internal campaigns aiming to reduce energy consumption should target this perceived lack of self-efficacy at the middle management level; neither a ‘top-down’ nor a ‘bottom-up’, but a ‘middle-out’ approach.

4.3. Limitations

There are a few limitations with the exploratory approach taken for the current study. Firstly, this is a cross-sectional study of an organisation at one point in time, limiting the transferability of our findings to an extent. However, as few studies of intra-organisational heterogeneity have been made at the present time, our findings provide a stepping stone for developing wider-reaching studies. Several other papers have examined changes in behaviour over time resulting from interventions in organisational settings (e.g. Boomsma et al, 2016; see Unsworth et al, 2013 for a summary) but have necessarily focused on individual offices or buildings where the effects of behavioural interventions can be isolated more easily. However, this would prove impractical when attempting to assess behavioural antecedents across a whole national-scale organisation as done here. Future research could examine the efficacy of the model proposed by the current study by comparing results of a similar questionnaire survey and replacing the ‘behaviour’ measure with externally-observed behaviour data.

Secondly, this study’s measure of energy-saving behaviours also relies on respondents’ self-reports. The validity of self-report questionnaire methods as a means of determining pro-environmental attitudes is often debated. Kormos & Gifford (2014) point out that self-report surveys should not be
used as predictors of objective (i.e. ‘actual’) pro-environmental behaviour. This is also recommended for household energy consumption behaviours (Frederiks et al, 2015), and other pro-environmental behaviours such as recycling (Huffman et al, 2014). However, as the particular organizational environment covered by this study has not been investigated previously, this can be considered as an exploratory study for future work to build upon. This paper has also implemented recommendations by Kormos & Gifford (2014) to reduce the impact of social desirability bias (although the effect of this on self-reports of pro-environmental behaviour is debated (Milfont, 2009). The exploratory factor analysis method used here (PCA) reflects this. This offers opportunities for future authors to use confirmatory analysis methods in similar settings to test the transferability of findings presented here.

5. Conclusions

This paper offers new insights for policy-makers and energy management staff in large organisations or public institutions. As demonstrated by the large variations between clusters, large companies’ internal energy engagement campaigns should be tailored to meet the needs of these different groups (as suggested by Greaves et al, 2013). The high level of engagement with this survey at the junior management level in turn suggests that this group is the most receptive to energy issues, although there is still a large degree of variation across responses. Secondly, organisations should recognise a diversity of attitudes to energy efficiency across staff populations, and design engagement strategies to take account of these. However, few strong links were found between particular demographic groups and cluster membership. Organisations should avoid segmenting energy engagement campaigns based on gender, age, length of experience and company department, as demonstrated by the cluster analysis presented here. These findings specifically address calls by Andrews & Johnson (2016) for integrated studies of individual and organisational drivers for energy efficiency, and for additional sector-specific research into energy behaviours in organisations.

The current study has added to the scientific literature by developing three inter-related frameworks by which future researchers may develop studies of energy consumption attitudes and intentions in large organisations. Firstly, we have observed six constructs which influence individuals’ energy consumption behaviours in organisations: technology adoption norms, personal evaluations of the
economic and environmental benefits to the organisation of energy efficiency, stated intention to save energy, perceived flexibility of performance goals, awareness of energy-saving information, and perceived efficacy of small-scale energy conservation actions. Secondly, we have proposed a causal framework for these constructs, and have identified economic evaluations as having the most influences over energy-saving intentions and behaviours among mid-level management staff. This model has promising implications for the applicability of the Theory of Planned Behaviour (Ajzen, 1991) in organisational settings, in line with Dixon et al (2015). However, less support is provided for current energy behaviour policy support in the UK, which tends to focus on other theoretical frameworks (e.g. Chatterton, 2011). Thirdly, five groups of employees with significantly different attitudes, personal norms, and perceived self-efficacy around energy-saving behaviours have been classified, and these have been identified as having a modest, but unconfirmed relationship with employee age and position in the organisational hierarchy. This paper proposes that individuals in organisations are as diverse as those observed in domestic consumer settings (as reviewed by Lopes et al, 2012), in terms of their attitudes toward energy efficiency.

Ultimately, none of the observations presented here suggest that internal behavioural engagement campaigns would prove ineffective at reducing energy consumption in large organisations. Our findings are most applicable to infrastructure operating bodies, which are responsible for a large volume of electricity use, but are likely to be relevant to other large organisations (i.e. 10,000+ employees). Future research should investigate energy attitudes and behaviours in other industries, or across firms of various sizes.

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References


Title:

Attitudes towards energy efficiency – a comparison of energy management specialists and other employees

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Abstract:

Studies of attitudes to energy efficiency in organisations have tended to focus on economic barriers, rather than drawing on the large body of research into individuals’ energy behaviours in domestic
settings. This paper presents a case study of the differences in attitudes between energy specialists and the rest of the staff population in a large infrastructure management organisation in the UK. A principal components analysis of data from two surveys identifies five main antecedent factors driving employee attitudes towards energy efficiency. Cluster analysis based on these factors is then conducted, classifying six groups with different attitudes towards energy efficiency in the workplace. The differences between energy-specialist staff and the general employee population have a higher ratio than differences observed for other demographic characteristics. Age, gender, pay grade, having directly reporting staff and years of experience also introduce significant, but less pronounced variations. The results point to a need for the resolution of conflicts between energy efficiency goals and other performance pressures, particularly the need for explicit consumption reduction targets, to encourage energy-efficient behaviour.
1. Introduction

The UK’s operator of main line railway infrastructure is under regulatory pressure to reduce greenhouse gas emissions 11% over the period 2014-2019 (Network Rail, 2015). Railways consume 1% of all electricity generated in the UK (Network Rail, 2013). The majority of this consumption arises from the operation of trains, and the morning and evening peak travel periods coincide with daily peaks in national electricity consumption (National Grid, 2013). However, the majority of the electricity consumed directly by the UK’s principal infrastructure operator is used in the operation of supporting buildings and facilities, rather than trackside assets. As such, addressing the energy consumption behaviours of individual employees is likely to have a major impact on the energy consumption of the organisation as a whole.

The firm has internally recognised that employee behaviour change can contribute; attitudes, contextual norms, and perceptions of organisational support of its employees need to be understood, to formulate effective intervention strategies. At the outset of this study, no formal, common energy consumption reduction targets or employee performance goals had been set for the whole organisation. Similarly, the suite of performance measures used to assess employee performance did not include any formal energy-saving objectives at a personal level. This raises an opportunity to assess behavioural influences acting on the organisation’s employees, in order to target internal energy efficiency initiatives more effectively. However, literature describing differences in energy efficiency attitudes (or even pro-environmental attitudes in general) between employees with different demographic characteristics within the same organisation appeared scarce.

Previous literature on energy-efficient behaviours in organisations typically originate from one of two perspectives; one deriving from economics-based studies focusing on barriers to energy-efficient practices (stemming from Sorrell et al, 2000), the other originating from a social-psychological perspective of interacting behavioural constructs, more-often employed to assess consumer pro-environmental behaviour (e.g. Greaves et al, 2013). As noted by several authors (e.g. Andrews & Johnson, 2016; Lo et al, 2012), there is currently a lack of understanding of how individual and organisational determinants act to influence pro-environmental behaviour, suggesting a need to draw closer links between these two fields of study. The remainder of this Introduction describes how an exploratory study of the type proposed here can help to improve these links, and compare which approach is most useful in developing energy awareness campaigns for employees.

1.1. Energy efficiency paradox

Research in the field of economics has generated the concept of the ‘energy-efficiency paradox’, or low adoption rates of energy efficiency measures despite their financial and environmental benefits (Decanio, 1998; Kounetas & Tsekouras, 2008; Martin et al, 2012). Under this paradigm, the energy-
The efficiency paradox is commonly treated as having arisen from a series of discrete barriers originating from primarily organisational or economic sources (e.g. Sorrell et al, 2000; Schleich & Gruber, 2008). Six barriers are commonly observed and documented, as reviewed by Sorrell et al (2011): ‘risk adversity’ in terms of financial and production-related risks, ‘imperfect information’ on energy-saving alternatives; ‘hidden costs’ relating to staff retraining or improving infrastructure support for new technologies; ‘access to capital’ for investing in energy-saving projects; ‘split incentives’ in relation to principal-agent problems (i.e. other parties being the main recipient of improvement benefits); and ‘bounded rationality’ whereby actors adopt the most rational alternative available given limited information.

With the exception of ‘bounded rationality’, these barriers were classified as being ‘economic’ in Sorrell et al’s original study (2000). However, more recent research has pointed out that behavioural barriers, largely dismissed by their study, are likely to play a larger part than these earlier studies would suggest (Cagno et al, 2013; Cagno & Trianni, 2014). Furthermore, the value of conceptualising ‘barriers’ as an impediments to achieving energy efficiency in organisations has occasionally brought into question (Shove, 1998), in terms of developing methods for engaging employees around environment issues in the workplace. This suggests a need to re-examine organisational energy consumption in light of individuals’ behavioural preferences, rather than focusing primarily on economic influences.

### 1.2. Attitude-behaviour gap

Meanwhile, in the fields of sociology and psychology, the ‘attitude-behaviour gap’ or ‘value-action gap’ has been identified as a factor explaining weak pro-environmental behaviour individually (e.g. Valkila & Saari, 2013; Shove, 1998; Kollmuss & Agyeman, 2002). Other sociological and psychological studies in organisational examine the gap using models of interacting attitudes, norms, and other social factors at the individual level (e.g. Greaves et al, 2013). This wealth of behavioural research suggests that factors other than economic barriers or a shortage of information provision may be driving the shortfall in energy-efficient technology adoption across various industries. Surveys in this field are often designed to test existing theories of behaviour. The most prevalent among these is arguably the Theory of Planned Behaviour (Ajzen, 1991), which conceptualises behaviour as arising from intentions, in turn arising from a combination of attitudes toward the behaviour, norms, and the perceived level of control an individual has over their own behaviour.

Previous social-psychological papers on energy-related attitudes and behaviours in organisations have tended to focus on single offices (e.g. Littleford et al, 2014; Littleford, 2013) or a limited number of such buildings (e.g. Tetlow et al, 2015). Others have drawn high-level comparisons of energy management styles across whole sectors (e.g. Kounetas & Tsekouras, 2008), often with only one respondent per surveyed company (e.g. Kostka et al, 2011/2013). The respondents to the majority of surveys in available literature are often internal company energy specialists, rather than typical day-to-day end users; wider-reaching surveys with more than one respondent per organisation are less commonly encountered. For example, a principal components analysis of a
cross-industry survey by Olsthoorn et al (2015) suggests that financial and regulatory risks associated with energy efficiency initiatives are perceived separately from technical ones. However, it is not clear whether these perceptions are held across the entirety of each business surveyed, or only from the perspective of the company representative responding to the survey. Cantore et al (2016) find that favourable attitudes toward energy efficiency measures play an integral part in their eventual adoption, and highlight the perceived importance of support from senior management in doing so. Once again, however, there is no indication of whether these views are held by different subsets of firms’ employee populations, nor did this study encompass the views of said senior managers.

One notable exception to this rule is a Theory of Planned Behaviour-based study by Lo et al (2014). Lo et al’s study examined cognitive factors and habits affecting decisions to perform a variety of energy-saving behaviours, finding that the influence of these factors varied between different behaviours and different organisations. Although their study determined the influence of the number of co-workers in each organisation on energy behaviours, it did not differentiate between the roles of respondents within those organisations. Case study surveys of energy-related attitudes within a single, large organisation were rare among currently-available studies scientific literature (Andrews & Johnson, 2016).

1.3. Differences between energy management staff and other employees

Studies of pro-environmental or energy-efficient attitudes across multiple organisations often note that responses to surveys often originate from environmental- or energy specialists within those firms, rather than employees in other disciplines. Observations of differences in attitudes and behaviours between managers with explicit energy-related responsibilities, and the general employee population are, oddly, hard to find. Wehrmeyer & McNeil (2000) identify that employees’ attitudes to environmental issues are not homogeneous, but can be classified according to spectra of eco- vs. techno-centrism, and preference for centralisation vs. individualism. This segmentation of the population is mirrored in studies of household energy behaviours. For example, Michelsen & Madlener (2013) observe that individuals can be classified as convenience-oriented techno-centrists, energy-saving eco-centrists, or those encouraged to reduce energy consumption by multiple sources. It therefore seems reasonable to assume that employee attitudes to energy consumption

One aim of this paper is to test whether different suites of antecedent factors govern the intentions and behaviours of energy-related management staff, and a general employee population, in terms of approaches to energy efficiency in the workplace. This paper also proposes that employee behaviours arise from a hybrid array of influencing factors, combining insights from both economic (i.e. Sorrell et al, 2004) and social-psychological (i.e. Ajzen, 1991; Triandis, 1977) research fields. As a corollary of the original aim of testing for attitude heterogeneity between different employee roles, it is also hypothesised that these influencing factors have varying levels of influence across different demographic subsets of the population, particularly between energy specialists and other employees.
2. Method

This paper takes a two-stage approach to determining differences between energy management specialists and the general employee population regarding attitudes, norms and self-efficacy towards energy use and efficiency. This two-part methodology has previously been applied in several settings to examine determinants of pro-environmental behaviours (e.g. Axsen et al, 2012; Gadenne et al, 2011; Michelsen & Madlener, 2013), and workplaces in particular (Wehrmeyer & McNeil, 2000). All analysis was conducted using IBM SPSS version 22.

Firstly, a principal components analysis (PCA) was applied to responses to a large-scale questionnaire survey to both types of employees of a major railway infrastructure operator in the UK, framed around the topic of “Energy: What do you think?” Questions for this survey were developed based on thematic analysis of an earlier series of interviews with a selection of asset managers and specialists in high-energy-intensity activities within the firm (not covered in this paper).

Secondly, factors identified by the PCA were subjected to two-step cluster analysis. This identifies subsets of employees with similar attitudes towards energy efficiency. Energy specialists and non-specialists were then compared, based on the relative levels of membership in each cluster for these two groups.

2.1. Survey design and distribution

Survey questions were initially designed to map to four main inputs: an earlier series of semi-structured interviews with asset managers at the organisation in question, Sorrell et al’s (2004) taxonomy of barriers to organisational energy efficiency, the Theory of Interpersonal Behaviour (Triandis, 1977), and the Theory of Planned Behaviour (Ajzen, 1991). A full description of the survey questions can be found in Table 1.

The Demographix® online platform was used to distribute the survey, in order to allow organisational branding to be applied to the survey forms. The endorsement of the organisation in this way was intended as a means of encouraging participation, as earlier interview discussions suggested that surveys with links to external organisations were likely to be ignored. Questions were arranged into three main groups when presented online, themed around ‘Energy’, ‘Technology’, and ‘Working Environment’ (which included questions about organisational pressures and environmental impacts).
Two different, compatible versions of the survey were distributed. Both surveys were voluntary, and neither survey offered any form of monetary- or prize-based incentive for completion. The first was sent to 746 energy-related management, engineering, and specialist staff via two emails (1 invitation and 1 reminder, 3 weeks apart). Participants were identified using organisation charts with the management group recruited from the following sections: the organisation’s energy management department, asset managers responsible for electrical equipment and plant, managers of projects associated with electrical equipment or railway electrification, environmental specialists, and engineers with electrical or electronic competencies. This is referred to throughout as the ‘Manager’ survey.

The second survey was a shortened version of the same questionnaire, made available to the remainder of the organisation’s approximately 36,000-strong employee population, promoted via two articles on the firm’s main intranet news service. This survey removed questions relating to energy management-specific topics, thought by interviewees and the researchers not to be within the knowledge of the general employee population. This is referred to henceforth as the ‘All-Staff’ survey.

Agreement-scale question responses were scored on a 5-point Likert scale ranging from ‘Strongly Disagree’ (value 1) to ‘Strongly Agree’ (value 5). 50 such questions were presented in the Manager survey, and 38 in the All-Staff survey. The comparison between the two groups is based on responses to questions common to both surveys, as shown in Table 1.
Table 35 - Questionnaire items from the two surveys. Unshaded items are common to both surveys. Shaded items were included only in the 'Manager' survey are provided here to increase transparency of the survey process, but are not analysed in this paper.

<table>
<thead>
<tr>
<th>No.</th>
<th>Question phrasing</th>
<th>No.</th>
<th>Question phrasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I don't think about energy use very often</td>
<td>26</td>
<td>Other [organisation] departments are quick to adopt new technologies</td>
</tr>
<tr>
<td>2</td>
<td>I think of myself as being careful with energy use</td>
<td>27</td>
<td>New technologies I have used have generally worked reliably</td>
</tr>
<tr>
<td>3</td>
<td>I have previously taken part in energy-saving activities at [the organisation]</td>
<td>28</td>
<td>It takes too long to adapt to new technologies in my [organisation] department</td>
</tr>
<tr>
<td>4</td>
<td>I tend to leave equipment switched on</td>
<td>29</td>
<td>Innovation in general is adequately supported across [the organisation]</td>
</tr>
<tr>
<td>5</td>
<td>I plan to use less electricity at home in future</td>
<td>30</td>
<td>Learning to use new technologies is frustrating</td>
</tr>
<tr>
<td>6</td>
<td>I plan to use less electricity in my place of work in future</td>
<td>31</td>
<td>I look for opportunities to use technologies whenever possible</td>
</tr>
<tr>
<td>7</td>
<td>I know who can give me information to help me save energy</td>
<td>32</td>
<td>In the last year, I have learned how to use a new piece of technology at work</td>
</tr>
<tr>
<td>8</td>
<td>I get frustrated when I see energy being wasted</td>
<td>33</td>
<td>Saving energy use by improving track equipment is easy for [the organisation]</td>
</tr>
<tr>
<td>9</td>
<td>I think that [a geographically-devolved] management structure has been beneficial to how energy use is managed at [the organisation]</td>
<td>34</td>
<td>New technologies tend to have beneficial impacts on safety</td>
</tr>
<tr>
<td>10</td>
<td>[External stakeholders] have a positive influence on [the organisation's] energy efficiency</td>
<td>35</td>
<td>It is easier to reduce energy use by [trains], than to reduce energy use by infrastructure</td>
</tr>
<tr>
<td>11</td>
<td>[The organisation's] energy data collection is highly detailed</td>
<td>36</td>
<td>It is [the organisation's] responsibility to reduce traction energy use</td>
</tr>
<tr>
<td>12</td>
<td>New energy-efficient technologies have generally worked reliably</td>
<td>37</td>
<td>I understand the changes that [a particular upgrade programme] will bring</td>
</tr>
<tr>
<td>13</td>
<td>Reducing [the organisation's] energy use should be a high priority</td>
<td>38</td>
<td>I have actively changed any kind of behaviour following a [organisation] campaign</td>
</tr>
<tr>
<td>14</td>
<td>I am responsible for the amount of energy I consume at work</td>
<td>39</td>
<td>I am able to influence large-scale business decisions in my [organisation] department</td>
</tr>
<tr>
<td>15</td>
<td>I am able to influence the amount of energy I consume at work</td>
<td>40</td>
<td>The targets I work toward give me room to use less energy</td>
</tr>
<tr>
<td>16</td>
<td>I intend to discuss energy use more often at work in the future</td>
<td>41</td>
<td>The targets other people have to work towards give them room to use less energy</td>
</tr>
<tr>
<td>17</td>
<td>Saving electricity is easy for my [organisation] department</td>
<td>42</td>
<td>Any working practices take a long time to change at [the organisation]</td>
</tr>
<tr>
<td>18</td>
<td>I have seen campaigns specifically around saving energy at [the organisation] before today</td>
<td>43</td>
<td>My general personal performance is disrupted by conflicts between my different targets</td>
</tr>
<tr>
<td>19</td>
<td>Saving electricity is a good way of reducing costs</td>
<td>44</td>
<td>[The organisation] receives the largest share of benefits from investment in the railway, compared to other companies</td>
</tr>
<tr>
<td>20</td>
<td>I think that energy saving campaigns work</td>
<td>45</td>
<td>Climate change is discussed more often than is really necessary</td>
</tr>
<tr>
<td>21</td>
<td>Improving [the organisation's] energy efficiency would reduce risks to energy supply</td>
<td>46</td>
<td>[The organisation] should be working harder to reduce our effects on the environment</td>
</tr>
<tr>
<td>22</td>
<td>There is sufficient expert assistance for [geographically-devolved regions] to manage their own energy use</td>
<td>47</td>
<td>I am happy with the way that [the organisation] handles environmental issues</td>
</tr>
<tr>
<td>23</td>
<td>There is sufficient manpower to improve energy efficiency</td>
<td>48</td>
<td>Changes I make to my energy use have a big impact on the world around me</td>
</tr>
<tr>
<td>24</td>
<td>Information I need for my role, on any subject, is easily available for me</td>
<td>49</td>
<td>I intend to discuss environmental issues more often at work in the future</td>
</tr>
<tr>
<td>25</td>
<td>[The organisation] easily adopts new technologies in general</td>
<td>50</td>
<td>[The organisation] could benefit from using small-scale renewable energy (such as solar panels)</td>
</tr>
</tbody>
</table>
2.2. Principal Component Analysis (PCA)

Principal Components Analysis (PCA) is a commonly-used dimension reduction method for large questionnaire datasets, generating links between responses to different questionnaire items, in turn allowing common factors between survey participants to be identified. Rotated PCA was carried out on the 38 questions common to both the Manager and All-Staff surveys (factors emerging after 13 rotations). It should be noted that Principal Axis Factoring is an alternative method of performing this process, although the difference is primarily in the underlying mathematics and generally considered to produce only minor variations in outcomes compared to PCA. For most projects, PCA and Principal Axis Factoring yield very similar results, as encountered during the initial analysis process associated with this paper. Hence, Principal Axis Factoring results have been omitted from this paper for clarity.

Items with factor loadings greater than 0.4 were considered as determinants of each factor’s respective qualitative characteristics; the phrasings of question item results meeting this criterion were used to interpret the meaning (and hence the name) of each factor respectively. These names are described in section 3.2. This criterion is in line with other PCA-based studies (e.g. Cantore, 2016), although other papers have used 0.5 as a minimum (e.g. Wehrmeyer & McNeil, 2000). These newly-identified factors were then tested for internal consistency based on Cronbach’s Alpha. Factors scoring higher than 0.6 on this scale were selected for inclusion in the cluster analysis process, as recommended by Hair et al (2014). Selection for this process also required a minimum of 3 item factor loadings of 0.45 or greater (similar to Gadenne et al, 2011), although in practice this requirement was superseded by the low Alpha scores for factors with only two high-loading items. This process was repeated for the two surveys separately, and on random subsets of the data to ensure that these factors were not erroneously influenced by one small part of the survey population.

2.3. Cluster Analysis

SPSS’ two-step cluster analysis process was applied to components derived from the PCA process which met the aforementioned criteria. This had the original aim of identifying groups within the organisation with similar attitudes, in order to tailor an internal energy awareness and engagement campaign. Cases (i.e. questionnaire results from different participants) were sorted by source (i.e. ‘Manager’ or ‘All-Staff’ survey), followed by the timestamp for their completion, to ensure repeatability of results. This process was repeated for the two survey datasets separately, and then with randomised ordering of cases to ensure that the clusters generated were not artefacts of the order in which forms were received. The validity of the cluster sets were also checked using the silhouette measure of cohesion and separation provided in SPSS.
3. Results

Firstly the characteristics of the questionnaire samples are presented. Secondly, a description of the PCA process is provided, focusing on an interpretation of the resulting factors. Finally, the results of the cluster analysis process are presented, discussing how the distribution of these differed across the two surveys.

3.1. Survey distribution and sample characteristics

The Manager survey (i.e. the energy specialist sample) received 292 fully-completed forms (response rate 39.1%), whilst the All-Staff survey returned 582 completed forms, for a total sample size of N = 874. A precise response rate for the All-Staff survey is not available, as it is not clear how many people accessed the webpages advertising the questionnaire prior to the original completion date. The All-Staff survey largely received responses from staff in similar pay grades to those targeted by the Manager survey, despite not being directly targeted at that particular group. This may have been due to the online distribution method chosen being favoured by that group. We can therefore say that this data is more representative of staff in mid-level managerial, administrative, engineering or specialist roles, rather than ‘frontline’ employees involved with maintenance or day-to-day operations or all employees in the organisation per se.

Demographic data were collected regarding employee gender, age group, functional department, pay grade, geographical region, number of years worked for the company, and whether the respondent had direct-reporting junior staff. A summary of demographic information is provided in Table 2.
Proportions of survey responses were broadly representative of the organisation as a whole in terms of age group, geographical location, and the number of years worked within the firm. Although females represented only 18.6% of responses, this compared favourably to the 15% representation among the whole employee population. The organisation’s Operations division was markedly under-represented (43.6% of survey respondents, compared to 70.7% for the whole organisation), whilst the Development Project Management, Strategy, and Health & Safety departments were somewhat over-represented. Other demographic categories varied only slightly in terms of composition, compared to the overall population.
3.2. Principal Components Analysis

Table 3 presents the results of the PCA process for the whole dataset. 10 component ‘factors’ were identified, the qualitative interpretations of which are described below. Together, these factors explained 54.7% of variance across responses. This level of explained variance is similar to other studies of this type for pro-environmental behaviours in other settings (Wehrmeyer & McNeil, 2000; Michelsen & Madlener, 2013; Barr et al, 2005). PCAs of the two population subsets (i.e. the ‘All-Staff’ and ‘Manager’ surveys separately) identified broadly similar sets of components, with small variations in factor loadings. The results of these two separate PCAs are omitted for clarity.

The first five of these components consistently met the selection criteria outlined in section 2.2, when tested across multiple subsets of the main dataset. These five factors explained 32.1% of variance in responses to the survey.

‘Technology Adoption Norms’ (Cronbach’s α = 0.744) describes participants’ perceptions of how easily other parts of the organisation (as opposed to respondents’ own departments) adopts new innovations and working practices, (questions 25 & 26), the comparative ability of their own department to adopt new technologies (question 28), and the pace of innovation and changes in working practices across the whole organisation (questions 29 & 42).

‘Benefit Evaluation’ (α = 0.649) is a measure of individuals’ attitudes towards the level of prioritisation energy efficiency should receive (question 13), in terms of financial benefits (question 19), impacts on the environment (question 46), and whether or not the company should employ renewable energy sources (question 50).

‘Goal Flexibility’ (α = 0.709) describes individuals’ perceived ability to fit energy efficiency goals around other performance targets (noting the absence of specific energy-related performance goals) (questions 40 & 41), and the level of influence they can exert over large-scale business decisions (question 39).

‘Energy Intentions’ (α = 0.770) describes personal intentions to curtail energy consumption at home (question 5) and at work (question 6), and discuss energy efficiency (question 16) and environmental issues (question 49) more often in future. This directly reflects the ‘Intentions’ construct from the theories from social-psychological theories, such as the Theory of Planned Behaviour, and was the only construct to do so.

‘Energy Awareness’ (α = 0.633) focuses on participants’ awareness of (question 18) and participation in (question 3) previous energy-saving efforts within the organisation, and awareness of others within the business who could provide them with energy-saving information (question 7).

The remaining five factors did not achieve a Cronbach’s alpha score greater than 0.6, and were therefore excluded from the cluster analysis process.
‘Energy Self-Appraisal’ (α = 0.593) represents individuals’ appraisal of their own day-to-day energy consumption (question 2), how often they think about energy consumption (question 1) and remember to turn off equipment (question 4) and their emotional response to the subject of saving energy (question 8).

‘Technology Awareness’ (α = 0.494) represents individuals’ appraisal of how easily they personally adopt new technologies (questions 31 and 32), and their receptiveness to and awareness of behavioural intervention campaigns around the adoption of new technologies (questions 37 & 38).

‘Energy Self-Efficacy’ (α = 0.597) describes how responsible people feel for their own energy consumption within the organisation, both individually (question 14) and as part of an organisational department (question 17), and the level of influence they are able to exert over their own energy consumption (question 15).

‘Technological Frustration’ (α = 0.365) links responses to two questions: the level of frustration experienced when using new technologies (question 30), and the level of disruption to work caused by conflicts between performance goals, implying that the deployment process can prove frustrating to individuals (question 43).

‘Environmental Norms’ (α = 0.384) links personal satisfaction with the way that the organisation handles environmental issues (questions 45 & 47), with the general availability of information across the organisation (question 24).
Table 37 - Characteristics of factors generated by the PCA process. Factors in italics were not included in the generation of clusters.

<table>
<thead>
<tr>
<th>PCA component factor</th>
<th>Question numbers (see Table 1 for full wording)</th>
<th>Factor loadings</th>
<th>Communalities</th>
<th>Cronbach's alpha</th>
<th>% variance explained (per factor)</th>
<th>% variance explained (cumulative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Adoption Norms</td>
<td>25 .788 .709</td>
<td></td>
<td></td>
<td>0.744</td>
<td>7.66</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>26 .739 .617</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28 -0.630 .466</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>29 .640 .475</td>
<td></td>
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<tr>
<td></td>
<td>42 -0.599 .455</td>
<td></td>
<td></td>
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<td>Benefit Evaluation</td>
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<td></td>
<td></td>
<td>0.649</td>
<td>6.83</td>
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<td></td>
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<td>50 .628 .493</td>
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<td>Goal Flexibility</td>
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<td>Energy Intentions</td>
<td>5 .801 .704</td>
<td></td>
<td></td>
<td>0.770</td>
<td>6.01</td>
<td>26.5</td>
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<td></td>
<td>6 .769 .715</td>
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<td></td>
<td>49 .522 .609</td>
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<td>5.61</td>
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<td>0.593</td>
<td>5.00</td>
<td>37.1</td>
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<td>2 .728 .597</td>
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<td></td>
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<td></td>
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<tr>
<td></td>
<td>4 -0.702 .526</td>
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<tr>
<td>Technology Awareness</td>
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<td>0.494</td>
<td>4.52</td>
<td>41.6</td>
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<td>37 .427 .372</td>
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<tr>
<td>Energy Self-Efficacy</td>
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<td></td>
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<td>4.51</td>
<td>46.2</td>
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<td></td>
<td>15 .761 .672</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>17 .534 .581</td>
<td></td>
<td></td>
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<tr>
<td>Technological Frustration</td>
<td>30 .735 .609</td>
<td></td>
<td></td>
<td>0.365</td>
<td>4.37</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>43 .650 .555</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Norms</td>
<td>24 .410 .495</td>
<td></td>
<td></td>
<td>0.384</td>
<td>4.13</td>
<td>54.7</td>
</tr>
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</table>
3.3. Cluster analysis

The two-step cluster analysis process generated 6 distinct clusters. This number was produced without pre-definition by the researchers. The silhouette measure of cohesion for this clustering solution was ranked as ‘Fair’, deemed acceptable for this exploratory study. The characteristics of these clusters are summarised in Table 4, and described in detail below.

The Low Organisational Support cluster is defined by a general willingness to save energy (‘Energy Intentions’) and the perceived flexibility of doing so within current performance goals (‘Goal Flexibility’). However, this group also perceived the organisation as being slow to adopt new technologies (‘Technology Adoption Norms’), and did not generally pursue energy-saving campaigns.

The Benefit Sceptic group is characterised by average scores across most factors, but an exceptionally low score for Benefit Evaluation. This may represent a perception that the benefits to the organisation of increasing energy efficiency are minimal, and that this overrides any personal support for (or detraction from) energy efficient practices on any other basis.

In contrast, those defined as having Conflicting Goals had high Benefit Evaluation scores, but very low Goal Flexibility, indicating that a personal preference for pursuing energy efficiency is perceived as being obstructed by (or at least contradictory to) current organisational performance goals in other areas. This represented the largest single group of employees, at 24.7% of the sample.

Personally Motivated employees could represent optimistic ‘champions’ of energy efficiency in the workplace, perceiving no particular barriers to personally pursuing energy efficiency. This group also appeared particularly confident that the organisation adopted energy-efficiency measures and innovations with relative ease.

The Low Technology Support group were acutely aware of previous organisation-led efforts to save energy, and scored highly for Efficiency Prioritisation, Goal Flexibility and Energy Intentions, but had low Adoption Norms scores, implying a perceived norm that other parts of the organisation would not support energy efficiency improvements.

Employees with Low Intention had a moderately high score for Goal Flexibility, but a very low score for Energy Intentions. This could be indicative of a general personal indifference towards reduce energy consumption, despite having the flexibility to do so.
Table 38 - Clusters defined by factors generated by PCA process – centroid differences from mean.

<table>
<thead>
<tr>
<th>Clusters - differences from mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Organisational Support</td>
<td>-.663</td>
<td>-.217</td>
<td>-.166</td>
<td>1.197</td>
<td>-.590</td>
<td>-.100</td>
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<tr>
<td>Benefit Sceptic</td>
<td>.444</td>
<td>-1.565</td>
<td>.413</td>
<td>.071</td>
<td>.309</td>
<td>.120</td>
<td></td>
</tr>
<tr>
<td>Conflicting Goals</td>
<td>.557</td>
<td>.191</td>
<td>-1.061</td>
<td>.219</td>
<td>.478</td>
<td>.400</td>
<td></td>
</tr>
<tr>
<td>Personally Motivated</td>
<td>.735</td>
<td>.176</td>
<td>.039</td>
<td>.306</td>
<td>.282</td>
<td>-1.589</td>
<td></td>
</tr>
<tr>
<td>Low Technology Support</td>
<td>-1.196</td>
<td>-.036</td>
<td>-.103</td>
<td>-.044</td>
<td>1.286</td>
<td>-.061</td>
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</tr>
<tr>
<td>Low Intention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N(total)</td>
<td>100</td>
<td>128</td>
<td>216</td>
<td>181</td>
<td>126</td>
<td>123</td>
<td>874</td>
</tr>
<tr>
<td>% of sample</td>
<td>11.4%</td>
<td>14.6%</td>
<td>24.7%</td>
<td>20.7%</td>
<td>14.4%</td>
<td>14.1%</td>
<td>100%</td>
</tr>
</tbody>
</table>
3.4. Relating clusters to demographics

This paper has noted where differences in cluster membership exceeded 5% of the total sample population of both ‘Manager’ and ‘All-Staff’ surveys combined (N = 874). A summary of difference in cluster membership, cross-tabulated against demographic characteristics is provided in Table 5. Cluster membership was significantly related to whether the respondent was an energy specialist or a general employee (p < 0.001). Energy specialists were more prevalent among the Benefit Sceptic (11%) and Low Technology Support (11%) clusters. Meanwhile, the general staff population were far more likely to belong to the Conflicting Goals cluster (14%), whilst being only slightly more prevalent than specialists in the other clusters (2-4% for Low Organisational Support, Personally Motivated, and Low Intention).

In terms of other demographic characteristics, cluster membership was significantly related to gender (p < 0.05), age (p < 0.001), pay grade (p < 0.001), years of experience in the organisation (p < 0.01), and whether the respondent had any direct-reporting junior staff (p < 0.001). Geographical location and organisational department did not exhibit statistically significant relationships with cluster membership (to p < 0.05 or less), and are therefore not presented in this paper for clarity.

<table>
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<tr>
<td>Energy specialist</td>
<td>12.7%</td>
<td>10.8%</td>
<td>29.4%</td>
<td>21.3%</td>
<td>10.7%</td>
<td>15.1%</td>
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<tr>
<td>Other employee</td>
<td>8.9%</td>
<td>22.3%</td>
<td>15.4%</td>
<td>19.5%</td>
<td>21.9%</td>
<td>12.0%</td>
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</tr>
<tr>
<td>% difference</td>
<td>-3.8%</td>
<td>11.4%</td>
<td>-14.0%</td>
<td>-1.8%</td>
<td>11.3%</td>
<td>-3.1%</td>
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</tbody>
</table>

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<tbody>
<tr>
<td>Male</td>
<td>12.1%</td>
<td>15.1%</td>
<td>24.7%</td>
<td>19.8%</td>
<td>15.4%</td>
<td>12.8%</td>
<td>701</td>
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<tr>
<td>Female</td>
<td>8.0%</td>
<td>11.0%</td>
<td>25.8%</td>
<td>25.2%</td>
<td>11.0%</td>
<td>19.0%</td>
<td>163</td>
</tr>
<tr>
<td>% difference</td>
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<td>-4.1%</td>
<td>1.1%</td>
<td>5.3%</td>
<td>-4.4%</td>
<td>6.2%</td>
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</thead>
<tbody>
<tr>
<td>18-34</td>
<td>16.3%</td>
<td>13.0%</td>
<td>26.4%</td>
<td>18.3%</td>
<td>8.5%</td>
<td>17.5%</td>
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<tr>
<td>35 and above</td>
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<td>15.3%</td>
<td>24.0%</td>
<td>21.7%</td>
<td>16.7%</td>
<td>12.7%</td>
<td>628</td>
</tr>
<tr>
<td>% difference</td>
<td>-6.7%</td>
<td>2.3%</td>
<td>-2.4%</td>
<td>3.4%</td>
<td>8.2%</td>
<td>-4.7%</td>
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<tr>
<td>High-grade</td>
<td>8.6%</td>
<td>20.6%</td>
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<td>15.2%</td>
<td>19.9%</td>
<td>14.3%</td>
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<tr>
<td>Low-grade</td>
<td>13.9%</td>
<td>9.4%</td>
<td>27.6%</td>
<td>25.5%</td>
<td>9.6%</td>
<td>13.9%</td>
<td>467</td>
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<tr>
<td>% difference</td>
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<td>6.2%</td>
<td>10.2%</td>
<td>-10.3%</td>
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</thead>
<tbody>
<tr>
<td>Yes</td>
<td>9.8%</td>
<td>18.5%</td>
<td>19.3%</td>
<td>16.2%</td>
<td>22.1%</td>
<td>14.0%</td>
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<tr>
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<td>14.1%</td>
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<td>9.1%</td>
<td>7.5%</td>
<td>-13.0%</td>
<td>0.1%</td>
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<table>
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<tr>
<th>Years of experience at firm</th>
<th>Low Org. Support</th>
<th>Benefit Sceptic</th>
<th>Conflicting Goals</th>
<th>Personally Motivated</th>
<th>Tech. Barriers</th>
<th>Low Intention</th>
<th>Population size</th>
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<td>0-5</td>
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<td>12.9%</td>
<td>22.2%</td>
<td>24.0%</td>
<td>9.8%</td>
<td>15.7%</td>
<td>325</td>
</tr>
<tr>
<td>6 or more</td>
<td>9.1%</td>
<td>15.7%</td>
<td>26.2%</td>
<td>18.8%</td>
<td>17.1%</td>
<td>13.1%</td>
<td>549</td>
</tr>
<tr>
<td>% difference</td>
<td>-6.3%</td>
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<td>-4.1%</td>
<td>-5.2%</td>
<td>7.3%</td>
<td>-2.6%</td>
<td></td>
</tr>
</tbody>
</table>

Table 39 - Cluster membership cross-tabulated by demographic characteristics of sample
Cluster membership did not vary greatly between genders. Females were slightly more prevalent in the *Personally Motivated* (5%) and *Low Intention* (6%) groups, whilst males were very slightly more prevalent across all other clusters.

Cluster membership also did not vary greatly across age groups. Younger employees (18-34 years old) were slightly more prevalent in the *Low Organisational Support* cluster (6%), whilst older (35+) staff were slightly more likely to perceive *Low Technology Support* (8%).

Differences in attitudes between pay grades were more pronounced. Higher pay grades (the top 3 tiers) were somewhat more likely to belong to the *Benefit Sceptic* (12%) and *Low Technology Support* (10%) groups. Lower pay grades were more likely to be *Personally Motivated* (10%) whilst experiencing more *Conflicting Goals* (7%) and *Low Organisational Support* (5%).

Staff with more than five years of experience at the organisation were slightly more prevalent in the *Low Technology Support* cluster (7%), whilst those with less than five years’ experience were more common in the *Low Organisational Support* (6%) and *Personally Motivated* (5%) groups.

Employees with direct reports were more common among the *Benefit Sceptic* (6%) and *Low Technology Support* (13%) clusters, whilst those without subordinates were more prevalent among the *Conflicting Goals* (9%) and *Personally Motivated* (8%) groups. This reflects the differences observed between energy specialists and non-specialists.
4. Discussion

As anticipated, several key differences in the energy conservation-related attitudes and other behavioural influences, between energy management-related staff and the general employee population were observed. PCA-generated factors influencing these attitudes also appeared to represent a combination of both economic and social-psychological perspectives. Firstly, the implications of the newly generated factors are discussed, in terms of their relationship with existing economically- and social-psychologically-oriented studies of energy attitudes and behaviours. Secondly, these clusters are summarised in terms of their demographic characteristics, highlighting the strong differences between energy specialists and the general employee sample. Finally, the characteristics of the identified clusters are discussed, in terms of addressing employee engagement to reduce energy consumption in infrastructure operators or other large organisations.

4.1. Relationship to other organisational energy behaviour studies

Some of the PCA-identified components corresponded to the Sorrell et al (2004) taxonomy of organisational energy efficiency barriers. Low scores for ‘Energy Awareness’ (such as with the Low Organisational Support cluster) could broadly represent examples of ‘imperfect information’ due to ineffective engagement campaign dissemination. A low ‘Benefit Evaluation’ score could be interpreted as a heightened sense of ‘risk aversion’ or ‘bounded rationality’, due to a shortage of support for low-cost or behaviour-based energy reduction initiatives. ‘Goal Flexibility’ also reflected aspects of ‘split incentives’, in that performance goals directly aimed at encouraging energy efficiency. However, the ‘principal-agent’ problem aspect of ‘split incentives’ (i.e. a perception that the main beneficiaries of improvements being someone else, or another company) was not present in this case. ‘Technology Adoption Norms’ reflected aspects of Sorrell et al’s (2000) ‘Hidden Costs’ and ‘Access to Capital’, but only in terms of technology deployment; aspects of these two barriers relating to costs of staff training or improving infrastructure did not emerge as part of the major, internally-consistent PCA components. Based on these comparisons, it can be said that some of the Sorrell et al (2004) barriers played more significant roles for some segments of the employee population, whereas others were absent or not significant. This raises the possibility that surveys regarding the perceived influence of each of these barriers may not fully reflect how they are perceived by different parts of each individual company; energy specialists answering cross-industry surveys may be misrepresenting the views of other staff.

Few of the identified factors directly matched the constructs defined by the Theories of Planned- (Ajzen, 1991) or Interpersonal (Triandis, 1977) Behaviour, with the exception of ‘Energy Intentions’, despite these being used when designing the survey. Neither of these theories are therefore directly supported as frameworks for understanding energy behaviours in organisations. However, the
factors generated by the PCA process suggest a few similarities with Ajzen’s theory, focusing on specific workplace practices for each of that theory’s constructs. Attitudes are reflected in ‘Efficiency Prioritisation’, Subjective Norms in ‘Technology Adoption Norms’, and Perceived Behavioural Control bears some similarity to ‘Goal Flexibility’. This highlights that existing theories of individual consumer behaviour may be applicable, and therefore engagement strategies designed for consumers may also have positive effects on organisational energy efficiency. However, further research is needed to ascertain the level of influence that Ajzen’s factors have over decisions in organisational settings (building on Greaves et al, 2013). Again, the variation in scores for each of the PCA-derived constructs across different staff clusters suggests that previous social-psychological surveys relating to energy-efficient behaviours across multiple companies or industries, with one respondent per firm, may misrepresent the views of non-energy-specialists in those firms.

4.2. Differences between energy specialists and other employees

The largest observed statistically-significant variations in cluster membership across demographic groups were between ‘Manager’ and ‘All-Staff’ samples, lower- and higher pay grade brackets, and those with- or without direct-reporting junior staff. Variations were less pronounced across gender, age group, and length of experience within the firm.

Survey results therefore suggest that the attitudes of energy specialists regarding energy use behaviours do not accurately reflect those of the wider employee population. This raises the possibility that cross-sector surveys of barriers to organisational energy efficiency, often responded-to by energy specialists within participant companies, may not accurately reflect the attitudes of the majority of staff in these organisations with respect to energy efficiency measures. The energy specialist sample was roughly evenly-spread between the higher- and lower sets of pay grades; this suggests that although senior managers and energy specialists had similar characteristics in terms of PCA factor scores, the two phenomena are not necessarily directly related. This differentiates the current study from other literature highlighting the importance of buy-in from senior management for achieving energy efficiency (e.g. Christina et al, 2014).

The higher proportion of energy specialists in the Benefit Sceptic cluster bears some relation to studies of pro-environmental behaviours other organisations; Cordano & Frieze (2000) observed that environmental managers who had experienced barriers to impact-reduction measures in the past may experience greater levels of frustration. This may have manifested here as a perception that any attempt to save energy within the firm is likely to be seen as low priority by others. This, combined with a perceived low level of efficient technology implementation by the rest of the firm (i.e. ‘Technology Adoption Norms’), suggests the perceived resistance to energy efficiency measures increases along with the level of experience an employee has in the field of energy efficiency.

Meanwhile, energy specialists also appear to underestimate the perceived importance placed on meeting other (non-financial) performance goals by other employees. In our case study, the presence of a non-binding goal (in terms of staff performance measurement) aimed at reducing
greenhouse gas emissions was not sufficient to drive employee behaviour change toward reducing energy consumption. This indicates that a clearer performance goal aimed at reducing energy consumption may be required, to improve the visibility of energy consumption as an issue on equal footing with other financial or regulatory targets.

Lo et al (2014) observe that the perceived importance of behavioural influences over energy-saving behaviours differs between organisations; the findings presented here highlight that these differences are also present within demographic subsets of larger organisations. This heterogeneity mirrors Lo et al’s (2013) own observations of inter-departmental differences in staff attitudes toward pro-environmental travel behaviours.

### 4.3. Implications for employee engagement strategies

The comparatively large size of the Conflicting Goals group corroborates earlier research suggesting that performance goals are a major concern for many employees, when attempting to implement what many perceive as nebulous, secondary aims around energy efficiency (Christina et al, 2014). These findings also corroborate the economically-oriented research suggesting that perceptions of the economic value and technological feasibility of energy efficiency need to be the key topics of employee engagement to achieve energy-efficient behaviours in the workplace (Schleich & Gruber, 2008; Schleich, 2009). Clearer presentation of energy consumption information alongside other performance-related or regulatory targets is could help achieve this; in our case study, daily performance against other targets was displayed electronically throughout their facilities, suggesting this would be fairly easy to deploy.

The prevalence of the Personally Motivated cluster among younger, less-experienced employees is encouraging for future initiatives to reduce electricity consumption, as this generation develops skills and progress upward through company hierarchies. This suggests that junior staff may be more willing to initiate projects aimed at saving energy, and that gentle awareness-raising campaigns within organisations would probably be most effective if targeted at this group.

This enthusiasm among younger staff is countered to an extent by the even spread of the Low Intention cluster across all demographics. It is not clear from these results whether this group have a low intention to save further energy because of a sense that they have already done all that they can to save energy, or that they simply are not interested in doing so. Nevertheless, the findings suggest that there are employees who are unlikely to engage with awareness-raising campaigns due to lack of personal interest; this seems to stand in opposition to previous observations that improving information availability alone may be sufficient to drive energy efficiency improvements in organisational settings (Matthies et al, 2011).

It should be noted, however, that no single demographic category completely dominated any single identified cluster. A similar survey to that presented here could assist managers with selecting a more personalised approach to encouraging energy savings at a local level, rather than assuming an employee’s attitudes based on demographic characteristics.
5. Conclusions

This paper contributes a detailed case study to the under-studied field of energy-related attitudes and behavioural influences in organisational settings. Observations suggest that the attitudes of energy specialists do not directly mirror those of employees in other roles, within large organisations, as demonstrated by differences in cluster membership between energy specialists and other employees.

The component factors identified by the PCA process support conceptualisation of energy efficiency behaviours in organisations as social-psychological constructs, in preference to economic barriers, as the components identified here were seen as both barriers and drivers to achieving energy efficiency by different employees. However, whilst sharing a few similarities, these components do not directly resemble constructs from commonly-referenced behavioural frameworks such as the Theory of Planned Behaviour. This suggests a need to refine existing theoretical frameworks of individual behaviour before further deployment in organizational settings.

Cluster analysis identified six key groups to consider when organisations develop their own internal energy engagement strategies. The attitudes of energy specialists are observed to differ significantly from those of the wider employee population, as identified by the observed differences in cluster membership between these two groups. This suggests that questionnaire responses in cross-industry surveys do not necessarily accurately represent the attitudes of individuals in the companies they represent.

None of the observations presented here detract from the overall need to address energy efficiency behaviours in organisational settings. Findings suggest that large organisations should tailor energy efficiency engagement campaigns to draw upon the enthusiasm of (lower-ranked) operational staff. This paper also highlights the need for energy specialists to promote and deploy clear energy performance goals to other members of staff, in order for energy efficiency to have an even playing field with other pressures on companies’ operations, as demonstrated by the prevalence of the Conflicting Goals cluster among non-specialist employees.

Although this paper represents a case study of a single large organisation, and therefore cannot directly represent the situation in another firm, it is suggested that heterogeneity of energy-related behavioural influences are likely to arise in other large businesses. In particular, infrastructure management bodies, geographically-dispersed firms with >10,000 employees, and firms without an explicit energy reduction strategy. Hence, three suggestions for future research arise. Similar questionnaires to those used in this paper could be developed for further case studies, to assess whether similar components arise in other organisations or sectors. Secondly, a new survey could be designed to test the new factors generated by the PCA process presented in this paper, rather than have them emerge from a survey designed to test other behavioural frameworks, as presented here. This could apply structural equation modelling to test how these factors determine energy consumption behaviours, as has frequently been done for other theories of pro-environmental
behaviour in other settings (Greaves et al, 2013; Cordano & Frieze, 2000). Finally, this study was conducted in an organisation which was yet to tie energy goals into measures of employee performance. It is anticipated that an organisation with explicit staff energy targets may return a significantly lower proportion of responses with Conflicting Goals, but comparisons of firms with and without energy reduction goals are needed to confirm this.

Research for this paper was conducted as part of an Engineering Doctorate (EngD) with the Sustainability for Engineering and Energy Systems doctoral training centre at the University of Surrey, with the support of Network Rail and the Engineering & Physical Sciences Research Council (EPSRC).

References


Littleford, C. (2013). Energy use by individual office workers: psychological and contextual influences on behaviour. Loughborough University,


Paper – *Energy Efficiency* (currently under review)


Network Rail Energy Survey

Dear Colleagues,

Thank you for choosing to take part in this survey; it should take between 10-15 minutes to complete.

The main purpose is to find out how you think about energy use in your role at Network Rail, how you believe that the rest of the company deals with energy, and where you think we can manage our energy more effectively and efficiently.

“Energy use” refers to the use of electricity, in your station, depot, office, or by the trackside. This can be for lighting, heating, communications, and other electrical or electronic equipment. Other forms of energy, such as heating from gas, are of interest as well.

There are a few questions on how you think about technology and your working environment, to provide us with some background information. We also ask for a few details about yourself, but do not ask for anything traceable such as name or email address. All information will be stored anonymously.

Our findings will be shared across the company by the end of 2015. We look forward very much to your contribution.

How you think about energy

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t think about energy use very often</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I think of myself as being careful with energy use</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I have previously taken part in energy-saving activities at Network Rail</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I tend to leave equipment switched on</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I plan to use less electricity at home in future</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I plan to use less electricity in my place of work in future</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I know who can give me information to help me save energy</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I get frustrated when I see energy being wasted</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing Network Rail’s energy use should be a high priority</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I am responsible for the amount of energy I consume at work</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I am able to influence the amount of energy I consume at work</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I would like to discuss energy use more often at work in the future</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Saving electricity is easy for my Network Rail department</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I have seen campaigns specifically aimed at saving energy at Network Rail before today</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
### How you think about technology

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information I need for my role, or any colleague, is readily available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Rail easily adopts new technologies in general</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Network Rail departments are quick to adopt new technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New technologies I have used have generally worked reliably</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It takes too long to adapt to new technologies in my Network Rail team</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovation in general is adequately supported across Network Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning to use new technologies is frustrating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I seek opportunities to use technology whenever possible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In the last year, I have learned how to use a new piece of technology at work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### How you think about your working environment

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I understand the changes that the ‘Digital Railway’ will bring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have actively changed any kind of behaviour following a Network Rail campaign</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am able to influence large-scale business decisions in my Network Rail department</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The targets I work toward give me enough room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The targets other people have to work toward give them enough room to use less energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any existing practices take a long time to change at Network Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My general personal performance is affected by conflicts between my different targets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please indicate how much you agree with the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change is discussed more often than it really necessary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Rail should be working harder to reduce our efforts on the environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am happy with the way that Network Rail handles environmental issues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changes I make to my energy use have a big impact on the world around me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I intend to discuss environmental issues more often at work in the future</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Network Rail Energy Survey – All-Staff version

Network Rail could benefit from using small-scale renewable energy (such as solar panels).

Energy activities

How regularly do you do the following things, approximately?

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Once per year</th>
<th>Once per month</th>
<th>Once per week</th>
<th>Everyday</th>
<th>This is done automatically</th>
<th>Does not apply to me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turn off computer monitors when not at your desk</td>
<td>☐</td>
<td>☐</td>
<td>☓</td>
<td>☓</td>
<td>☑</td>
<td>☛</td>
<td>☐</td>
</tr>
<tr>
<td>Turn off lights when no-one else is left in the room</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Turn off heating when no-one else is left in the room</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Turn off other unnecessary electrical equipment</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Turn things off completely, rather than in &quot;standby&quot; mode</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Find ways of increasing travel reimbursement to reduce energy use</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Find ways of turning off plant equipment to reduce energy use</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Reduce energy use in maintenance</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Leave items plugged in, even when they’re not being charged</td>
<td>☐</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
</tbody>
</table>

Energy opportunities

Please outline ways in which you think Network Rail could save energy

How can Network Rail support you in saving energy?

Any other comments relating to energy use?

Background information

Finally, we need some basic information about yourself. All responses are anonymous and the information below is collected for analysis only.

When you have finished, please press the "Submit Answers" button at the bottom of this page.

[Blank space]

Please tell us your gender

[Blank space]

Please tell us your email

[Blank space]

Network Rail Energy Survey (Rupert Zierler (ruoerpuert@networkrail.co.uk))
Please tell us your approximate age

COMPLIANT QUESTION

[Please select an answer]

18-24
25-34
35-44
45-54
55 or above

Which area of the business are you in?

COMPLIANT QUESTION

[Please select an answer]

Infrastructure Projects
Finance
Human Resources
Digital
Communications
Network Operations
Safety, Technical and Engineering
Group Strategy
Infrastructure Maintenance
Property

Route:

COMPLIANT QUESTION

[Please select an answer]

Anglo
London North East & Midland
London North West
Scotland
South East
Wales
Wessex
Western
Central
Not applicable

Band:

COMPLIANT QUESTION

[Please select an answer]

Executive Leadership Team
Band 1
Band 2
Band 3
Band 4
Band 5
Band 6
Band 7
Band 8
Executive Coaching Group
Frontline Maintenance Group
Other

Do you have any staff reporting directly to you?

COMPLIANT QUESTION

[Please select an answer]

Yes
No

How long have you worked for Network Rail?

COMPLIANT QUESTION

[Please select an answer]

Less than 2 years
2-5 years
6-10 years
11-15 years
More than 15 years

Do you work full-time or part-time?

COMPLIANT QUESTION

[Please select an answer]

Full-time
Part-time

Do you work a shift pattern?

COMPLIANT QUESTION

[Please select an answer]

Yes
No
Thank you very much for completing this questionnaire.

We hope to share our findings with you before the end of 2015. In the meantime, enjoy finding out more about the environmental impacts of energy by copying and pasting the links below.

Find out how you can save energy at home:
http://www.energy-savingtrust.org.uk/

Further information on World Environment Day:
http://www.unep.org/wed/wed2015/

How would you achieve a low-carbon future? Find out using the following tool:
http://my2050.60cc.gov.uk/

[Image only]