The EngD in Sustainability for Engineering and Energy Systems Annual Conference 2015

Proceedings

9th–10th September 2015
University of Surrey
Welcome from the Programme Director, Prof. Chris France

The Annual Conference is our collective opportunity to learn about new projects, catch up on progress with others and to hear about the outputs and impacts of those nearing completion. Over the last few years, working with Research Engineers (REs), the Programme Team has worked hard to innovate with the conference format and content and this one is no exception! This year, with the event moving from its usual early summer slot (to accommodate the five-hundred delegate Conference of the ‘International Society for Industrial Ecology’ hosted by Surrey) means that our Research Engineers are all at a significant juncture in their research work with annual (twelve/thirty-six month) reports, confirmation dissertations about to go off to examiners or preparing to submit final theses. In consultation with the Feedback Forum we have decided to align the Conference submissions with these reporting processes to showcase all of the hard work invested in getting to these stages.

This year we are joined by four new people on the Practitioner Doctorate in Sustainability (PDS) who will be describing their nascent projects. The intention is that the Annual Conference will become a joint event as the PDS grows.

Two features of the Conference that I would like to bring to your attention are:

- The Three Minute Thesis competition: a great way to encourage researchers to communicate their work in a pithy and persuasive manner to different audiences
- The ‘Consultancy Challenge’: Research Engineers and their supervisors have come up with some fascinating problems, a selection of which we will be tackling in multidisciplinary groups in workshops led by final year Research Engineers.

Feedback is an essential component of the Conference. We have set up a simple mechanism to solicit feedback from all participants – please give generously of your time and efforts, whether in the oral or poster sessions, as Research Engineers benefit significantly from the diversity of inputs that our audience can bring.

I hope that you will have an enjoyable Conference.

Director of the IDC in Sustainability for Engineering and Energy Systems
## Timetable

**WEDNESDAY, 9TH SEPTEMBER 2015, LEWIS CAROLL BUILDING
LECTURE THEATRES: 01 AND 02 AC 01**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Registration</td>
<td>01 AC 01</td>
</tr>
<tr>
<td>09:30 - 09:45</td>
<td>Welcome and Introduction</td>
<td>02 AC 01</td>
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<tr>
<td><strong>Presentation Session 1</strong></td>
<td></td>
<td><strong>02 AC 01</strong></td>
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<tr>
<td>09:45 - 10:05</td>
<td>Sustainable Phosphorus Recovery from Waste</td>
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<td></td>
<td><em>Rosanna Kleemann</em></td>
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<tr>
<td>10:05 - 10:25</td>
<td>Towards Generic-Optimal Control of Domestic Heating Systems</td>
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<td></td>
<td><em>Craig Brown</em></td>
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<tr>
<td>10:25 - 10:45</td>
<td>Food for thought: how should local authorities encourage households</td>
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<td></td>
<td>to recycle food waste?</td>
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<td></td>
<td><em>Linzi Shearer</em></td>
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<tr>
<td>10:45 - 11:30</td>
<td>Break and Poster Session</td>
<td>01 AC 01</td>
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<tr>
<td><strong>Presentation Session 2</strong></td>
<td></td>
<td><strong>02 AC 01</strong></td>
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<tr>
<td>11:30 - 11:50</td>
<td>Asset management of aging cast iron truck main: models for the</td>
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<td></td>
<td>determination of residual strength</td>
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<td></td>
<td><em>Azadeh Fahimi</em></td>
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<td>11:50 - 12:10</td>
<td>The Role of Life Cycle Assessment (LCA) as a Decision-Support Tool for Emerging Materials</td>
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<td></td>
<td><em>Sophie Parsons</em></td>
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<tr>
<td>12:10 - 13:00</td>
<td>Lunch</td>
<td>01 AC 01</td>
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<tr>
<td><strong>Consultancy Challenge</strong></td>
<td></td>
<td><strong>02 AC 01</strong></td>
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<tr>
<td>13:00 - 13:40</td>
<td>Consultancy Challenge Introduction</td>
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<tr>
<td>13:40 - 16:00</td>
<td>Groups break off to discuss</td>
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<tr>
<td>16:00 - 16:30</td>
<td>Groups report back to Plenary for judging</td>
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<tr>
<td>16:30 - 17:15</td>
<td>Break and Poster Session</td>
<td>01 AC 01</td>
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<tr>
<td>17:15 - 17:30</td>
<td>Consultancy Challenge Winners announced</td>
<td>02 AC 01</td>
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<tr>
<td>17:30 - 17:45</td>
<td>IDC Director’s closing comments</td>
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<tr>
<td>17:45:00</td>
<td>Day one Close</td>
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*Accommodation Check-in*

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<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
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<tbody>
<tr>
<td>19:00 - 21:00</td>
<td>Conference Dinner</td>
<td>Lakeside Restaurant</td>
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</table>
# Timetable

**THURSDAY, 10TH SEPTEMBER 2015, LEWIS CAROLL BUILDING LECTURE THEATRES: 01 AND 02 AC 01**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Location</th>
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<tbody>
<tr>
<td>09:00</td>
<td>Registration Opens</td>
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<tr>
<td>09:30 - 09:45</td>
<td>Welcome</td>
<td>01 AC 01</td>
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<tr>
<td></td>
<td><strong>Presentation Session 3</strong></td>
<td>02 AC 01</td>
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<tr>
<td>09:45 - 10:05</td>
<td>Integrated Design Strategies for Mixed Plastic Waste Pyrolysis</td>
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<td></td>
<td><em>Matthew Gear</em></td>
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<tr>
<td>10:05 - 10:25</td>
<td>Energy and Climate Change Implications of the Future of Gaming</td>
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<td></td>
<td><em>Joshua Aslan</em></td>
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<td>10:25 - 10:45</td>
<td>Development of Robust Hybrid Modelling Techniques in the Wastewater</td>
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<td></td>
<td><em>Anthony Wu</em></td>
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<tr>
<td>10:45 - 11:30</td>
<td>Break and Poster Session</td>
<td>01 AC 01</td>
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<tr>
<td>11:30 - 12:15</td>
<td><strong>Three Minute Thesis Session 1</strong></td>
<td>02 AC 01</td>
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<tr>
<td></td>
<td>Frederick Pask</td>
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<td></td>
<td>Noemi Arena</td>
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<td></td>
<td>Craig Brown</td>
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<td></td>
<td>Abdul Miah</td>
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<td></td>
<td>Rosanna Kleemann</td>
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<td></td>
<td>Emilia Melville</td>
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<tr>
<td>12:15 - 13:15</td>
<td>Lunch</td>
<td>01 AC 01</td>
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<tr>
<td>13:15 - 14:05</td>
<td><strong>Three Minute Thesis Session 2</strong></td>
<td>02 AC 01</td>
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<tr>
<td></td>
<td>Stefanie Niekamp</td>
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<td>Linzi Shearer</td>
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<td>Rupert Zierler</td>
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<td>Sophie Parsons</td>
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<td>Hristo Dikanski</td>
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<td>Azadeh Fahimi</td>
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<td></td>
<td>Helen Skudder</td>
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<tr>
<td>14:05 - 15:10</td>
<td>Break and Poster Session</td>
<td>01 AC 01</td>
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<tr>
<td>15:10 - 15:40</td>
<td>IDC Director’s closing comments</td>
<td>02 AC 01</td>
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<tr>
<td>15:40</td>
<td>Day two closes</td>
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## Poster Programme

<table>
<thead>
<tr>
<th>Stand Number</th>
<th>Poster Name</th>
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<tbody>
<tr>
<td>1</td>
<td>Generational Change in Relation to Technological Adaptation and Innovation in the Civil Nuclear Energy Sector</td>
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<tr>
<td></td>
<td>Abeer Abdalla (Rolls Royce)</td>
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<td>2</td>
<td>Life Cycle Engineering Of A Self-Chilling Beverage Can</td>
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<td></td>
<td>Noemi Arena</td>
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<tr>
<td>3</td>
<td>Strategies for Future Proofing Social Housing through Climate Change Adaptation and Mitigation</td>
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<td></td>
<td>Andrea Botti (PRP Architects)</td>
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<td>4</td>
<td>Are our bridge foundations fit for future river flows?</td>
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<td></td>
<td>Hristo Dikanski (Network Rail)</td>
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<tr>
<td>5</td>
<td>How can moments of change contribute to more sustainable lives? – A Research Project in Cooperation with IKEA and Hubbub UK</td>
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<td></td>
<td>Patrick Elf (Hubbub and Ikea)</td>
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<td>6</td>
<td>Encouraging sustainable travel within Surrey</td>
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<td></td>
<td>Nick Grudgings (Surrey County Council)</td>
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<td>7</td>
<td>Sustainable Odour management within Thames Water</td>
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<td></td>
<td>Behzad Haji Mirza Beigi (Thames Water Ltd.)</td>
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<td>8</td>
<td>Advanced Modelling of Heat-Mass Transfer in Foods and Beverages for Sustainable Manufacture, Storage and Distribution</td>
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<td>Paschalia Mavrou (Unilever)</td>
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<td>9</td>
<td>Polycentric approaches to UK sustainable energy transitions</td>
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<td></td>
<td>Emilia Melville (Buro Happold)</td>
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<td>10</td>
<td>Product-based environmental metrics for use within aerospace, defence, space and security industries (ADS): context, successes to date and likely contributions to knowledge and impact</td>
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<td></td>
<td>Abdul Miah (ADS Group)</td>
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<td>11</td>
<td>Multi-criteria decision support for sustainable material choices</td>
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<td></td>
<td>Stefanie Niekamp (TWI Ltd.)</td>
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<tr>
<td>12</td>
<td>Sustainable process heating</td>
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<td>Frederick Park (3M)</td>
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<tr>
<td>13</td>
<td>How do we engender a company's sustainability needs through a ‘shifting’ supply chain?</td>
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<td></td>
<td>Erica Russell (Carillion)</td>
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<tr>
<td>14</td>
<td>Cutting crime, cutting carbon</td>
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<td></td>
<td>Helen Skudder, (ACPO Secure by Design and the Home Office)</td>
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<tr>
<td>15</td>
<td>Embedding energy efficiency behaviour frameworks within Network Rail's business practices</td>
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<tr>
<td></td>
<td>Rupert Zierler (Network Rail)</td>
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Noemi Arena
Noemi Arena graduated in chemical engineering on 20th July 2011 at the “University of Naples Federico II” with the thesis on: “Carbon Dioxide Adsorption in a Sound-Assisted Fluidized Bed of Activated Carbon”.
From 1st March to 30th September 2012 worked at Magaldi Group and Institute of Combustion Research in a project focused on the process aspects of an innovative system for solar energy utilization.
From 1st October 2012 is Research Engineer at the University of Surrey and is working on an activity focused on the optimization of an innovative package to chill a beverage on demand, which utilizes the adsorption process of carbon dioxide on activated carbon.

Joshua Aslan
Joshua Aslan graduated from University College London in 2013 with an MSci in Physics. He is currently in the second year of the Engineering Doctorate programme at the University of Surrey in partnership with Sony Computer Entertainment Europe (SCCEE).

Andrea Botti
Andrea graduated from an MSc in Architecture and Building Engineering at the University of Bologna, Italy in 2008 and after practising in architectural firms in Italy, Spain and Australia, he furthered his interest in sustainability as he completed an MSc in Advanced Sustainable Design at the University of Edinburgh in 2012.
After having worked both in professional and academic environments, Andrea joined the EngD SEES on September 2014, based at PRP Architects, to focus on environmental design strategies as well as behavioural aspects with the aim to develop strategies for climate change adaptation and mitigation for social housing.

Craig Brown
Craig Brown is an EngD Research Engineer with Bosch Thermotechnology Ltd. His research interests include physical modelling of domestic heating systems, numerical optimisation and intelligent control. More specific research interests include echo state neural networks, adaptive filtering and differential evolution - on which he has recently published in Soft Computing. He holds an MEng in Chemical Engineering from the University of Birmingham where he received a Howard Wagstaff Memorial trust scholarship for academic excellence.

Hristo Dikanski
Hristo is a third-year research engineer, creating a climate change adaptation methodology for asset management in Network Rail. His work focuses on adapting bridge management, ensuring that whole-life costing models used in the railway industry are flexible and reliable.
Having graduated in 2012, Hristo holds a 1st Class Masters degree in Civil Engineering from the University of Bristol.
Here his passion for sustainable engineering was born, which he now applies in an industry context.
In his spare time, Hristo gets out of the bustling city whenever he can and enjoys winter and summer sports alike in the great outdoors.

Azadeh Fahimi
Azadeh Fahimi is a fourth year research engineer working on a collaborative project between Thames Water Innovation Clean Water Network and University of Surrey entitled “Trunk Mains: Developing understanding, tools and models for characterisation, performance assessment and risk mitigation”.
Previous to this she has worked as a senior water engineer and lead design engineer, on a variety of water and wastewater projects for major clients such as Thames Water, Environment Agency and South East Water. She holds and MSc in Water and Environmental Engineering from Univeristy of Surrey.

Matthew Gear
Matthew Gear graduated from the University of Surrey with a 2.1 MEng in Chemical and Bio-Systems Engineering and has returned to the University to pursue an EngD in Sustainability for Engineering and Energy Systems. He is in the second year of his EngD project working with Recycling Technologies Ltd in Swindon. The company aims to develop a process plant to recycle plastic into a storable fuel or potentially a chemical feedstock. Matthew is working on engineering design and environmental impact of the process and associated products.

Nicholas Grudgings
Nick Grudgings studied Mechanical and Manufacturing Engineering at Bath University before working as a strategy consultant for four years. He came to Surrey University to undertake an EngD in sustainable transport with Surrey County Council. His project theme is on the balance between behaviour change and infrastructure development when encouraging sustainable travel modes.
Behzad Haji Mirza Beigi
Behzad Beigi completed a bachelor degree in Chemical Engineering at the University of Manchester followed by a Master’s degree in Petroleum Refining at the University of Surrey. Behzad then took up a research on the topic of harvesting microalgae for biodiesel production within waste water industries, where he scaled up from laboratory data in order to evaluate the cost efficiency of a proposed scheme at mass scale. In doing so he proposed a number of engineering solutions that would improve on the existing proposed designs. Behzad then started an EngD in association with Thames Water on the topic of sustainable odour management within sewage treatment works last year. Behzad has been investigating the means of minimising odour from sewage treatment works. Also he has been evaluating a number of state of the art odour treatment units with the aim to minimize costs and environmental impacts of the units whilst avoiding any nuisance to local residents.

Rosanna Kleemann
Rosanna first attended the University of Surrey in 2010 to study for an MSc in Water & Environmental Engineering. With a strong water and environmental background the EngD project entitled “Sustainable Phosphorus Recovery from Waste” was a perfect fit for Rosanna. The project aims to turn wastewater into a resource through the recovery of phosphorus (P) and the production of P rich fertiliser. A major outcome of this project is the initial development of a new P recovery process. During her EngD, Rosanna has worked to increase awareness of the looming P crisis and discuss solutions under development. She has featured on many television and radio programmes including BBC, Sky news, Al Jazeera, and the Guardian and Independent newspapers.

Emilia Melville
Emilia’s EngD is sponsored by the Sustainability team at Buro Happold, a multidisciplinary international engineering consultancy. Her research contributes to expanding the team’s city systems offer by studying the management of resources by communities. Trained as an engineer, Emilia has a background as a sustainability consultant in Buro Happold, and in social enterprise as a founding director of the Bristol Energy Cooperative. She is actively involved in the growing community energy sector in Bristol and brings insights and connections from this to her research.

Abdul Miah
Abdul Miah joined the SEES EngD programme in May, 2013, as a Research Engineer for the “Product based-environmental metrics for use within Aerospace, Defence, Space and Security industries(ADS)” research project. He graduated in 2009 with a 1st Class degree in Civil and Engineering with Honors, and previously worked as a Sustainability Research Assistant for a 3yr FP7 Funded EU project called “QUIESST” researching techniques for assessing the sustainability of civil infrastructure systems before joining. Abdul is passionate about the application of sustainability principles for improved environmental, social, and business outcomes, and keen to work across multiples business and public sectors.

Stefanie Niekamp
Stefanie graduated in Mechanical Engineering (BSc and MSc) at the University of Bochum in Germany. She focussed on energy and process technology and gained experience in various industrial placements e.g. with Evonik Industries and Pleiger GmbH. In 2012 she started her engineering doctorate with TWI Ltd, Cambridge. Her research is aimed at providing decision support approaches and tools for sustainable industrial systems. Within this context she is evaluating the life cycle costs and performance of materials and investigating multi-criteria approaches for combining these different aspects. Her current project is on ships, but the approach is transferable to other sectors too.

Sophie Parsons
Sophie Parsons is an Engineering Doctorate student based at the National Physical Laboratory (NPL). Her research at NPL uses life cycle assessment (LCA) methodology, with a focus on producing guidance for the better inclusion of uncertainty in the LCA of emerging materials. Through improving how uncertainty is communicated her work aims to make LCA more transparent, improving the way it is used by product designers and policy-makers to direct decision-making. She is currently working on guidance for the LCA of nanomaterials as part of a mandated European Committee for Standardisation (CEN) 352 ‘Nanotechnologies’ project being carried out at NPL.
Research Engineer Biographies

Freddie Pask
Freddie has a MEng in Environmental Engineering from the University of Nottingham. His research is sponsored by 3M and he is embedded deep within the UK manufacturing sector. The project title is to “improve the sustainability of process heating”. Freddie is going into his fourth year of the EngD program with the research focused on reducing process energy consumption within ovens, as well as enhancing the oven’s ability to manufacturer quality product. Outside of work Freddie enjoys getting cold and wet during a variety of outdoor activities, before warming up with tasty food and a good beverage.

Linzi Shearer
Linzi Shearer has a MA (Hons) in Psychology from the University of Glasgow and an MSc in Environmental Studies from the University of Strathclyde. Her EngD is in conjunction with Surrey County Council, and her project seeks to investigate the effectiveness, feasibility and acceptability of various informational behaviour change interventions for encouraging food waste recycling behaviour. Prior to joining the EngD programme Linzi was employed as a Research Assistant at the David Livingstone Centre for Sustainability in Glasgow.

Helen Skudder
Helen Skudder is currently enjoying her EngD placement alongside the Home Office and the Association of Chief Police Officer’s Secured by Design crime prevention initiative. Researching into the ‘carbon costs of crime’ has already taken Helen on a police attachment to see front line crime reporting and to the Houses of Parliament, among other government departments across Whitehall. Originally from Margate in Kent but now residing in Hastings, East Sussex, she has always lived by the coast and her university years were no different. A masters degree in Environmental Science and a undergraduate in Geography with American Studies were both undertaken in sunny Swansea University with an intercalary year abroad at the University of Tennessee in Knoxville. Helen is looking forward to the second half of her EngD here at the University of Surrey and the further opportunities her research will produce along the way!

Anthony Wu
Anthony Wu graduated with a 1st class honours degree in MEng in Chemical and Process Engineering at the University of Surrey. He is currently in his second year of the EngD Programme. His research is on the development of hybrid modelling techniques applied in wastewater treatment processes, in particular the anaerobic digestion and activated sludge processes. This will lead to more robust process models that can support the monitoring, control and optimisation of these processes. The developed methodology will contribute towards making small-scale anaerobic digesters (a renewable technology) more viable through the real-time estimation of biogas production and early detection of process faults. It will also contribute towards reducing the energy consumed by activated sludge processes. He is based at Perceptive Engineering Limited in Daresbury, Cheshire. Perceptive is an engineering consultancy that specialises in intelligent monitoring and control systems.

Rupert Zierler
Rupert grew up near Camden Town in north London. Despite having no direct family connections with railways, they fascinated him from an early age, resulting in a disastrously unsafe system of his own in the garage. A place on the Surrey EngD with Network Rail was sought to develop this interest in a less calamitous way, whilst building on existing strengths. Rupert previously studied a Masters in Transport Engineering and Operations at Newcastle University, with a dissertation investigating attitudes towards rail travel. He also studied Natural Sciences at Durham University, and worked as an audience researcher in the family business.
Doctoral Practitioners

Abeer Abdalla
Abeer has gained her BSc with a first class honours degree in Civil Engineering from the University of Khartoum in 2007. She has then worked in contracting organisations, engineering consultants and a laboratory for materials testing and quality control in Sudan and the United Arab Emirates. In 2010 Abeer completed her MSc in International Construction Management and Engineering at the University of Leeds. Prior to joining the University of Surrey she was involved in infrastructure projects as an Office Engineer at the capital of the U.A.E., Abu Dhabi. Abeer has joined this year’s group of Doctorate Practitioners, and is working with Rolls-Royce Plc to research “Generational Change in Relation to Technological Adaptation and Innovation in the Civil Nuclear Energy Sector”.

Patrick Elf
Patrick Elf has a degree in International Management from the Cologne Business School, Germany and the Universidad Viña del Mar, Chile. He also holds a Master’s degree in Sustainable Development from the Forum for the Future and Middlesex University and is currently undertaking research as the Practitioner Doctorate Student for IKEA and Hubbub UK. Prior to his current position he worked for the London Sustainable Development Commission (LSDC) at the Greater London Authority and gained cross-sector insights while working for the Food and Drink Federation, TUI Travel Plc. and The Crown Estate. His research interests include sociology, psychology, sustainable consumption and behaviour change.

Paschalia Mavrou
Paschalia is a graduate of the Department of Mechanical Engineering at the Aristotle University of Thessaloniki. Following her graduation she worked for two years as a Research Engineer in the Laboratory of Process Systems Design and Implementation in the Chemical Process and Energy Resources Institute of the Centre for Research and Technology-Hellas. Her work focused mainly on the appropriate selection of working fluid mixtures for solar Organic Rankine Cycles.

Paschalia joined the Centre for Environmental Strategy in June 2015. She is based with Unilever Research Colworth and the topic of her research is the advanced modelling of heat and mass transfer in foods and beverages for sustainable manufacture, storage and distribution.

Erica Russell
Erica Russell is a Doctoral Practitioner within the Centre for Environmental Strategy (CES) at the University of Surrey. Erica is based at Carillion plc, Construction Services who are looking to further develop their existing sustainability programme. Russell will be researching and testing methodologies that can enhance company sustainability through its supply chain. The partnership is for three years, from May 2015- April 2018. Erica has worked in various roles in industry for 30 years, both in public companies and in other private sector businesses. She has spent the last 9 years working with partners and businesses within the UK and Europe to integrate Sustainable Business practices into ‘normal’ business advice. This included a major UK Government programme piloted by the South East Regional Development Agency (2007-2010) in which sustainability was embedded into Business Link and advisors trained, metrics developed and over 20,000 companies were directly engaged on relevant ‘sustainability actions’. Recently she has led or contributed to several EU projects working on the circular economy and SMEs, understanding and communicating sustainability in business, understanding the role of innovation in small companies and the development of an online innovation platform.

Erica completed her Masters in Sustainable Development at the University of Surrey in 2010.
Sustainable Phosphorus Recovery from Waste

Rosanna Kleemann a, b, *, Jonathan Chenoweth a, Roland Clift a, Stephen Morse a, Pete Pearce b, Devendra Saroj c

a Centre for Environmental Strategy, University of Surrey, Guildford, GU2 7XH, UK
b Innovation Centre, Thames Water, Island Road, Reading, RG2 0RP, UK
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Phosphorus (P) is an essential nutrient for all living organisms; it is a non-renewable resource which has no substitutes in the environment. P, along with nitrogen and potassium, is a key component of fertiliser. China, Morocco and the USA control over two-thirds of world’s phosphate rock supply. In 2008, P prices rose by over 800% in a six month period and have since remained unstable. The UK is reliant on phosphate rock imports for food production; a total of 138 kt P is imported each year. As the population booms, P use in the form of fertiliser will increase dramatically. P recovery from waste can alleviate reliance on imported P and reduce vulnerability to fluctuating prices. This EngD project investigates the possibilities for improving P efficiency in the economy through P recovery from waste and the production of P rich fertiliser.

The project aimed to investigate effects of full scale P recovery in Slough wastewater treatment plant (WWTP). Operation of full scale P recovery processes have been little reported in literature, especially discussing whole site effects. Mass balances showing P flows through the entire WWTP network were created to examine effects of P recovery. Mass balances exhibit an average 72±7% P recovery from centrifuge centrate, 8.8±0.7% total P and 20.5±3.2% PO4-P is transferred from WWTP influent into recovered P fertiliser. Recovering P reduces flows of P throughout each process in the WWTP as shown in mass balances. P recovery reduces P load to BNR, improving process performance, allowing the site to achieve final effluent P discharges more easily. FeCl3 solution dosing must be reduced in Slough WWTP to improve P recovery. Reducing FeCl3 solution dosing to minimum required to eliminate odours onsite provides chemical savings of approximately £100K. As a result of reducing chemical usage onsite sludge cake volumes decrease. Loading, haulage, stockpiling, and spreading of sludge cake to land costs are reduced, saving ~£13K. Other costs avoided include polymer, centrifuge anti-scaling chemical, and adhoc OPEX expenses for pump and pipe rehabilitation amounting to over £31K. In total £148K can be saved onsite from recovering P and £20K/year revenue can be made from fertiliser sales. Knowledge of the operational and financial benefits promotes the uptake of P recovery by water companies across the globe.

Effects of Fe on microorganism dynamics of the biological nutrient removal (BNR) process were assessed in Slough WWTP during the commissioning of P recovery system. FeCl3 solution dosing is used onsite to support BNR, but excess Fe can inhibit microorganisms from removing P biologically. Fortnightly samples of BNR sludge were collected over a one year period. No literature is currently available reporting the extended observation of BNR sludges for one year, nor at full scale WWTP. Lab scale BNR performance experiments were conducted on BNR sludge along with PCR sequencing of the sludge sample. PCR sequencing provides information on microorganisms present in sludge and population diversity. Combining lab scale results with Slough WWTP sampling data showed that as FeCl3 solution dosing decreased, BNR performance increased. Shannon-Weiner diversity index showed high microorganism diversity does not equate to good BNR performance. Indeed, a crash in diversity and subsequent recovery of diversity resulted in increased BNR performance. Such extensive data on BNR sludges has not been reported in literature to date. A wealth of information is now available on the BNR process and microorganisms as a result of this research.

A parallel project objective was to develop a novel method for P recovery from incinerated sewage sludge ash (ISSA) and pyrolysed sewage sludge char (PSSC). P recovery from ISSA is well established, but P recovery from PSSC using same techniques as ISSA has not been reported in literature. P was released from solids through sulphuric acid (H2SO4) leaching. H2SO4 solution of varying molar concentrations was mixed with ISSA and PSSC for 30 minutes contact time followed by filtering to separate solids from liquid. P and other metals were measured using inductively coupled plasma mass spectrometry (ICP-MS). Additional analysis was conducted on solids using x-ray powder diffraction (XRD), x-ray fluorescence (XRF), scanning electron microscope (SEM) and BET surface area to compare solids before and after acid leaching. Results showed that at 0.8M H2SO4 solution, ~80% P was released from ISSA, whereas at 1M H2SO4 solution ~90% P was released from PSSC. The release of heavy metals from ISSA


exceeded heavy metal release from PSSC; primarily due to the reduction of heavy metals in the pyrolysis process compared to the incineration process. Using BET surface area analysis it was discovered that PSSC solid pore size was improved through acid leaching, meaning the residues can be reused as adsorbents for odours, and brownfield rehabilitation following P release. This project serves as baseline research from which novel full scale P recovery technology can be developed.

Aside from technical aspects of P recovery, effects of P recovery on UK P flows were estimated using mass balance approach. 15±5% P recovery from all UK WWTP reduces imported P fertilisers by 9.1±2.6%. P lost to water bodies lessens by 9.5±2.7%, reducing risk of eutrophication and reduction of agricultural land P stock by 3.0±0.9% is achieved. However, more significant improvements to P efficiency are gained by recovering P from WWTP influent and pyrolysis of sewage sludge. At this level of recovery, a national P fertiliser stock of 21.71±0.95 kt P/year is produced. This reduces P imports by 36.2±1.1%, and reduces agricultural run-off onto water bodies by 21.7±1.9%.

These project aims, individual in their parts, combine to improve the understanding of P flows in WWTP and how to recover P for best economic and environmental gain. This research has shown that P recovery substantiates environmentally and financially on local WWTP and national UK basis. This research can be used to inform decision makers and influence the incorporation of P recovery into legislation.
Towards Generic-Optimal Control of Domestic Heating Systems
Craig Brown

The energy used for heating and cooling is significant. By some estimates, 20% to 40% of the energy consumption of a developed country is due to buildings. Of this, 50% is for heating and cooling. In England, where cooling is rarely needed, heat is typically delivered by the combustion of natural gas in an individual gas fired boiler located within the building.

Due to the energy intensity of residential heating, various government interventions have been made in an attempt to reduce the associated greenhouse gas emissions. Examples include the Renewable Heat Premium Payment (RHPP) scheme and more recently the Renewable Heat Incentive (RHI). These policy instruments are aimed to increase the appeal of what we’ll broadly refer to as alternative heating appliances. Examples are heat pumps, solar thermal panels and micro combined heat and power units (mCHP). These are less emissions intensive than gas and oil fired boilers.

Bringing these alternatives to market and securing mass-uptake is a challenge. The real world performance of alternative appliances can differ dramatically from that observed in steady state testing (the heat load of a household rarely reaches a steady state due to varying weather and occupant behaviour). Furthermore, in situations where the minimum heat output of the appliance is in excess of the heat load of the household (common especially in combi systems), the appliance must cycle on and off. Gas fired boilers may cycle with little loss in performance, but this is not always true for alternative appliances. The new appliances are also typically more expensive to buy than the traditional choices.

As well as emissions output and energy efficiency, other desirable attributes of a heating appliance include reliability, safety, low upfront and operating costs, quiet operation, low space requirements, the ability to deliver excellent thermal comfort, the ability to effectively manage legionella and ease of installation. Legislation, anticipated changes to legislation, culture of the target market and competitor activity will also influence the likelihood of a given technology succeeding.

As already alluded to, one costly aspect of bringing a new technology to market is developing the control system. The challenge of effectively controlling domestic heating systems is that houses, users and installers vary. This means that controls must be designed to perform well in a range of situations, including when the system is unbalanced, radiators are under or over sized and in the presence or absence of Thermostatic Radiator Valves (TRVs). Reliable performance is normally achieved through rule based control systems based on heuristics or 'rules of thumb'. As a consequence, control is unlikely to be optimal in any particular house but likely to be good – heuristics handle uncertainty well.

Academically, there are 3 problem areas of interest to this research project. Firstly, the problem of controlling alternative heating appliances effectively and to their full (optimal) performance potential. Secondly, the problem of comparing appliances or technologies in a manner that reflects the limitations of the technology and not the control strategy. Finally, the problem of having to develop another rule based control algorithm for every new appliance—to make a realistic comparison to other appliances and to bring that product to market.

These problem areas inspired much research into machine learning and nature-inspired computing. I developed a ‘proof-of-concept’ control system based on state-of-the-art recurrent neural networks that can learn a heating system from scratch and am in the process of submitting a paper describing it. On the way, I published a genetic optimisation method in the journal Soft Computing for when reliable optimisation with lower memory use is required, such as in control.

I worked with my sponsor company in the early stages of the EngD to bring system simulation capability to the Company’s Worcester site and completed a novel simulation study on Stirling engine based micro-CHP appliances. For alternative appliances, the heuristics that work for boilers may no longer be as effective. In the early stages of development, simulation has become an important tool for validating new controllers. Simulation work carried out during the EngD has been influential with regards to what renewable technologies to pursue, has contributed concrete improvements to product quality and encouraged the uptake of model based design methods at the Worcester site, the benefits of which will be reaped for years beyond the completion of this EngD.

Though rule based control is an effective solution to the problem of controlling hybrid systems, it has limited flexibility. Consider the aforementioned hybrid system containing a boiler and heat pump. If the boiler were replaced by a mCHP, the control strategy would most likely perform poorly. It is not practically possible to freely experiment with
different combinations of appliances in a hybrid system—investment is needed in the control system each time, even in simulation—reliable technology comparisons (normalised for control quality) are costly.

A related issue is the development of mathematical models for new technologies as they arise. To help with this, I developed a state-of-the-art parameter estimation tool for estimating the unknown parameters of new mathematical models. This tool was first used in the Stirling engine project and has since been used for parameterising gas heat pumps, thermostatic radiator valves, PID controllers and more. Though it is difficult to estimate the value of the tool to the sponsor company, the time it has saved its engineers is notable. Moreover, the tool allows users to easily validate the accuracy of their models—accurate models results in better development or strategic decisions down the line.
Food for thought: how should local authorities encourage households to recycle food waste?

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“Just as we use R&D to develop ‘hard science’ into useful technological solutions, a similar process can be used to develop basic behavioural science into large-scale policy innovations. … What has been missing is a concerted effort by researchers, policy-makers, and businesses to do the ‘engineering’ work of translating behavioural science insights into scaled interventions, moving continuously from the laboratory to the field to practice.” (Alicott & Mullainathan, 2010).

Each year, an estimated 7.2 million tonnes of household food waste is thrown away in the UK. While food waste occurs across all stages of the supply chain, much of the food wasted in developed nations is due to consumer shopping and food management behaviours. In the UK local authorities are responsible for the collection and disposal of domestic food waste, which has traditionally been collected together with residual waste (general rubbish) and sent to landfill or energy recovery plants. If collected separately, food waste can be used as feedstock for anaerobic digestion, a process that produces energy and bio-fertilizer. Accordingly, the number of households with access to a separate source segregated food waste collection service in England rose dramatically from 11% in 2008 to 42% in 2014.

Despite this impressive growth in service provision, the amount of food waste collected for ‘recycling’ is still only a fraction of that which remains in the residual waste stream, suggesting that these new services are not currently performing to their potential. The success of any recycling programme is dependent on effective household participation. Since 2010, the government has been championing the use of insights from the fields of psychology and behavioural economics to ‘nudge’ individuals towards adopting more sustainable lifestyles. Behaviour change approaches, which offer a potentially cost-effective solution for improving recycling rates, are therefore intrinsically appealing to local authority waste managers who are increasingly being asked to ‘do more with less’.

One approach is to develop informational messages informed by the principles of psychology and behavioural economics. However, due to the relatively recent introduction of this service, there is little evidence about which types of messages are most effective for encouraging food waste recycling behaviour. It is also important for local authorities to understand the factors that influence the acceptability of such measures, as there is little point in introducing a measure that will be widely rejected by the public. Research on sustainable transportation has revealed that policy measures are usually considered to be more acceptable when individuals: are aware of the environmental problems associated with not engaging in the behaviour and assume responsibility for these problems, and/or feel a stronger moral obligation to contribute to the solution. Conversely, measures have been found to be less acceptable if they are perceived to be: unfair or ineffective at reducing environmental problems or if they threaten/restrict freedom of choice. Finally, even if authorities do manage to identify measures that are both effective and acceptable, these can only be introduced if it is practically feasible to do so. Previous research has shown that a number of administrative, political and technical factors can influence feasibility. The aim of this research, therefore, was to identify effective, acceptable and practically feasible behaviour change interventions that local authorities could introduce to encourage food waste recycling behaviour.

Social norm messages have proven to be a particularly effective, and cost-efficient, measure for encouraging other pro-environmental behaviours. Study 1 (N = 3310 households), a non-randomised quasi-experimental field study, quantitatively explored the relative effectiveness of different types of social norm and informational message (Figure 1) for encouraging food waste recycling behaviour in Woking, Surrey. Messages were distributed using wheelie bin hangers, and participation behaviour was measured pre and post intervention in both treatment and control groups. It was hypothesised that social norm messages would lead to a greater increase in participation than the informational messages. Unfortunately, results were inconclusive. Participation rates had decreased post-intervention across all study groups (including the control group), and differences in baseline participation behaviour (due to the lack of random assignment of participants to groups) made it difficult to detect if there was an intervention effect. In lieu of having conclusive results about the relative efficacy of these messages, a supplementary doorstep survey of a random sample of these households (N = 152 respondents) was conducted (Study 2). Results from this questionnaire, which included a series of behavioural and evaluative questions, indicated that more simplistic messages, delivered via a medium that provides a more prolonged degree of exposure, should be most likely to motivate a change in behaviour.
A recent study by the Waste and Resources Action Programme (WRAP) found that placing ‘no food waste’ stickers on the lids of refuse bins at the same time as distributing leaflets and a roll of free caddy liners resulted in food waste tonnage uplifts of anywhere between 15% and 48%. However, this combined intervention was expensive to implement (£1.70 per household), the actual tonnage uplift that could be achieved in Surrey is unknown, and there is uncertainty about the sustainability of impacts in the longer term. Study 3 (N = circa 99,000 households across 3 local authorities), a randomised control trial, was therefore designed to quantitatively examine the isolated impact of the sticker (Figure 1), the most cost-effective aspect of the WRAP intervention (£0.30 per household). Results of this trial (due in September) will inform the wider rollout to the remaining 451,000 eligible households in Surrey. Delivering this intervention at scale is estimated to cost £115,000 and will require a sustained minimum of 7% uplift in food waste tonnages to break even in year 1.

Finally, Study 4 (N = circa 350 households), a cross-sectional postal questionnaire, has been designed to fill the gap in knowledge about the factors that influence public acceptability of various policy measures. Responses will be compared to those derived from Study 5 (currently in development), an online survey of local authority decision makers, to ascertain the extent to which their decisions actually reflect public opinion. The outcomes of both surveys (due later this year) will be used to inform decision-making about which interventions to introduce.
Asset Management of Aging Cast Iron Trunk Main: Models for the Determination of Residual Strength

Azadeh Fahimi

Trunk mains are the life line of the water supply system. They are typically of large diameter, between 12 and 48 inches (approximately 450 – 1200 mm) and convey large volumes of water between treatment works local distribution networks, sometimes over quite significant distances (several hundred kilometres). Compared to distribution mains, trunk mains tend to have low failure rates, but when they do fail, the consequences are potentially much more significant, with direct, indirect and societal costs. A major trunk main failure can cause substantial flooding and interrupt drinking water supplies to a large number of customers. The catastrophic consequences of failure of trunk main assets along with the critical role they play within the water supply network necessitate proactive asset management strategies that could improve resilience of the network and reduce failures as much as possible. However the extent and size of this network of underground assets make the widespread replacement unfeasible and management strategies based on targeted replacement of deteriorated parts of the network become paramount.

A significant proportion of trunk mains network in many countries is still made of aging cast iron material. Remarkably, these aging assets have in fact outlived the pipes that replaced deteriorated parts of the network. Even so, many cast iron pipes are beginning to approach, or have already exceeded, their design life: consequently, out of a large population of pipes, some are failing whilst some still have considerable residual life.

Asset management, in this context focussing on the targeted replacement of degrading main, requires tools and models for the prediction of the future performance of the network. Several mechanistic deterioration models have been developed in recent years, which attempt to predict the condition of cast iron pipes, but few methodologies have specifically targeted water trunk mains. Worldwide, the requirement for a robust deterioration model that enables the accurate prediction of condition and performance of cast iron trunk water mains remains one of the water industry's key challenges.

Critical to developing the right deterioration methodology is to establish the main deterioration mechanism i.e. the main process that governs ageing and failure. Recent experimental work on cast iron trunk mains has investigated a number of parameters, with corrosion seeming to be the most significant cause of deterioration (particularly when compared with fatigue). However the prediction of deterioration is not easy. It depends on:

- the ability to characterise the material (in terms of the microstructure, the mechanical properties controlled by this microstructure and hence the performance);
- its local condition (in terms of soil chemistry and loading from the soil, foot and vehicular traffic and the impact of buildings and other services)
- operational pressures placed upon the network by its users.

In regards to trunk mains, local conditions (both in ‘global’ terms and at the district metering level) can affect the deterioration of such pipes. The size of the pipe can also have an impact on the behaviour observed due to a combination of geometrical considerations and the depth that pipes are buried – smaller diameter pipes are typically buried more shallowly than larger diameter pipes.

The developed deterioration models generally enable the prediction of the future condition of the mains based on the condition assessment of the individual pipes or the future performance of a network based on extrapolation from the limited information which is generally available across the network. Such tools are therefore reliant on a) good quality data from the field (although such data can be difficult to obtain for cast iron trunk mains) and b) realistic structural models of the strength and loads placed upon the pipe. In the latter case, loss-of-section models (strength of material) have traditionally been used to characterise the effect of corrosion, but fracture mechanics has been shown to be a useful approach in certain situations.

This project, being part of a wider, collaborative project between Thames Water and University of Surrey, has reviewed existing deterioration models for cast iron trunk mains and sought to modify these based on information arising from other areas of the project. In particular, new understanding of the corrosion of cast iron trunk main, the use of fracture mechanics to predict failure and non-destructive evaluation data gathering techniques has provided significant insight into improvements that can be made to deterioration models.
The present research has shown how loss-of-section models (which are still relevant) can be used with fracture mechanics models to provide boundaries to the failure “envelope”. In both cases, geometrical and operational conditions have been taken into account. As part of this work a previously developed methodology to calculate the resistance capacity of a cast iron pipe on the basis of loss of section has been reviewed. The principles of the developed methodology have been employed to estimate the resistance capacity of cast iron pipe in accordance with the fracture mechanics theory. On this basis, a pipe containing a corrosion pit has been analysed as if a section along its ring contains a longitudinal crack. In this methodology, the flexural strength of a “section” containing a defect is defined by any combination of internal force and bending moment that corresponds to a fracture mechanics failure condition i.e. stress intensity factor becomes equal to the critical stress intensity factor known as fracture toughness.

In line with the proposed methodology to estimate the flexural strength of a section with reduced thickness, here the flexural strength of a section containing a crack like defect is also represented in the form of an interaction diagram of moments and forces. It was found that the location of the corrosion defect in relation to the ring can be determinant of the mechanism of failure i.e. loss of section vs fracture mechanics.
The Role of Life Cycle Assessment (LCA) as a Decision-Support Tool for Emerging Materials

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Understanding the potential environmental impacts of the materials we use is important. By doing this we can choose whether or not to regulate, reduce or ban substances proven to present significant risk to human health and ecosystems. But in order to make environmental decisions effectively, we must collect and communicate information in the right way.

Communicating scientific information to support decision-making is challenging. Often facts are uncertain and values in dispute, but the stakes are high. Dialogue cannot simply be reduced to a singular, one-dimensional standard. Instead decision-support information should reflect the level and degree of understanding about a substance or product, drawing on a breadth of scientific information from a number of areas.

For product decision-support understanding life cycle impacts is vital. This enables a fuller picture of any potential environmental impacts through the whole life of the product; from raw materials production all the way through to end of life. To do this often Life Cycle Assessment (LCA) is used. The technique evaluates total inputs and emissions from the product system across the life cycle, and calculates an equivalency-based impact score. Using LCA as a comparative technique it can be used to avoid any future surprise by evaluating both the system under assessment and future potential alternatives.

Despite the potential LCA has to inform decision-making, with regards to emerging and new materials, it’s use is challenging. Here uncertainties are very high, information is sparse; however, potential impacts could be huge. LCA in this context cannot be used to extract a singular, highly certain, determination of a products relative impact.

This Engineering Doctorate (EngD) considers the role LCA plays in decision-making for emerging materials. It evaluates LCA in the context of past decision-making; the role LCA has in communicating current environmental assessment challenges; and how LCA might be used in the future to inform future decision-making practices. To do this it uses a case-study approach using the findings from real worked case-study examples to better understand the role of LCA in each context.

In the context of past decision-making, life cycle considerations were used to evaluate the decision to regulate lead from electronic solders under the Restriction of Hazardous Substances directive (2002/95/EU). The research appraised the decision in context with comparative assessments made on lead-free alternative solders. It found no evidence to suggest substantial benefit to regulating lead from a full life cycle impact perspective, with focus on reducing the perceived risk posed by lead towards human health. Human health impact does appear to be reduced; however, this is countered by increased global warming impact. Overall, this research highlighted the important role taking a full life cycle based approach has in informing decision-making, as an alternative to more narrow risk-based assessments.

In the context of current decision-making, one particular challenge for LCA is applying it towards nanomaterials. Most current LCAs ignore any nano-specific impacts caused by the nanomaterial themselves. Few studies have been able to effectively evaluate the technology. This section of the project contributes to a mandated European Committee for Standardisation (CEN) project currently being carried out by the sponsor organisation - the National Physical Laboratory (NPL). The project is to produce a guidance document for the application of LCA towards nanomaterials to go alongside the existing standards for LCA. This is part of wider CEN/TC 352 Nanotechnologies standards activities.

Overall, this adds to a greater understanding of the role of uncertainty assessment in LCA of emerging materials. Uncertainty guidance for LCA often focuses on the type of uncertainty you are assessing, but does not consider the level of uncertainty alongside this. As a whole uncertainty is often poorly considered in LCA studies and this is particularly the case in LCA studies for emerging materials. The research has shown the role that scenario analysis plays in evaluating emerging materials systems, alongside expert engagement and an approach to data collection which includes risk assessment-type data. Where the distribution or ranges in data were not known, statistical analysis could not be performed, nor could any meaningful probability assessment such as Monte Carlo analysis. The results of this research form a framework approach to dealing with uncertainty based on uncertainty level which has not been considered for LCA previously.
Finally, the EngD addresses the role LCA has in informing future decision-making. This was assessed in the context of business decision-making. The case study example used was that of alternative transparent conductive materials for electronic touch screens to replace current indium-based screens. Survey research was carried out based on both questionnaire and interview approaches. Overall, the research found that LCA was thought to be useful in gaining life cycle data for energy, carbon emissions and water use; however, other impacts such as those relating to health and safety and the environment were more relatable to risk assessment evaluation mechanisms. Being able to evaluate customer demand and materials performance was deemed to be more important aspects to industry – both now and in the future.

In summary, the EngD project contributes to understanding the role of LCA in the context of emerging materials systems. Rather than expecting LCA to deliver a singular numeric determination to guide decision-making; a more holistic use of LCA in combination with other techniques such as expert assessment and risk evaluation and the inclusion of appropriate uncertainty analysis guided by techniques used which reflect the level of uncertainty can be used instead. The project has evaluated some of the key challenges in LCA for decision-support, encompassing past, current and future decision-making, in order to enable the effective use of LCA as a decision-support tool towards emerging materials.
Integrated Design Strategies for Mixed Plastic Waste Pyrolysis

Matthew Gear

Recycling Technologies Ltd is currently running trials on a process that will be able to convert mixed plastic waste into a saleable hydrocarbon product with multiple possible uses both as recycling and recovery. Development of pyrolysis technology for mixed plastic wastes (and other organic wastes) is an area of growing interest in both industry and academia and shows promise for for improving the sustainability of plastic waste. Currently a 1/10 scale pilot plant is under construction (the RT700) with a view to scale up to a full scale mode (the RT7000). It is a valuable opportunity for study as the project itself covers the entire design process from the initial designs of a pilot plant, and its evaluation and development through to full scale up.

The overall aim of this project is to establish an integrated design framework for early R&D pilot plant development particularly for fluidised bed pyrolysis processes and related technologies. To complement technical considerations, environmental considerations must be taken into account in design. Life Cycle Assessment (LCA) is broadly accepted to be one of the most powerful tools for environmental assessment. It has power in providing a holistic view of the cradle to grave environmental performance across a wide range of impact categories each representing an environmental issue. In the following 2 years, this project will examine to what extent LCA can be used at such an early stage for decision support. The benefits and limitations of an integrated design approach to using LCA with a detailed design spreadsheet, a simulation, or a combination of both as the technical design basis will be evaluated. This includes evaluating where the best operational range lies for the fluidised bed combustor along with any potential issues from running outside this range.

The design scheme for chemical process plants is well established and follows a standard process that involves, in order; setting an objective; collection of physical and chemical data; generation of designs; and finally optimisation and the final design. For pilot scale plants at R&D level such as the pyrolysis plant that is at the centre of this study following this approach presents significant challenges, particularly for modelling the process. Review of the literature for pyrolysis of plastic shows that the results are highly dependent on conditions in the reactor and are given at fixed feed compositions and temperatures. Publications of laboratory studies of pyrolysis may be conducted in completely different conditions to those that the process will be operating in. Differing feed compositions will result in varying chemical products and differing distributions of solid, liquid and gaseous materials. Pyrolysis products also interact and react within the reactor giving a wide and unpredictable range of compounds. It is therefore impracticable to locate physical property and chemical kinetic data within the literature for all of the components and reactions involved. The combination of all these factors means that the use of literature for direct use in the design of the Recycling Technologies process is problematic. Questions remain on the best combination of design approaches that could be used as a design basis.

The RT700 pilot plant has been designed to be flexible in order to overcome this issue, and provide information for future refinement. This is particularly true in the fluidised bed combustor which is designed to be tested at a range of operating conditions. This process stage is where a carbon rich char by-product is burnt along with a fuel gas to provide energy in order to sustain the process. There is a lack of clarity in the literature with respect to the optimal gas velocity for the operation of the combustor. This flow velocity is critical to the design as it determines the physical size of the unit and will determine behaviour and performance. Operation in sub optimal conditions may cause losses in thermal efficiency and other associated problems.

LCA has been integrated at an early stage before the RT700 pilot plant has even been constructed with a view of assessing its applicability. LCA can be used to highlight areas where improvement is likely to have the biggest benefit as well as show which applications for the product are most environmentally beneficial. Literature is very clear in recommending that LCA is performed as early in development as possible in order to maximise the benefits and minimise costs that resultant design changes impart. It follows that the best time to do this is before the process has been constructed as this is where changes have potential for the largest influence on performance and lowest cost.

In the time up until now, a technical design spreadsheet, process simulation using Aspen Plus and initial prospective LCA using GaBi has been set up. Evaluation of the design strategies and LCA against real data from the pilot plant is planned once the RT700 pilot plant has been commissioned which is due very soon. Outputs will include a full process LCA, evaluation of potential design approaches including early integration of LCA, and evaluation of the performance and behaviour of the fluidised bed combustor across a range of operational conditions.

Publication of the LCA results in a journal such as “Waste Management” will aid upstream plastic producers in...
performing their own LCA's by enabling them to use data for the RT7000. Conclusions for the design tools and integration of LCA will aid in applications where a pilot plant is being developed especially for related pyrolysis process technologies (e.g. biomass) and other processes where prior knowledge is limited. Finally, recommendations for the design of fluidised bed combustion technologies can be used in the varied applications that they are employed. Target journals for the work on the combustor will be “powder technology” or another similar journal. Recycling Technologies Ltd will use the information gained from this project for full scale design work and also for communications of environmental performance.
Energy and Climate Change Implications of the Future of Gaming

Joshua Aslan

The energy efficiency of games consoles has become an important topic and current concern for several international policy initiatives and NGO publications, due to the aggregated effect of energy consumption per device and high sales volume. Calculating the carbon emissions of games consoles is a multifaceted problem, complicated by unknowns in user behaviour and increased functionality of new generation games consoles introduced to the market in late 2013.

Webb, et al. (2013) produced the most rigorous estimates to date of the energy use of games consoles in the use phase; using power consumption measurements of consoles and a detailed analysis of user behaviour from consumer surveys. Within Europe, this research contributed significantly to the successful implementation of a Voluntary Agreement (VA) under the Eco-design directive; demonstrating that energy efficiency measures, identified from the research, for the PlayStation® 4 will lead to energy savings in Europe equivalent to the electricity use of Latvia.

However, despite this body of research there are still many uncertainties concerning the future carbon impact of games consoles. Firstly, these estimates have been reliant on consumer surveys for user behaviour; and do not consider the full range of functions modern games consoles offer. On top of this uncertainty, a transition is predicted within the industry, with the introduction of distributed services, namely cloud gaming. Cloud gaming, differs from downloaded and disc based games, as the processing of game data takes place on a server (rather than a console) and is streamed through the Internet to the user’s device. There is currently no research into the carbon impact of cloud gaming.

The carbon impact of a cloud gaming service, such as Sony’s PlayStation® Now, is therefore heavily dependent on the energy use of the Internet, in addition to the user’s device. In order to estimate the carbon impact of cloud gaming, an understanding of the energy intensity of data processed remotely on a server and streamed through the Internet is required. This term is most widely defined as Internet energy intensity; the metric for which this research will adopt to measure this is kilowatt-hours per gigabyte (kWh/GB).

There is little consensus within the field of existing literature for determining Internet energy intensity, with estimates varying up to four orders of magnitude, ranging from 134 kWh/GB to 0.02 kWh/GB. This research has begun to conduct a meta-analysis in order to determine the most robust estimates within the literature. This research has highlighted so far that the main discrepancies are due to the range of system boundaries considered in analysis. The system boundary for this analysis is typically broken down into the following sections; Internet core network, Metro/Wide Access Network, Local Access Network, undersea or intercontinental cable, data centres, Customer Premise Equipment and edge devices. The observed large range between estimates can be partially attributed to the range of components considered within the system boundary. Each of the 14 papers considered claims to estimate Internet energy intensity, however it is clear that no value can be obtained from comparisons between an estimate that considers a system boundary consisting of the Internet core only to one that considers all of the aforementioned components. The same argument can also be made for the range observed within the literature for such components as the year in which data was collected, the types of technologies considered, the geographical location of the network observed and other technological assumptions.

This research will make the argument for using life cycle methodology to estimate Internet energy intensity; the approach followed most closely by Malmadin, et al. (2012) – the most robust estimate observed. This will provide more clarity for future analysis to draw from, in a field where accurate estimates are critical in order to determine, for example, the environmental value of shifting services from dedicated platforms to cloud based delivery of content. A familiar example for the application of such research could be to consider the environmental impact of DVDs or Blu-rays compared to Internet movie downloads or streaming services such as Netflix. This is also analogous within the gaming industry, where the three methods of gaming are now disc-, download- and cloud-based. Mayers, et al. (2014) calculated that gaming downloads of 8.8 GB or over are more carbon intensive than disc based gaming; contrary to the popularly assumed notion that virtualisation of services is always environmentally positive. This was true as of 2010, however, and significant changes today in both games consoles and Internet technologies mean this threshold is unlikely to have stayed the same, with no research to date concerning cloud gaming. This highlights the importance of contributing to greater accuracy in estimating Internet energy intensity.

The results from this meta-analysis will be used to help determine the environmental impact of a cloud gaming service and improve existing knowledge of gaming downloads. Research has been conducted to update estimates of games console energy use. Power measurements of the PlayStation® 4 have been taken across all functions and
will be continued through the duration of this project for each chassis update released. Newly available industry data for usage behaviour is currently being analysed, which will give more clarity to the actual nature of console use; reducing the reliance of estimates on consumer surveys. This together with a plan to fill in the known gaps for the life cycle carbon footprint of consoles, will allow for a more holistic estimate of the carbon footprint of gaming, expanding the system boundary of research beyond games consoles and use phase energy consumption.

Results and conclusions drawn from this research can be used to further inform the landscape on which stakeholders negotiate actions. The 2017 revision of the Ecodesign VA for games consoles, for example, will require the industry to present research on the status quo of games console energy use. Future European regulations, which could affect distributed services such as cloud gaming, may also benefit from research focused on Internet energy intensity. The gaming industry will also benefit from this with greater understanding of the environmental impact of both the games console and cloud gaming service. Broader industry recognition of this project has also been acknowledged, with a joint research venture planned with BT in this area, who are keen to understand how cloud gaming could impact the energy use of the UK Internet network.

References
Development of Robust Hybrid Modelling Techniques in the Wastewater Treatment Processes

Anthony Wu

This EngD project aims at developing hybrid modelling techniques for better process monitoring and fault detection in wastewater treatment processes. It is focused on two processes in particular: farm-fed anaerobic digestion and activated sludge process. From an environmental perspective, this research would support the sustained use of anaerobic digestion (which is a form of renewable energy) and reduce the energy usage from the activated sludge process. The project is a collaboration between the University of Surrey and Perceptive Engineering Limited (an engineering consultancy specialising in advanced process control), with financial support from the Engineering and Physical Sciences Research Council (EPSRC).

Process modelling represents the knowledge about a process in the form of abstract mathematical equations. They support the process operation by providing real-time performance benchmarks; helping the operators understand the process; for early fault detection; and for comparative studies on alternative modes of operation. There are generally two approaches to process modelling: first principles models and data-driven models. First principle models are based from conceptual theory and derivations of established laws; data-driven models applies statistical analysis on historical data to identify correlations between variables. The key difference relates to the type of information that is initially available, and the process models developed have different strengths and weaknesses. Hybrid models combine these two approaches, and my work is to look for innovative combinations to develop more robust models to use in industry. For both anaerobic digestion and activated sludge process, there are two key challenges to overcome: the lack of useful data and model complexity.

Both processes are slow, and project finances limit how much time can be allocated to collecting data. Historical data (if it is even available) is not particularly useful there is not much variation; these units have traditionally operated under a very reserved (and arguably inefficient) approach because of the costly implications of a major fault. This results in very small datasets to work with. Strictly first principle models and strictly data-driven models only take particular types of information, and neither performs well here. Hybrid models can utilise different types of information (process data, conceptual knowledge, operator experience etc.) and widens the pool of available information to build a model from. The challenge of rapid model identification using small datasets is the technical area that this research aims to advance. The results have potential impacts in other industries facing the same challenges; such as in the pharmaceutical industry where process models are useful but the means to collect data (batch trials) are very expensive. Model complexity is an application challenge. These processes have many complex interactions and need sophisticated models to accurately describe. But complex models require more process information to support, which are often unavailable (and are too expensive to acquire). The operators who use and maintain these models are often non-experts, need simpler and more transparent process models.

The EngD project has focused on farm-fed anaerobic digestion for the first two years, and is shifting towards the activated sludge process in the remaining two years. The work on anaerobic digestion helped facilitate my understanding and build a foundation in some hybrid modelling techniques, which will support the upcoming project tasks. I have developed a process model to estimate the biogas production of a co-digestion unit in real-time, based on typically available information measured in an anaerobic digester. This was extended to consider the operational revenue and costs of the process unit based in the UK, and became an economic calculator. The model has been implemented on a 500kW anaerobic digester in Glebe Farm (near Gloucestershire). The manuscript is being drafted, and I aim to submit to the Bioresource Technology journal. Additionally, I have worked on using multivariate statistical analysis techniques to aid early fault detection and diagnosis. This simplifies the process management for the farmer, and provide some guidance on corrective actions when a fault is detected.

In terms of activated sludge process, I will be investigating ways to build process models with very small datasets. I have identified areas that I plan to explore, and to summarise the work-plan:

Task 1 (present – month 24): Complete the remaining work on anaerobic digestion, including manuscript submission of the economic calculator and early fault detection techniques in real-time monitoring.

Task 2 (month 24–25): Explore the use of constrained optimisation. Data-driven models struggle with the model structure if there is not much data; they often end up being unrealistic or overly sensitive. Theoretical knowledge and operator experience can be used to outline a rough model structure, from which data-driven techniques are used to find the parameters. It makes use of first principles to give a realistic structure, and the computationally fast data-driven techniques to rapidly build the model.
Task 3 (month 25-28): Explore the use of model migration techniques. It tackles the challenge of limited data by looking at similar processes (such as the same unit on a different site) and extracting information from those to use for this process. This widens the pool of available information, and makes it easier to develop a process model.

Task 4 (month 28-36): Explore the use of subspace identification. The theory is based around alternative representations of the same data (called a subspace). A complex process can be represented in a subspace, and this altered form can be described using a simpler model. The model output (in the subspace) is then translated back to the original form.

Task 5 (month 36+): review and document the techniques explored and agree on what other areas or specific techniques should be explored for the remaining year.

In terms of journal publications, the research is more orientated towards journals relating to applied engineering. The research on hybrid modelling techniques in the activated sludge process is to help reduce the energy consumed by the process, and the Applied Energy journal would be a good place to publish that work. The fault detection techniques for the anaerobic digestion process will be reviewed later to see if there is sufficient material for a journal publication.
Generational Change in Relation to Technological Adaptation and Innovation in the Civil Nuclear Energy Sector

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Under the 2008 Climate Change Act, the UK has set a minimal target of 80\% reduction in greenhouse gas emissions by 2050 relative to the 1990 emission levels as a baseline. Nuclear energy is currently a reliable contributor of circa 16\% of UK electricity, and it is expected to play a vital role in the future decarbonised electrical supply. The nuclear industry needs to assess current and future world conditions and constraints, and determine its viability as an attainable cheap, low-carbon energy source. (Department of Energy and Climate Change, 2011)

It has been suggested that the stagnant period the industry underwent following the Chernobyl incident caused a slowing of innovative studies and technological breakthroughs, and has contributed to a loss of expertise and a thinning of skills base due to workforce retirement. (Nuclear Innovation and Research Advisory Board, 2015)

Rolls-Royce has commissioned this research with aims to investigate the potential impacts future megatrends may have on the industry’s ability to deliver a low carbon energy system. Examples of issues to be considered may include current perceptions on innovative information and communication technology (ICT) and its applicability in the industry. These perceptions are to be collated from appropriate stakeholder groups, such as retirees, employees and potential workforce. Another area is the public perception on civil nuclear energy; their understanding of current issues, constraints, and its safety and reliability.

Data collated is expected to facilitate a more solid database for the industry to better understand its position in the global energy industry, and potentially inform Government and policy makers while they set out national nuclear strategies. It must be realised that public approval is imperative for nuclear energy to achieve the aforementioned set targets (Nuclear Innovation and Research Advisory Board, 2015). Moreover, data would seek to identify if there is a perceived existing prejudice against innovation, both from within and outside the industry and help set up a framework to assess the benefits, risks, optimal implementation methods, and implications on existing skill base in relation to innovative ICT. It has also been suggested that the reduced investment in the industry after Chernobyl, has led to a ‘generation gap’ in terms of skills and expertise. This research will seek to identify the scale of such a gap, and as a result, develop innovative knowledge databases to facilitate the transfer of knowledge and skills across generations.

References


Life Cycle Engineering of a Self-Chilling Beverage Can
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The principles of life cycle engineering have been applied to define a sustainable manufacturing chain for a new consumer product, a self-chilling beverage can. This is able to cool the beverage at the point of consumption, thereby avoiding refrigerated storage.

The chilling action is provided by endothermic desorption of carbon dioxide previously adsorbed onto a bed of activated carbon, contained in an inner component of “chill on demand” can called the Heat Exchange Unit (HEU).

The focus of this research is to devise a way to ensure the best cooling performance with a minimal global environmental impact at reasonable cost. Accordingly to this, a multidisciplinary approach has been adopted in order to optimize the self-chilling can product.

It started with the heat exchange investigation inside the bed of activated carbon during the adsorption/desorption process. The cooling effect depends on the amount of carbon dioxide adsorbed and the heat of desorption. The amount of CO₂ depends on the specific surface area and composition of activated carbon, and its particular form of activation [1, 2]. Several experiments on a simulated self-chilling can have been carried out to determine the temperature behavior of the system and evaluate the adsorption heat in the bed of activated carbon bonded with graphite.

A complementary activity in the project is developing a Life Cycle Assessment considering each of the principal components of the can: activated carbon, aluminium, steel and carbon dioxide (Figure 1).

![Diagram of Chill on demand product system.](https://example.com/diagram)

The results show that production of the adsorbent dominates the overall environmental impacts of the delivery system (Figure 2) and that this makes the chill on demand more harmful for the environment than the conventional refrigerated beverage can (Figure 3).
From these results a deeper analysis on the activated carbon manufacturing has been conducted.

It is well known that the activated carbons are the “material of the future”, due to their excellent performance in a number of process applications such as water purification, coffee decaffeination, wine decolourization, treatment of drinking water, industrial flue gas cleaning, air conditioning and many more [3, 4]. They have particularly favourable characteristics for adsorption processes, thanks to their high porosity, large surface area, high surface reactivity and ease of compaction into a packed bed. However, a review of existing literature in the public domain suggests that a comprehensive assessment of the environmental impacts of their manufacture has not yet been reported.

This study considers activated carbons produced from waste coconut shells in Indonesia. Coconut shells are often utilized as raw materials for activated carbon production, due to their abundant supply (which improves the economic viability of their manufacture) and high density and high purity. It is also claimed that they have an environmental advantage over coal-based carbons [5].
Estimates for the total environmental burdens over the Life Cycle have been obtained by developing mass and energy balances for each of the process units of adsorbent production, with the support of the STAN (SubsTance flow ANalysis) software [6], which allows following the fate of any single substance or element in the input and output streams of each process unit to be identified (Figure 4).

The results obtained from energy and mass balances are then converted to environmental impacts by using the software package GaBi 6.0, and the related life cycle inventory databanks Ecoinvent 3.0 and GaBi Professional. The assessment of the life cycle environmental impacts was developed by means of the impact CML–2001 methodology developed at the University of Leiden, which utilizes midpoint impact categories [7]. It should be noted that the developed LCA did not encompass the entire life cycle of the product from “cradle-to-grave”. As in several LCAs of agricultural products, a “cradle-to-gate” analysis has been applied, which limits the boundaries of the system assessed to processes from raw material acquisition to the delivery of the product: use and final disposal of the activated carbon depend on the system in which it is used [8] and therefore have not been included.

The details of the positive or negative contributions from all the stages of the manufacturing chain have been identified and quantified, in terms of truly global and more localised impact categories. This assessment indicates (Figure 5) that Climate Change potential turns out to be one of the most significant global impacts, while Human Toxicity is the most relevant localised impact category.

Figure 4 Mass flow Sankey diagram of the activated carbon production system under analysis. All the flows are expressed as tonne/day.

Figure 5 LCIA of AC manufacturing (normalization: world, year 2013 CML–2001 person equivalents).
The overall environmental performance of the manufacturing process is dominated by the stages of crushing and tumbling (where the coconut, or the activated carbon product, are crushed to obtain powdered or granulated material). Their huge contribution to the overall impact is mostly related to the high consumptions of electrical energy, which in the Indonesian energy mix is largely produced form hard coal.

From these results, it has been decided to carry out a sensitivity analysis by exploring some alternative scenarios: localizing the AC production in New Zealand (where the coconut shells are sent from Indonesia and the final product is then transported to California for utilization) and assuming that the AC manufacturing company utilizes the coconut shells as feedstock for AC production but also as biofuel for the production of electric energy necessary to the internal consumption (then, mainly the crusher&tumbling unit).

Figure 6 reveals that the sustainability of activated carbon from waste coconut shells collected in Indonesia could be improved greatly by manufacturing the adsorbent in New Zealand or by using a waste biomass (the same coconut shells) as biofuel for the production of electrical energy necessary for the process.

However, it appears that, even if the activated carbon is produced in New Zealand and with a high percentage of HEU recovery and reuse, the global environmental impact of the Chill on demand system with this current design is higher in most categories than that of a conventional can refrigerated in a single door cooler. A design improvement is then required to make the self-chilling can not only convenient but also environmentally friendly.

References

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Strategies For Future Proofing Social Housing Through Climate Change Adaptation And Mitigation

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Key words: adaptation, mitigation, vulnerability, social housing, building retrofit.

Background

The need for mitigation: carbon emission reduction targets

With the Climate Change act in 2008, the UK Government has set an ambitious legally binding target to reduce Greenhouse Gas (GHG) emissions by 80% in 2050, with 5-yearly staging posts. The strength of the targets mean that reductions are required in all sectors, particularly for the building sector which accounts for 37% of total UK GHG emissions.

While current building standards and regulations require high energy efficiency levels, it is estimated that 70% of the buildings that exist today will still remain in 2050 [1]. England has one of the oldest dwelling stocks in Europe, thus it is imperative to address low-carbon building retrofit if we are to meet the carbon budgets.

The need for climate change adaptation: climate change impacts

While early policies and measures have focused on climate change mitigation, there has been an increasing recognition that, regardless of how promptly and effectively mitigation policies will be implemented, the undergoing and future changes are causing a number of adverse impacts on our lifestyle and the built environment.

Probabilistic climate change scenarios indicate that the impact of climate-related issues on the built environment could be critical [3]. With regards to social housing, key climate impacts include harmful effects on residents’ health from extreme temperatures, poor comfort conditions and more risk of damage from flooding [1].

Risk factors, present and future vulnerability

The main causes and risk factors associated with some key climate change impacts (i.e. overheating in homes) are well understood [4].

Evidence shows that certain areas present characteristics that make them exceptionally vulnerable, due to overlaying layers of vulnerability: social and demographic, geographic, physical environment, such as social housing schemes in dense urban environments in Greater London and the South-East [1]. However there is still lack of evidence about the detailed scale of the problem and further research is needed to determine the extent of impacts such as overheating, water stress etc. [5]

Further attention will also need to be given to the exacerbation of those impacts that will result from the combination of predicted changes in climate with increased urbanisation and an ageing population.

Aim of the research

The following objectives were set in the initial proposal:

a) Analyse current and predicted effects of climate change to model vulnerability of existing and future social housing to selected climate change impacts. The risk-based approach will include understanding the entity of estimated climate change impacts in order to identify a hierarchic set of risks that need to be addressed.

b) Develop, test and evaluate a portfolio of retrofit solutions from a technological and socio-economic point of view, with focus on the most relevant options for a realistic perspective of 2030 leading to a pathway to 2050.

c) Produce deliverables including a library or set of design guidelines, and a decision-making framework that will enable assessing a wide range of adaptation and mitigation options to include with both retrofit and new build of medium and high-rise social and mixed-tenure housing. Such measures could potentially be combined also with extensions, new infill buildings and inter-linked building solutions.
PRP Innovate Project Work

The present section describes two projects I have been involved in, while at PRP Innovate, which have been instrumental towards building crucial knowledge and skills to make significant progress with the research. Both projects aim at investigating thermal comfort on vulnerable parts of the population: “Design Red Lodge for a Future Climate” involved an overheating risk assessment for elderly and care home residents; “Amberley House Post Occupancy Study” seeks to understand to which degree user behavior can affect thermal comfort, including how residents cope with extreme temperatures.

Design Red Lodge for a Future Climate; Red Lodge Care Facilities, New Earswick, York

The project’s main objective was considering the potential impacts, for 2030s, 2050s and 2080s, assessing vulnerability, health and social aspects for both residents and care workers.

A risk assessment was carried out, based on main ‘hazards’, such as direct and indirect solar gains and reduced heat losses. The following step was instrumental to map the risk of future overheating and identify the most critical areas of the scheme.

A sensitivity analysis was performed to test measures in isolation, and compare their effectiveness to the baseline. The results were presented at a stakeholder workshop and each measure was rated against meaningful criteria. For each room type, a future adaptation scenario was recommended, including a timeline for the highest-rated measures to be implemented.

Amberley House Post-Occupy Monitoring Study

The study includes post-occupancy monitoring of a residential development, consisting of 100% affordable units, built and certified under the PassivHaus standard.

Key research questions include, among others:

• Evaluate how the information / training received by residents impacts on their energy behaviour.

• Evaluate residents’ perceived comfort levels in terms of temperature, humidity, indoor air quality (IAQ) and understand how they behave to set and adapt to their desired comfort conditions.

Interim Findings

• All rooms tend to be too warm, both in winter and in summer, leading to severe discomfort.

• In some rooms the high temperatures depend on external / building-related factors, such as south facing bedrooms, lack of shading, top floor rooms and un-ventilated loft spaces, modest thermal mass etc.

• However, high occupancy and an inappropriate use of both the heating and ventilation systems are also crucial factors. User behaviour is key in controlling temperatures.

References

Are our bridge foundations fit for future river flows?

Hristo Dikanski

Research background
Weather-related disruption is a pressing issue for the railway industry in Britain. Extreme weather events can cause delays and cancellations across the network, result in significant economic losses and even cut off entire communities, as happened in Cumbria in 2009 and in Cornwall in 2014 following flooding events. Such issues are projected to increase in frequency and intensity in the future due to climate change.

This research focuses on one particular weather-related risk: bridge scour. Scour is the removal of river bed material at bridge foundations due to hydraulic action and is most common cause of bridge failure in the UK, as well as worldwide. It is a complex process that is not deeply understood by engineers. To quantify expected scour depths and risk numerous heuristic prediction methods exist but their generally low accuracy introduces uncertainty to the analysis.

Global climate change affects local weather and rainfall patterns, which results in changes in river flow regimes. This can directly affect scour depths and the risk of bridge failure. These processes, however, include uncertainties from various sources, which present asset managers with a serious challenge. Uncertainties are associated with climate modelling, downscaling global climate to local weather patterns, catchment response in terms of river flow and ultimately the effect all these have on scour depths and risk of failure.

Aim and objectives
Network Rail’s asset management procedures are based on historical knowledge, and may not capture future changes, brought about by climate change. A limited understanding of the potential impacts climate change may have on railway assets and the overarching uncertainty increase the challenge for sustainable adaptation. Managing scour risk is a good example of an asset management process that is an important risk to the railway assets and may be affected by climate change.

This research aims to develop a methodology for the assessment of the impact of changing climatic drivers on bridge scour risk in Network Rail. This methodology can act as a foundation for a broader climate change adaptation methodology for bridge scour. This aim will be achieved via the following objectives:

- Compile a range of tools to model the chain of processes linking climate change and bridge scour risk
- Using the above tools, assess the potential effects of climate change on bridge scour for selected case study bridges
- Quantify and summarise the relevant uncertainties in the analysis and make recommendations on how to approach them
- Comment on the adequacy of current scour risk management procedures in Network Rail and make recommendations for potential improvements in the scour risk assessment method
- Make recommendations for the delivery of effective climate change adaptation measures for bridge scour
- Based on the reflections from bridge scour risk, make recommendations for developing detailed methodologies for other climate risks and asset types

Successes to date
A methodology has been set up to model the chain of processes linking climatic drivers and bridge scour risk. After applying the procedure for two selected case study bridges in the south-west of England, the procedure was automated to enable a sweep analysis across a larger sample of structures.

The methodology is tailored to Network Rail structures and is based on data available to the network operator. Thus, detailed analysis can be undertaken on a bridge-by-bridge basis, which provides tangible benefits for whole-life asset management.

To maximise the value of the analysis two assessment stages have been introduced. The first, more general stage includes a high level assessment at an aggregate level and aims to highlight bridges, which are particularly sensitive to potential increases in river flows as a result of climate change. The second stage includes a more detailed climatic and hydrological analysis of the highlighted catchments, providing a more accurate assessment of the potential impacts.

Preliminary results suggest that the current workload prioritisation will not need to be substantially changed due to climate change. However, the projected increases in river flows will increase scour risk for structures and may...
necessitate certain intervention measures and investments to take place earlier than planned, which needs to be factored into the long-term funding cycle.

**Future aims and impact**

In addition to the impacts of climate change on railway assets, this research studies the wider issues around the relationship between climatic drivers, weather events and asset performance. Thus, it can enable Network Rail and other infrastructure operators to improve their management of assets today.

One future objective for this research is to increase Network Rail’s understanding of the relevant uncertainties associated with climatic drivers and their effects on bridge scour. This will be done via a comprehensive sensitivity analysis of the inputs for the different stages of the modelling procedure. Thus, the parameters, which have the largest impact on the final estimation of risk, can be identified. This can help target future efforts in research and investigation in order to maximise the value of investments.

This research will inform the development of Network Rail’s structures policy for Control Period 5 (2019-2024).

**Contributions to knowledge**

This research will:

- Increase Network Rail’s understanding of the relationship between climatic drivers and bridge scour risk
- Enable Network Rail to assess the likely impacts of climate change on the scour risk for individual assets, including relevant timescales and confidence intervals
- Increase Network Rail’s understanding of the uncertainties in the current scour risk assessment and make recommendations for potential improvements
How can moments of change contribute to more sustainable lives? – A Research Project in Cooperation with IKEA and Hubbub UK

Patrick Elf

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Research Aim
IKEA aims to create a movement for sustainable living among UK households and communities, building momentum for inspirational sustainable solutions. The campaign is based on initial stimulation of sustainable living changes in a sample of households using a range of selected products. The overarching goal of the PD project is to evaluate this programme and in the process to explore how far a focus on household transitions (‘moments of change’) can be used to promote more sustainable consumption shifts by households, and how far the programme enables household ‘champions’ to act as effective role models and communicators to peers across their social networks.

Abstract
An improved understanding of human behaviour, especially with respect to consumption, has the potential to drive changes in behaviour which have increasingly negative impacts on the environment. Consumer behaviour is relevant, “nudge-able”, often irrational and driven by external factors. There is growing academic and policy interest in better understanding of consumption patterns and of the factors that can help to promote more sustainable consumption and shift the focus of consumers towards more sustainable products and services. This research project is still in a very early stage so that this poster presentation can be seen as a first outline of the intended corporate project. It will aim at examining how changes in habits can be accommodated and enforced through moments of change. The research will draw on both social psychology and sociology of sustainable lifestyles and practices, and explore the successes and limitations of the proposed corporate initiative.

Partnering Organisations
IKEA is the world’s largest furniture retailer. The Swedish multinational company was found in 1943 and today operates 353 stores in 46 countries on four continents (Europe, North America, Asia and Australia) with a 12,000 items strong product-range.

In recent years IKEA adapted a strong approach towards sustainable development which is now, together with the code of conduct IWAY, integral part of its business strategy.

Hubbub UK is a new and highly ambitious environmental charity that is supporting IKEA in communicating environmental issues through a fresh, positive, sociable, collaborative and open way which intend to eventually result in a change in behaviour.

Their work combines innovative communication strategies with the latest scientific thinking aiming to change human lifestyles to protect the environment.

Methodology
The IKEA Sustainable Living Project (SLP) is designed as a three year social experiment using ethnographic research. It aims to add to the growing research interest for moments of change, i.e. moments with a significant impact on one’s life such as leaving school and/or starting university, becoming a parent or retiring, and will build on the findings gathered throughout the process. Prior to the research project broad themes have been identified for each of the three years:

Year One of SLP is ‘I will’: this involves working intensively with 150 households to understand what support they needed to live more sustainably. Year Two will then explore the question ‘I have, will you?’, using the experience of the first set of households to stimulate others to act. Year Three is ‘We have, will you’, aiming to become a broader campaign urging organisations to make it easier for people to live more sustainably.

A range of approaches will be utilised to understand and capture the full depth and richness of factors which contribute to consumer behaviour and driving change. This is likely to include, but not limited to:
• **Quantitative research** with both consumer and so called co-workers i.e. employees at IKEA.
  
  o **IKEA Family:**
    - Almost 5 million customers will be invited to participate in a survey about customer needs.
  
  o **Co-Workers (including senior executives if possible)**
    - Surveys to generate an overview of the understanding of sustainable development of co-workers. This will explore how to best target their interest in sustainability and contribute to an improved engagement with related initiatives.

• **Qualitative research** with both consumer and co-workers
  
  o Empiric research will be key to generate an in-depth understanding of underlying motivation to buy and sell more sustainable products.

• **Action research** (predominately co-workers)
  
  o This can help to better engage with different stakeholders and to generate an improved understanding of why sustainability matters to IKEA.

• **Longitudinal studies**
  
  o This has the potential to create a good case with strong evidence.

**Results**

It is hoped that the research will lead to results that can contribute to IKEA's Vision 2020 strategy for sustainability through the following:

• An improved understanding of the impact the research has delivered in achieving tangible environmental, financial and social benefits.

• A proven understanding as to how the campaign has impacted upon awareness, values and attitudes to sustainability.

• Evidence whether the campaign has helped to shift behaviour patterns and consumer choice. In addition, whether the campaign has delivered wider impact in other households, communities, organisations and at a policy level.

• An understanding of what worked - Which elements of the campaign have been successful and what components in the campaign design and implementation created this positive impact.

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Encouraging sustainable travel within Surrey

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Industrial Sponsor: Surrey County Council

Background
Cycling or walking to work makes the average commuter fitter, richer, happier and longer living. Residents in streets with less traffic have more friends than their counterparts in traffic-severed neighbourhoods. Shops in streets with more cyclists have a greater turnover. A country with a drastic increase in cycling and walking to work would see a corresponding decrease in its CO2 emissions and air pollution.

Most of Holland, several major European cities (including Cambridge and Oxford) have shown that having a mode-share of up to 50% of commuter journeys by bike and foot is possible... but the average across the UK is still stubbornly low – around 2% for cycling and 10% for walking.

Given the proven benefits, many local authorities are keen to know how they might encourage walking and cycling. It is generally recognised that such encouragement will require infrastructure development as well as behaviour change and marketing strategies, but infrastructure is expensive, and authorities are under significant budget pressures.

Aim
The aim of this project is to determine how UK authorities can optimise their spend on cycling and walking infrastructure. Recent literature has indicated that, for cycling in particular “there has been surprisingly little research on how to decide how to prioritize and choose locations for [...] infrastructure investments”, and as such this has become the initial aim of the project:

Previous work in this field has used census data from 2001 to identify factors that affect cycling levels (such as hilliness, distance to work characteristics, and population demographics). This project aims to repeat this research with 2011 census data and a focus on the identification of factors that are constraining cycle to work levels in each area. Of particular interest is the identification of areas where lack of cycling infrastructure is constraining cycle to work levels.

Once these areas have been identified, the project can move on to determining how the routing of cycling infrastructure, and any marketing programs alongside it, can be adjusted to optimise the uptake of cycling. It may also be possible to extend these techniques for use with infrastructure and behaviour change programs related to walking.

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2 Estimation of the determinants of bicycle mode share for the journey to work using census data. Parkin et a, 2008

Method
The 2011 census holds information on cycle-to-work levels at many different levels of population. The smallest is the ‘Lower Super Output Area’ - small areas of geography containing approximately 100 residents. There are about 35,000 of these in England and Wales. Such a large dataset enables the researcher to examine how small changes in hilliness, weather, parking charges, public transport provision, cycling infrastructure, traffic and other variables impact levels of cycling to work. A model can be constructed that predicts the level of cycling expected given information on these variables, and from this, areas that are particularly susceptible to changes in those variables controlled by the local authority can be identified.
Results to date

The model is still under construction, but it is currently able to predict about 65% of the variability in cycling levels when driven by physical variables, or 75% when utilising physical and demographic variables together. Some of the more interesting findings to date are:

- The relative performance of cycling against alternative modes within the local area appears to be one of the more important determinants – if residents can access their city by bike in comparable times to car and public transport alternatives, they will cycle significantly more

- Student numbers appear to positively affect the level of commuter cycling, even though students are explicitly omitted from the census data in use. It is theorised that perhaps seeing more people cycling (as students are more likely to do than the general population) might encourage cycling levels – a positive feedback effect

- Parking costs appear to have a positive effect on cycling levels – the higher the parking costs the more cyclists

- Cycle lanes appear to have a positive impact, but perhaps not as high as might be expected (although there is as yet no measure for the differing quality levels of infrastructure provision within the model)

Further work

Much of the work to date has focussed on the physical factors governing cycling levels, but of particular interest as the model develops will be demographic elements. If an authority understands the effect new cycle lanes will have on specific segments of society then interventions can be targeted at those deemed to be most in need.

Finally, there is also a political aspect to the work. If the model is not usable then it is not useful. It must be able to fit alongside current planning norms within authorities and be flexible enough to allow users to balance differing priorities, budgets and stakeholder preferences.
Sustainable Odour Management within Thames Water
Behzad Haji Mirza Beigi

Thames Water is the largest water company in the UK serving 9 million customers with potable water and treating the wastewater from 14 million customers in the London and Thames Valley regions. Thames operates 350 Sewage Treatment Works (STW) with a high level of diversity in size, design and operation conditions. There are 250,000 properties within 1km of a Thames Water sewage works. This illustrates the potential impact of odours that escape from Thames Water sites. Furthermore odour treatment can constitute up to 15% of the total energy consumption within an STW. Hence the Research Engineer has set out to make a difference by identifying and justifying the means of maximising sustainability of odour management within Thames Water.

Due to the diversity in properties of Sewage Works, the optimal solutions to odour problems must be defined specific to the operations and sites in question. In other words there could never be a universal optimal solution for sustainable odour management. Numerous solutions to odour problems are under ongoing investigation by the RE. These solutions have been categorised under three groups. The first group is the improvement of the housekeeping of the STWs. Poor housekeeping of the STWs or operating with faulty equipment or operating under flawed operation conditions are amongst the main sources of odour nuisance. Sound operation would guarantee that parameters such as pH, temperature, turbulence and retention time of sewage and sludge are kept at a range to minimize the odour generation and emission rates. Housekeeping techniques are generally the most economically and environmentally sustainable means of odour management. However with time housekeeping solutions can become compromised. Also same housekeeping solutions are non-applicable or inadequate in the cases of downtime or faulty processes.

Second category of solutions is referred to as “cover and treat” solutions. In such cases the entire source of malodour is covered by a structure (e.g. a building) and malodorous air from the structure is ventilated into an Odour Control Unit (OCU), whereby the odorous molecules are removed from air or reduced to odourless molecules. OCUs achieve this by either chemical, physical or biological means or a combination of these mechanisms. Cover and treat schemes can be designed to reliably eliminate odour nuisance. However they are often expensive and come with a high environmental impact. The RE has identified numerous types of OCUs and the level and type of odour that they are suitable for. The RE aims to quantify the variables contributing to cost and environmental impacts of some of the more promising OCUs. The RE expects to then use the learnings to propose a framework in which the most sustainable alternative could be identified. Biological OCUs are regarded as the most sustainable alternatives; as they use no chemicals and the units have expected working lives of up to 30 year. One of the main problems with conventional OCUs is that they work under a single pH value whereas different malodours are best removed under different pH values. The RE is therefore investigating a state of the art biological OCU which operates under a pH profile ranging between pH 2 to 7. Evaluating, quantifying and optimising the performance of this new technology, is one of the main constituents of the RE’s research in the first two years of the EngD.

Figure 1: Schematics of the emerging odour control technology to be characterised by the RE.
The third category of solutions is via introduction of chemicals. Some examples of this include spraying large amounts of chemicals with a pleasant odour in order to mask the malodours. Another example is to add chemicals to sewage or sludge that would readjust the pH and hence increase the solubility of malodourous compounds. This would reduce the emission rate of malodours to the air. This category of solutions is by far the most expensive and environmentally damaging alternative and should only be used as a temporary measure and only in extreme scenarios.

The RE has developed an interactive database of STWs within Thames Water with their existing OCUs. The database has been equipped with the capability to classify the existing OCUs with respect to their characteristics (e.g. design characteristics, size, performance, means of maintenance, etc). The RE has also developed a model to predict the odour emission rate from different sources.

In conclusion the RE is at the beginning of a 4 year endeavour to attain comprehensive understanding of the ways of treating or abating odours leading to a holistic approach to minimising odour nuisance sustainability.
Advanced Modelling of Heat-Mass Transfer in Foods and Beverages for Sustainable Manufacture, Storage and Distribution

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The use of heat and mass transfer calculations in food processing can help identify inefficiencies in energy and material use as well as insufficient product quality. In particular, food product quality is of the essence as for health and safety reasons products of decreased quality are disposed of. In developed countries 40% of the total food waste is attributed to the manufacturing industry.

Unilever is one of the leading consumer goods companies in the world. Its product portfolio includes food and beverages among others. Unilever was one of the first companies to launch a Sustainable Living Plan with which they aspire to decouple their growth from their environmental impact. Their goal is that by 2020 the company will have doubled its business whilst having decreased its environmental impact. The reduction of waste as well as a more efficient resource and energy use could assist the company in achieving this goal.

The manufacture of ice cream is one of the most energy intensive processes. Ice cream is a complex multiphase food colloid consisting of ice crystals, air bubbles, fat and sugar solutions [1]. The typical stages in the production of ice cream are mixing, pasteurization, homogenization, ageing, freezing and hardening. The product assembly and packaging takes place by combining ice cream with other components like cones, chocolate or fruit among others. In particular ice cream cones consist of a wafer cone which is internally coated with a chocolate mixture and subsequently filled with ice cream. The purpose of the chocolate coating is to prevent the transfer of moisture from the ice cream to the wafer. In order to eliminate moisture transfer from the outside, the ice cream cones are packaged in a laminate of aluminium foil paper. The product is kept in cold stores at temperatures of about -25°C. In every stage of transport care should be taken to ensure that the ice cream is not subjected to increased temperature that can result in quality deterioration due to recrystalisation and coarsening.

The aim of this project is to develop heat and mass transfer models in the ice cream manufacturing, storage and distribution processes. The inputs for the model will be the physical and chemical properties of ice cream components. If some of the required data will not be available appropriate experiments will be designed and conducted to measure them. The developed heat and mass transfer models will be used to optimise the product quality while aiming to reduce energy consumption and material waste at the same time. To conclude this project, life cycle assessment will be used to ascertain the potential benefit of the improved process in terms of environmental impact.

References
Polycentric approaches to UK sustainable energy transitions

Emelia Melville

This research aims to contribute to a whole system transformation of the UK energy system, by focusing on the role that local authorities and the community energy sector can have in catalysing this.

The research agenda has been developed through engagement with a number of community and local energy projects at a variety of scales and localities in the UK, and through engagement with the Ostrom Workshop literature on polycentric governance, common pool resource management and institutional analysis.

The methodology is one of co-production of analysis, where practitioners in a variety of positions within the UK energy system will be invited to feed back on the analysis of local energy governance projects. Their feedback will be incorporated as the analysis progresses, and the learning they gain from participation in the research will be monitored through before and after interviews.

Organisations and individuals are seen as having the ability to take action on their own initiative in an interdependent context. The actions of local organisations are more effective if they are coordinated, and the options available to them are constrained and enabled by national level policy, regulation and infrastructure provision. This perspective is theorised as ‘polycentric’, where a polycentric system is defined as “A pattern of organisation where many independent elements are capable of mutual adjustment for ordering their relationships with one another within a general system of rules” Vincent Ostrom (1972, p. 21). A research agenda for polycentric approaches to energy systems has been set out by Goldthau (2014) and Sovacool (2011).

Context

Climate change is a problem of a global scale and it can be difficult for ordinary citizens to see a way to intervene in international negotiations. However, Ostrom (2010) offers us an alternative approach: to consider multi-scale governance of climate change, and see local level action as part of an interdependent network of activity which is both influenced by and influences global change.

In the UK, the community energy sector has grown rapidly over the past seven years (Seyfang et al., 2013), as has interest in municipal energy governance (BuroHappold, 2015). This activity can be seen as contributing to the ‘thousand flowers’ pathway identified as one of three potential pathways to a low carbon electricity future for the UK (Foxon, 2013).

In addition to using a polycentric perspective on energy analysis, the research considers the value of commons, private and public property regimes for different aspects of energy systems, linking to the problem of climate change which can be seen as a tragedy of the commons, a market failure, or a failure of public domain governance (Young, 2011).

Successes to date - case studies

This research takes an empirically grounded approach to understanding the potential and limitations of the thousand flowers pathway, through case studies in the community energy sector and in energy services development by local authorities. Projects to date include:

1. **Innovate UK funded exploration of the potential for community governance of demand response**

   Exploring the financial viability of community based electricity demand response. It concluded that the sources of value were too dispersed for this to be financially viable in the current market, and local energy markets could provide a solution in the longer term (Melville & Cooke, 2013).

2. **Low Carbon Networks Fund project testing community scale peak electricity demand reduction**

   Testing the relevance of Ostrom’s (1990) common pool resource management principles for a community scale electricity demand response initiative. Concluding that mutual monitoring is seen as ‘big brotherish’, but that individual monitoring would be valuable for household learning.

3. **Participant observation of the developing relationship between Bristol Energy Network and Bristol City Council**

   Participant observation with both organisations has provided insights about the different framings of legitimacy used by each, the roles each has played, and the tensions between them.
4. Creating a narrative and facilitating an event for a Cornwall Energy Island

Engagement with a wide range of stakeholders both within and outside Cornwall, and understanding of local and barriers and drivers for energy transitions, and potentially effective actions as perceived by workshop participants. Deepened understanding of national constraints on local action.

5. B&NES energy services governance

Interviews with a number of local authorities around the country, revealing the diversity of approaches to local energy governance, and relationships between local authorities, private sector and community energy groups.

The insights from this work inform the analysis going forward, and relationships developed through this work will be drawn on to recruit research participants.

Expected contributions to knowledge

The research aims to contribute to knowledge in a number of ways

- A more detailed understanding of the roles of local authority and community organisations in a transition to a more sustainable UK energy system.
- An understanding of the ways in which participating in this analysis affects the perspectives of practitioners, and the kind of language that makes the analysis meaningful outside of academia
- Potential identification of institutional changes that could achieve a more sustainable energy system

This research aims to make a contribution in two theoretical areas

- Common pool resource management and theories of energy systems as commons
- Polycentric governance of energy systems

Expected impact

For the research participants

- A greater understanding of the context in which they are working, the actions that can be effective, and the way their actions are constrained and enabled by different stakeholders
- The development of workshop tools that can be used in participants’ work contexts for further exploration and dissemination of these insights

For BuroHappold as the sponsor company

- Appreciation of role of local authorities and community organisations in sustainable energy transitions
- A tested approach to providing consultancy to local authorities developing their energy services
- Transfer of these approaches to other sectors e.g. water and waste

For wider society in enabling sustainable energy transitions

- Enable more effective action for local sustainability transitions through a greater understanding of governance
- Dissemination of the findings through publications, and directly through research participants and BuroHappold’s consultancy offer

References


Product-based environmental metrics for use within aerospace, defence, space and security industries (ADS): context, successes to date and likely contributions to knowledge and impact

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Environmental issues are becoming increasingly important for the Aerospace, Defence, Space and Security (ADS) industries, and requests from government, customers, and others for environmental information about ADS products are becoming widespread. Products from these industries are diverse and capital intensive, and range from complete aircraft, defence equipment, and the manufacture of systems, to sub-systems and components. Presently, requests for product-based environmental information within the ADS industries vary in their format and scope, and responses to these vary significantly in their methods of compilation. This lack of consistency reduces the industry's ability to optimise their products for the environmental aspect of sustainability and reduce business risks. To help address this need, the ADS working group on ‘Design for Environment (DfE)’ identified a set of six product-based environmental indicators as forming a useful core of environmental information: energy consumption, water consumption, waste production, hazardous substance use, recyclability potential, and access to resources. In order to address the issue of consistency within the industry, it was recognised that agreed methodologies for measuring the set of indicators would need to be developed. The overall goal of the research project, therefore, is to complete the development of methodologies for measuring two product-based environmental indicators for use within the ADS industries, and test if they are fit for purpose.

The project is now in its 3rd year. This poster presentation provides an account of the main research successes to date, and the likely contributions to knowledge and industry impact following completion.

1. Stakeholder analysis and intended applications of product-based environmental information within the ADS industries: the output of any set of environmental indicators needs to support decisions which benefit the broader environment, business, and stakeholders involved in their use. However, the identification of project stakeholders, their relative importance, their perceptions of information ‘need’, and potential roles regarding the creation and use of information from these product-based environmental indicators were little explored within the ADS industries and academic literature. Initial research activities therefore engaged a key informant group comprising of the funding companies and consolidated inputs from other ADS member organisations to ascertain the underlying drivers, potential end applications, and key stakeholders for the development and use of the indicators. Findings here showed a wide range of drivers and possible applications for the development and use of product-based environmental indicators within the ADS industries ranging from in-house eco-design to reporting to regulators and making environmental products declarations. However, standardisation and the need to broadly support environmental risk management activities were commonly identified by the group as important for reducing business risks and the environmental impact of the ADS industries.

2. Stakeholder requirements and industry criteria for the measurement of the indicators: Following the stakeholder analysis, there remained a need to further understand and elicit the industry requirements for developing the indicator measurement methods. After consulting a variety of data sources and carrying out further research (i.e. industry and academic literature reviews, industry observations, key informant interviews, and questionnaire surveys), a set of industry criteria for developing the product-based environmental indicators for use within the ADS industries was developed. Industry requirements include developing methods which are practical, based on widely available data, able to support a wide range of uses, and useable by SMEs and suitable for rolling out to the complete ADS value chain.

3. Draft methodology for measuring the ‘energy consumption’ product-based environmental indicator: four approaches for measuring the embodied energy footprint of ADS products were identified following a review of the academic literature and existing methods used within the ADS industries. The identified methods vary in their scope, use of specific and generic data, and theoretical basis. Each method has the potential to be adopted as a single industry standard method for calculating and reporting the embodied energy footprint of ADS products. However, the relative differences, suitability for the ADS industries, and the cost/benefit of implementing the four possible methods are little explored within both the ADS industries and academic literature. To understand and explore these aspects further, the project is currently piloting the implementation of all four approaches for
measuring the embodied energy of ADS products using a range of typical products. The pilots aim to mainly understand the practicalities of implementing each method in practice, the value of adopting each method to the business, and improve or adjust the overall methodology based on feedback. To evaluate the effectiveness of the possible methods, the project will make use of industry/participant observations, interviews, and group workshops. Thematic analysis will be mainly used to combine data sources, code data, and identify themes and patterns with regards to understanding the relative cost and benefit of implementing each method. Completing the pilots will provide the information needed to make an informed choice regarding the final methodology for consistently reporting the energy footprint of products within the ADS industries.

The remaining duration of the project will focus on completing the development of the energy consumption indicator as well as one other indicator. The completed research is expected to lead to several contributions to knowledge: the process for arriving at the final methodology (including lessons learnt), using each indicator as a ‘case study’ for identifying the generic issues in developing such methodologies, and the development of a practical and common methodology for cost-effectively measuring two product-based environmental indicators for the ADS industries. Additionally, the completed research may also support the development of appropriate product-orientated environmental standards, policies and legislation for the benefit of the ADS industries.
Introduction: In order to develop sustainable industrial systems, there is a need for decision support approaches and implementation tools. Such a tool should enable decision makers to integrate economic, ecological, and other sustainability measures in a rational way, considering the whole life cycle. It requires trade-offs to be assessed to arrive at optimal solutions. One key aspect is the choice of sustainable materials, which requires a holistic evaluation of their performance over the whole life cycle. Generally three objectives have to be met when implementing new materials, namely a minimisation of

- Life cycle costs,
- Health and safety risks,
- Environmental impacts.

Approach: To address this, a multi-criteria decision support framework has been developed [1], that helps decision makers to systematically integrate a holistic set of life cycle sustainability measures. Individual, context specific criteria can be chosen for evaluation. These should be determined by a range of stakeholders in order to cover the decision at stake holistically. The impact of these aspects on costs, risks, and environmental impacts is evaluated subsequently.

Application: The framework is demonstrated through a case study in the shipping sector for evaluating the best material alternative to replace conventional steel components in the ship structure. High strength low alloy (HSLA) and composite materials are being investigated. These are regarded as promising material options for reducing crack and corrosion issues as well as enabling a more light-weight structural solution to reduce fuel consumption. A life cycle cost and performance assessment combines economic, environmental, and risk factors to determine quantitative performance measures and thereby identify optimum solutions. The evaluation is done in close cooperation with the stakeholders involved, which include shipyards, ship operators, material scientists, laboratories, and a classification body in order to achieve maximum usefulness of the approach. The different aspects are combined through a multi-criteria decision analysis (MCDA) approach (Figure 1).

Results: The life cycle cost and performance assessment clearly showed the importance of considering the whole life cycle when evaluating the performance of the proposed solutions. Even though both material concepts have higher initial costs than the currently used conventional steel, their total life cycle costs appear to be lower, especially due to the savings in operational costs in the case of a more lightweight structure. The distribution of relative life cycle costs (compared to conventional steel) is depicted in Figure 2.

**Figure 1:** MCDA approach, evaluating life cycle costs and performance of different options considering a whole life cycle perspective – adopted from [2]
However, it is important to also consider other objectives, such as minimisation of health and safety risk and environmental impacts. Currently the proposed solutions show an equal or higher risk in all life cycle stages compared to the current solution of conventional steel (Figure 3a). Further research efforts are required to gain confidence that these risks or, indeed other types of risks that can be identified, are reduced to an acceptable level.

HSLA shows similar performance to conventional steel with regard to environmental impacts in initial and end of life stage. However, if less material is used, that leads to emission savings, especially during the operational stage. The same applies to composite materials, where the emission savings during the operational stage outweigh the increased impacts in the other stages (Figure 3b).

**Discussion:** Learning outcomes of this research include the importance of taking a long term perspective for a holistic analysis. This may however not be immediately evident to decision makers, which often tend to focus on short-term targets. It is also entirely reasonable for different life cycle stages to have different predominant stakeholders. It was observed that there is no “one-size-fits-all” tool that is applicable to any kind of industrial system. Instead the proposed framework provides a great amount of flexibility and can be targeted towards the specific application.
Summary & Outlook: The approach provides structured decision support, which includes the consideration of competing objectives and the assessment and visualisation of trade-offs. The framework is capable of integrating the view of different stakeholders as well as different types of data. This research project sets out an approach that can be used to identify the types of data and the analyses required in such assessments. It helps to identify optimum alternatives and to present the key information in a clear way. It has been demonstrated on a case study in the shipping industry and will be applied to other case studies in the future. Additionally, future work can also add functionality to the model. In particular, there will be further emphasis on probabilistic and statistical tools to ascertain confidence in calculated output values. This will help to deal with limited and uncertain input data; thus introducing an additional perspective for rational decision making.

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References
Sustainable process heating
Freddie Pask

Manufacturing is a key driver of the global economy and the sector has an important role to play in helping to create a sustainable future. Many of the ‘easy’ opportunities to improve sustainability in the manufacturing industry have already received significant attention in factory environments. However, there remains opportunities which are more difficult to address but can still deliver sizable benefits; process heating within ovens is one such area. Despite heating applications being common throughout the industry, there is a shortage of specific research on practical guidance for sustainability improvement of industrial ovens.

This research looks to reduce energy consumption within ovens, as well as improving the oven’s ability to manufacture quality product. Furthermore, a set of sustainability indicators, and an accompanying methodology, has been developed to aid investment decision making. Three bodies of research have developed that address sustainability of process heating slightly differently. The intension is that combining all of the research will give a multi-faceted insight into how sustainable development can be applied to industrial ovens. Further detail on the three bodies of research are provided below.

1. The first research body is a systematic methodology to optimise industrial ovens for energy saving. It follows a 6-Sigma format, and is therefore in a language that engineers worldwide are familiar with. The approach looks to analyse key process variables to understand which factors can be optimised to reduce energy, while ensuring that product quality does not diminish. This methodology has been applied to two ovens within 3M. The first optimisation project is has been implemented saving of £58,000 annually. A second project is underway and also has important energy and cost savings. Once both projects are complete, 607 tCO₂ will be offset. The methodology has been published and distributed globally to 3M engineers who work in related areas and wish to reduce energy.

2. The second body of research is a holistic approach to improve the sustainability of industrial ovens. This is a progression from the first body of research as it not only focusses on energy saving, but also on product performance. The approach includes product understanding, process improvement and process optimization. This research aims to promote the concept that product and process understanding can lead to significant sustainability improvements within an oven system. It has been demonstrated at a 3M manufacturing facility and has provided evidence that thorough product understanding can highlight opportunities for energy saving, as well as quality enhancement.

3. The final body of research has been to develop a sustainability indicator set for industrial ovens. Seven criteria have been chosen with industrial experts which can be used to evaluate investment decisions. The criteria include: system air flow, production efficiency, operating costs, quality, capital investment, toxicity and employment opportunity. As well as the indicator set, a method of multiple criteria analysis has been developed that incorporates Fuzzy set theory and Monte Carlo simulation. These statistical techniques can be used to evaluate quantitative and qualitative data with uncertainty, and provide insight into the risks involved with alternative investment options.

The three bodies of research have different slightly objectives and scope, but all have the underlying theme of sustainable development and process heating. Together, it is hoped that they provide a meaningful contribution to knowledge that has an impact in industry and academia. The research has been designed to deliver value to 3M UK factories in the short term. Through the projects already implemented, as well as future projects which have been identified, the hope is that that this research will continue to deliver benefits to the environment, 3M’s economic performance and the employees who interact with the oven systems.

This EngD program is entering its fourth year and over the coming months the intension is to tie up any loose ends of the research, as well as to publish journal articles on the second and third research bodies. In terms of industrial projects, there is ongoing work looking to establish more sustainable ovens at 3M Atherstone, with activities ranging from lab based experiments of adhesive cure (the hardening of a polymer) understanding to installation of hardware for greater process control.
How do we engender a company’s sustainability needs through a ‘shifting’ supply chain?

Erica Russell

This research work is in collaboration with Carillion plc’s Construction Services Business Unit. The focus for the work is their UK and Canadian based construction contracting activity and encompasses work on large scale private and public buildings, utilities, rail and telecoms infrastructure (current ‘order book’ for this division is £2.4bn). There is a desire to build upon a strong track record of more than 15 years’ of Sustainability Reporting and have the goal of ‘Leading the Way’ within the sector. It is anticipated that the work carried out through this research will be used to support both Business Unit and Corporate key performance indicators and reporting.

The organisation wants to extend their current reporting boundaries to include their supply chain. This is partly driven by the company’s ethical stance and by changes introduced in the Global Reporting Initiative (GRI) through the G4 guidance in 2013. This requires companies to consider the materiality of all aspects, including upstream i.e. the supply chain, and downstream, which could include customers. The UK construction sector represents £103M of Gross Value Added (GVA) and employs 6.3% of the workforce, which includes a large number of small and medium sized enterprises (Rhodes 2015). Construction supply chains are complex and changeable. Recent UK government funded research reviewed five construction projects, value £10-£25m, and concluded that the supply chain extended to Tier 3 and on larger projects found between 50-70 suppliers at Tier 2 (E.C Harris LLP 2013). Work is frequently project focused which leads to dynamic supply bases.

Currently Carillion primarily deal with Tier 1 contractors and, consequently, have carried out only limited mapping of their supply chain. They have in place a number of metrics, embedded within their supplier Pre-Qualification Questionnaire (PQQ), which include those required for sustainability reporting. Communication to the supply chain is directly through the Supply Chain team and, once on site, by Project Managers. Carillion does not provide a supplier newsletter or have a method of communicating electronically with their total supply base.

At the commencement of the work a literature review will be undertaken to gain an understanding of the existing research base and to identify gaps in knowledge. To achieve Carillion’s ‘Leading the Way’ aspiration and GRI targets, it is envisaged that the research will need to consider a number of interrelated issues. It will initially need to contribute to the development of a definition of sustainable procurement. It will also be required to identify the short to medium term economic, social and environmental challenges that are likely to affect the company. To achieve this it is proposed to draw together three areas of insight: future key trends through foresighting, desk research into existing input and output analysis in the construction sector and a benchmarking of key industry competitors and sustainability leaders based on their published sustainability reports. Additionally key industry standards such as CEQUAL, EU Peps, LEED and BREAM will be considered and relevant metrics assessed. This, information will help provide weighting of key aspects and highlight potential future risks and from this it is envisaged that a new/refined set of priorities will be identified by Carillion that better reflect the extended boundaries demanded by the G4 reporting.

Based on these priorities it is anticipated that a supplier’s potential impact levels on sustainability issues could be rated. It is likely that this rating would be based on a range of indicators e.g. the value of contracts, the level of business risks, in addition to environmental and social impacts. Carillion’s short term aim is to ensure all suppliers meet core sustainability requirements whilst those identified with a higher impact rating would be selected for more intensive engagement.

As a prerequisite to intensive engagement the research will be required to extend the companies knowledge of its supply base structure and understanding of its ‘fluidity’. An analysis of the supplier base will use Carillion’s internal data interrogation system, Spend Cube, and engagement with the Supply Chain team. Selected Tier 1 suppliers will be surveyed prior to the start of the engagement programme to understand their current sustainability levels and the barriers and opportunities to operating in a more collaborative value chain scenario. It is anticipated that this approach can be repeated with Tier 2 and 3 suppliers but will require ‘buy-in’ from Tier 1. Methods for supply chain engagement will be reviewed and in collaboration with Carillion’s supply chain management evaluated. Testing will be carried out to identify the most effective forms of supplier engagement and provide an evaluation of cost, value-add to the business e.g. potential cost savings, or new materials, and the ability to capture supplier sustainability improvements as part of Carillion’s GRI reporting. Outcomes of the work will be assessed through a final survey.
Whilst still at an early stage of development it is anticipated that this research will offer an approach to effective engagement with the full value chain to support increased added value through demonstrable improvements in sustainability thus helping establish Carillion’s credentials to lead the sector.

References
Cutting crime, cutting carbon

Helen Skudder

Crime directly and indirectly impacts people and businesses on a daily basis (e.g. CCTV surveillance, insurance, street design, policing and so on). Victim based crime surveys across developed countries are finding that many types of common or street crimes, such as assault, burglary and car crimes, have declined dramatically since the 1990s (Farrell et al., 2014). The Crime Survey for England and Wales, for example, saw a peak in 1993 for household crime, followed by a steep decline, which is also echoed in a decline in police recorded crime figures (Home Office, 2012).

This reduction of crime has obviously led to benefits in terms of reduced burden on society and reduced costs to the economy. While the extent of these impacts are well researched, there is, however, an as yet untold story covering the impacts of crime on the natural environment.

Pease (2009) identified a carbon-crime blind spot where environmental impacts are overlooked in regards to crime and crime prevention studies and policies. Our research aims to quantify these environmental impacts. In order to do this we assess the carbon footprint of crime and how this has changed over the last couple of decades. The methodology combines police recorded crime statistics, monetised cost of crime estimates and carbon emission factors, which convert these costs into a carbon footprint.

Initial research has showed that recorded crime in England and Wales resulted in just over 2 million tonnes CO₂e for the year 2011. This carbon footprint is equivalent to the direct annual energy use of around 450,000 UK homes and so is a significant impact.

Analysis into how this footprint has changed over time has showed that whereas the number of offences recorded annually by the police fell by 17% between 1990 and 2011, the carbon footprint dropped by 37% over the same period. These results highlight the potential carbon reductions that might be achieved if crime levels are cut further in the future.

In particular, the research has highlighted specific offences that have led to this carbon reduction over time. The number of recorded vehicle thefts and burglaries have fallen dramatically over the period and resulted in carbon savings in recent years. This is due to the high proportion of emissions that result from the replacement of damaged or stolen property (i.e a vehicle).

The number of more personal offences, such as homicide or serious wounding have either remained at a stable rate over time or increased slightly, but not sufficiently to counteract the drop in carbon resulting from property related offences.

Of course there are limitations to the study including the availability of emissions factors, the changing practices of police recorded crime and the assumptions made regarding the emissions that arise from criminal activities. However, this research project has identified the potential savings of emissions which can be gained by reducing crime, and we aim to further explore the possibility of reducing this carbon footprint in the future. Incorporating information about this environmental impact into the toolkit which UK policy makers use to value crime would address the ‘carbon-crime blind spot’ and may enable more sustainable approaches to crime prevention to be evaluated and assessed. Future work will, in addition, assess the carbon footprints of crime prevention measures in order to compare these to the footprint of the crime they aim to prevent.

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

Rupert Zierler

Introduction
Railways in the UK represent 1% of the entire country’s electricity consumption – approximately equal to that of all households in Northern Ireland per year (3.2 TWh). A significant proportion of this power is used for train traction power, but infrastructure assets also consume a large amount of energy. Being responsible for these assets, increasing energy efficiency is becoming a high priority among Network Rail’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. Employee behaviours around energy use need to be better understood, to aid with the deployment of potential behaviour change programmes across Network Rail’s operations in stations, depots, offices, and by the trackside.

Barriers to energy efficiency in organisations are gradually becoming better understood. One set of barriers in particular, proposed by Sorrell et al (2000, 2004, 2011) has been repeatedly applied to assess organisational energy behaviours. These barriers are risk adversity, clashes between incentives, hidden costs (largely related to training staff), access to capital, bounded rationality (i.e. staff acting rationally within the limits of their own knowledge), and imperfect information access. However, research based on this framework tends to focus on energy efficiency in manufacturing settings, offices, or draws generalised cross-industry comparisons. The barriers are also largely economically- rather than behaviourally-oriented. Application of this framework to assess transport infrastructure organisations also appears to have been largely overlooked.

Parallel to this, theories of environment-related consumer behaviours have also developed. Two of these theories have frequently been applied to assess purchasing (i.e. buying new equipment) and curtailment (i.e. using less) behaviours around energy efficiency. The Theory of Planned Behaviour (TPB) (Ajzen, 1991) and the Theory of Interpersonal Behaviour (TIB) (Triandis, 1977) have been shown to have roughly equal merit in assessing pro-environmental behaviours (Bamberg & Schmidt, 2003), and both have occasionally been applied in organisational settings (e.g. Greaves et al, 2013). This EngD project proposes that one or both of these theories may explain energy behaviours at Network Rail with greater accuracy than when viewed through the lens of the economically-oriented barriers mentioned previously.

In summary, this EngD research project aimed to determine which behavioural barriers to energy efficiency are most significant at Network Rail, assess whether employee energy behaviours reflect those proposed by studies of consumers, and identify how where behavioural interventions are needed to reduce the energy intensity of railway infrastructure operations.

Method
To achieve this, a self-report questionnaire was deployed across the company using their main intranet news service, accessible by almost all Network Rail staff. This asks questions around attitudes based on a Likert-based agree-disagree scale, the frequency of individual behaviours, a few open-answer questions, and establishes personal demographic details. Two versions of the survey were produced; one made available to all of Network Rail’s 36,000 staff via an intranet news platform, and another deployed via email among a subset of managers, engineers and specialists with roles thought to have high levels of influence over Network Rail’s energy use. The latter of these contained additional questions around their decision-making processes in relation to energy-efficient technology adoption, whilst remaining compatible with the all-staff survey. 874 (292 general staff and 582 managers') completed surveys were returned.

Each survey question is cross-referenced to the Theory of Planned Behaviour, Theory of Interpersonal Behaviour, and the six Barriers mentioned previously. Additionally, a series of scoping interviews at Network Rail conducted during the earlier half of this EngD programme suggested further barriers, particularly relating to Network Rail’s position at the boundary between public and private governance. The significance of these will also be tested using questionnaire data, and were used as guidance for phrasing many of the attitude questions.

Results
The large number of responses gathered by this survey enables several forms of analysis, some of which were still in progress at the time of going to press. The applicability of each theoretical framework to the dataset is currently in the process of being confirmed. So far, regression analysis of the various theoretical constructs favours the TPB as an explanatory model, although even this does not reflect the collected data entirely. The TPB
is also favoured by reliability analysis, although again, these tests currently fall a little short of commonly-accepted levels.

To address these shortcomings, factor analysis was applied to reveal whether there were any other emergent behavioural constructs within the questionnaire data. So far, these new factors appear to reflect a hybrid of all theoretical frameworks, although the TPB is dominant among them. Unique factors generated by this process include ‘Disposition Towards Technology’, and ‘Energy Stewardship’.

A few points also arise from cross-tabulating data from each individual question with staff demographics; details which can be used to engage with individual teams at Network Rail. For example, younger staff feel less able to access energy information or influence energy-related business choices, but get less frustrated by energy wastage despite having greater concern for the environment in general.

**Conclusion**

These preliminary results imply that research into consumer energy behaviours may be more applicable in large organisations than previously thought. They also put the idea that behavioural factors need greater weighting when studying barriers to energy efficiency in organisations of this type and scale than economically-oriented studies would suggest. Future analysis intends to look at differences between groups, particularly between energy specialists and more general staff.

Once analysis of survey data is complete, a forecast model around the benefits of undertaking behaviour change programmes in Network Rail can be developed. This is intended to take an agent-based approach, modelling interactions between employees, with their characteristics determined by theoretical constructs to be decided upon following this analysis. This research is already making an impact, supporting a recently-started energy management improvement programme. This will help determine which energy efficiency schemes should be deployed locally or nationwide, such as consumption reduction competitions between depots.

**References**


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