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Mapping Engineering & Development Research Excellence in the UK: An Analysis of REF2014 Impact Case Studies

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Introduction

In recent years there have been calls for United Kingdom academic engineers to engage with the challenge of international development (UKCDS/RAE, 2014; cf. Niesuma and Riley, 2010). Despite a long colonial history of infrastructure development in the Global South, there is little information about current practices, and engineers' representations of their activities. In this paper we use the impact case studies submitted to the Research Excellence Framework (REF) 2014, a government exercise which determines funding allocations for university departments, to map the current status of engineering and development excellence in the UK. The submissions are divided into cognate subject-based 'Units of Assessment' (UoA). The opening sections of this paper discuss the assessed REF, and make some general observations about engineering and international research in all REF impact case studies case studies. We then examine the UK academic context of engineering & development, focusing on the institutional and funding context.

We found that engineering and development research is occurring across many UoAs. Many of the storylines are rooted in an ecological modernist discourse (Spaargaren and Mol, 1992; Mol, 1995; Hajer, 1997; Huber, 2004), which seeks to combine economic value, efficiency, and environmental stewardship in narratives about the research excellence of engineering and international development work.

REF Process

The REF replaced the Research Assessment Exercise (RAE), which had taken place approximately every five years since 1986. The results of REF2014 were published in December 2014, and submissions were made public soon after. REF2014 was carried out by the four UK higher education funding bodies, but managed by a team based at the Higher Education Funding Council for England (HEFCE) and overseen by a steering group. The outcomes were used in determining the research funding allocation made to Higher Education Institutions (HEIs) by the UK government, and to provide public accountability for investment in research, as well as provide disciplinary and HEI benchmarks (King's College London and Digital Science, 2015: 14-15).

REF2014 was different from previous research assessment exercises in that an attempt was made to measure the social impact of research. Impact was defined as 'any effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life beyond academia' (REF, 2011: 26). The format for an impact case study is clearly defined as a short four-page document which has five sections:

1 summary of the impact

2 a description of the underpinning research
3 references to the research
4 details of the impact
5 sources to corroborate the impact (King's College London and Digital Science, 2015: 15).

The case studies were assessed using two criteria: 'reach' – 'the spread or breadth of influence or effect on the relevant constituencies', and 'significance – 'the intensity or the influence or effect', and the impact discussed could span twenty years. Panels scored the case studies, each of which had research user-members. A four-point scale was used. In total £1.6b of public funding for the next five years was determined by the evaluation of the impact case studies.

The REF2014 impact case studies provide a unique and rich dataset that gives a snapshot of particular kinds of impact activity, which had not been captured in this way previously. There are also drawbacks to using the REF2014 case studies as a dataset. First the case studies were written for a specific academic panel in accordance with particular rules in order to be assessed and gain research income. Second, many were written, or edited, by professional non-academic writers, and third some impacts were not included because they were seen as 'too risky' to be included in submissions (Manville et al, 2015). Fourth, while the dataset provides a useful overview of the terrain of engineering and development, the map it provides focuses on impacts arising from academic research only. From conducting this study it became clear to us that much is going on in non-academic domains of UK engineering that have impact in the South, including that which occurs in NGOs, industry and the military, among other sectors, but would not be captured in an exercise like REF2014.

Another aspect of the dataset worth pointing out is that the engineering panel, Panel B, had the highest rates by far of redaction and partial redaction, presumably due to the commercially or military/security sensitive nature of the work being done in the departments being assessed (see Table 1).

Table 1. REF2014 Panels Redaction and Partial Redactions

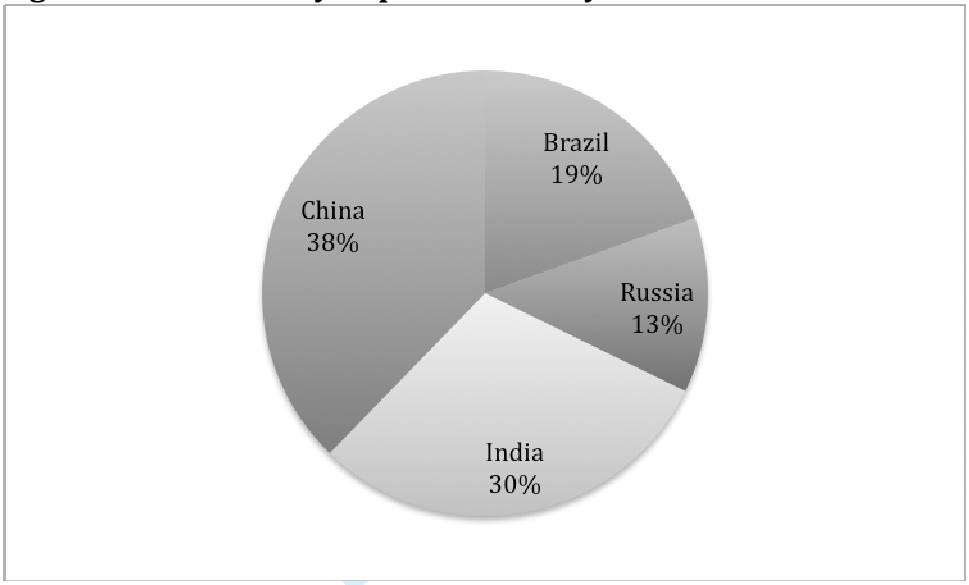
	Panel A (life Science)	Panel B (engineering and physical sciences)	Panel C (Social Sciences)	Panel D (Arts & Humanities)	Total
Total submitted case studies	1,621	1,667	2,040	1,647	6,975
Redacted case studies	27	182	67	20	296

% total submitted case studies by panel	2%	11%	3%	1%	4%
Partially redacted case studies	87	209	75	57	428
% of submitted case studies by panel	5%	13%	4%	3%	6%

(Source: King's College London and Digital Science, 2015: 19)

Another point to mention regards impacts in countries beyond the UK. Just under half of the (48%) countries mentioned in all case studies referred to just 10 countries (USA, Australia, Canada, Germany, France, Ireland, China, Netherlands, India and Italy), and of the countries in the Global South mentioned in the impact case studies, most were from BRIC (Brazil, Russia, India, China) countries, especially China and India (see Figure 1). Within the BRIC countries, China was mentioned most followed by India, Brazil and Russia.

Figure 1. BRIC Country Impact Case Study Distribution



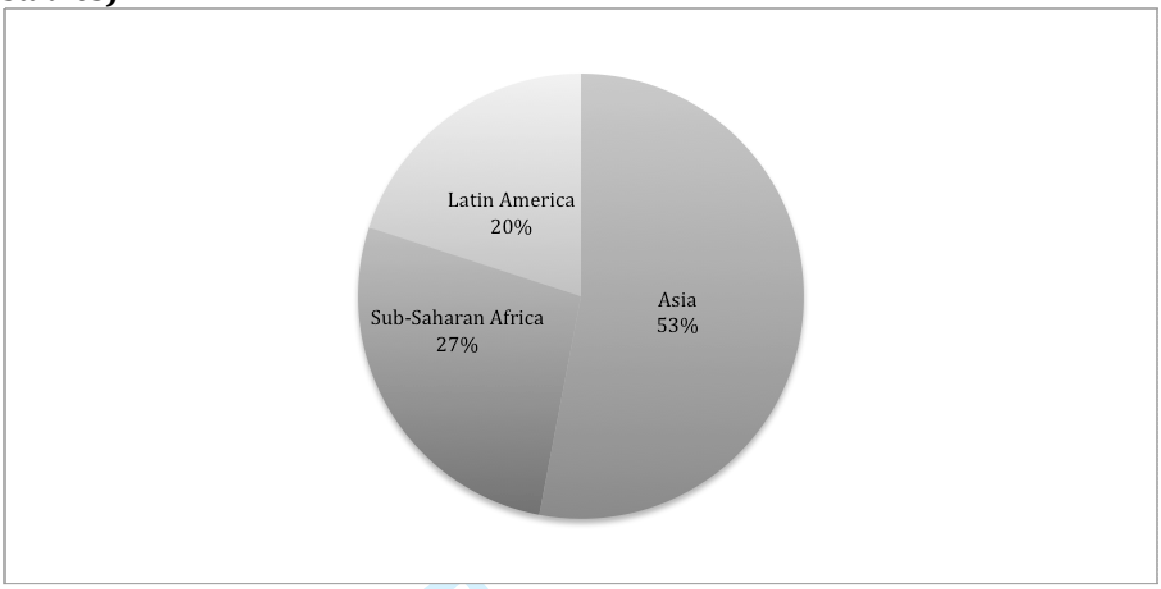
(Source: compiled from King's College London and Digital Science, 2015, Figure 31: 68).

Two further points about the dataset are that linkages with Brazil occurred across UoAs, while links with China were concentrated in the medical and engineering panels (King's College London and Digital Science, 2015: 67). Overall, case study impacts show a wide range of activities across many UoAs.

Developing Countries in REF Impact

Figure 2 shows the numbers of developing countries mentioned in the 'details of the impact' section of REF impact case studies. There were 23,420 instances of developing countries being mentioned in this section, and of this 17,932 were from outside the UK. The figure below shows numbers of mentions from Latin America, Sub-Saharan Africa and Asia, as a percentage of all non-UK mentions (see Figure 2).

Figure 2. Regional Distribution of Developing Country Mentions (all case studies)



(Source: Compiled from King's College London and Digital Science, 2015, Fig 13: 41)

Engineering & development research in the UK: Institutions and Funding

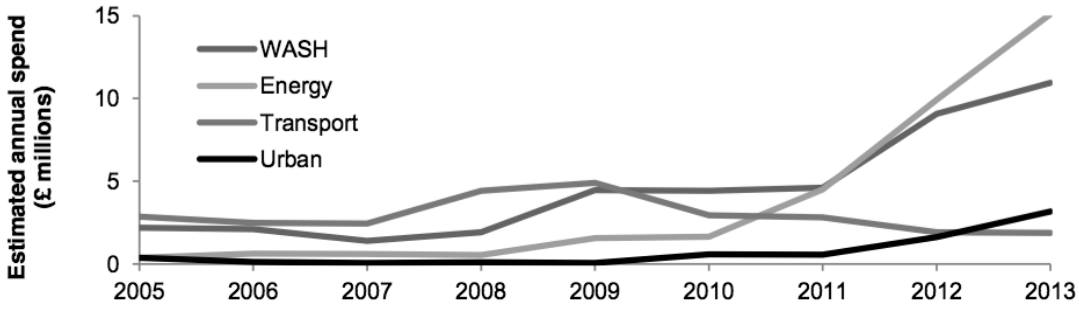
Though there is significant UK institutional support and funding for engineering & development work, much research that emerges is practice-based. It is commonly believed that there are a number of disincentives for conventional academic engineers to work in the engineering and development research field. These include difficulties around what is valued in the REF, the resources available and the consequent rewards for this work. These include:

- publishing applied research in high impact journals;
- sourcing data for REF impact case studies;
- the lack of research council funding;
- the interdisciplinary nature of the field;
- few promotion prospects for academics interested in engineering and development;
- the low status of the development field within conventional engineering (UKCDS/RAE, 2014:3; cf. Robbins, 2007)

At the same time there is a persistent need for infrastructure development - energy, water, sanitation & hygiene (WASH), roads, transportation and information and communication technologies, and urban development, which often cross-cuts many of these infrastructure areas. This was outlined in the report of a UK government High Level Panel on the post-2015 development goals, where such development was seen as key to poverty reduction and an enabler of other kinds of growth. The UK Department for International Development (DfID) has begun to invest more heavily in infrastructure research; a three fold increase between 2000 and 2013 (UKCDS/DfID, 2014: 1). Figure 3 shows the increase in DfID spending in selected

areas of research investment since 2005. Similarly, the Engineering and Physical Sciences Research Council (EPSRC) has invested around £17m under their 'International Development' socio-economic theme.

Figure 3. DfID Investments in Infrastructure Research 2005-2013



(Source: UKCDS/DfID, 2014, fig 2, p. 2)

Concurrently DfID research is increasingly interdisciplinary in nature, rather than primarily engineering, and linked with broader issues such as climate change as it connects with international development. The researchers being funded to carry out this research are based at a number of different UK Universities, and include Cambridge, UCL, Imperial, as well as Loughborough, Birmingham, Coventry, Cranfield and Oxford Brookes. The leading infrastructure for development research groups are seen as being situated in University departments at Loughborough, Cranfield, Cambridge, Imperial and UCL. (UKCDS/DfID, 2014: 2) Loughborough and Cranfield were both part of a select few institutions globally to win funding through the Gates Foundation's 'Reinvent the Toilet Challenge' in 2011 and 2012.

A growing area of engineering & development research is in energy for development (see Figure 3). Around 1.4 billion people around the world, and 600 million in Africa have no access to electricity, and around the same number in Africa only have intermittent access to electricity. Around 2.8 billion use biomass for heating and cooking, which causes 4.3 million deaths per year due to fires and smoke inhalation. DfID funded research in this area focuses on renewables; grid, off-grid and mini-grid electricity; household energy; bioenergy; energy and gender; and the relationship between energy infrastructure and economic growth. EPSRC also funds energy for development research, in partnership with DfID and on its own. The collaborative projects include the EPSRC/DfID Understanding Sustainable Energy Solutions (USES) programme (£5m EPSRC investment), the SCORE Consortium led by Nottingham University (£1.8m) and two off-grid electricity generation projects (over £7m total). Investments are being made to expand the impact of this work through the Low Carbon Energy for Development Network, which is supported by the EPSRC (UKCDS/DfID, 2014: 5-7).

Within energy research DfID has been investing more in aspects of bioenergy, including cookstoves, and technologies and models to deliver energy services. The

transportation agenda focuses on application, and blends academic research with production of standards and guidelines. Urbanisation is a cross-cutting theme which works across most infrastructure sectors, and is increasingly being combined with efforts to address resilience and adapatation to climate change. Finally in other areas relevant to engineering & development, DfID spent around £13m on agricultural innovation research in 2013, invested in research bringing brain imaging technologies to Africa, and is increasingly interested in supporting research on sustainable construction, in areas like bamboo architecture (UKCDS/DfID, 2014: 14). To what extent is this funding support percolating through to impact case studies?

Mapping Engineering & Development through the REF Dataset

In this research, we sought to find out what the terrain of UK engineering & development looked like. In order to do this we divided up the panels between us and analysed each case study to see:

1 Whether it could broadly fit within one of five branches of engineering (systems, mechanical, electrical, civil and chemical);
2 If it involved work with, or in, the Global South;
3 How excellent engineering & development is defined;
4 Where it takes place;
5 Which groups are involved, and with whom do they collaborate;
6 What comprise their formal and informal networks.

These six questions were chosen in order to search for relevant cases in engineering & development, informed by a broad understanding of research excellence and the core components of innovation. For cases that met our criteria, we then filled in one-page summaries, based on the questions above, for each case (see Table 2). This particular case is unusual in our dataset, in that it emphasises appropriate technology with a high human impact. Most of our cases, as discussed below, emphasised economic impact using an ecological modernization argumentation.

Table 2. Queen's Belfast One Page Summary

Queen's Belfast: Removing arsenic from groundwater	
What makes excellent engineering?	Addressing a well-known chemical pollutant and health issue. Elegant, innovative and cheap, treatment plants promote growth of arsenic-oxidising bacteria in underground aquifers rather than use chemicals to remove arsenic. They create no waste. Replacement of a halfway technology - adsorption or membrane processes (pump & treat).
Who is engaged in E4D in the UK?	Queen's University Team led by Bhaskar Sen Gupta
What kind of engineering?	Water, health, chemical - Subterranean Arsenic Removal (SAR) technology for 'in situ' treatment in aquifers.
Formal and	Government water agencies in India, Cambodia and

informal networks?	Malaysia.
With whom do they collaborate?	Grants at different stages from the EC, World Bank, British Council/DFID, RAE. European and Indian research partners from the start through the grants. Queen's has set up research centres in Calcutta and Kuala Lumpar to work closely with overseas partners - Bengal Engineering and Science University, National Metallurgical Laboratory, IEMS (TATA Steel) and University of Malaya for further developing the SAR technology and running training programmes.
Direction of technical flow?	Interaction with partners
Appropriate to Best-with-Best spectrum	Appropriate combined with 'Best-with-best'.
Impacts/benefits	Eight SAR treatment plants which can run on electricity/wind/solar power. 25-year life with very little maintenance; locally source components. 9 Villages in India, Cambodia and Malaysia serving over 13,000 people with decontaminated water at very low cost. People in advanced stages of arsenicosis showing signs of recovery. Community and rural outreach activities.
Developing country dimension	Targeted explicitly at developing countries.
REF summary: A Queen's University team led by Bhaskar Sen Gupta installed the world's first chemical free water treatment plant in the arsenic belt of India to benefit rural people living on per capita income of less than 1 US$ a day. With nine facilities in India, Cambodia and Malaysia, more than 13,000 people are receiving their water supply from Subterranean Arsenic Removal (SAR) plants (www.insituarsenic.org). Many villagers who started using clean water from the community plants in 2008 have shown significant signs of recovery from chronic arsenicosis.	

Findings

We found 121 cases that met our criteria. These cases came from all engineering panels, plus Biology, Planning & the Built Environment, Chemistry, and Geography & Environmental Studies. This indicates that there are many cases across a wide

spectrum of disciplines that can fall within the engineering & development field. That said, there is almost no engineering & development occurring across large areas of the humanities and social sciences, including where it might be expected, such as in the Art & Design, and Media, Library & Information Management panels. Within the cases that met our criteria there is a predominance of UK-driven 'best-with-best' department network linkages, versus those based on appropriate technology. Figure 4 shows the distribution of engineering and development impact case studies across disciplinary panels, with half appearing in engineering panels, followed by 26% in Maths and Science panels, 14% in Social Sciences & Humanities Panels, and 10% in Health & Agriculture Panels (see Figure 4).

Figure 4. Engineering and Development Impact Case Studies: All Panels (N=121)

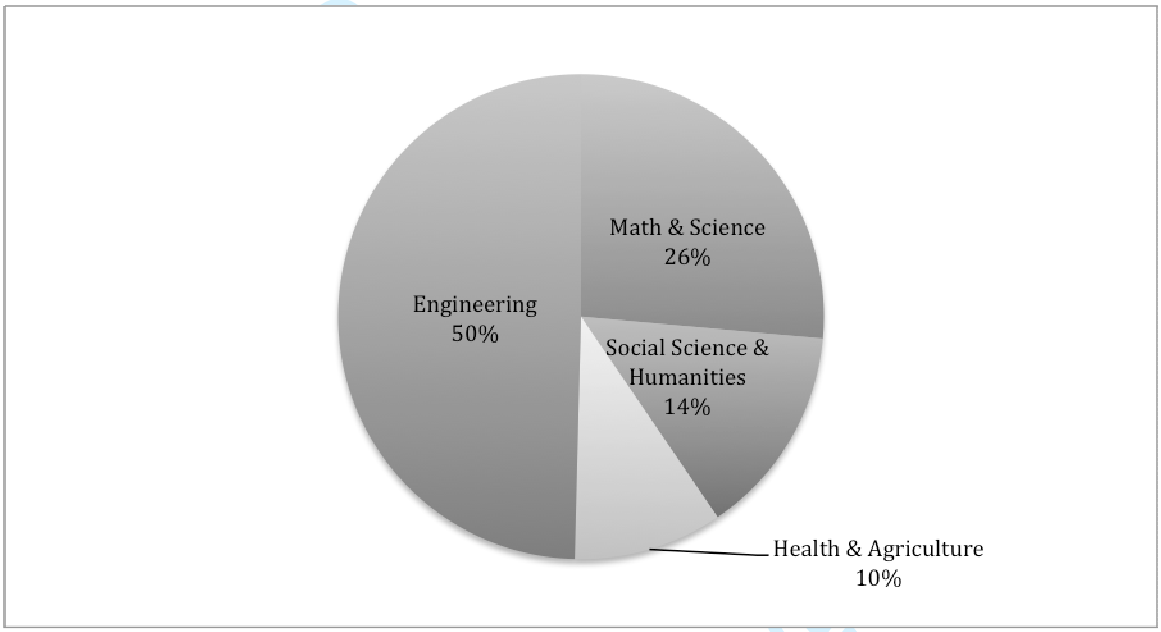
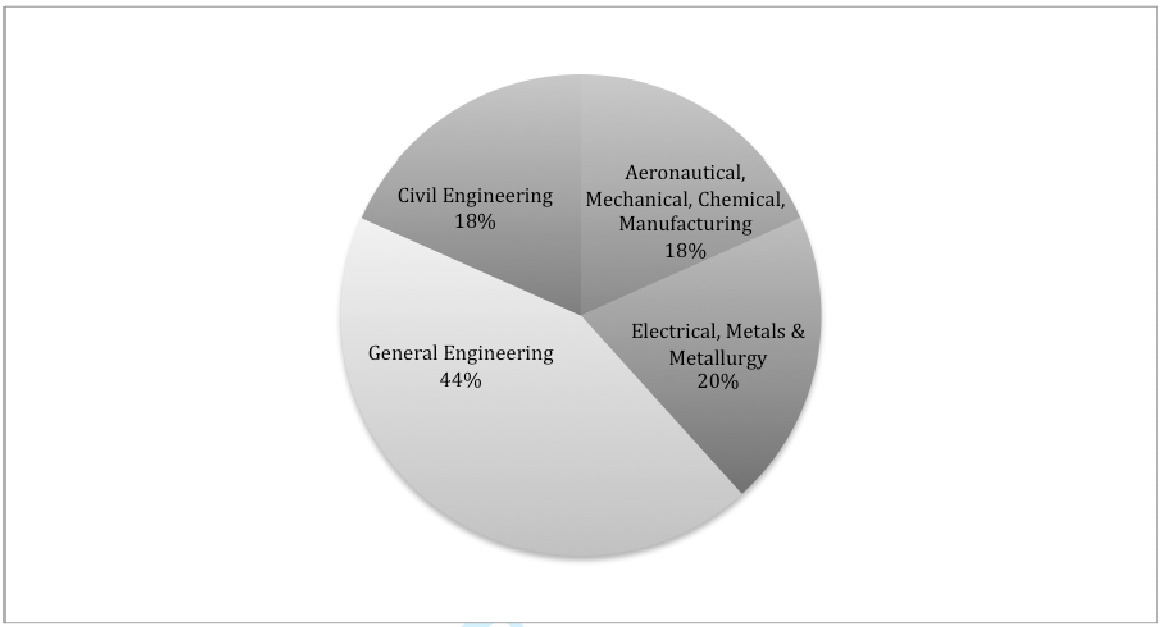


Figure 5 shows the distribution of engineering and development case studies across engineering panels (see Figure 5). Of the 60 cases, 44% appeared in the General Engineering Panel, 20% in the Electrical, Metals and Metallurgy Engineering Panel, 18% in the Civil Engineering Panel, and 18% in the Aeronautical, Mechanical, Chemical, and Manufacturing Engineering. We found it somewhat surprising that there were not more cases in Civil Engineering, which is traditionally the domain where a great deal of development engineering takes place; albeit Civil Engineering did have a higher *proportion* of development cases, around double that of other engineering panels.

Figure 5. Engineering & Development Case Studies within Engineering Panels (N=60)



Argumentation of Impact Case Studies

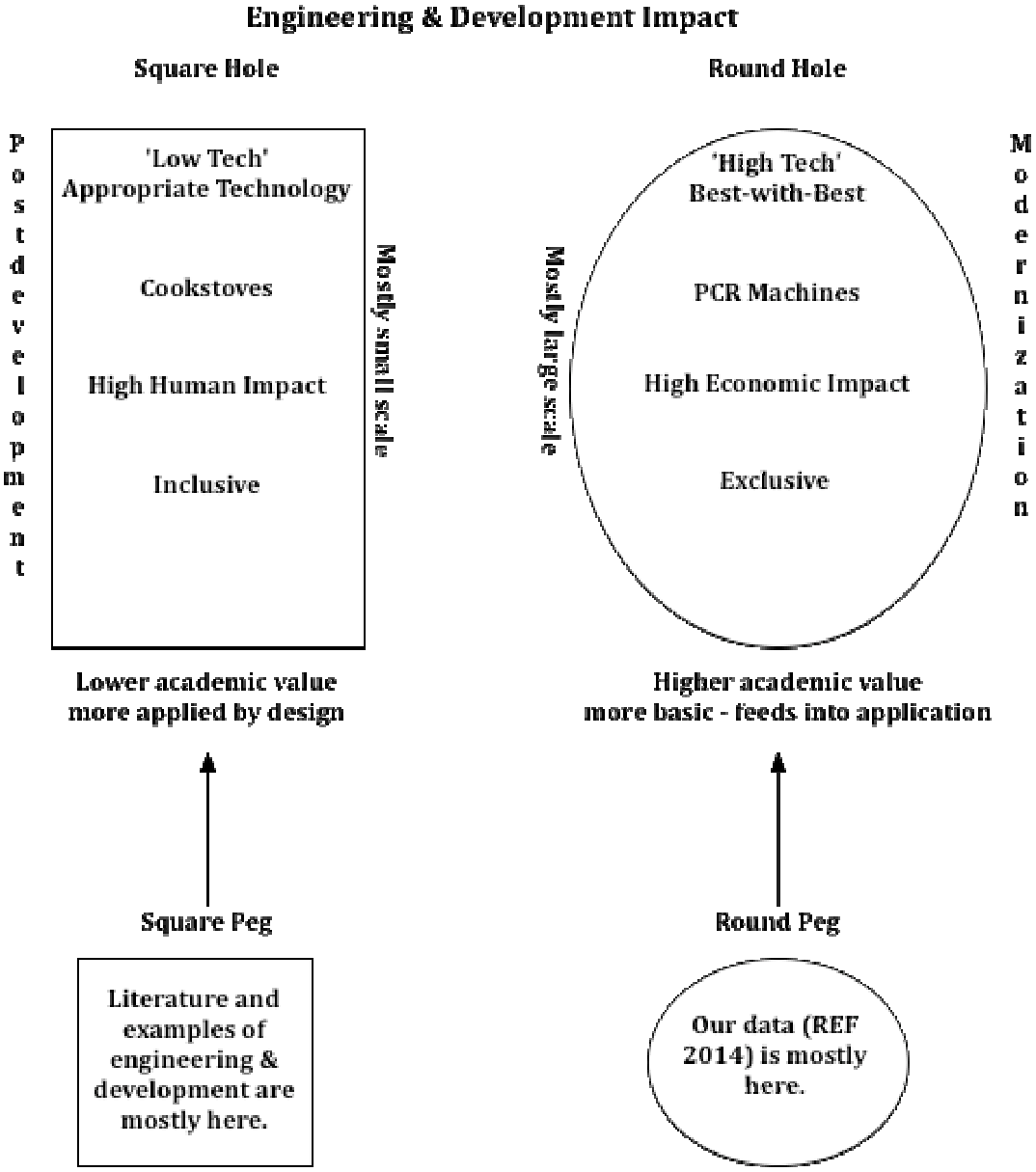
In addition to mapping the terrain of engineering & development practice within REF 2014, we also looked at how arguments around engineering and development were constructed in the impact case studies. Here we found a preponderance of ecological modernist argumentation; emphasising quantitative economic and environmental data, some argue, is a typical way in which engineers are taught to discuss the value of their designs or artefacts (Bucciarelli, 1994; Petroski, 1992; Vincenti, 1990).

In this research we also came to realise that we were at times facing the challenge of trying to hammer 'round pegs into square holes', and 'square pegs into round holes' (see Figure 6). In other words, much of the international development literature and indeed our own initial concepts of 'engineering & development' from having worked with development engineers are largely around fairly low tech and often small scale infrastructure development (e.g. water supply systems for villages and peri urban areas, which lie on the outskirts of cities). These often border on 'appropriate technology', including design of, for example, better cookstoves that reduce fatalities in developing countries. This approach includes such processes and technologies which are often fairly low cost, have a high human health and inclusive impact and downstream economic impact (from improved worker health for example), and the theoretical discourse in which they are framed often implies postdevelopment, and complex systems. While there are UK engineering departments that work in this domain, the academics who work there sometimes struggle to find academic value in what is often a very applied, practice-based, field of study. That said, going into the research we expected to see a number of impact case studies that emphasised high

human impact, perhaps elaborating ingenious ways of making high tech products more accessible to the poor through frugal engineering, by producing say a low cost IPad, or a simplified (Jaipur) knee joint.

What we found instead when we sifted the cases of UK-developing country engineering was a more linear innovation story around best-with-best departmental and technology linkages; the case illustrated in Table 2 above was unusual in that it combined elements of both best-with-best and appropriate technology. The impact narrative was often around economic impact through production of monetary income or value rather than around high human impact by reaching and improving the lives of vast numbers of poor people. The technologies involved were often 'high tech' such as the design and manufacture of polymerase chain reaction (PCR) machines, which are used to amplify DNA segments and used in a variety of health, forensics and other applications. The narratives bore a resemblance to ecological modernist discourse in the sense that the argumentation was linearly framed, partly the result of the rules of REF2014, stating that the piece of research led to the production of quantitatively expressed economic returns, while also ameliorating environmental, health and safety challenges. The engineering case studies also had the highest numbers of redactions of any case studies, suggesting exclusion for the purpose of protecting intellectual property or highly sensitive military or security issues. The combination of economic, environmental, and human health & safety in the corporate social responsibility literature is sometimes described as the 'triple bottom line', and it seeks to broaden concepts of value. REF impact case studies are an opportunity to create argumentation for the *value* of research beyond strictly academic and teaching domains (Kearnes and Weinroth, 2011). It is interesting that the argumentation that was chosen in many of the engineering & development case studies was framed along ecological modernist lines.

Figure 6. Pegs and Holes



Modernization and Ecological Modernization

The liberal economic school shaped the development of modernization theory. The school emphasised free markets, which it argued address many social welfare needs more effectively than the state. Rostow (1971) in *The Stages of Economic Growth* presented a work that was both a kind of social history of how economic growth took place in the North and a treatise on how development should unfold in the South. Rostow postulated that growth occurred in five stages:

1 traditional society
2 preconditions for take off
3 take off
4 drive to maturity
5 high mass consumption.

For Rostow, while countries go through the five stages in a linear fashion, the length each stage takes may vary from country to country. The model emphasizes development success rather than failure, which is the basis for the critique advanced by the dependency perspective that followed it. The modernization perspective saw technology as a basis for social change. In other words, modernization thinkers saw responses to new technologies generating social change. For example, sometimes technologies are developed but not widely used then they are picked up by groups of people, at which point they become transformative. Innovation and technology are closely connected for modernization thinkers in the sense that scientists and engineers come up with ways to make life better for people and this interrelates with social change. To give a contemporary example, mobile telephones have had a huge positive impact in the South where there is limited telecommunications infrastructure that connects diverse communities, giving people access to information, allowing for education and business transactions, and therefore development, to take place.

While modernization was subjected to substantial criticism in the 1970s, due also to the failure of most countries in the South to develop in the ways predicted by its advocates, it was revived in the 1990s mainly to understand the developmental successes of countries like South Korea or city states like Singapore, Taiwan, and Hong Kong (Crenshaw et al., 2000; Ingelhart and Baker, 2000; Kim, 1994). Modernization scholars also developed a specific environmental variant of the perspective around that time, ecological modernization (Spaargaren and Mol, 1992; Mol, 1995; Hajer, 1997), which argued that protecting the environment was not incompatible with meeting people's wants and needs through (economic) development. Ecological modernization had its roots in the thinking of Joseph Huber (2004) who believed that industrial society develops through three stages:

1 the industrial breakthrough
2 the construction of industrial society
3 the ecological shift of the industrial system.

This shift occurs through a process he calls 'super-industrialization', which involves the development of new technologies. Also like other modernization thinkers, he saw ecological modernization as a historical phase of modern society (Mol, 1995). Ecological modernization also draws upon the 'reflexive modernization' school (Beck et al., 1994), specifically Beck's risk society (Beck, 1992). Beck emphasized the unperceivability of many 'high consequence' risks, such as climate change, or nuclear radiation, which we cannot smell, hear, see or feel. Reflexive modernization has at its core the idea of reflecting back – so for example a pessimistic variant of this perspective might argue that it is modern institutions and modern life that have produced environmental problems, for example most of the major environmental problems we face are man-made, which those same institutions must now try to correct, and they may not manage it.

A more optimistic variant of this idea, however, is that institutions do reflect back and in so doing they can adapt to incorporate environmental challenges through practices like developing environmental technologies, reusing materials, and producing goods and services more efficiently, realising we have no alternative to this approach. Thus, these optimistic ecological modernization writers believe that 'the only possible way *out* of the ecological crisis is by going further *into* the process of modernization' (Mol, 1995, p. 42; italics in original). For them, ecological problems can be dealt with in a rational way by incorporating economists, natural scientists, corporate executives, engineers, sociologists, policymakers and others to deliver integrated sustainable development solutions. Indeed, for many, sustainable development – which, at its most basic, is that which meets current needs without compromising the ability of those in the future to meet theirs – is paradigmatic of ecological modernization (Hajer, 1997). Such a project consists of the promotion of an agenda that argues that sustainability can be managed simply through a switch to greener technology, and otherwise pursuing 'business as usual'. This agenda does not allow for the interrogation of whether resource use needs to be more fundamentally restricted in order for sustainable development to be achieved (Robbins, 2001).

Ecological modernization policy discourse arose in the 1980s and has characteristic features:

> 'ecological modernization, first and foremost, introduces concepts that make issues of environmental degradation calculable. Most notably, ecological modernization frames environmental problems combining monetary units with discursive elements derived from the natural sciences. This provides a common denominator through which costs and benefits of pollution can be taken into account...The shift to the discourse of ecological modernization represents a general trend in the Western world. That is to say, we can see the same ideas, concepts, divisions and classifications emerging in different countries and international organisations, such as the UN, the OECD, or the European Union.' (Hajer, 1997: 26-27)

The paradigmatic notion underpinning ecological modernization discourse is the idea that 'pollution prevention pays', and as such environmental, health and safety challenges become vehicles for innovation rather than a threat to development.

> 'Not only does it open up new markets and create new demands; if executed well, it would stimulate innovation in methods of production and transport, industrial organisation, consumer goods, in short, all those elements that Schumpeter once identified as the forces that produce the 'fundamental impulse that sets and keeps the capitalist engine in motion.' In this sense the discourse of ecological modernization puts the meaning of the ecological crisis upside-down: what first appeared a threat to the system now becomes a vehicle for its very innovation.' (Hajer, 1997: 32-33)

As such the argument of ecological modernization theorists is that this has become 'the most credible way of 'talking Green' in spheres of environmental policy-making and increasingly functions as the organising principle for the innovation of institutional procedures.' (Hajer, 1997: 31) The ecological modernization framing of engineering & development was a common feature of impact case studies, as illustrated in Table 3 (see Table 3 below).

Table 3. Ecological Modernization Storylines in Engineering & Development Impact Case Studies

'Direct benefit of MoSSaiC is improved slope stability, evidenced by absence of landslides in these communities despite exceptional rainfall…indirect benefits include…, rainwater harvesting…reduced water bills (…saving EC$63,000), and savings to Government of community relocation costs.' (Geography, UoA 17)
'Modelling impacts of climate on infectious disease….malaria reduces GDP by at least 3% annually…enabled robust climate-driven malaria prediction systems…better understanding of changing risks to economic growth arising from malaria epidemics driven by climate change (Geography, UoA 17)
'reducing tropical deforestation as a means of mitigating global change, as well as enhancing protection of tropical biodiversity and contributing to sustainable rural development (Geography, UoA 17)
'The economic value of Bt/CpTI cotton is estimated at as approx. £600 million per year… The absence of negative effects on the environment, and positive effects in the form of reduced input costs through lower pesticide usage (by up to 40%) have led to the conclusion that Bt/CpTI cotton has made a positive contribution to sustainability in Chinese agriculture.' (Biology, UoA 5)
'identifying which farming methods provide sufficient crop yields to feed the world's population, whilst having the lowest impact on sustainability.' (Biology, UoA 5)
'development of a commercial biofuel from waste….The most recent agreement with Brazil will create more than 150 new jobs in the UK. At the end of 2011, TMO Renewables reported a net worth of almost £11 million.' (Biology, UoA 5)

'Locust swarms have the potential to affect the livelihoods of one in ten people on the planet….the success of *Metarhizium* as an effective, environmentally-friendly locust control option…[BCP]… was taken over by the US crop-technology company Becker Underwood in 2010, which was in turn bought by BASF in 2012.' (Biology, UoA 5)
'Prof Zhao's development of an innovative hybrid engine…was exploited by its industrial partner…the largest…in China holding 80% of the domestic market…notable fuel savings of 4.7-10%, equivalent to 3.6-7.2 tonnnes of carbon saving' (Mechanical Engineering, UoA 12)
'acoustic emission monitoring…applied to...bridges (UK, Europe, India…): significant economic gain, enhanced industrial practice, prevention of serious safety risks to society; marked reduced CO_2 emissions…' (General Engineering, UoA 15)
'advanced computational models for simulating the energy and environmental performance of the built environment…taken up by industry worldwide (Hong Kong, Dubai, Qatar)…reduction of CO_2 emissions by 80%...saving £100-£200 annually per household…' (Architecture and Built Environment, UoA 16)
'Fluorescent PET sensors…sales of $50m…The research, therefore has led to both economic impact as well as significant health benefits.' (Chemistry, UoA 8)
'Anaerobic-aerobic sequencing biological wastewater treatment systems…use up to 68% less energy…full scale treatment plant built by L'Oreal in China…reduced sludge by 20%, CO_2 emissions by 28%, chemical use by 30% (Civil Engineering, UoA 14)
'A novel approach to climate science…over 260,000 members of the public worldwide [including in developing countries engaging] in a climate modelling project….exploring the equilibrium response to doubling CO_2 levels…the value of this CPU time has been estimated as $22.5M' (Physics, UoA 9)
'Improved flood risk modelling...global impacts…in assisting insurers with their underwriting…flood mapping in developing countries…at the leading edge of applying uncertainty concepts to risk models…[spinout] company's annual turnover £13m…ideal for modelling flood risk in developing countries, where flood mapping has previously been uneconomic.' (Earth Systems, UoA 7)
'Increased crop yields and a reduction in the need for synthetic pesticides, through a new patented technology…rapidly commercialised for use in global production…yield increases…equivalent to…a farm gate value of approx. $60M in this one crop for one year alone….[patent registration] is also progressing in Australia, Mexico, Brazil and Argentina' (Earth Systems, UoA 7)
'Optimising crop production and sustainable irrigation technologies…one of the greatest threats to global food security…had multiple positive impacts on water use efficiency in agriculture on several continents, most reliably quantified in northern China…estimated total saving of around 80-100 million cubic meters of irrigation water per annum in this one catchment alone…reduced water use but also increased quality and decreased harvesting costs, leading to a 30% increase in profit per unit water used.' (Earth Systems, UoA7)
'Drought monitoring and early warning for African food security…are now used

in food security (to anticipate drought and predict crop and livestock yields); in health planning (to predict outbreaks of rain-promoted diseases such as malaria); in aid (to guide the allocation and distribution of relief food and water); and in economic planning (to plan mitigation activities and investment in infrastructure)' (Earth Systems, UoA7)
'innovative extreme weather services for the real-time monitoring of global tropical storms…achieved significant commercial and humanitarian impacts worldwide…included £1.319 million of income generated by sales of commercial products…contribution to lives saved in Bangladesh from topical storm Mahasen (2013)…prompted Lord Leven, the Chairman of Lloyd's, to state that "TSR are the first to offer a level of precision which is of practical use."' (Earth Systems, UoA7)
'A novel geochemical toolbox…permitted saving of up to $70M in global mineral and petroleum exploration programmes (e.g. Andes of S. America…)….gives mineral and/or petroleum companies an enhanced economic advantage by improving reserve estimates and/or reducing exploration budgets and/or minimising the environmental impacts of exploration.' (Earth Systems, UoA7)

Post-development and appropriate technology

In contrast to an ecological modernization perspective, writers from the post-development perspective direct their criticism at development itself (Escobar, 1995; Rahnema and Bawtree, 1997; Nanda, 1999; Ziai, 2007). They base their analysis on the effects of US President Harry Truman's 1949 inauguration speech, which called for a 'brave new program for making the benefits of our scientific advances and industrial progress available for the involvement and growth of underdeveloped areas' (Sachs, 1992, p. 6). From that moment onwards, they argue, people in the South were defined as underdeveloped and in need of assistance. Development became an obstacle to improving conditions of the poor and underprivileged, rather than a means to transform it. Post-development is a restatement of the critique of the modernization perspective, but it is also a powerful interrogation of the notion that industrialization is necessary for Southern countries.

Appropriate technology, and 'engineering for development' map well onto the themes in post-development (Eckersley, 1992). Appropriate technology is that which is small-scale, environmentally sound and locally relevant, and the movement grew out of social and environmental concerns about problems with capital-intensive industrialization, which became especially pronounced during the energy crisis of the 1970s. In 1970, a group at the University of Sussex produced the 'Sussex Manifesto' (Singer et al., 1970) for the UN highlighting the importance of science and technology for development. While the UN deemed it too radical at the time, consigning it to the annex of a report, the manifesto nonetheless anticipated a number of approaches to innovation that are commonly accepted today. One example is the importance of adopting a systems approach, which means seeing science and technology innovation emerging from a system comprised of key agents (universities, the government, and business) that provide an enabling environment

for innovations to occur. Engineering for development highlights engineering's role in development and it endeavours to 'meet basic human needs or even "end poverty" through the implementation of technology', though some incarnations have been criticised for neglecting the social factors that inform development interventions. (Nieusma and Riley, 2010: 30)

While not a strong feature in our dataset, there were some examples of case studies that adopted an appropriate technology storyline, outlined in Table 4 below.

Table 4. Appropriate Technology Storylines in Engineering & Development Impact Case Studies

'PISCES estimates that it has improved clean energy access and livelihoods via bioenergy for approximately 180,000 people in Kenya, India, Sri Lanka and Tanzania. It did so, for example, by bringing together stakeholders to facilitate the translation of basic science into marketable technologies in East Africa. As a direct result of these forums, training and market mapping, PISCES has facilitated the distribution and use of 30,000 efficient gassifier stoves.' (Anthropology & Development Studies, UoA 24)
'…work on transport and mobility in Africa has resulted in the international development community and national governments recognizing that transport and mobility challenges must be addressed to improve economic and social wellbeing in rural communities in sub-Saharan Africa and elsewhere, particularly among vulnerable populations.' (Anthropology & Development Studies, UoA 24)
'The Centre for Disaster Resilience's (CDR) research is leading to a reduction in the vulnerability of communities world-wide to the threat posed by hazards of natural and human origin...supporting the development of a more resilient built environment…understand[ing] how infrastructure reconstruction programmes have impacted on women, vulnerable groups, and social cohesion among local communities in conflict affected areas of Sri Lanka' (Architecture, Planning & Built Environment, UoA 16)
'Twenty years of comprehensive research into long-lasting insecticidal nets (LLINs) …have contributed substantially to the prevention of around 1m deaths from malaria between 2008 and 2013. The research made a direct impact on guidelines and strategies issued by WHO as well as driving new technologies for insecticide-treated nets (ITNs), with downstream commercial benefits. (Public Health, Health Services & Primary Care, UoA 2)
'A Queen's University team led by Bhaskar Sen Gupta installed the world's first chemical free water treatment plant in the arsenic belt of India to benefit rural people living on per capita income of less than 1 US$ a day. With nine facilities in India, Cambodia and Malaysia, more than 13,000 people are receiving their water supply from Subterranean Arsenic Removal (SAR) plants…. Many villagers who started using clean water from the community plants in 2008 have shown significant signs of recovery from chronic arsenicosis.' (Civil & Construction Engineering, UoA 14, see also Table 2 above)
'This study analysed the shallow well drinking water quality of 17,000 rural

Malawians. Initial data indicates that water quality can be improved by up to 80%. This has the potential to improve the water quality for 1.5 million Malawians…Water-related diseases are responsible for 80% of all illnesses in developing countries and kill more than five million people every year…There is a vital need to develop cheap, sustainable ways to improve water quality.' (Architecture, Built Environment & Planning, UoA16)
'In the past two decades, Sub-Saharan African countries have undergone exceptionally rapid urbanisation, which has impacted significantly on land use, generally, and housing in particular. Research by the Alliance has found that the dominant reality of land use mechanisms – based on the needs, desires and capacities of the poor majority – is at odds with typical policy and practice approaches, which tend to be highly normative, predicated on major urban redevelopment, and thus over-ambitious and resource intensive.' (Architecture, Built Environment & Planning, UoA16)

These storylines are interesting in that they emphasise livelihoods, which combines social, environmental and economic dimensions, poverty reduction, and improving the lives of the vulnerable. Several of these cases are systems-based and were submitted to UoAs in the Social Sciences main panel. Two, however, the bed nets and arsenic water treatment plant, are both technology-based and submitted to STEM panels suggesting this type of argumentation may be possible for other cases.

Most development thinking has a strong streak of technological determinism; that is most argue that technologies shape societies, which would be critiqued by scholars of science and technology who have argued since the mid-1980s that in reality this process is more complex (Hackett, et al., 2007). The point was made that society also shapes technology, notably in a book by Mackenzie and Wacjman entitled *The Social Shaping of Technology* (1999), which maintained that technologies like weapons systems are very much a product of their powerful, often male, politician, business, scientist and engineer policymaker, funder and designer imaginations. This was part of a larger argument that technology is socially constructed (Bijker, et al., 1989). Since then, many science and technology studies scholars see a mutual shaping of technology and society (Callon, 1986; Latour, 2005). Modernization perspectives are often linear and based on an understanding that development occurs in well-defined stages, they also tend to focus on development success and on internal factors within countries that produce development outcomes. Developing modern science, technology and innovation is part and parcel of growth for modernization thinkers; especially that which is modelled on what has occurred in the North. The post-development perspective spearheads the critique of big development, and dovetails nicely with calls for appropriate technology. It advocates the belief that development as an idea has done more harm than good for the South, where people should be free to chart their own futures using locally relevant and sustainable technologies that allow them and their descendents to live in harmony with the Earth.

Conclusion

REF2014 was the first exercise in the history of UK research evaluation to include impact case studies. These case studies are publicly available and are a rich data resource as well as a major evidence source of the huge impact of UK research. In the documentation research impact was defined as that which has 'any effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life beyond academia' (REF, 2011: 26). In practice this meant that those writing impact case studies could choose from a wide variety of approaches to create impact narratives. We started this research perhaps naively thinking that we would find significant numbers of engineering & development REF2014 impact case studies that were pro-poor, humanitarian, inclusive and appropriate. We found instead a more conventional set of academic impact case studies most, not all, based on best-with-best departmental linkages, with a more traditional exclusive and innovation-centric approach. The argumentation linked environmental health and safety amelioration with growth in economic value in a way that was consistent with ecological modernization argumentation. While ecological modernization argumentation proliferated in the dataset this is not to say that the cases that invoked such argumentation may not also have had important humanitarian impacts, or appropriate technology aspects that were less prominent or obvious; what is interesting to us are the choices that authors made, as evidenced in the case studies, about how to present impact. We intend to carry out interviews with REF case study authors to uncover some of those choices in a future research project.

One notable finding is that engineering & development cases were present across the academic disciplinary spectrum, not just in civil engineering, where those working in international development might commonly assume is where most 'development engineering' takes place. The DfID funding regime for engineering & development prioritizes infrastructure development (WASH, energy, transport, and urbanization), this is an applied research agenda that tends to have limited value within a REF context. At the same time there were a small number of case studies, some systems focused and on the fringe of engineering others firmly rooted in infrastructure development, which did have an appropriate and humanitarian argumentation, emphasizing improvements in health and the livelihoods of the poor and other vulnerable groups. In these case studies the economic dimension was occasionally present, but normally less specified and more often presented as a downstream impact. It suggests that should engineering communities wish to think more in terms of the humanitarian impacts of their research in future research exercises, that this will be possible.

Our future research aims to examine cases within the hybrid space that we believe exists between the round and square holes in Figure 2. EPSRC, which has traditionally focused on a best-with-best approach is currently working together with DfID, traditionally more humanitarian and applied, to fund REF-able research on more inclusive engineering & development projects, such as the Energy & International Development: Understanding Sustainable Energy Solutions (USES) programme (UKCDS/RAE, 2014). UK engineers have an important role to play in

addressing the challenges of international development, and the extent to which high level research can be embedded and supported in academic funding regimes and exercises like the REF will allow for better addressing of significant global challenges such as the Sustainable Development Goals and Global Grand Challenges.

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