Energy Research Partnership

**Cross-cutting Report**

# INTERNATIONAL EMISSIONS ABATEMENT OPPORTUNITIES
# FINAL REPORT

***The Energy Research Partnership***

The Energy Research Partnership is a high-level forum bringing together key stakeholders and funders of energy research, development, demonstration and deployment in Government, industry and academia, plus other interested bodies, to identify and work together towards shared goals.

The Partnership has been designed to give strategic direction to UK energy innovation, seeking to influence the development of new technologies and enabling timely, focussed investments to be made. It does this by (i) influencing members in their respective individual roles and capacities and (ii) communicating views more widely to other stakeholders and decision makers as appropriate. ERP's remit covers the whole energy system, including supply (nuclear, fossil fuels, renewables), infrastructure, and the demand side (built environment, energy efficiency, transport).

ERP is co-chaired by Professor David MacKay, Chief Scientific Advisor at the Department of Energy and Climate Change and Dr Keith MacLean, Policy and Research Director at Scottish and Southern Energy. A small in-house team provides independent and rigorous analysis to underpin ERP's work.

ERP is supported through members' contributions:

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### The Energy Research Partnership Cross-cutting Reports

The ERP Cross-cutting Reports provide an overarching insight into the Research, Development and Demonstration (RD&D) challenges for key low-carbon technologies. Using the expertise of the ERP membership and wider stakeholder engagement, each report identifies the innovation challenges that face a particular technology, the state-of-the-art in addressing these challenges and the organisational landscape (both funding and R,D&D) active in the area. The work identifies critical gaps in innovation activities that will prevent key low-carbon technologies from reaching their full potential and makes recommendations for investors and Government to address these gaps.

The following have been involved in the ERP International Emissions Abatements Opportunities Review:

**Lead Analyst** Dr Mark Workman, Energy Research Partnership

**Steering Group:**

| | | | |
|---|---|---|---|
| Tom Delay (Chair) | The Carbon Trust | Duncan McLaren | Friends of the Earth |
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The views are not the official point of view of any organisation or individual and do not constitute government policy.

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**Boxes**

## ERP International Emissions Abatement Opportunities Review - Key Insights

The international Emissions Abatement Project sought to compare and contrast the UK's performance and current strategies for decarbonisation to 2020 with those of key international comparators: Germany, Japan, US, China and India.

The objectives of the review were to:

- Assess whether the UK's power generation capacity development is more capital intensive than in these other countries;
- At an international and UK level, highlight technical needs, general emissions and energy consumption trends / issues in respective sectors which require addressing to mitigate rapid emissions growth based on present deployment agendas to 2020;
- Assess the opportunities that other nations' emissions trajectories may present to the UK in terms of business value creation, technology transfer or collaboration based on national deployment (TRL 9) agendas (as opposed to research and development (TRL 1-8) and multi-national company perspective).

The key insights from this work are:

1. ***Review of Emission Abatement Trajectories for Respective Nations.***

- Though the trajectories and emissions abatement technology mix developed within nations surveyed have some areas of commonality, they are also varied for very different reasons based on a number of context specific issues - see figure ES1.

***Figure ES1:*** Summary of energy and emissions related drivers / priorities for each of the nations surveyed.

| | UK | Germany | Japan | US | China | India |
|---|---|---|---|---|---|---|
| **Demographics**<br>Population age structure | ⇨ | ⇩ | ⇩ | ⇨ | ⇨ | ⇧ ⇧ |
| **Urbanisation**<br>Present % and growth pa | 80% (+0.7) | 74% (0) | 67% (0.2%) | 82% (1.2) | 47% (2.3) | 30% (2.4) |
| **Economic Development**<br>GDP growth rates | ⇨ | ⇨ | ⇨ | ⇨ | ⇧ | ⇧ |
| **Energy Demand**<br>Energy Infrastructure Dev | ⇨ | ⇩ | ⇩ | ⇨ | ⇧ | ⇧ |
| **Energy Self Sufficiency** (%) | **81** ⇩ | **40** ⇩ | **20** ⇩ | **77** ⇧ | **80** ⇩ | **74** ⇩ |
| **Environmental Impacts**<br>Degree of Concern | ⇨ | ⇨ | ⇨ | ⇨ | ⇧ | ⇧ |
| **Industrial Policy**<br>Stimulus Funds to Low Carbon (% GDP) | M (0.1) | H (0.3) | M (0.2) | M (0.6) | H (1.2) | L (0) |

**Colour Code -** Impact on energy use and emissions**:**
- represents low concern / low impact.
- represents strong concern / high impact
- represents moderate concern / impact

**Arrows** - signify trends to 2020 and 2050.
**Statistics** - relate to the drivers as a function of the stated metrics.

- The UK is pursuing similar abatement programmes to the other countries in this survey - switching from coal to gas, maintaining nuclear (except in Germany) and with regards to renewables generation, predominantly deploying wind, biomass and solar technologies.
- All nations both in the OECD and rapidly emerging economies have energy efficiency and demand side management (DSM) programmes to reduce capital build requirements although these vary widely in scale, potential and ambition.

***2. Capital Intensity of UK Power Generation Capacity Development to 2020.***

- Despite the energy efficiency and DSM programmes, all nations have highly capital intensive generation build programmes. In terms of net capacity build to 2020, as a function of present capacity, the UK's projected increase (17%) is on a par with the US (12%) and Japan (10%) and substantially less than Germany (26%), China (91%) and India's (123%) - though in absolute terms China's addition of 840 GW is the largest outlay of generation capacity.
- In terms of value capture opportunities based on the deployment activity, the UK needs to consider how best to establish energy research and industrial policy frameworks to help grow, and capture value within international (low carbon) industrial value chains where the competitive advantage for process innovation will almost certainly lie in Asia.

***3. General Emissions and Energy Consumption Trends.***

Based on this review, the following over-arching insights cross all the nations and sectors were found:

- Many nations are unable to implement measures which would allow abatement opportunities to be exploited, for example due to market failure or insufficient human resource to enforce regulations.
- Demand side measures are increasingly important to address in order to meet emission abatement targets. The realisation of lasting demand side reductions, that avoid rebound effects, will require a substantial shift in behaviour / attitudes to energy consumption.
- There is a pressing requirement for substantially improved datasets for energy consumption and sources of emissions from respective energy systems. Without this, the ability to develop and assess the effectiveness of policy frameworks to address emissions will be highly problematic. Low carbon and energy efficiency policy initiatives should have data collection and evaluation resources built into their delivery capacity.
- There are areas in all sectors which are vitally important to the realisation of abatement opportunities that are under-researched such as the socio-economic behaviour in buildings abatement opportunities and business models for materials efficiency to realise net abatement in the industrial sector. These need to be systematically assessed and prioritised as a matter of urgency.

***4. Collaborative Opportunities based on National Deployment Rates and Patterns.***

- Different opportunities will arise in different phases of abatement technology development, necessitating different types of collaboration. Based on national deployment agendas (TRL 9), this work has identified, at a high level, indicative areas that the UK would be in a position to collaborate and the type of collaboration, on a sectoral basis with this group of countries - this is detailed in section 4. This should be fed into further work seeking to identify the UK's overall international engagement priorities, which also takes into account comparative strengths by matching up UK capability to develop technologies, the relevance of the technologies to national energy systems and the potential for business to exploit the technology. The ERP work on International Engagement will seek to address this.

## 1. Background and Study Objectives

The international Emissions Abatement Project sought to compare and contrast the UK's performance and current strategies for decarbonisation to 2020 with those of key international comparators; these included Germany, Japan, US[1], China and India - see box 1. To do this it surveyed the carbon abatement applications / technologies deployed, with a focus on the power sector and the degree to which demand side issues are being addressed. This permits assessment of the primary objective of the review: ***whether the UK's power generation capacity development is more capital intensive than in these other countries***[2].

The work applied a consistent framework of analysis of emission abatement trajectories and implementation strategies of the selected nations to 2020, set in context through a qualitative review of the relevant national circumstances, on a sectoral basis as follows:

- The power generation sector was assessed relative to policy announcements and modelled generation mixes; and
- opportunities in the industrial, transport and built sectors were assessed based on national policy announcements and cross-sectoral surveys.

These issues were validated by interviews with subject matter experts.

A second objective of the review is ***to highlight technical needs, general emissions and energy consumption trends / issues in respective sectors which require addressing to mitigate rapid emissions growth based on present deployment agendas to 2020***. This was undertaken across all the sectors.

This allowed the final objective of the review to be fulfilled: ***an assessment of the opportunities that other nations' emissions trajectories may present to the UK in terms of business value creation, technology transfer or collaboration based on national deployment agendas*** from a deployment perspective[3]; this was predominantly undertaken for the power generation sector. This component of the project will feed into another piece of ERP work - the International Engagement Project - which seeks to increase the resolution of this aspect of the work by matching up UK capability to develop technologies, the relevance of the technologies to energy systems and the potential for business to exploit the technology.

***Box 1: Respective role of the six nations in this review in global economic, energy and emissions activity.***

The six nations in this review constitute a substantial proportion of global levels of economic, energy and emissions activity. According to PWC (2012), in Purchasing Power Parity terms, they are six largest nations by economic activity (US$ 2009 Trillion: US 14.3**(1*)**, China 8.9 **(2)**, Japan 4.2 **(3)**, India 3.8 **(4)**, Germany 3.0 **(5)** and UK 2.3 **(6)**).

Though the characteristics for each nation are divergent, the key trend that they have in common is that they are forecast to display substantial economic growth over the period to 2020; for China and India the rate of growth to 2050 could be 7 and 10 fold, respectively (PWC, 2012). All are presently net importers of energy resources and to fuel this economic growth are anticipated to

[1] The UK, Germany, US and Japan are members of the Organisation for Economic Co-operation and Development (OECD) and may be referred to as the OECD bloc in this review.

[2] It is worth noting that a more capital intensive route is not necessarily more expensive on a life time basis. You can have a more capital intensive build phase but a minimal operational cost phase which on a long run basis results in a less expensive life-time cost. Indeed Mott MacDonald (2010) state that `*Generating plant can be broadly categorised either as being expensive machines for converting free or low cost energy into electricity energy (renewables and nuclear) or else lower cost machines for converting expensive fuels into electrical energy (fossil fuel or else biomass)*.' Capital intensive development might also support other economically beneficial outcomes through, for example, more intensive R&D.

[3] This review focuses on national deployment activity only, *i.e*. the abatement opportunities that are being exploited / sought to 2020 (i.e. ~TRL 9), rather than national R&D activity or those activities which multi-national organisations from these countries of origin which by their very nature work internationally - see Box 5.

increase energy imports due either to declining domestic fossil fuel reserves and / or rapid rate of economic development with the possible exception of the US due to the recent ability to exploit tight gas and oil reserves.

The combination of stage of economic development, rate of economic growth, differing energy consumption patterns makes the nations in this review all sit in the top 10 of global $CO_2$ emitters as follows: China 8.950 **(1)**, US 5.25 **(2)**, India 1.84 **(4)**, Japan 1.16 **(5)**, Germany 0.83 (**6**) and the UK 0.5 **(9)** $GtCO_2$ (Olivier et al., 2011). Their roles as the world's largest emitters of $CO_2$ are likely to remain for the foreseeable future though Russia and Brazil will also rank amongst the top 10.

(**Number in bracket indicates global rank in 2011*.)

The review is structured as follows:

- The respective drivers for national energy consumption and emissions abatement trajectory choice are summarised in section 2 (Contextual Factors). Here the trends that are leading to the development of present energy profiles; a description of emissions trends for respective nations since 1990, present emissions on a sectoral basis and pledged targets to 2020; and emissions abatement trajectories are assessed along with areas where collaboration may be undertaken to better assess and mitigate rapid emissions growth.
- Section 3 then goes on to describe power generation, industrial, transport and built sector development, trends, patterns and opportunities for UK collaboration based on national deployment activity and emissions to 2020. For the power generation sector an assessment of the capital intensity of the UK profile relative to the other nations is also made. Finally, cross-sectoral perspectives are highlighted.
- The overarching insights from the review and recommendations for policy makers and suggested follow up work are then made in Sections 4 and 5, respectively.

## 2. Contextual Factors

The scale and rate of transition required to transform the present fossil fuel based economy to a low carbon system is both unprecedented - see box 2 - and complex - see IIASA, 2012. Nations are engaging with this challenge in very different ways typically also aiming to ensure energy security to maintain economic growth. The trajectories and emissions abatement technology mix developed within nations have varied for very different reasons. Least cost has not necessarily always been a priority. The choice of path has been based on a number of contextual factors including access to low cost energy resources, structure of the economy, public acceptance and stage of economic development. For example, Germany's decision to revoke the nuclear plant life extensions and pursue a renewables based trajectory was a function of public concern for the safety of nuclear technology despite the majority of the capital for the plant having been already written off; the Chinese drive for 20% of its energy to be generated by renewables is a function of concern of increased energy insecurity, air quality impacting on health / quality of life and industrial policy which seeks to capture international renewable market share; and the UK's drive for a greater proportion of offshore wind generation capacity relative to onshore, despite the substantially greater costs, is a function of the lack of public acceptance of onshore wind farms.

***Box 2: The scale and rate of the transition to a low carbon energy system is unprecedented***.
Global energy consumption has grown from ~50 EJ in 1900 to >540 EJ in 2009 - virtually an eleven fold increase in just over a century (Smil, 2010). Increased primary fuel use has been almost exclusively fossil (with small amounts of nuclear and renewable - mainly hydroelectric), while end consumption growth has been increasingly dominated by electricity. The role of energy services has actually increased more than 11 fold due to substantial improvements in energy conversion

efficiency. Gross World Product has increased around 60 fold over the same timeframe.
The rate of decarbonisation to achieve emissions targets, required to keep global temperatures to within 2°C of the pre-industrial mean, range from 4 to 6 % sustained annually between now and 2050 for the countries studied. Though decade long sustained rates of decarbonisation have been recorded - for example, when the French power sector shifted to nuclear intensity fell by 4.2% annually in the 1980s, the UK dash for gas resulted in 3% annual reductions for the 1990s and the most was demonstrated by China in the 1990s of 5.8% annually - these rates were not sustained beyond a decade and in all cases slowed down or in some cases were reversed. Furthermore, it is worth nothing that absolute decarbonisation was highly dependent on rates of economic growth with the UK and French having progressive absolute reductions and the Chinese having substantial growth due to economic growth rates of 8-10%.

In order to understand the present emissions profiles, anticipated emissions trajectories to 2020 and the reason for the different abatement opportunities undertaken by the nations in this survey a number of contextual energy related issues were analysed. From this, figure 2.1 was derived.

***Figure 2.1:*** Summary of energy and emissions related drivers and priorities for each of the nations surveyed.

| | UK | Germany | Japan | US | China | India |
|---|---|---|---|---|---|---|
| **Demographics**<br>Population age structure | ⇨ | ⇩ | ⇩ | ⇨ | ⇨ | ⇧⇧ |
| **Urbanisation**<br>Present % and growth pa | 80% (+0.7) | 74% (0) | 67% (0.2%) | 82% (1.2) | 47% (2.3) | 30% (2.4) |
| **Economic Development**<br>GDP growth rates | ⇨ | ⇨ | ⇨ | ⇨ | ⇧ | ⇧ |
| **Energy Demand**<br>Energy Infrastructure Dev | ⇨ | ⇩ | ⇩ | ⇨ | ⇧ | ⇧ |
| **Energy Self Sufficiency** (%) | 81 ⇩ | 40 ⇩ | 20 ⇩ | 77 ⇧ | 80 ⇩ | 74 ⇩ |
| **Environmental Impacts**<br>Degree of Concern | ⇨ | ⇨ | ⇨ | ⇨ | ⇧ | ⇧ |
| **Industrial Policy**<br>Stimulus Funds to LC (% GDP) | M (0.1) | H (0.3) | M (0.2) | M (0.6) | H (1.2) | L (0) |

**Colour Code -** Impact on energy use and emissions:
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**Statistics** - relate to the drivers as a function of the stated metrics.

Population growth, structure and urbanisation rates are an important determinant of energy demand and often a reflection of and a driver for economic development particularly in emerging economies where urban dwellers have higher incomes and better access to energy services. In terms of demographics, the metric selected for figure 2.1 is that of population growth to 2050 and old age dependency ratio (Number of working age persons to those 65 years+). To 2050, there will be growing populations in India (42%), UK (16%) and US (29%). Declining populations in China (4%), Germany (8%) and Japan (14%) with the working dependency ratios as follows:

- In UK and US the working age dependency for the elderly will fall from present 4 to 1.8 and 5.1 to 2.1, respectively in 2050;

- In Germany and Japan this will shift from 3.2 to 1.2 and 2.8 to 1, respectively;
- China displays the most rapid decline from 8.3 presently to 1.8 in 2050 with around 3.4 in 2025 (Magnus, 2008 - p170); and
- In India the ratio is best at 11 and falling to 4.2 in 2050.

The rates of urbanisation anticipated in the rapidly emerging economies will be substantially greater than in OECD countries. This is a function of high rates of economic growth in China and India, in the recent past[4], and relatively low growth rates of between 0 to 3.5% in the OECD nations albeit based on larger economies. All these factors are resulting in increased energy demand particularly in rapidly emerging economies where development of additional generation capacity is running at 10's to 100's of GW pa and in OECD nations growth is at single digit increases per annum.

The rapidity with which the emerging economies are increasing their energy demand is impacting on their energy security with both China and India becoming increasingly dependent on imported energy resources (e.g. NDRC, 2012). Japan and Germany have the lowest self-sufficiency which also stands to deteriorate with the decision to remove nuclear from the German generation mix and the public concerns of re-activating the Japanese nuclear fleet following the Fukushima nuclear accident in March 2011[5]. The UK is moderately well positioned at 0.81 but with the decline in N. Sea oil and gas supplies (at ~4 and ~6 % pa, respectively) will be increasingly dependent on imports. The US, though presently dependent on imports for 23% of their energy needs, is likely to be increasingly energy secure as a result of the shale gas revolution and the ability to exploit tight oil reserves (EIU, 2012a). The potential impact of the shale gas revolution on the energy security of nations outside of the US is discussed in Box 3 (see also Bressand, 2012).

**Box 3: The role of unconventional gas on future national energy mixes and emissions profiles.**

The shale gas boom in the US has resulted in the spot price for gas (Henry Hub) to stand at $4/MMBtu compared to $9/MMbtu for UK gas and $15/MMBtu for Asian Liquefied Natural Gas (LNG) in 2011. The US, having been an importer of gas, is now a net exporter with the UK being a recipient of US gas in 2010 (EIA, 2011). Furthermore, a forecast by the US Energy Information Agency (EIA) anticipates that shale gas production in the US will triple by 2035. However, anticipation of a gas glut that may result from the global exploitation of substantial unconventional reserves (which are five times larger than conventional reserves) is predicated on a number of uncertain issues:

- Firstly, unconventional gas resources in the US remain very uncertain and those resources outside of the US are even more so (JRC, 2012);
- Secondly, it is highly unlikely that the rapid ramp up in production of unconventional gas in the US will be able to be replicated in other parts of the world, especially Europe (Stevens, 2011); and
- Finally, the environmental impact of unconventional gas is not known and the introduction of regulation may inhibit the rapid further development of the resource.

The ability to address these questions, especially for Europe, will most likely only materialise after 2020. In the interim, this is creating substantial investment uncertainty in the conventional gas and renewables sector as investment is being drawn away from LNG infrastructure development and renewables. There are two critical concerns with this situation:

- Firstly, that if gas generation infrastructure is developed which anticipates a glut of cheap gas - which then fails to be

[4] From 1993 to 2007 China averaged growth of 10.5% pa and India 6.5%.

[5] It may be argued that a nation with a nuclear programme should have its own domestic uranium supplies or a functioning fast-breeder programme for this to be considered a secure energy source, however, the relatively low quantities of uranium required and its availability from secure sources (relative to the unstable middle east for oil and gas, for example) makes this a relatively secure energy source. In the IEA, OECD National Energy Balances (2011a), nuclear energy supplies are categorised as domestic.

realised - nations will be locked into gas generation which will be reliant on highly constrained and therefore expensive gas supply due to the lost decade of investment in LNG and other gas infrastructure.

- Secondly, with regards renewables, a related problem is that there will be a lack of development which means that if shale gas fails to deliver nations will be locked into a higher carbon future than would otherwise have been. Furthermore, the scale of deployment needed to reduce renewables costs will be delayed.

Both these issues could therefore potentially result in a more expensive scenario than one which involved development of a broader generation capacity mix.

In summary, the impact of shale and unconventional gas on the future gas markets and energy generation mix is potentially highly disruptive and could materially impact national abatement trajectories. However, such are the uncertainties with the extent of reserves, environmental impact and the ability for US production ramp up to be replicated elsewhere that it is too early to predict a gas glut and therefore lock in energy mixes based on such a prediction. It is suggested therefore that there is a need to develop policies that will take into account the uncertainties for unconventional gas development on international gas prices (Moore, 2012).

Against these energy related issues overlay environmental concerns. In the case of OECD countries the main environmental drivers are based on those of climate change and fulfilling the emissions pledges made for the 2009 Copenhagen Accord. In the case of the US, the lack of federal regulation is making for weak emissions based regulation which is the main reason for the low impact rating of this variable. For Japan, the situation is complicated by public concerns over the safety of nuclear plant and in Germany by the revoking of the Nuclear Act in 2011. However, for the rapidly emerging economies the impact of environmental issues is more immediate - hence the high rating. In the case of China, World Bank (2012) estimates suggest that environmental degradation results in annual damage equivalent to 9% of GDP and poor air quality air kills an estimated 1.3 M pa. In India, bad sanitation and water pollution costs 6% of national income.

Finally, with regards industrial policy for low carbon technology development, this metric is based on the proportion of the stimulus packages that went to clean tech sectors as a proportion of GDP (HSBC, 2009). China, US and Germany have invested heavily (>0.3% of GDP) viewing the development of the sector as an opportunity. The UK and Japan appear to have not taken the opportunities to the extent as the other nations (<0.3% of GDP) and India did not invest any stimulus funds to the clean tech sector.

Insights from the contextual analysis undertaken in this review are as follows:

- In the short to medium term, energy demand is rising in all countries, slowly in developed economies and fast in developing economies. In the long term it is likely that Germany and Japan will reduce as a function of the demand side policies and ageing, contracting populations.
- All the nations in this review, with the possible exception of the US, will become increasingly dependent on imported energy sources to 2020 and 2050. This is of particular concern to the UK, Germany and Japan due to declining or limited indigenous energy reserves. The deployment of renewable and nuclear power is seen as a way of mitigating energy security concerns as well as fulfilling respective environmental agendas.
- For rapidly emerging economies the main priority is meeting the energy demands of economic growth so the exploitation of all available economic domestic energy resources to the maximum is the key driver. This is also the motivation for energy efficiency and conservation measures in these nations.
- Environmental concerns are an overlay on the issues of growing energy demand and security of supply concerns: carbon emission limits, air quality standards and nuclear waste issues.
- Some countries see investment in low carbon renewable technologies as an integral element of their industrial policy, increasing efficiency and creating a new high value sector, others see it as a lower priority.

- Based on demographic economics, structures of respective economies (state of economic transition), rate of urbanisation, rapid technology diffusion and fuel switching it is anticipated that baseline emissions will peak before 2050 for all the nations in this review with the exception of India. India's younger population, greater capacity for further urbanisation and need to develop a manufacturing sector to employ the growing working age group is likely to lead to emissions peaking beyond 2050.

The overarching deduction from the review of contextual drivers for each nation is that they are highly varied.

***Emissions and Targets to 2020***

Figure 2.2 displays $MtCO_2$ emissions by sector for each of the nations in 2009 and the emissions pledges to 2020. Two issues worth highlighting in this figure are:

- The UK and German emissions have fallen by 12.9 and 23.1% since 1990. In Japan and the US they have slightly increased by 3.1% and 4.9%, respectively. In the case of China and India they have increased substantially by 174.3 and 179.9%, respectively.
- The OECD nations have absolute emissions reductions in their pledges whereas the rapidly emerging economies have GDP linked emissions reductions targets which, due to their rapid growth, results in a substantial increase of emissions to 2020.

Therefore, the UK and Germany are seeking to reduce emissions based on a downward trend whilst Japan and US are seeking to do so from an upward trend. For China and India, it is a case of attempting to further relatively decouple emissions intensity per unit of GDP.

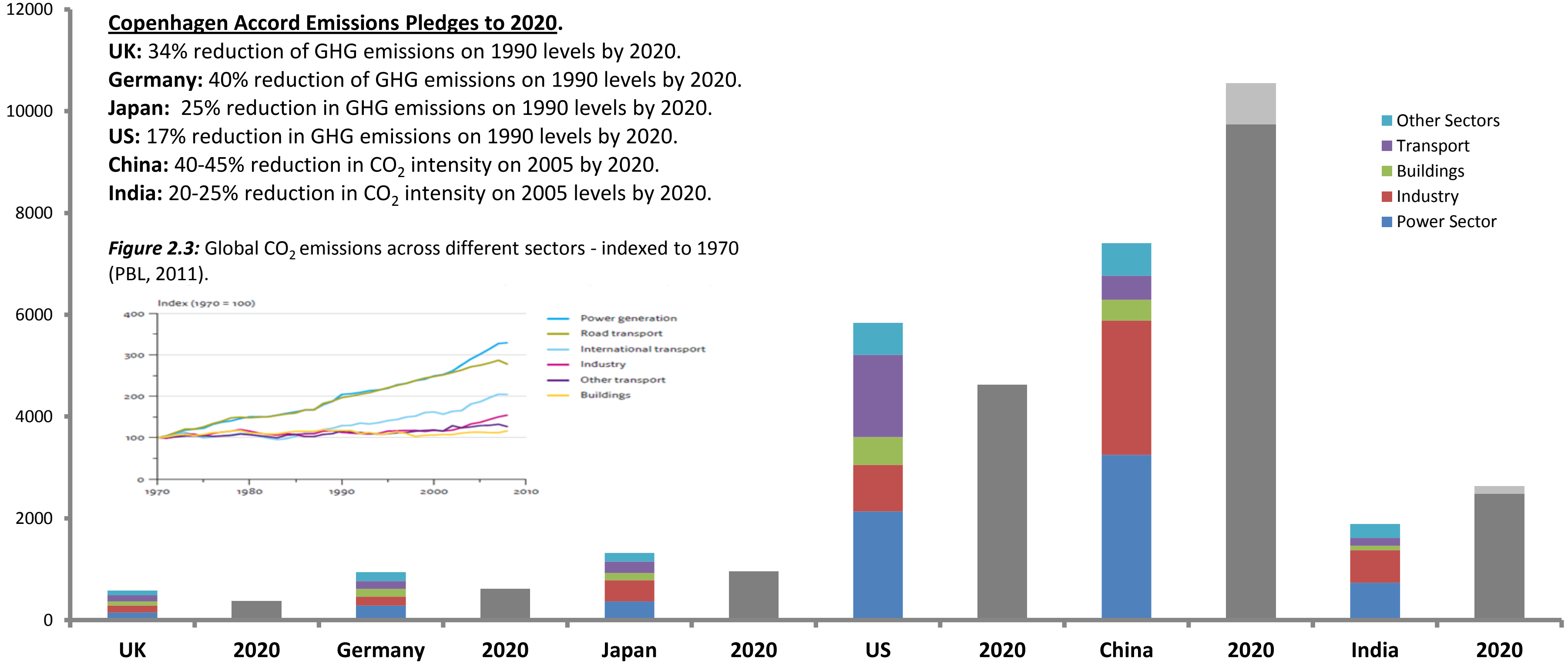
On a sectoral basis, it can be seen that, other than for Japan, the sector with the largest emissions is power generation accounting for 38% of all emissions in the nations surveyed. The sector has also shown the most growth since 1970 due to the increased electrification of energy services - Figure 2.3. The next largest emitter is generally the industrial sector followed by transport (which has also increased substantially since 1970) and then buildings. These sectors will be reviewed in this order in the context of their abatement opportunities or emissions growth trends for each nation.

***Data Needs***

From the contextual analysis the following general trends are worth highlighting along with recommendations for potential UK collaboration are made:

- Emissions data are subject to significant errors mainly due to inaccuracies in national energy use data. Annual revisions are common. The substantial error margins in emissions data measurement and accounting, particularly for emerging economies, has implications on the ability to develop meaningful national emissions reduction targets as the discrepancies in accuracy may actually dwarf the emissions reduction targets, robust climate science and the appropriate mitigation policy. A meta-analysis by Andres et al. (2000) showed that by 1993, revisions of 1983 data (10 years previous) amounted to an average 8.8 percent decrease, with 25 countries making revisions larger than ±10 percent. For example, with regards China this lead to emission in 2000 being revised upwards by 23% between 2006-07 (Gregg et al., 2008). There are ongoing concerns regarding the under-reporting of Chinas emissions (The Economist, 23rd June 2012 - p64). Uncertainty in aggregate emissions data for developing nations translates into the quality of sectoral data for industry, transport and buildings complicating analysis undertaken on a sectoral basis. For more details of emissions data issues see WRI CAIT (2010), Olivier et al., (2011) and Marland (2008). The

***Figures 2.2 & 2.3** (embedded):* $CO_2$ emissions by sector in 2009 and targets for 2020 for each nation in the survey (figures in table below in $MtCO_2$).
*Source:* International Energy Agency (2011b): $CO_2$ Emissions from Fuel Combustion (Edition: 2011). ESDS International, University of Manchester.




**Copenhagen Accord Emissions Pledges to 2020.**
**UK:** 34% reduction of GHG emissions on 1990 levels by 2020.
**Germany:** 40% reduction of GHG emissions on 1990 levels by 2020.
**Japan:** 25% reduction in GHG emissions on 1990 levels by 2020.
**US:** 17% reduction in GHG emissions on 1990 levels by 2020.
**China:** 40-45% reduction in $CO_2$ intensity on 2005 by 2020.
**India:** 20-25% reduction in $CO_2$ intensity on 2005 levels by 2020.

***Figure 2.3:*** Global $CO_2$ emissions across different sectors - indexed to 1970 (PBL, 2011).



| | UK | 2020 | Germany | 2020 | Japan | 2020 | US | 2020 | China | 2020 | India | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Power** | 147 | | 284 | | 368 | | 2,134 | | 3,245 | | 734 | |
| **Industry** | 137 | | 176 | | 414 | | 915 | | 2,639 | | 638 | |
| **Buildings** | 85 | 371 | 157 | 608 | 147 | 959 | 547 | 4,621 | 414 | 9,740 Variation for intensity 810 | 90 | 2,480 Variation for intensity 155 |
| **Transport** | 120 | | 149 | | 220 | | 1,614 | | 470 | | 150 | |
| **Other** | 95 | | 175 | | 169 | | 631 | | 639 | | 278 | |
| **Total** | **583** | | **940** | | **1,318** | | **5,840** | | **7,408** | | **1,891** | |
| ***Var 1990*** | **-12.9 %** | | **-23.1 %** | | **+3.1 %** | | **+4.9 %** | | **+174.3 %** | | **+179.9 %** | |

degree of uncertainty in levels of man-made emissions is likely to increase as the contribution of emissions from countries with less reliable datasets become more industrially active.

- There is a growing body of literature advocating the use of consumption based accounting to better address emissions mitigation frameworks. Figure 2.4, highlights the implications of consumer based accounting for the UK. This has reciprocal impacts for export based economies such as China where in 2004, 23% (or 1.1 $GtCO_2$) were estimated to have been exported - equivalent to slightly less than the total emissions for Japan (Tyndall Centre, 2007). For more detail on emissions based accounting see Defra, 2012, Peters et al., 2011 and Davies et al., 2010.

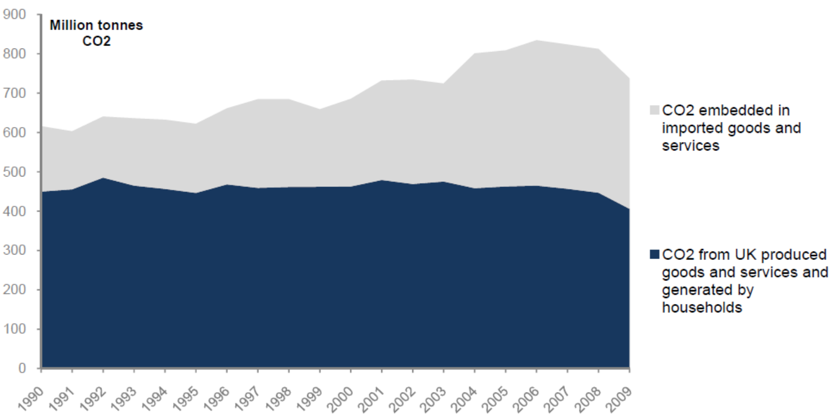



***Figure 2.4:*** Shows that $CO_2$ emissions for the UK associated with imported goods and services accounted for around a quarter of the carbon dioxide footprint in 1990 (166 million tonnes ($MtCO_2$, 27 per cent); by 2009 their share had increased to just under half (331 $MtCO_2$, 45 per cent).

There is a need to appreciate national emissions inventories using both production and consumption based accounting techniques in order to better understand the underlying causes of respective national emissions profiles therefore potentially facilitating the design of more appropriate and effective mitigation policy frameworks.

Based on these trends, there is a need:

- For international initiatives to address emission measurement issues with the greatest priority being on the development of capacity for developing nations; this may be undertaken via the UN or EU.
- To seek to develop frameworks to incorporate consumption based accounting alongside production based criteria to allow better designed mitigation policy.

***Recommendation:*** The UK should collaborate with nations which have capacity gaps in the ability to effectively measure emissions with a view to developing common international standards. Frameworks to account for consumption based emissions in mitigation initiatives should be assessed in order to validate the value and feasibility of such an approach.

***Negative Emissions Technologies***

- With the shift from emissions targets set on the basis of scientific criteria to being volunteered by nations means that there is an increased likelihood of the 2°C climate target being missed (IEA, 2010a and UNEP, 2010) - see Box 4. The Copenhagen Accord (COP 15) marked a shift from scientifically set top down emissions targets to nationally volunteered abatement targets. A review of the pledges made at COP 15 relative to those required by climate scientists suggests that there will be an overshoot of between 4.7 to 7.1 $GtCO_2$ in 2020 to maintain a 50% probability of reducing climate change to 2°C. Assuming that the emissions levels set by the scientific community are robust, the bottom up approach will result in an overshoot of the cumulative emissions required to maintain the 2°C target. This suggests, in line with other measures (IEA, 2013), there is the need to consider negative emissions technologies to remove $CO_2$ from the atmosphere and keep atmospheric emissions to `*safe levels'*.

**Box 4: The need for the development of work in negative emissions technologies.**

In the UNEP (2010) meta study of Integrated Assessment Models (IAM), negative emissions technologies played a role in the majority of trajectories for energy and industry from 2060 to 2070. However, the need to consider them in a timeframe of less than 58 to 48 years has significant implications as negative emissions technology development is presently a highly fragmented and nascent technology. Though early work undertaken suggests that some technologies are potentially cost competitive with some mitigation systems and have the technical advantage of separating the source of emissions from possible sinks for $CO_2$, potentially meaning that they have a role in a suite of mitigation measures - more work is needed (Grantham, 2012a). In particular, there are a multiple set of considerations to be taken into account to develop negative emissions technologies which needs to be considered by government, both for governance and scale up, should they be needed as a matter of priority. These include but are not limited to:

- Public Engagement to avoid a backlash as has happened in Genetic Modification, Biofuels and Nano-technology.
- Establishment of a governance framework to account for environmental impacts and allow certification of technologies as truly being negative emissions (The Royal Society, 2009).
- Role of institutions (existing or new ones) to manage negative emissions technology development.
- The development of regulatory, policy frameworks for scale up and assessment of their role in the interaction with existing laws, conventions and legal liability frameworks.
- Their impact on existing and role in future international climate change agreements (Barrett, 2008).
- International agreements on a set of standards as to how to measure, monitor, report and verify (MRV) the effectiveness of different negative emissions technologies.

This means that negative emissions technologies and adaptation strategies must be integral to mitigation policy framework development.

Negative emissions governance and development is an area that will require focus in the coming decade.

***Recommendation:*** The UK should consider establishing capacity to better understand negative emissions technologies with a view to engaging the international community to develop global governance frameworks or guidance on best practice - which-ever is considered more pragmatic and timely. This will result in complementary synergies and risk sharing should scale up be required.

## 3. Analysis by Sector

From the review of the contextual issues, the ability to implement emissions abatement opportunities in respective nations, is complicated by the following issues:

- In OECD nations, energy markets are semi-regulated with the issues of energy security, environmental impact and industrial policy being subject to public policy. Though in rapidly emerging economies energy markets are planned, the ability to effect the appropriate investment is impacted by the fixing of energy prices which may not reflect the appropriate signals or may not be those that the market would send;
- In OECD nations, the ability for public policy to act as an effective tool for `*regulation'* of the energy sector within environmental targets is variable, being subject to private sector and electoral influence.
- For the development of many abatement technologies, the best strategy isn't clear at this stage. For some technologies, the strategy of collaborate to grow the market size is considered to be sensible. However, the dynamics of energy markets and regulation often prohibits this - leading to other reasons for

collaboration such as the establishment of complementary capability and in others, due to the scale of investment required, will be a function of sharing risks and costs.

### 3.1 Power Generation Sector

Each country's present power generation capacity is described (table 3.1) and then modelled projections of respective electricity mixes to 2020 are compared to national renewables and low carbon abatement policy targets. In scenarios that focus on reducing emissions significantly to 2050 (>80%), the power generation sector is considered to be the key sector for emissions reduction as it allows for abatement though the electrification of other energy services such as heat and transport. Studies indicate that targets cannot be met without the sector being decarbonised almost completely by the mid-2030s whilst energy for electricity generation is anticipated to account for 40% of global energy consumption in 2040 (ExxonMobil, 2011). Due to its potential role in attaining emission abatement opportunities across other sectors, the abatement opportunities in the power sector are also well documented.

***Table 3.1:*** Summary of power generation mix for respective nations in this review (IEA, 2011a and ABB, 2011).

| Nation | Intensity ($gCO_2$/KWh) | Power Generation Mix in 2010 |
|---|---|---|
| **UK** | 435 | Gas, hard coal and nuclear are the main elements of the UK generation mix making up 38% (30.7 GW), 35% (28.4 GW) and 13% (10.2 GW), respectively. Renewables share of capacity is low with onshore and offshore wind making up 4% (3.57 GW) and 2% (1.27 GW) and biomass <1% (0.23 GW) and approximately 3% of electricity generated in 2010. |
| **Germany** | 433 | In 2010, German electricity generation mix was made up of 54% fossil fuel (52.9 GW of coal, 23.8 GW of gas and 5.9 GW of oil), 9% nuclear (reduced from 13% with the removal of 8.3 GW of plant from the 21.5 GW fleet in May 2011) and 36.4% renewables (5.4 GW hydro, 2.2 GW biomass, 24 GW of onshore wind, 3.2 GW of onshore wind and 17.3 GW of solar PV). |
| **Japan** | 438 | Prior to Fukushima, electricity generation capacity was dominated by fossil fuels, nuclear and hydro. Fossil fuel plant made up 61% capacity comprising coal (46 GW), Gas (72 GW) and Oil (50 GW) which is increasingly run as back up capacity. Nuclear plant made up 18.1% (54 GW) and hydro 17.1 % (47 GW) of capacity. |
| **US** | 508 | In 2009, the US generation mix was made up of 77% fossil fuel (395 GW of natural gas, 332.5 GW of coal and 73 GW of oil). The low carbon component is made up of 10% (104 GW) each of nuclear and hydro and 3.3% of wind, biomass/waste, solar PV and Geothermal. |
| **China** | 842 | In 2009, total installed power capacity in China stood at ~931 GW with 70% (650 GW) of coal based thermal power, 21% (197 GW) hydro-power, 1% (9 GW) nuclear, 3% (26 GW) of wind and >1% (~3 GW) of other renewable power generation. |
| **India** | 963 | In 2009, the Indian power generation sector totalled 168 GW in capacity with 52.2% (88 GW) of coal, 11.2% (19 GW) natural gas and 5.9% (10 GW) oil. Low carbon capacity runs at 36 GW of hydro, 4.2 GW of nuclear and 11.5 GW of others. |

A review of the power generation sector and abatement opportunities across the countries in this survey reveals the following general trends and issues:

- The OECD nations have the least carbon intensive power generation mixes ranging from 433 $gCO_2$/KWh for Germany to 508 $gCO_2$/KWh for the US; all OECD nations have a substantial proportion of their power generation mix based on fossil fuels meaning that there is scope to reduce these emissions intensities yet further, for example, targets for the UK to 2030 are ~50 $gCO_2$/KWh. China and India have substantially higher (50% > world average) emissions intensities due to the dominance of coal in both generation mixes.
- For all countries in the survey, energy security is facilitated by ensuring that a mix of technologies is selected to avoid over reliance on a few key technologies. This allows energy resource diversification and results in differentiation between nations selected energy mix as a function of natural resource

endowments. It also results in the development of energy pathways that are not necessarily least cost. The extra cost of diversification effectively forming a premium for energy security.

- With regards China and India, meeting the energy demands of rapid economic growth is the key challenge for both these countries and a potential constraint on future growth. As a result any technologies which impact on the economic competitiveness of the energy generation system are relegated to niche roles. For example, in China this is particularly relevant to the low priority given to the development of Carbon Capture and Storage.
- The work has highlighted the need to emphasise `*Technology Forwards Modelling*'[6] as a complement to back-casting techniques[7] to identify policy gaps and the sensitivities within policy frameworks to develop abatement technology rollout to hit prescribed targets. The use of the combination of these two techniques will also allow the identification, development and scale up requirements of adaptation and negative emissions technologies within a wider framework of mitigation measures.

***Assessment of nature of capital intensity of power generation system development for respective nations and impact on energy innovation and development investment***

Based on the above methodology, figures 3.1 to 3.4 were derived and display the following:

- Figure 3.1, highlights the capital intensity of all power generation development programmes to 2020 for the nations in this review, relative to present capacity;
- Figure 3.2, displays net additional energy generation capacity to 2020 broken down by technology type for all the countries surveyed - in Giga-Watts;
- Figure 3.3, power generation development represented in UK declared net capacity (DNC) to 2020 for all the countries surveyed - in Giga-Watts; and
- Figure 3.4, power generation system flexible component relative to variable and limited flexibility component for each country surveyed in 2009 and in 2020.

Analysis of the power generation sector abatement opportunities across the countries in this survey highlights three key points and raises a key question to reconcile - as follows:

- Firstly, that the UK is pursuing similar abatement programmes to the other countries in this survey - switching from coal to gas, maintaining nuclear (except in Germany) and with regards renewables generation predominantly deploying wind, biomass and solar technologies;
- Secondly, all nations both in the OECD and rapidly emerging economies have energy efficiency and demand side management (DSM) programmes to reduce capital build requirements although these vary widely in scale, potential and ambition - see below;
- And finally, despite the energy efficiency and DSM programmes, all nations have highly capital intensive generation build programmes. In terms of net capacity build to 2020, as a function of present capacity (figure 3.1), the UK's projected increase (17%) is on a par with the US (12%) and Japan (10%) and substantially less than Germany (26%), China (91%) and India's (123%) - though in absolute terms Chinas addition of 840 GW is the largest outlay of generation capacity.

[6] Forecasting penetration rates of technologies to the future based on historical levels of technology take up.

[7] Establishing a desirable technology penetration end state and working back to present situation with levels of technology uptake being set at key timeframes between the end and present date.

The reasons for capital intensive build in the OECD and rapidly emerging economies are different.

For OECD countries build intensity is attributable to the following:

- To the age of the existing conventional generation fleet which have either reached end of life or will be unable to continue under environmental policy such as the Large Combustion plant Directive in the EU. In the UK, the average age of the coal fleet is 40 years old, nuclear 32 years, gas and oil 20 years; in Germany, the average age of the lignite fleet is 35 years, hard coal 33 years, and gas and oil 21 years (RWE, 2009); in US the average coal fleet is ~40 years old[8] (only ~30 GW is <10 years old); and in Japan the fossil fuel fleet is relatively young due to the need to ensure optimal conversion efficiency.

  The age of plant in rapidly emerging economies is lower, for example, in China where the majority is <10 years old and in India where over 60% (~50 GW) is <20 years old (IEA, 2011c).

  For OECD countries this will lead to substantially greater gross build requirements than suggested by the statistics in figure 3.1 (and IEA (2011d) for the extent of power generation fleet retirements). This in itself represents an abatement option as the replacement of capital stock will result in the introduction of plant with improved conversion efficiency - see for example Ecofys (2011) which calculated that the $CO_2$ abatement that would result from replacing US fossil fleet with the most efficient technologies would be 0.5 $GtCO_2$ of savings pa.
- The drive to deliver generation capacity that is low carbon as set by policy. Renewables, due to their lower load factors, require more capacity replacement per unit of conventional plant. There is also the need for back up capacity to cover for intermittent generation from renewables.

For emerging economies, capital intensive build is a function of the need to develop new generation capacity in order to fuel their rapidly expanding economies. Furthermore, for both China and India the renewables and low carbon (*i.e.* nuclear) agenda augments the drive for energy and economic security as these sources reduce exposure to energy commodity price fluctuations.

Furthermore, taking the statistics in figure 3.1 and applying a Declared Net Capacity (DNC)[9] factor - figure 3.3 - one can see that the net increase in power generation capacity reduces to 0% for the UK and Germany, 10%, 7%, 79% and 112%, respectively for Japan, US, China and India indicating that the UK and Germany are investing in greater proportions of intermittent capacity whilst the others are increasing base-load capacity.

[8] http://www.iea-coal.org.uk/site/2010/database-section/coal-power?LanguageId=0

[9] Declared Net Capacity Factor is the maximum continuous rating of the generation sets in stations less the power consumed by the plant itself and is reduced by the plant itself and is reduced by a specified factor to take into account the intermittent nature of some renewable energy sources. Conventional Generation statistics are from Mott MacDonald (2010) and Renewables are from DECC (2012) - Renewable Energy Statistics Data Sources and Methodologies. These DNC statistics are indicative as the factors are derived from a single UK co-efficient which may not be completely appropriate for other nations which are not easily available.

***Figure 3.1:*** National Energy Mix in 2009 and to 2020 broken down by technology type for all the countries surveyed - GW. Figures indicate % increase.

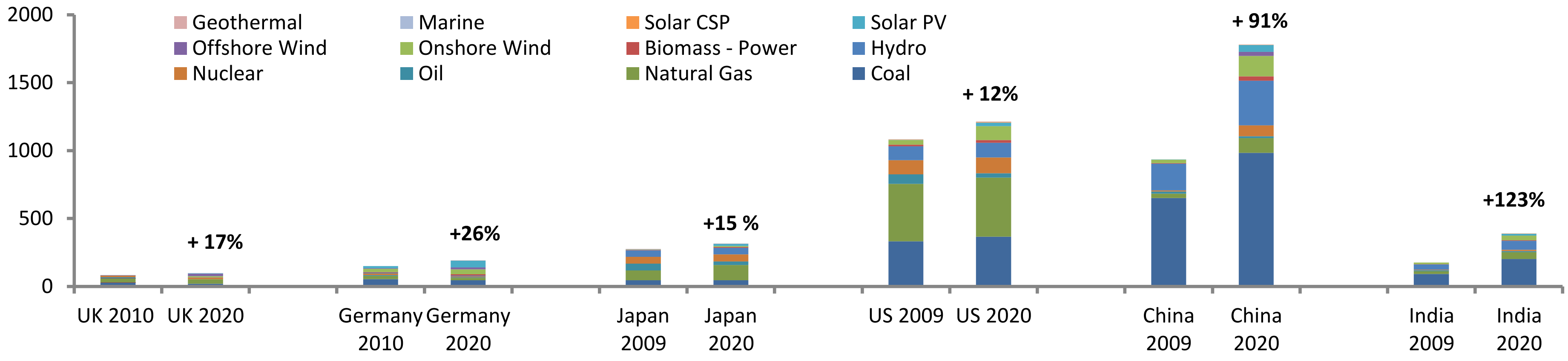
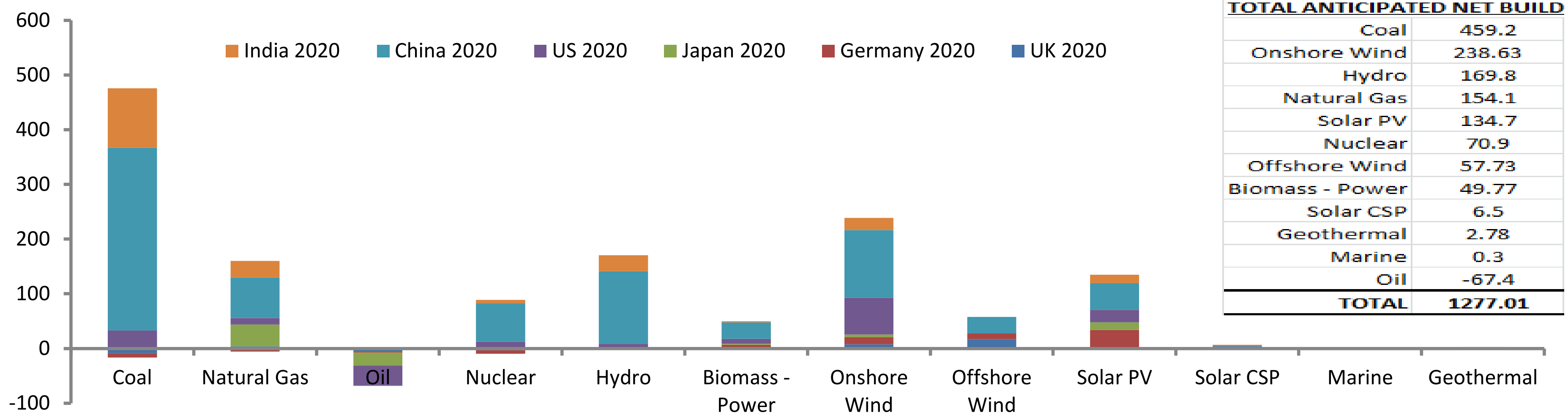
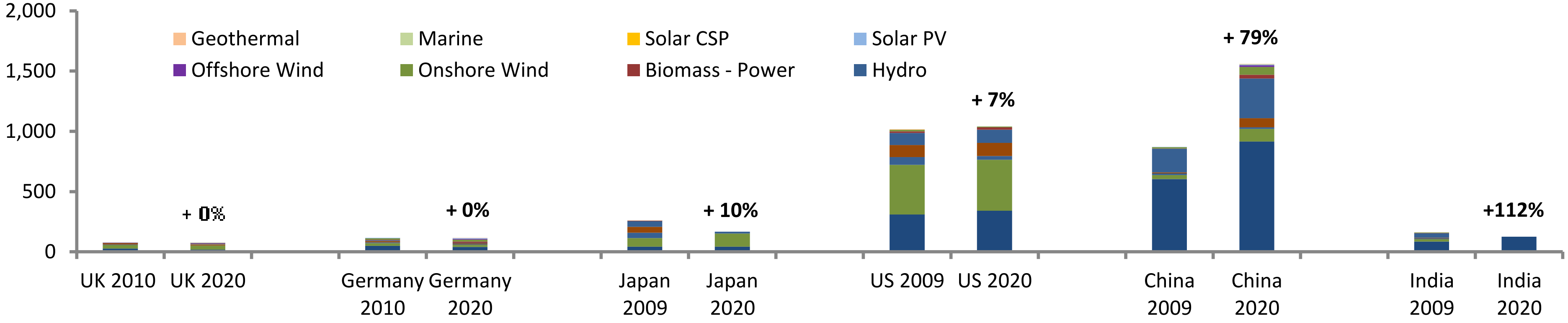



***Figure 3.2:*** Net additional energy generation capacity to 2020 broken down by technology type for all the countries surveyed - GW.



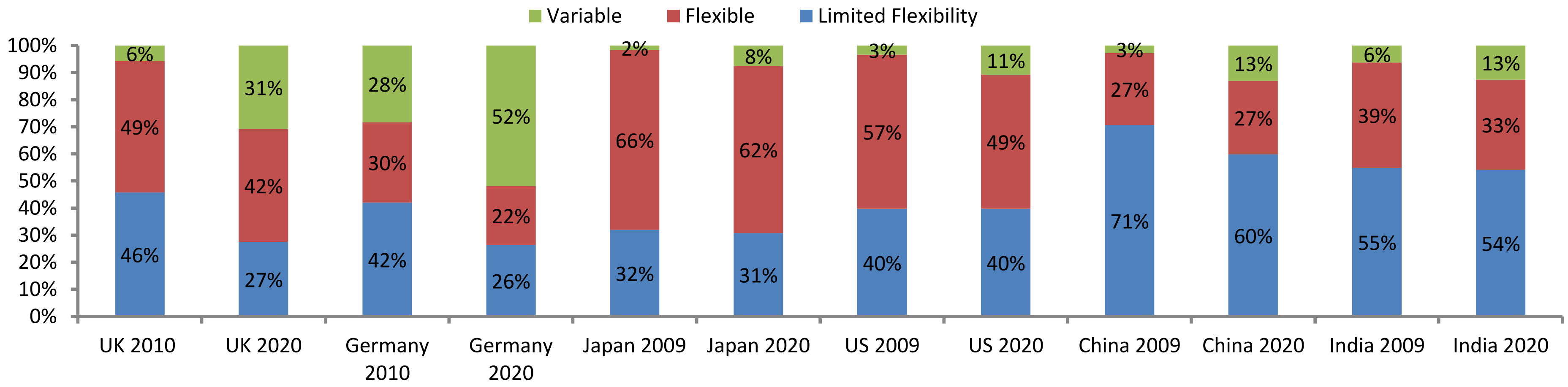

| TOTAL ANTICIPATED NET BUILD | |
|---|---|
| Coal | 459.2 |
| Onshore Wind | 238.63 |
| Hydro | 169.8 |
| Natural Gas | 154.1 |
| Solar PV | 134.7 |
| Nuclear | 70.9 |
| Offshore Wind | 57.73 |
| Biomass - Power | 49.77 |
| Solar CSP | 6.5 |
| Geothermal | 2.78 |
| Marine | 0.3 |
| Oil | -67.4 |
| TOTAL | 1277.01 |

***Figure 3.3:*** Power Generation represented in declared net capacity (DNC)* to 2020 for all the countries surveyed - GW (based on UK DNCs).




**Declared Net Capacity is the maximum continuous rating of the generation sets in stations less the power consumed by the plant itself and is reduced by the plant itself and is reduced by a specified factor to take into account the intermittent nature of some renewable energy sources.*

***Figure 3.4:*** Power generation system flexible component relative to variable and limited flexibility component by country 2009 and in 2020



***Technology Areas***

Other key insights and recommendations from the power generation sector review are as follows:

- **Energy demand reduction** through energy efficiency improvement and demand side management (DSM) is a key component for all energy plans.
  - With regards energy efficiency measures (ABB, 2011):
    - UK. The National Energy Efficiency Action Plan 2008-2016 sets an energy savings target of 136.5 TWh (9% reduction on reference consumption over the period) by 2016 from the buildings, transport and small industry sectors excluding sectors under the EU ETS.
    - Germany. The National Energy Efficiency Action Plan (2008-2016) sets an energy savings target of 231 TWh (9.4 % reduction on reference consumption over the period) by 2016 from the buildings, transport and small industry sectors excluding sectors under the EU ETS.
    - Japan. The New National Energy Strategy within which the Energy Conservation Frontrunner Plan stipulates a 30% improvement in energy efficiency by 2030.
    - US. There were a raft of measures in the early 2000's, the most targeted being the EPA's National Action Plan for Energy Efficiency (NAPEE) which targets energy savings of 200 TWh by 2025.
    - The Chinese and Indians have introduced substantial measures to improve energy efficiency and conversation but these are not targeted specifically at electricity but energy generally. For example, the interim reduction is 17% and 5% in energy intensity by 2015 for China and India, respectively. The 2020 targets are in Figure 3.1, above.
  - The main manifestation of attempts to introduce DSM for respective countries has been via smart meter / grid initiatives. All see the development of the smart grid as a priority and allocated substantial funds to its development as well as targets. For example, the UK is seeking to install 53M smart meters in 29 M homes between 2014 and 2019 (DECC, 2011a); Germany has invested €140 M in 4 year programme; in the US, $4.2 B will allocated to the technology area in the American Recovery and Re-investment Act; and China is seeking to introduce 50 to 60 M smart meters in 2011 and is spending US$ 59 billion to build a \`strong and smart' grid by 2020 (Greentech Initiative, 2011). Though the intentions of these programmes have been well documented the quantitative impact on generation capacity development has not.

  Only two energy savings plans forecast an absolute reduction in electricity consumption in the near term. Germany is seeking to reduce electricity consumption by 10% in 2020 and Japan by 6% in 2030.

  With the greater shift of energy services to electricity the ability to deliver/restrict capacity development within the bounds projected in the generation system modelling (Figure 3.1) will be highly dependent on demographic, social, political and economic issues as well as the efficiency and DSM management programmes (Chatterton, 2011; Kerret and Shvartzvald, 2012; and Crossley, 2013). The ability to fulfil the intended reductions is subject to demographic, social, political and economic issues which may mean that they are not realised. Those nations with ageing populations and with \`*high value add - low energy intensity'* manufacturing bases such as Germany and Japan are in the best position to fulfil demand reduction objectives due to the demand base being reduced rather than necessarily a function of effective measures.

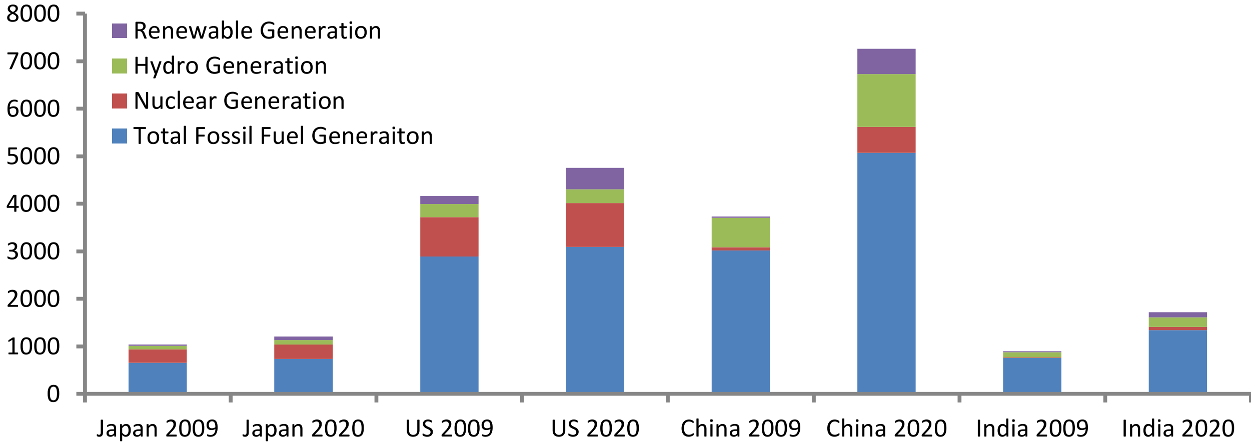
There would be substantial benefit in understanding how Japan and Germany implement effective energy reduction programmes.

***Recommendation:*** With the development of the UK Green Investment Bank and Green Deal much could be learnt from the German and Japanese initiatives. This will result in complementary synergies being developed.

- Carbon Capture and Storage (CCS) is an essential technology which requires urgent development in order to provide $CO_2$ abatement in the future electricity generation system which is being locked into a fossil fuel heavy generation mix in the intermediate term - Figure 3.1. Carbon Capture and Storage development will also assist optimisation of negative emissions technologies.

  For the past decade, coal has been the fastest-growing global energy source, meeting 47% of new global electricity demand (IEA, 2010b) and is anticipated to continue to grow (EIU, 2013a) as nations continue to exploit their resource endowments (e.g. China's recent development of Xinjiang region which has 40% of the nations' reserves (EIU, 2012b). Figure 3.5, displays the quantities of fossil fuel generation capacity relative to non-carbon emitting generation capacity and also shows that for Japan, US, China and India 58% of additional electricity to 2020 will be produced from fossil fuel sources. Based on UK emissions factors[10] an estimate of the amounts of $CO_2$ that will be produced by these countries will total 8.2 $GtCO_2$ per annum; this represents an increase of 27% on 2009 emissions from the power sector. This does not include emissions from auto-producers which produce between 8 - 12% of the total electricity in the countries surveyed.

  ***Figure 3.5:*** Amount of fossil fuel relative to low carbon / renewable generated electricity (TWh) as an indication of the amount of CCS capacity that has to be developed in the period to 2050.




  *In many low carbon scenarios the power sector needs to be virtually completely abated by 2030 to attain 80% emissions targets in 2050.*

The UK should seek to establish its demonstration CCS project as a matter of priority in order to gain experience in the technology which will be vital globally in developing the capacity to mitigate emissions in the power generation sector. Furthermore, with the drive to develop shale gas, there is the need to develop

[10] Per GWh of electricity produced 909$tCO_2$ for coal, 653$tCO_2$ for oil and 398 $tCO_2$ for gas- p126, Table 5A (DECC 2011b).

sub-surface resource management (Elliot et al., 2012). The UK also has substantial $CO_2$ storage capacity and this may represent a market opportunity for nations short of storage capacity[11].

***Recommendation:*** The government should make this a priority. The collaboration would be based on the need to share risks due to the capital intensive nature of CCS as well as the ability for complementary synergies being developed and market growth opportunities.

- Conventional nuclear technology development (Generation II and II+) will be greatest in China and India to 2020 with an increase of 71 and 6 GW, respectively - Figure 3.1. In contrast the Japanese and US conventional programmes are losing impetus (due to Fukushima and cheap shale gas, respectively) and the Germans have sought to remove nuclear from their mix by 2022 (Chatham House, 2012a and WEC, 2012c). With the centre of gravity of development of nuclear capacity shifting to Asia, albeit with western technology for the short-term, there will potentially be nuclear technology migration to Asia. In response to this and to maintain niche nuclear capacity, the US is developing Small Modular Reactors (SMR) which avoid the multi-billion capital outlay required for developing conventional reactors.

The UK will be one of the few established nuclear generation fleet operators which is still expected to have an active nuclear build programme beyond 2020. With limited, niche nuclear supply chain capacity, the UK should seek to identify how best to develop competitive advantage in this area. One avenue could be to seek to collaborate with the US on the development of SMR technologies. This would allow the UK to develop expertise in a niche area of nuclear power generation whilst enhancing the economics of nuclear build.

***Recommendation:*** Government should seek to identify which areas of the nuclear value chain the UK has competitive advantage and consider collaboration with the US SMR programme. This collaboration would allow complementary synergies to be developed, market growth opportunities and risk sharing.

- Germany will be the first large scale electricity system dominated by intermittent renewables generation capacity (by 2020) - potentially up to 52% - Figure 3.4. The ability to exploit the full potential of this generation capacity will be heavily dependent on the ability to establish reliable interconnection with neighbouring countries (which presently stands at 16GW), Transmission and Distribution capacity as well as substantial energy storage development. It remains to be seen whether this is realisable in the current policy framework.

The UK should develop collaborative engagement with the Germans firstly to learn from their experiences in managing high proportions of intermittent capacity in anticipation of the UKs increased capacity (31% in 2020) and then secondly with a view to exporting the experiences overseas - see below. It is noteworthy that the UK is less well endowed with interconnection (4GW) compared to Germany (16 GW) so balancing the UK grid may be more challenging - see below.

***Recommendation:*** This engagement should be facilitated by government and executed by industry. This collaboration would allow complementary synergies to be developed and market growth opportunities.

- Development of storage capacity, research into CCS technologies that allows plant to maintain flexible generation capacity, designing load-following nuclear capacity, dynamic demand and dispatchable

[11] For example, the UK has an estimated 428 years $CO_2$ production to storage ratio compared to Germany's ~25 years. The ability to rent storage space will be predicted on a number of legal issues (IPCC, 2005) and on the evolution of EU Directives in this area - see Times dated 4th April 2012 p39.

renewables are priorities - particularly for the UK due to the limited interconnection and gas storage capacity (14 days capacity which compares to Germany at 69 days at present rates of consumption). This may be an opportunity for the UK to develop a lead in grid management for high proportions of intermittent capacity on electricity networks which will occur later in other networks (IEA, 2012).

The development of UK capacity in the ability progress the associated technology required to balance the electricity network with high proportions of variable capacity appropriately represents a business value and technology transfer opportunity.

***Recommendation:*** This should be facilitated by government and executed by industry. This collaboration would allow complementary synergies to be developed, market growth opportunities as well as risk sharing.

- All nations are dependent on substantial investment in the timely development and reinforcement of their Transmission and Distribution (T&D) systems in order to exploit their renewable capacity. There are substantial planning and investment issues which stand to delay connection for the majority of nations.

  With greater proportions of intermittent renewables on EU energy system portfolios, due to the implementation of the Renewable Energy Directive, the need for interconnection to balance respective grids will be increasingly pressing - Figure 3.4. Prioritisation of nations to develop interconnection will need to be reconciled in the context of the level of connected intermittent capacity on respective grids.

The UK needs to be aware of T&D and intermittent energy generation capacity developments in EU countries. How and with whom the UK develops interconnection needs to be reconciled in the context of UK and partnering nation state needs.

***Recommendation:*** Government needs to develop capacity to collaborate with other EU nations and maintain awareness of developments in this area.

- All nations are introducing substantial amounts of energy policy - the interaction of which are not fully understood (Deutsche Bank, 2009, 2011 and E&Y, 2012). Furthermore, in the case of the UK and Germany, the interaction between EU and national policies is increasingly complex.

UK policy initiatives should have data collection resources built into the delivery capacity in order to assess their effectiveness and interaction with other policies. This will assist in ex-post analysis of their effectiveness and will allow quantitative analysis of interaction with other policies.

***Recommendation:*** This should be developed by government and validated by 3rd parties.

- Resources impacts of the power generation build programmes across the nations surveyed should be considered when designing domestic energy policy and low carbon manufacturing capacity development. This is particularly salient with regards biomass but not exclusively so.

The resource impact of the UK energy programme in the context of other national programmes needs to be assessed. This is salient with regards future gas supply, the availability of rare earths at economically competitive rates should there be the desire to develop low carbon manufacturing capacity and the availability of biomass supply from abroad.

***Recommendation:*** Governments should collaborate to understand respective energy programmes and assess the impact of resource use in energy generation capacity.

- The UK and Germany will potentially experience a capacity crunch late in the decade due to the implementation of a number of environmental policies and the difficulty in delivering new plant capacity in a timely manner. For this to be averted there may be a need to utilise old inefficient plant to cover the supply gap which will potentially increase emissions until new more efficient plant development is realised.

There are three issues that are relevant to the UK in this area:

- UK policy complexity should be reduced and certainty enhanced in order to attract investment;
- Planning regulations whilst, maintaining transparency and participation, need to be more effective for nationally critical infrastructure projects;
- And, there is a need to invest in technologies that assist in grid balancing with high levels of intermittent generation capacity without the increasing emissions.

***Recommendation:*** Government needs to address these issues.

***Industrial Opportunities***

- Based on figure 3.2, the key issue for the UK is how to prioritise engagement with other nations in order to develop best practice for abatement opportunities and how best to establish industrial policy frameworks to focus investment to optimise value capture in international low carbon industrial value chains when the majority of deployment is taking place in Asia. From the anticipated low carbon technology deployment to 2020, the UK would be in a position to collaborate with the following nations (shaded) with a view to developing the global market in the following generation technology areas.

| | ***Country (GW to be installed to 2020)*** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Technology** | ***UK*** | ***Germany*** | ***Japan*** | ***US*** | ***China*** | ***India*** | ***Collaboration Opportunities*** |
| **Hydro** | 0 | 0 | 2 | 6 | 133 | 29 | None due to limited UK deployment. |
| **Biomass** | 2 | 5 | 2 | 9 | 30 | 2 | All nations in this survey. |
| **Onshore Wind** | 8 | 13 | 5 | 67 | 124 | 22 | All nations in this survey. |
| **Offshore Wind** | 17 | 11 | 0 | 0 | 30 | 0 | With Germany and China. Some in US but limited. |
| **Solar PV** | >1 | 33 | 14 | 23 | 49 | 15 | All nations in this survey |
| **Solar CSP** | 0 | 0 | 0 | 3.5 | 2 | 1 | None due to limited UK deployment. |
| **Marine** | 0.3 | 0 | 0 | 0 | 0 | 0 | Needs to be further assessed for other nations. |
| **Geothermal** | 0 | 0.28 | 0 | 2 | 0.5 | 0 | None due to limited UK deployment. |
| **Nuclear** | ***See section on nuclear, above.*** | | | | | | |

The UK should seek to assess how best to engage nations based on their respective deployment plans, maturity of their value chains with a view to seeking to develop mutually beneficial synergies or seek comparative advantage. This would require an assessment of UK's competencies at different parts of the value chain relative to those of other nations for individual technology types.

- The cost of producing capital intensive power generation technologies, including renewables, will be increasingly cheaper in China compared to anywhere else in the world. This will be a function of:

- Scale of the domestic market which at >800 GW is twice as large as the other nations combined (in net terms - Figure 3.2) and therefore the realisation of economies of scale that will be reached by building so many identical plants in a short timeframe;
- Increasing capacity in the Chinese supply chain allowing more components to be locally constructed, access to cheap state subsidised capital and relatively cheap labour; and
- The Chinese see this as a way to develop their economic development agenda thereby potentially go up the value chain (EIU, 2011).

A breakdown of the renewables development in the nations surveyed to 2020 is shown in Table 3.2, below. It can be seen that to 2020, 48% of all renewable capacity deployment will take place in China.

***Table 3.2:*** Breakdown of renewable capacity deployment to 2020 in the nations surveyed.

| | Total for 6 nations (GW) | China (GW) | Proportion in China |
|---|---|---|---|
| **Onshore Wind** | 238.6 | 124 | 52% |
| **Offshore Wind** | 57.7 | 30 | 52% |
| **Solar PV** | 134.7 | 50 | 37% |
| **Concentrated Solar Power** | 6.5 | 2 | 31% |
| **Biomass Power** | 49.8 | 30 | 60% |
| **Geothermal** | 2.8 | 0.5 | 18% |
| **Marine** | 0.3 | 0 | 0% |
| **Total** | **491.4** | **236.5** | **48%** |

***Note***. Hydro capacity development is 169 GW of which 133 (78%) is in China and takes the total to 661 GW of renewable development to 2020.

Implications of this are that China's (1) choice of energy technology will have an impact on cost reductions for those technologies globally and (2) will therefore potentially be able to access emerging markets with deals that substantially undercut those of other nations. This is already starting to happen, for example, in January 2011 India's Reliance Power signed a US$10 B deal with Shanghai Electric for power generators that was 30-40% below the offer from General Electric and with the financing deal from the China Development Bank was nearer to 60% discounted[12]. This also fulfils Chinas agenda of seeking to move away from its export dependence on the west as well as going up the value chain (EIU, 2011). This may also potentially lock out OECD nations from accessing emerging markets due to the fact energy systems will be standardised to Chinese plant configurations.

The UK should seek to develop collaborative research programmes with other nations with large renewable build programmes including China. The need to strategically identify which technology areas to engage in is also a priority as well as assess how best to capture value from international low carbon value chains in areas where the UK has competitive advantage.

***Recommendation:*** Government should develop an industrial strategy to facilitate optimum collaborative engagement and maximisation of value capture from international manufacturing value chains - see Box 5. This will result in complementary synergies being developed and market growth opportunities.

**Box 5: What is the value in of domestic manufacturing in low carbon technologies and what role should governments take in designing Industrial Strategy?**

Global trade has increased at a faster rate than GDP due to globalised supply chains which gather parts from all parts of the world, assembled them in different parts and then ship them to consumers anywhere in the world. A study by the

[12] http://www.ft.com/cms/s/0/b852a826-2272-11e0-b6a2-00144feab49a.html#axzz1p6FG3Lxy

OECD (2008) suggested that in 2003 >50% of manufactured imports were classified as intermediate goods. In such international manufacturing supply chains, it is often difficult to assess where the business value capture and economic benefits accrue and therefore the role or form that indigenous manufacturing capacity development should take.

In globalised electronics supply chains it has been found that value capture for different parts of product manufacturing chain is highly dependent on where the intellectual property (IP) for the product originates. For example, Dedrick et al. (2008) in a study limited to laptop computers and IPODs, found that around half the value capture occurs for Apple (in the US) and 18% for suppliers of components (Taiwan and China) and only 2% on the manufacturing part (China) - 26% is captured at the distribution and retail end in the country of sale.

The relevance of information technology (IT) value chain models for developing analogies in low carbon energy manufacturing value chains requires caution (Smil, 2010). Furthermore, the limited availability of reliable data and methodological impacts of different types of analysis (e.g. input-output, computable general equilibrium and macro-economic modelling) to derive assessments of gross/net economic benefit to GDP and employment of low carbon technology capacity development is subject to much uncertainly (e.g. Pollin et al., 2009).

However, what is clear both from this work and a growing body of literature (e.g. Institute for Manufacturing, Cambridge) is that there is a role for government to frame Industrial Strategy so as to optimise value capture from increasingly complex globalised manufacturing value chains. Industrial strategy, synonymous with protecting inefficient business with subsidies and trying to pick winners, now needs to look at a suite of broader issues. These include, but are not limited to:

- An understanding of the impact of the digital revolution that is taking place in the manufacturing sector (Economist dated 21st April 2012). The implications that it will have on business models (for example, the blurring between manufacturing and services), the diminished role of labour costs, the role of supply chains in industrial clusters and reduced thresholds to attain economies of scale.
- Awareness of what other nations are doing and how to develop collaborative ventures and seek comparative advantage as appropriate. For the low carbon sector, it can be argued that comparative advantage for many technologies is yet to be established hence the substantial investment being undertaken to attain first mover advantage in some nations.
- Improvement in domestic skills base via education and training to support manufacturing initiatives (see for example, The US National Science Board Science and Engineering Indicators (2011)) and the design of immigration policy to attract a highly mobile global entrepreneurial cadre (e.g. Hunt et al., 2009 and Kerr et al., 2009).
- Business Environment (World Economic Forum, 2012) to ensure a level playing field for enterprises of all kinds, the development of the appropriate infrastructure and tax breaks (Mirrlees Review, 2011) and policy stability to attract private sector investment (both domestic and especially foreign multi-national) - see WEC 2012a.
- The establishment of the appropriate research base and innovation ecosystem to support the appropriate value chains (e.g. McKinsey, 2013) whilst ensuring a sound understanding of the framework for the enforcement of Intellectual property (WEC, 2012b).
- There is also a need to improve economic statistics and trade measurements so as to provide the quantitative understanding of global value chains including the role of the service trade (McKinsey, 2012).

### 3.2 Industry

The countries in the survey make up >60% of present world manufacturing output by value. From figure 3.6, it can be seen that the OECD countries have displayed a downward trend since 1970 with the US making up >20%, Germany >6% and the UK ~3% in 2010. Japan's proportion peaked in 1990 and then declined to ~11%. The rapidly emerging economies are on an upward trajectory with India making up ~2.5% and China displaying a spectacular increase from ~3% in 1990 to >18% in 2010.

***Figure 3.6:*** Proportion of manufacturing (2005 prices) for each country as a % of world output (UNCTAD).

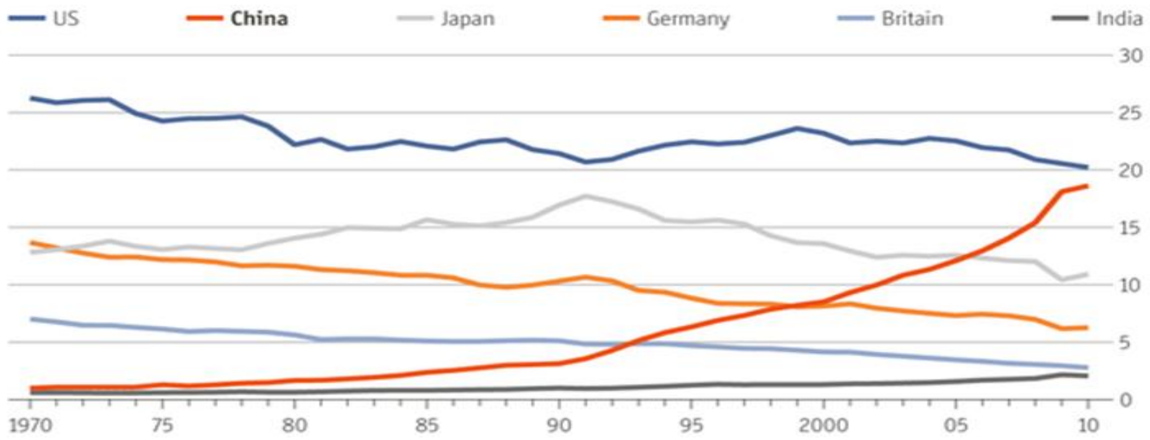



Figure 3.7 shows that emissions intensity (*i.e.* direct emissions from fuel combustion in industry per value added from manufacturing) of the sector has decreased significantly over last 40 years. The OECD countries in this review all follow a very similar trend - decreasing from around 3 $kgCO_2/\$$ in the 1970s to less than 0.5 $kgCO_2/\$$ today. This is largely due to incremental improvements in energy efficiency as well as a shift from low value, high energy intensity products to high value products, which often have lower energy intensity. For example, whilst the share of energy consumption from the manufacture of machinery and equipment is small, this sector contributes significantly to industrial value add - Figures 3.8 and 3.9. China and India had a much higher emissions intensity of around 16 $kgCO_2/\$$ in the 1970s. These two countries have shown a dramatic improvement in their manufacturing emissions intensity, dropping to around 2 $kgCO_2/\$$ today[13]. In China, these improvements have been due to mandatory shut down of smaller operations, consolidation of facilities and the adoption of international best available technology for new builds. The growth of energy efficiency companies suggests scope for more improvement (EIU, 2012c).

The review of the industry sector highlights the following key insights:

- The proportion of manufacturing as a function of the total economy in each country varies substantially as does the part of the value chain that each country specialises in; this has an impact the emissions intensity of the sector and the extent of abatement opportunities available in each country - Figures 3.8 and 3.9.
- For all nations, energy efficiency offers the largest potential to reduce industrial emissions. Fuel and feedstock switching tends to be the next followed by CCS. The role of CCS in 2020 is limited but its projected role in 2050 ranges between 2.0 to 2.5 $GtCO_2$ from industry (IEA, 2012).
- The policies implemented for industrial emissions reductions are inconsistently applied and the impact of policy measures (e.g. carbon trading) and regulation has yet to prove they have had a substantial impact (Odyssee, 2009).

The globalisation of industrial value chains makes the sector considerably more mobile than it was previously. The vibrancy of the industrial sector in any nation is also considered to be vital for a balanced modern economy but it can also be difficult to make the economic case to decarbonise the sector. For

[13] It should be noted that whilst this emission intensity should be cut further, it cannot be expected to converge entirely with the OECD average, due to the very different composition of intensive energy users in respective industrial sectors.

***Figure 3.7:*** Trends in the emissions intensity of manufacturing (kg $CO_2$ emitted per US$ of industrial value add).

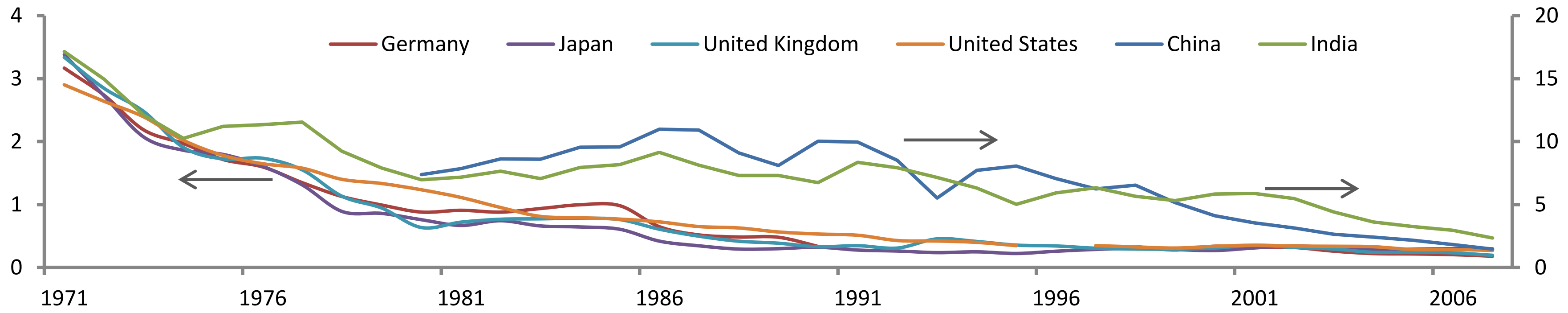



***Figure 3.8:*** Comparison of % share of industry value-add by sector.

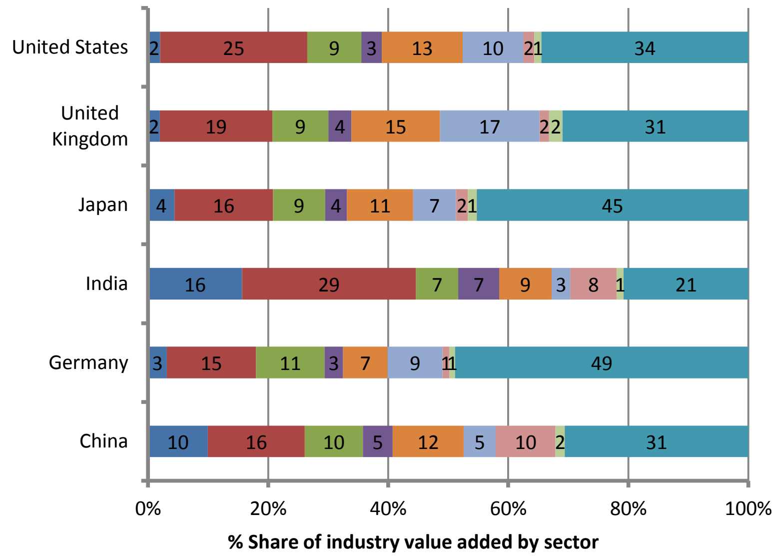
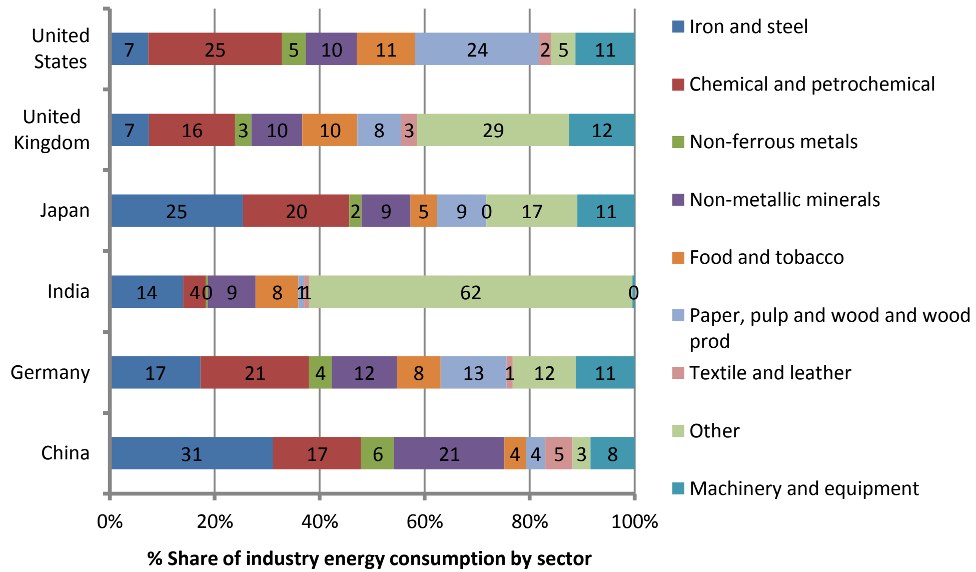



***Figure 3.9:*** Comparison of % share of industry energy consumption by sector.




***Notes:*** $CO_2$ figures include direct emissions only, indirect and process emissions are not included.
***Sources:*** IEA $CO_2$ Emissions from fuel combustion and UNIDO and value add figures and energy consumption figures from UNIDO and IEA Energy Balances.

example, efficiency measures tend to build in long-term competitive advantage which is not always recognised or prioritised by sub-sectors within the industrial sector. Therefore, the ability to introduce policies that result in industrial sector abatement without the industry moving overseas is an intricate balance that policy makers have to reconcile.

Other key insights / trends and recommendations from the industry sector review are as follows:

- The quality of energy and emissions data that is reported from the Industry Sector is inconsistent and of poor quality often due to reasons of commercial confidentiality. This makes designing policy and allowing the financial case for abatement opportunities, particularly from efficiency, to be highly problematic.

There is a **need** for initiatives to develop mechanisms to improve the quality of industry energy and emissions data disclosed without compromising the potential commercial sensitivity of the data.

***Recommendation:*** The government should collaborate with international organisations to improve the quality of data from the industrial sector. This collaboration would allow complementary synergies to be developed to address emissions growth.

- International programmes for Industrial Carbon Capture and Storage (CCS) development are limited and industry's over reliance on CCS has its risks due to the fact that it allows industrial emissions growth to continue based on a technology that may never be realised for technical reasons or economic viability. By 2030, a decision should be made as to whether alternative measures to CCS need to be prioritised to reduce industrial emissions - see below.

Industrial CCS **needs** to be demonstrated to assess its technical and economic viability by 2030 and therefore whether it has a material role in the abatement of industrial emissions in the medium to long term.

***Recommendation:*** The government should advocate international collaborative trials of industrial CCS as a matter of priority to assess its role in industrial emission abatement. It should work with industry to facilitate this.

Should industrial CCS be seen to have a role in abating industrial emissions then the ability to prioritise $CO_2$ geological storage capacity for negative emissions and power generation needs to be reconciled. Limited storage capacity may mean the need to minimise the requirement from industry to only those sectors which are difficult to avoid such as cement and chemicals; this will mean for sectors where alternative strategies exist they should be adopted - see below.

This collaboration would allow complementary policies to be developed to address emissions growth, risk management and potential market growth.

- The potential difficulties in realising industrial CCS or allocating sufficient geological storage requirement means that materials and process efficiency will need to play an integral role to reduce emissions within industry to those required to hit 2$^{o}$C climate target. The role of, opportunities from and mechanisms to implement process and materials efficiency / use reduction is under studied.

There is a **need** to validate the limited evidence base on process and materials efficiency, develop the framework policy mechanisms and business models that may potentially allow it to be realised within conventional investment cycles whilst ensuring the reduction of emissions.

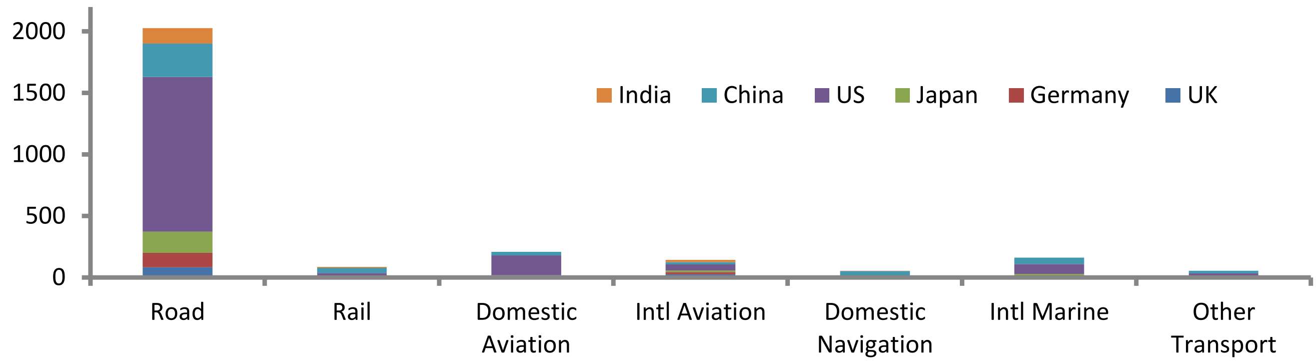
***Recommendation:*** The government should facilitate international collaboration in this area which should be easier to implement than in other areas due to the area being less sensitive to intellectual property concerns. The UK research community should focus a work stream in this area as a matter of priority and undertake collaboration with the other research agencies in other key industrial nations. This collaboration would allow complementary strategies to be developed to address emissions growth.

### 3.3 Transport

Historically, increases in demand for travel have far outstripped the benefits of fuel efficiency. As a consequence the transport sector is one of the two sectors (along with Power) where emissions have been increasing in absolute terms since 1970 - figure 2.3. Road transport accounts for 75% of transport sector emissions for the nations in this survey (figure 3.10), is anticipated to grow substantially (WEC, 2011) and is therefore the focus of the review[14].

Personal transport, in passenger km terms (pkm), in the road transport sector accounts for between 63 and 83% of total pkm in the OECD nations in the review. Though, the figures are lower at 48% and 25% for China and India, respectively, the increase in personal wealth in these economies will result in a potential explosion of personal transport mode pkms, particularly light duty vehicles (LDVs) and passenger light trucks. The IEA baseline scenario estimates that numbers of these vehicle types will double to 2 billion by 2050 (IEA, 2009).

***Figure 3.10:*** Emissions from transport sector from the different motorised modes in 2007 for the respective nations in the survey ($MtCO_2$).




The review of the transport sector highlights the following key insights:

- The transport sector is a global market and immediate technical opportunities for abatement are similar[15].

[14] Aviation is also important: the growth of aviation emissions is also projected to increase rapidly - potentially with a 4 fold increase to 2050 (IEA, 2009), aviation emissions are also more harmful to the environment due to altitude in the atmosphere that they are emitted and the ability to turn over the aircraft fleet is problematic due to increased size of the global fleet and time that it takes to design, develop and roll-out new aircraft models (>10 years) - for more details see Chatham House, 2012b - p16. The international nature of this issue precludes detailed analysis of this in this work though it is referred to in that there is a need to reduce demand for air travel.

[15] These include: Internal Combustion Engine (ICE) efficiency improvements; alternative fuels such as Biofuels, Compressed Natural Gas (CNG), Liquid Natural Gas (LNG) and liquid petroleum gas (LPG); and alternative power trains such as hybrids, Plug In Hybrid Electric Vehicles (PHEV), Hydrogen Fuel Cell Vehicles (HFCV) and Electric Vehicles (EVs).

- There are multiple mechanisms to substantially improve vehicle efficiency including the implementation of negative cost, non-technical measures but historically, fuel economy gains have given way to increased weight and power, driven by consumer preferences.
- Low carbon innovation in the transport sector will more than likely need to be driven primarily by strong regulation. This is due to the market signal provided by consumer preferences being limited as peoples willingness to pay for personal transport services is considerable[16].
- The ability to turn-over the vehicle fleet and transition the support infrastructure sufficiently quickly to allow the dominance of a single technology to 2050 using spontaneous transition rates will be highly problematic especially as it is becoming increasingly evident that alternatives to the Internal Combustion Engine are unlikely to be cost-competitive in the short to medium term (Hillibrand, 2012). It is also likely that there will be a need for policy to both increase the rate of transition and reduce demand for transport.
- Advanced technology development information transfer between countries is particularly important in this sector. Therefore the ability to facilitate international and cross-industry approach to ensure technology and infrastructure solutions are compatible is critically important to realise effective abatement in the sector.

Though the UK does not have a home-owned volume producer it has substantial capacity for engineering expertise in the sector in niche areas - as evidenced by the presence of the majority of the world's motorsports industry. The UK needs to engage in international initiatives to develop standards and technologies whilst assessing how best to obtain the best value capture opportunities from its niche strengths.

Other key insights / trends and recommendations from the transport sector review are as follows:

- Vehicle stock data quality issues for all nations, especially those with the greatest potential growth, are poor which will make identifying the appropriate policy and assessing effectiveness difficult. There is a lack of consistency of performance standards for vehicles which makes inter-comparison between nations and technology type problematic. This will become increasingly difficult to assess as future technologies will push emissions upstream.

There is a **need** for international collaboration to:

- improve national vehicle stock datasets and performance standards especially in rapidly emerging economies;
- harmonise efficiency and emissions measures, testing standards and regulation criteria internationally in order to allow the design of the appropriate policy to enhance the development of the appropriate power-trains; and
- develop international standards for GHG footprint based life cycle assessment for power-trains. The US system appears to a useful area to develop best practice.

***Recommendation:*** Government should work with international bodies and the vehicle manufacturing industry to improve vehicle datasets and harmonise measures, standards and regulation criteria. This collaboration would allow complementary synergies to be developed to address emissions growth.

[16] See: http://onclimatechangepolicydotorg.wordpress.com/2013/03/15/where-the-price-of-emitting-carbon-is-700tonne-your-local-petrol-station/

- There are multiple technology options for the decarbonisation of transport. At present state of technological development none offer distinct advantages to be of clear benefit and dominate the transport sector in 2050 (LCA Works, 2012 and EIU, 2013b).

There is a **need** for international collaboration to share R&D information (e.g. McKinsey 2010) to develop advanced vehicle technologies and agree frameworks to assess the most technically and economically beneficial power trains using a standardised, comprehensive set of assessment criteria. The latter is the most efficient way to design the appropriate policies as to the potential role of alternative technologies as best as current knowledge allows.

***Recommendation:*** Government should seek to work with:

- The vehicle manufacturing industry to develop collaboration in new vehicle technologies, without compromising commercial confidentiality, as a matter of priority; and
- international bodies to agree the best frameworks to assess novel power-trains to facilitate the identification of the appropriate technology and accelerate their penetration into the transport fleet.

This collaboration would allow complementary synergies to be developed to address emissions growth as well as risk sharing and potential market development.

- The focus of present abatement initiatives has been based on technology uptake rather than mechanisms to reduce demand. Demand reduction will be required to address climate targets in the transport sector. Substantial proportions of the transport sector are under researched - areas that require further work include the ability to initiate and embed behavioural shifts in transport reduction and modes, aviation (which stands to increase substantially in the coming four decades), marine, non-motorised transport and the development of the built environment to reduce transport needs.

There is a **need** to improve and co-ordinate research in transport demand side reduction, other modes and the integrated role of the built environment. For the body of work that already exists in these areas there needs to be a drive to integrate the findings into policy.

***Recommendation:*** The UK research community should seek to develop these themes as a matter of priority as well as collaborate with other nations to share datasets and best practice. Mechanisms need to be found to embed the findings into an integrated policy framework. This collaboration would allow complementary synergies to be developed to address emissions growth - e.g. Automotive Council, 2011 and 2013.

### 3.4 Built Environment

The role of urban areas and therefore the built environment will increase substantially in the next four decades due to the increasing tendency for urbanisation - particularly in rapidly emerging economies where the population, household numbers and service sector activity will grow (see Table 2.1). In the OECD buildings, particularly residential ones, have long life spans (100+ years compared to 25-35 years in emerging economies) and were built to specifications that are well below those needed now to address the abatement required in the sector e.g. in Germany it is estimated that buildings built in pre-1970 consume 55 to 130% more energy per $m^2$ than modern buildings; the majority of these buildings will be remain in 2050. Therefore the role of retro-fitting will be vital in attaining abatement targets. However, rates of retrofit are low at ~1-2% of existing housing stock pa due to barriers which include: (1) the highly heterogeneous nature of the stock; (2) the transaction costs and disruption of implementing low carbon measures; (3) the low priority users give to emissions and energy bill reductions; and (4) lack of attention given to the social dimension in the diffusion of innovations (Jennings et al., 2011). Both the rates and extent of retrofit vary between countries, and there are opportunities to learn from Germany in particular, regarding regulation and incentives for retrofit.

The review of the built sector highlights the following key insights:

- Intensity of the energy services utilised in the built sector, on a per capita basis, is increasing as a function of social trends in OECD nations and better access to energy services and economic development in rapidly emerging economies. This is manifest in reduction of persons per household, the increase in the size of dwellings and the increase in energy consumption e.g. in the UK the mean internal temperature of homes during winter has increased by ~12$^{o}$C in 1970 to 17.5$^{o}$C in 2007 (DECC, 2011c).
- Though building shells have significant impact on the energy consumption other aspects such as heating, fittings and appliances have a significant role and a substantially shorter life-span; therefore they also represent key abatement opportunities e.g. in China energy efficiency standards in appliances have a potential to save>540 TWh of electricity in 2020 (LBNL, 2010).
- There are a substantial number of mature technological solutions but the main difficulties lie in getting them adopted at scale. Indeed, there will be the need for a basket of supporting measures involving public and private investment, technical, institutional co-ordination, regulatory and financial incentives etc. to be implemented for the exploitation of opportunities for emissions reduction. For this reason their realisation will be a function of the convergence of social, political and economic drivers which will be difficult to optimise.
- Data on opportunities for abatement by technology / policy is very much dependent on the input assumptions based on modelling. Furthermore, the modelling of abatement mechanisms in the built environment tend to under-represent key aspects required to realise the abatement opportunities. For example, large scale economic models don't include endogenous technological innovation, while bottom-up engineering, cost-optimisation energy models don't include empirically robust user behaviour. As a result there is often a substantial gap between anticipated modelled impacts and those actually realised.

Other key insights / trends and recommendations from the built sector review are as follows:

- The quality of data for the built sector is extremely poor across all nations and especially for rapidly emerging economies where data is almost entirely based on estimates. Furthermore, the sector is substantially under researched, for example:
  - there has been a lack of analysis as to the effectiveness of national energy efficiency policies. For example, in the non-exhaustive IEA database of the 408 national policies listed for buildings only 7 had included policy evaluations suggesting that there has been a lack of lessons developed from previous policies (Jennings et al., 2011);
  - And, how to best accelerate the transition to low carbon heating has received limited attention (Grantham, 2011).

There is a **need** to improve data sets in the built environment across all nations. There is also a need to better develop an understanding of the effectiveness of past policies and the reasons that they underperformed so that future policy can be better designed. To facilitate better policy design there is the need to develop a better level of understanding of the mechanisms by which decarbonisation of the built sector can take place.

***Recommendation:*** The UK government should seek to engage with international bodies:

- to establish best practice and collection of buildings datasets;
- undertake analysis of policies so as to understand which mechanisms work in the relevant circumstances;
- And, develop a better understanding of how transitions in the built sector may be facilitated

This collaboration would allow complementary synergies to be developed to address emissions growth.

- It is generally recognised that technology development, though important for developing technical potential, has a limited role in the actual realisation abatement opportunities in the sector. There is a need to develop a better understanding of the role of socio-economic behaviour in the realisation of abatement in policy. This is going to be very difficult with the increasing electrification of services (Gutowski, 2011) and therefore the increased role of gadget appliances in house-hold energy consumption (Yergin, 2011)[17].

The role of socio-economic behaviour in the implementation of abatement opportunities in the built sector **needs** to be better researched and particularly, better embedded into policy.

***Recommendation:*** The UK research community needs to prioritise this so that policy may be better designed to motivate users to implement abatement measures. This collaboration would allow complementary synergies to be developed to address emissions growth.

- There have been successful examples of energy reduction policy implementation in the built sector. For example:
  - The Japanese Top Runner Programme for appliances which has resulted in savings of approximately 56 TWh to 2010;
  - In California building standards and codes and appliance programmes in commercial and residential buildings saved 8 TWh and 27 TWh, respectively, in 2000;
  - And, Germany has had success with the use of economic incentives for retrofitting through the KfW $CO_2$ Reduction and Building Rehabilitation Programme which has saved approximately 12.5 TWh between 1995-2005. Germany has also developed `*Whole house'* solutions and identified the need for skills improvement in the building trade for installation and implementation (Power et al., 2011).

The UK should seek to develop an understanding of those policies that have worked in different countries with a view to understanding how they may be best applied to the UK.

***Recommendation:*** The UK government and research community should seek to systematically assess the best practice in buildings efficiency measures in Germany, Japan and the US. This collaboration would allow complementary synergies to be developed to address emissions growth and potential market growth.

[17] In US in the 1970's appliances consumed 12% of household energy use; this has now increased to 45% as a function of the increase in gadgets and the increase in the size of appliances with has consumed any potential energy savings.

### 3.5 Cross-Sectoral Perspectives

The abatement opportunities in any one sector will have an impact on others. For example, the deployment rates of intermittent generation has to be considered in the context of the availability of flexibility offered by demand side mechanisms such as batteries in EVs and thermal storage with heat pumps. The high deployment of intermittent generation without the demand side flexibility capacity will have substantial impacts on the efficiency of the generation system (ERP, 2012). Therefore the need for whole systems research that optimises changes in one sector by integrating the impacts or understanding the trade-offs on others is vital. It is only when this is better understood will a more coherent policy framework be developed to allow the market mechanisms so that the system can be delivered efficiently.

Initiatives for whole system research in the energy sector should be a priority both for UK energy policy development and the realisation of abatement opportunities in other countries.

***Recommendation:*** Government should collaborate with academia (e.g. UKERC) and industry to develop capacity in the integrated analysis in order to incorporate the findings into policy. Collaboration with other nations will allow synergies to be developed as well as assist in the understanding of this area.

## 4. Overarching Insights and Recommendations to Policy Makers

In relation to the reviews objectives, the following insights have been found for this study:

***Capital Intensity of UK Power Generation Capacity Development to 2020.*** The UK has no more capital intensive net build programme as the other nations reviewed. In terms of net capacity build to 2020, as a function of present capacity, the UK's projected increase (17%) is on a par with the US (12%) and Japan (10%) and substantially less than Germany (26%), China (91%) and India's (123%) - though in absolute terms China's addition of 840 GW is the largest outlay of generation capacity.

***General Emissions and Energy Consumption Trends.*** The review of the abatement opportunities and trajectories for the nations in this review highlights the following recurring themes for the majority of nations across all sectors:

- Many nations are unable to implement measures which would allow abatement opportunities to be exploited, for example due to market failure or insufficient human resource to enforce regulations.
- Demand side measures are increasingly important to address in order to meet emission abatement targets. The realisation of lasting demand side reductions, that avoid rebound effects, will require a substantial shift in behaviour.
- There is a pressing requirement for substantially improved datasets for energy consumption and sources of emissions from respective energy systems. Without this, the ability to develop and assess the effectiveness of policy frameworks to address emissions will be highly problematic. Low carbon and energy efficiency policy initiatives should have data collection and evaluation resources built into their delivery capacity.
- There are areas in all sectors which are vitally important to the realisation of abatement opportunities that are under-researched such as the socio-economic behaviour in buildings abatement opportunities and business models for materials efficiency to realise net abatement in the industrial sector. These need to be systematically assessed and prioritised as a matter of urgency.

***Collaborative Opportunities based on National Deployment Rates and Patterns.***

The overarching finding of the work is that it highlights the following:

- Though trajectories and emissions abatement technology mix developed within nations surveyed have some areas of commonality - they are varied for very different reasons based on a number of context specific issues. Least cost has not necessarily always been a priority.
- The UK needs to consider how best to establish energy research and industrial policy frameworks to best capture value from international (low carbon) value chains where the competitive advantage for process innovation will almost certainly lie in Asia.
- The UK should consider the opportunities that may lie within the international arena and prioritise its international engagement activities for collaboration based on the following criteria:
  - Facilitating the development of a larger global market for abatement technologies;
  - Developing complementary sets of comparative advantage to mutual benefit of partners;
  - And, to share large capital investments and risks.

There is also the need to consider comparative strengths by matching up UK capability to develop technologies, the relevance of the technologies to national energy systems and the potential for business to exploit the technology.

This work has identified, at a high level, indicative areas that the UK would be in a position to collaborate and the type of collaboration, on a sectoral basis based on deployment activity (TRL9) of the nations in this review as follows:

| Area | Reason for Collaboration | | | Opportunity / Need for Collaboration | | | | | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | *Market Growth* | *Complement* | *Risk M'ment* | *Germany* | *Japan* | *United States* | *China* | *India* | |
| **General** | | | | | | | | | |
| Emissions measurement and governance | | ✓ | | | | | | | There is a **need** to improve emissions measurement. The UK should seek to develop standards with other nations. Greatest need is to measure emissions in rapidly emerging economies due to the rapid growth. |
| Negative emissions governance | | ✓ | ✓ | | | | | | Majority of negative emissions technologies are at R&D stage and they are increasingly likely to be **need**ed in the medium term. The UK should assist the development of international governance and best practice. |
| **Power Generation Sector** | | | | | | | | | |
| Energy efficiency, DSM | | ✓ | | | | | | | Work with Germany and Japan who have had successful programmes. China is developing a large scale smart meter programme. |
| Grid innovation and technology development | ✓ | ✓ | | | | | | | Work with Germany to support the rapid rate of intermittent generation capacity development on respective grid networks. Development of load following nuclear, dispatchable renewables, dynamic demand,flexible CCS |
| Biomass | Requires further analysis[1] | | | | | | | | China is deploying 30 GW of biomass generation whilst other nations are deploying between 2 - 9 GW of capacity. |
| Onshore Wind | | | | | | | | | China and the US are deploying 124 and 67 GW of onshore wind, respectively. Other nations are deploying between 5 - 22 GW of capacity. |
| Offshore Wind | | | | | | | | | China and Germany are deploying 30 and 11 GWs of offshore wind capacity, respectively. The US also has some deployment but this limited and is not forecast to make material contribution to the 2020 energy mix. |
| Solar PV | | | | | | | | | China and Germany are deploying 49 and 33 GWs of solar PV capacity, respectively. Other nations are deploying between 14 to 23 GW of capacity. |
| Marine Technology | | | | Requires further analysis[2] | | | | | The UK potentially could have 300 MW of marine technology deployed by 2020. Marine technology is not considered to make a material contribution to other nations energy mixes by 2020. |
| Carbon Capture and Storage Demonstration | ✓ | ✓ | ✓ | | | | | | There is a **need** to demonstrate Carbon Capture and Storage technology for the power sector as a matter of priority. It is key to the decarbonisation of the power generation sector which is now locked, in the medium term, to a high emissions trajectory. |
| Nuclear Technology Specialisation | ✓ | ✓ | ✓ | | | | | | China and India are the expected to have the most robust nuclear deployment programmes to 2020. This may result in nuclear technology migration to Asia. The UK intends to maintain a domestic nuclear programme the UK should seek to identify niche areas where it can specialise. The US is developing Small Modular Reactor capacity which may be an area for collaboration. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Industrial Sector** | | | | | | | | | |
| Data improvement | | ✓ | | | | | | | There is a **need** to improve industrial emissions and energy data reporting to allow the design of the appropriate policies for abatement. |
| Industrial CCS Demonstration | ✓ | ✓ | ✓ | | | | | | There is a **need** to understand the technical and economic viability of industrial CCS and the role it will have in industrial emissions abatement. |
| Role of Process and Materials Efficiency | | ✓ | | | | | | | Even with the realisation of industrial CCS there will be a **need** to seek to minimise industrial emissions utilising other strategies. |
| **Transport Sector** | | | | | | | | | |
| Vehicle Data and Standards | | ✓ | | | | | | | There is a **need** to improve and harmonise transport datasets to allow the design of the appropriate policies for abatement. |
| Development of low carbon power trains | ✓ | ✓ | ✓ | | | | | | There is a **need** to ensure technology and infrastructure solutions are compatible to realise effective abatement in the sector. |
| Demand Reduction | | ✓ | | | | | | | There is a **need** to incorporate transport demand reduction mechanisms into policy to be able to realise 2°C target. |
| **Built Sector** | | | | | | | | | |
| Data improvement | | ✓ | | | | | | | **Need** for the development of systems and frameworks are a priority to better assess opportunities and the best policies. |
| Socio-economic behaviour into policy | | ✓ | | | | | | | The **need** for integrated baskets of mutually supporting policies to realise the roll-out of technologies and realisation of abatement opportunities. |
| Buildings retro-fit | ✓ | ✓ | | | | | | | Especially with the Germany for the best retro-fit programme. Japan has had a successful appliance efficiency programme. The US have also had some successful programmes. China is introducing some programmes. |
| **Cross-cutting Issues** | | | | | | | | | |
| Technology innovation | ✓ | ✓ | | Identify how best to capture value from appropriate energy value chains - design research and industrial policy accordingly. This will be highly dependent on energy technology value chain. | | | | | |
| Technology manufacturing | | ✓ | | Work with nations with large low carbon build programmes to develop process innovation expertise. This will be highly dependent on individual energy technology value chain. | | | | | |
| Integrated analysis | | ✓ | | The development of a better understanding of impacts and trade-offs of changes in any one sector on others to design better policy. The UK would benefit from collaboration other nations | | | | | |

**Key - Reason for Collaboration:**
Market Growth
Complementary sets of comparative advantage
Risk Management

- Strong Synergies / Need (where referred to in the accompanying notes)
- Moderate Synergies / Need (where referred to in the accompanying notes)
- Limited Synergies / Need (where referred to in the accompanying notes)
- No Synergies

1. The type of collaboration that nations can participate in for these respective technology types depends on component of the value chain and requires further analysis.
2. The UK is a pioneer in marine technology development. Its role in other nations energy systems is dependent on how the technology develops within the UK; at present its role is limited.

## 5. Follow-Up Work

This work has fed into one strand of engagement with government and will have an additional 2 as follows:

- ***A policy note to government***. In the ERP-DECC meeting of 30th November 2010, Greg Barker raised the concern that there was a perception the UK was lagging other countries in its ability to implement carbon abatement applications and technologies. Specifically, that the UK was focused on capital intensive supply side solutions whilst other countries, for example Germany, were addressing demand side issues negating the need for large scale capital expenditure. This work addresses these concerns and a policy briefing was sent to Greg Barker on 20th July 2011.
- ***Feeding into the Global Strategic Trends 5 (2014) publication on Energy Technology Development to 2045***. The work in this review will be used by the Futures Team, Development Concepts and Doctrine Centre, MOD Shrivenham to write an essay on the future of energy and transport technology which will feed into the Global Strategic Trends 5 publication. The Global Strategic Trends 5 publication maps global macro-drivers upon which the MoD and other government departments base their strategic planning; the next publication makes forecasts to 2045[18].
- ***Feeding into the ERP International Engagement Project***. The ERP International Engagement project seeks to improve the resolution of the collaborative component of this work by matching up UK capability to develop technologies, the relevance of the technologies to energy systems and the potential for business to exploit the technology to provide a comprehensive assessment of areas where the UK should engage with other nations for business value creation, technology transfer and/or collaboration.

***Mark Workman, Lead Analyst for***
***International Emissions Abatement Opportunities Project***

[18] http://en.wikipedia.org/wiki/Global_Strategic_Trends_Programme

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