A whole system analysis of how industrial energy and material demand reduction can contribute to a low carbon future for the UK

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CENTRE FOR INDUSTRIAL ENERGY, MATERIAL AND PRODUCTS

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Changing the use of materials needed to produce products including material substitution, light weighting and circular economy

Changing the way the final consumer (industry, households or government) use products to reduce energy demand including product longevity and shifts from goods to services.

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Industrial energy and material demand reduction: an opportunity in the UK

One third of all energy used today powers the globally connected production industries that make the buildings, infrastructure, vehicles, equipment and other goods that support the everyday activities of UK citizens. Most of this energy is used efficiently to produce large volumes of a few bulk materials, so a key opportunity to reduce global 'greenhouse gas' (GHG) emissions is to decrease the demand for these materials. This report presents a holistic view of this opportunity for the UK.

Global warming arises from the stock of carbon dioxide and other GHGs in the atmosphere, and if emissions of these gases continue to increase, average temperatures will rise sufficiently by the end of this century to create significant changes in global climate. Governments are therefore setting policy targets to reduce GHG emissions, and the UK is committed to reducing its domestic emissions to 20% of 1990 levels by 2050.

Most GHG emissions arise from the combustion of fossil fuels for energy, and globally just over a third of this energy is used in industry, mainly to produce a few key materials. Two materials, steel and cement, account for nearly a half of all such industrial emissions, but after decades of effort driven by costs, there are few remaining opportunities for improving the energy efficiency of existing processes. Almost all cement and around a quarter of steel are used to make buildings and infrastructure in the UK. The other major uses of material include vehicles, industrial equipment, appliances and other durable goods purchased in households, as well as consumable goods such as paper, and packaging.

As the UK has reduced its industrial production in favour of growth in service sectors, most GHG emissions are created by the purchasing of goods produced in other countries, and this should shape the strategies to reduce the British contribution to global warming. For example, in 2007, nearly 20 million tonnes of steel were added to the UK stock of goods in use, but only 15% of this was made within the country.

Annual demand for steel in the UK has been relatively steady in the past 40 years, alongside a slow decline in the use of cement. However, prior to 2008, although reported UK territorial emissions were falling by around 1% per year (this reduction needs to be increased to 3.4% per year to meet the 2050 target), the total GHG emissions created by consumer purchases increased at just over 1% per year (although the recession since 2008 has led to a reduction in these total emissions). Drawing on a purely domestic picture of material production can be misleading. Gross Domestic Product (GDP) in the UK is rising, while its territorial demand for materials has been reducing. But this does not reflect the true situation – Britain has actually become dependent on imported materials and goods.

To date, materials have had little attention within climate mitigation policy. The UK has traditionally developed economic policies with GDP growth as its primary measure of success, although it also now aims to reduce its territorial GHG emissions. Thus, UK purchasing of imported goods and materials will likely continue to grow, and its net impact on global emissions will increase. In contrast, this report shows that alternative metrics, which relate a broader idea of welfare and quality of life to the stock of goods in the country (rather than the rate of purchasing), could lead to a reduction in the UK demand for materials. Hence its contribution to global emissions could also reduce, while improving the British quality of life and potentially enriching UK employment.

How does UK purchasing of goods cause carbon emissions?

Industrial production of goods causes around a third of the world's energy related carbon emissions. It is important to look beyond the emissions associated with industries based in the UK, as around 50% of emissions caused by UK purchasing occur abroad and are embodied in imports. The emissions related to UK purchasing can be estimated by tracing flows of either money or materials.

Global industrial emissions and products

Human activity leads to the emissions of carbon dioxide and other GHGs via agriculture, land-use change, and waste disposal, but above all from burning fossil fuels for energy. Around one third of this energy is used in industry, and in addition, the chemical reactions of some industrial processes also release GHGs. The understanding of how industry causes carbon emissions can be simplified by recognising the global importance of five materials, as shown in Figure 1. Figure 2 shows how these five materials are used in the UK. Not surprisingly, buildings and infrastructure are a key use for many materials. Vehicles and industrial equipment are also important, as are the purchase of household goods, such as appliances and paper.

There is a link between industrial production and the other uses of energy shown in Figure 1, a building constructed with extra insulation may require less energy for heating, and a smaller lighter car requiring less material production will also use less fuel to run. These connections are obviously important, but the focus of this research is on the energy used in industry itself, and is motivated by one critical fact: the energy intensive materials industries pay heavily for energy – typically it's a third of their costs – so they have always been motivated to use less, and are therefore already extremely efficient. In order to reduce energy demand in industry, and its associated emissions, it is important to look at opportunities to use less material. Are there alternative ways to design, maintain and upgrade the goods shown in Figure 2 in ways that it is possible to continue to live well, but with less new material?

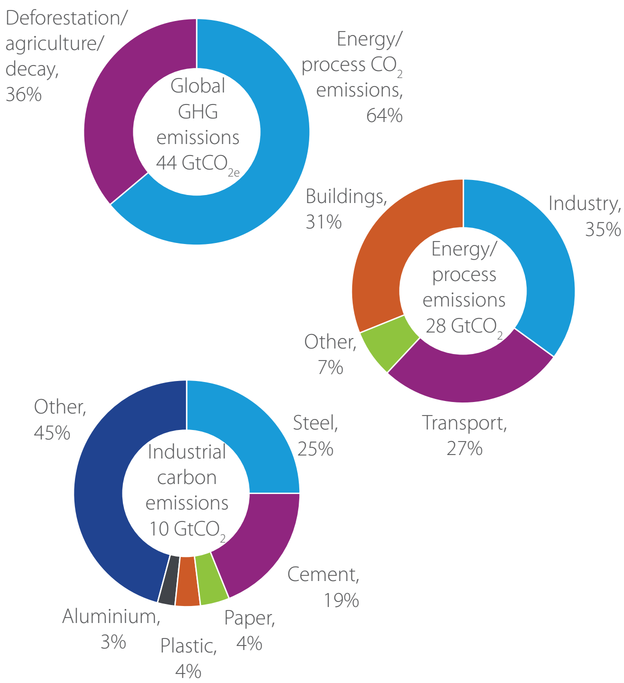


Fig 1: Greenhouse gas emissions caused by human activity, organised to show the global importance of (a) energy from fossil fuels (b) industry and (c) five key materials.

Most UK products are made in other countries

A high proportion of goods purchased by UK consumers are imported; resulting in around 50% of GHG emissions related to UK purchasing being generated abroad. The decline of UK manufacturing in recent decades has led to a reduction in its reported national, indigenous production-based carbon emissions, but shifting the source of emissions between countries does not reduce their effect on global warming. The interest of this research is therefore to understand the impact of UK purchasing of goods, wherever it occurs – moving the focus from production to consumption-based GHG emissions accounting, using a 'whole systems' perspective.

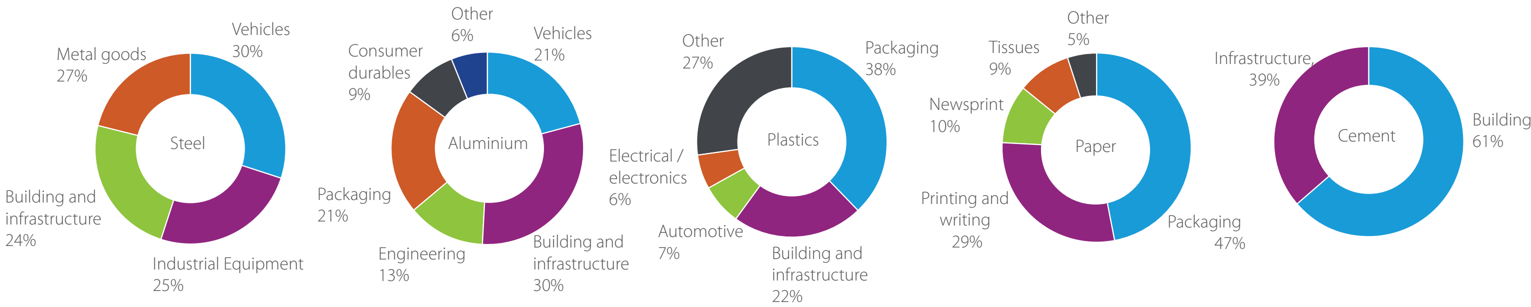
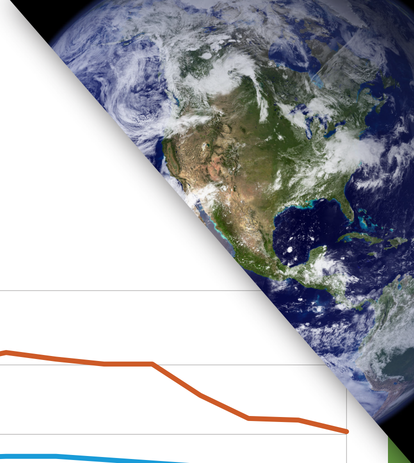


Fig 2: Emissions-intensive materials are used in a wide variety of products by the UK



Most countries, including the UK, maintain only limited accounts of physical flows and stocks of materials and products. However, it is possible to estimate these flows and the carbon emissions released during their production by associating them with the flows of money between sectors and between countries, as reported in national accounts. This approach has been used in Figure 3 to show how UK purchasing consistently causes more emissions than its production: net imports increase Britain's responsibility for emissions by about 25-30%.UK climate policy today considers only production emissions, but the Energy and Climate Change Committee of the UK's House of Commons has recently recognised that policy making should also consider the impacts of purchasing.

Using the same approach, Figure 4 shows how emissions caused by UK purchasing arise from production and trade. This demonstrates that GHG emissions can be reported either according to the production sectors in which they were released, or by the consumption or purchasing which drove this activity. The first approach motivates mitigation options within the supply chain; the second shows how different purchasing behaviours could reduce emissions.

The production of the major materials highlighted on the previous page occurs within the 'primary industries' category in Figure 4, and Figure 5 shows the influence of these materials on emissions produced or purchased in the UK. These figures illustrate a key mitigation opportunity: reducing UK production emissions by closing UK factories will simply shift jobs and emissions to other countries, but reducing the emissions caused by UK purchasing could be achieved potentially without loss of UK employment if less material is purchased from other countries. The employment implication of material resource productivity is an issue that will be critically evaluated. It should be noted that there can be some discrepancy between the estimates of emissions related to material use if tracing monetary flows (as here) or physical flows (as on the next page). This is recognised and we are working to fully understand how the methods differ and where each should be applied when examining our material use.

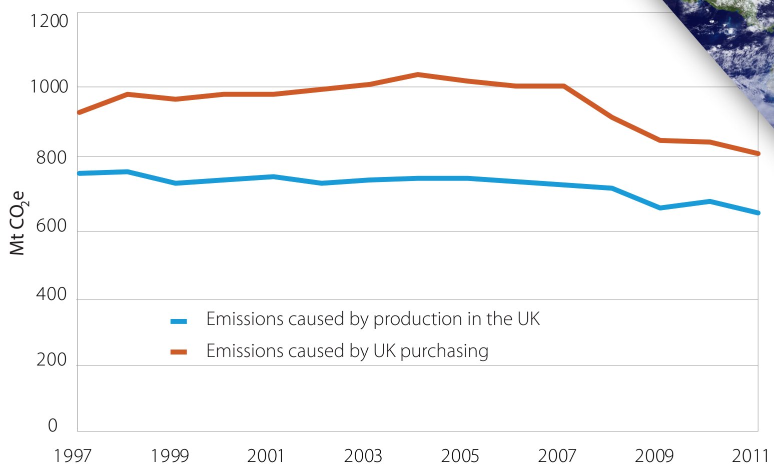


Fig 3:The UK's carbon emissions attributed either to production or to purchasing. The units used in this figure, "CO2e" or "Carbon Dioxide Equivalent", allow us to include the impacts of other greenhouse gases, such as methane, whose impact has been converted to an equivalent release of carbon dioxide.

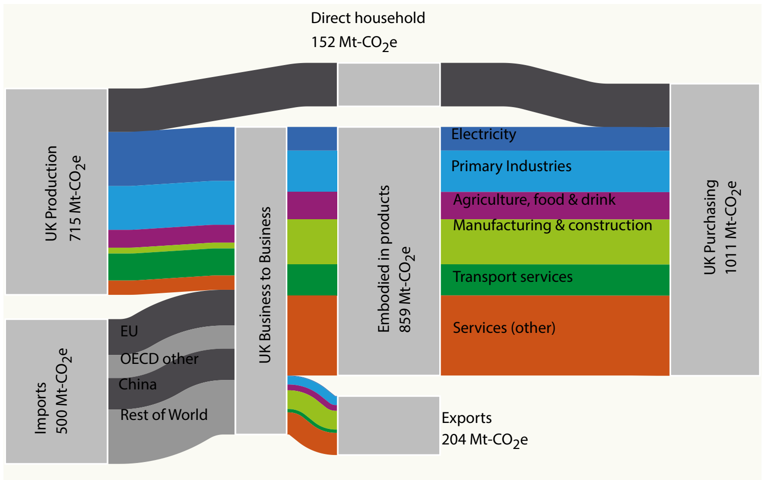


Fig 4: Emissions in 2007 driven by UK purchasing on the right of this figure arise from UK production, minus its exports, but greatly increased by its imports. [The width of each category line is proportional to its emissions. See Figure 16 for further detail on the interactions between sectors.]

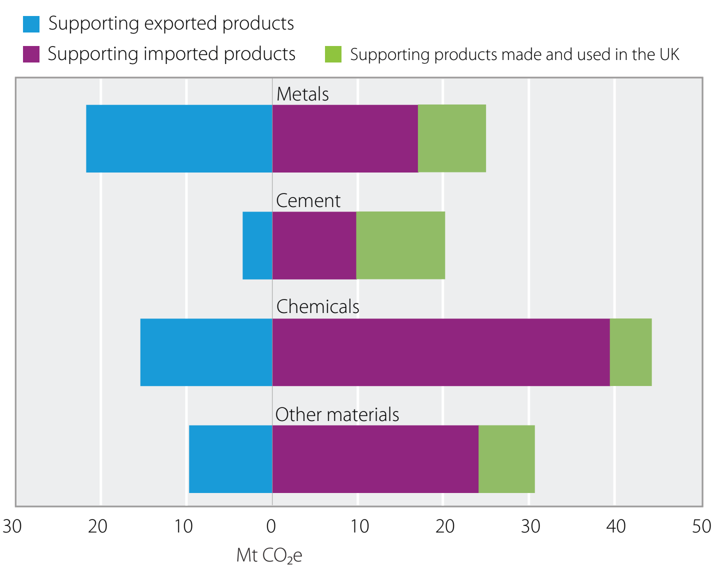


Fig 5: Emissions in 2007 associated with materials in the UK.

Steel and cement: the backbone of the UK economy

Globally, producing steel and cement leads to around one sixth of all GHGs related to energy and processes. These two materials, which provide the strength and stiffness of buildings, infrastructure, vehicles and equipment, are vital to human activities. In parallel with the effort to understand the monetary flows in the economy associated with purchasing materials, these two key materials have therefore been examined in detail. Figures 6 and 8 show the flows of steel (in 2007) and cement (in 2010) caused by UK purchasing and were assembled from an array of governmental, industrial, academic and trade-association data, spanning from mining to final products. Cement and steelier also used overseas in producing factories, infrastructure and machinery to manufacture goods that are purchased by the UK. Materials used in this manner are not included in the flows shown in Figures 6, 7 and 8 (where only the materials entering UK stocks are shown), but the associated emissions are accounted for in Figure 5 above.

Steel is produced from iron ore (primary production), or scrap (secondary production, which is generally less energy and emissions intensive.) Liquid steel from either source is cast and mainly rolled to form intermediate stock products such as sheet and bars. These are then sold into the manufacturing and construction sectors for shaping, cutting and finishing before being assembled into the final products delivered to customers. Construction makes most use of UK produced steel, but the largest use of steel in the UK is within vehicles, mainly embodied in imported vehicles.

In 2007 the UK purchased 20 Mt (mega-tonnes) of steel embodied in final goods. Only 3.3 Mt of this were made in the UK. (The rest of the UK's 15 Mt of final steel production was successively exported at different stages, as shown in the trade flows of Figure 7.) Around 7 Mt of internal scrap arise within the manufacturing processes and are collected and recycled. In total 19% of all intermediate steel products are scrapped in production, but the rate is higher – nearly 30% – for sheet steel, which is rolled into constant width coils, and then cut to shape. Even though end-of-life scrap collection is very efficient, this internal scrap exceeds the contribution of end-of-life scrap to current recycling processes. The liquid stages of steel production to the left of the diagram are the most energy intensive, and even though recycling is less intensive than primary production from ore, these losses and internal scrap significantly increase the emissions associated with steel. 28 Mt of liquid steel was produced to supply the 20 Mt of final demand.

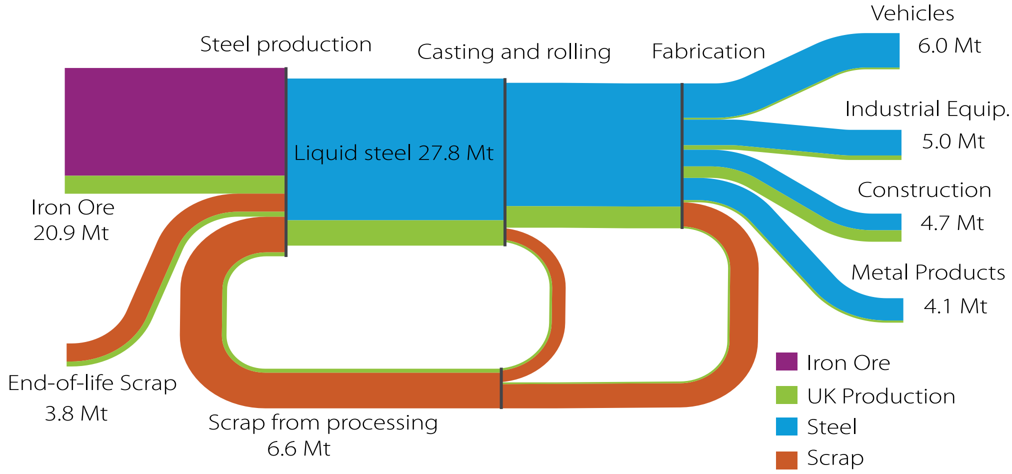


Fig 6: Material flows for UK steel consumption, 2007.

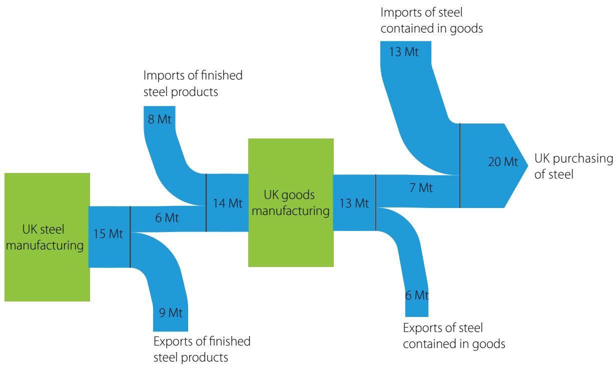


Fig 7: UK steel consumption in final product terms, 2007.

In contrast to the international flows of steel into and out of the UK shown in Figure 7, cement is not traded to the same extent, due to its small value to mass ratio. Most cement used in the UK is produced domestically. The physical flows of cement in the UK during 2010 are shown in Figure 8, in which year approximately 11 Mt was used in developing the stocks of buildings and infrastructure.

The cement production route is largely standardised. Clinker is produced in a kiln (the UK uses three different kiln technologies with varying efficiencies) and then is ground with other materials to make cement. Clinker production is the most energy-intensive part of the process, in which emissions are also released from chemical reactions. Reducing the ratio of clinker-to-cement allows energy and emissions savings, but can also affect the cement's properties. In 2010 this ratio stood at 68% for UK produced cement.

Most cement is mixed with other materials (not shown in Figure 8) to produce concrete, but cement is by far the most energy and carbon intensive component of concrete. 61% of the cement consumed in the UK in 2010 was used in buildings, with the remainder used in infrastructure.

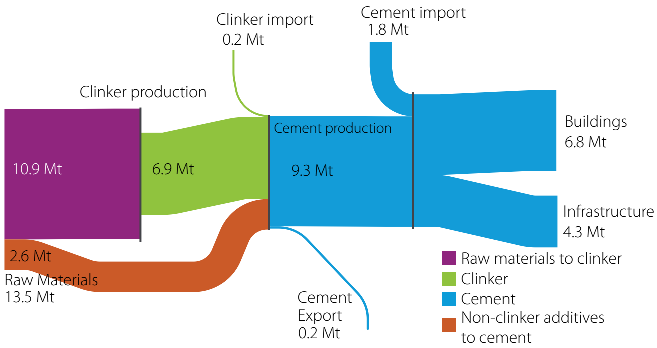


Fig 8: Material flows for UK cement consumption, 2010.

How has our demand for products and materials evolved over time?

Growing demand for products and services in the UK has increased the emissions caused by consumers and other purchases. However, demand for steel and cement in the UK has changed only slowly in the past 40 years, and most steel purchased today is estimated to replace existing stocks.

Trends in the emissions caused by UK purchasing

GHG emissions caused by UK purchasing generally increased until 2007, and then decreased with the financial crisis of 2008 and the recession that followed. Figure 9 provides an explanation for this pattern: the black line shows these emissions (as in Figure 3, but excluding the direct household emissions in Figure 4) relative to 1997; the other, coloured, lines which sum to the black line, relate the changes in these emissions to six separate drivers. Overall, demand (per person) for goods and services in the UK rose to a peak in 2007, followed by a slight decline; alongside a small growth in UK population. Variations in the purchasing preferences of UK consumers, in the proportions of trade between different business sectors and in the sources of imports have had only a small effect on emissions. Nevertheless, the average GHG emissions intensity of the industries supplying goods and services to the UK has fallen, partially because (following the 2008 economic downturn) imports to UK businesses

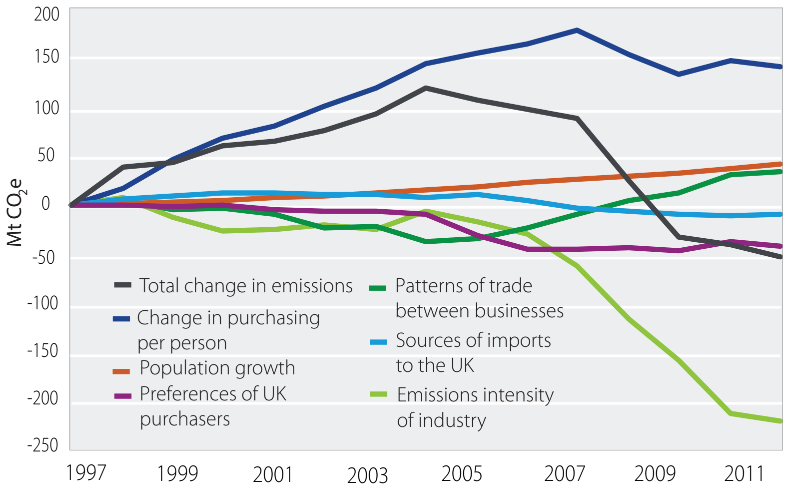


Fig 9: Drivers of change in GHG emissions caused by UK purchasing since 1997

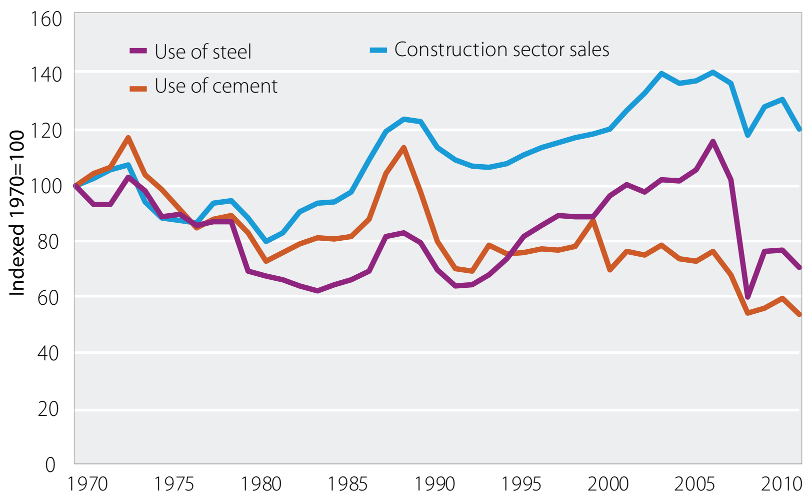


Fig 10: Relative changes in the use of steel and cement in the UK and the total sales of the UK's construction sector since 1970.

Trends in the use of steel and cement in the UK

Almost all cement is used in construction which also uses a quarter of steel, so Figure 10 contrasts the mass of steel and cement purchased in the UK over four decades with the sales (adjusted for inflation) of the construction industry. As might be expected, there is some correlation between the requirement for these materials and construction activity, but while the sales in the construction sector have grown, the use of steel has been roughly constant and there has been a slow decline in the use of cement. This partially reflects a shift in design preferences in the UK towards steel-framed buildings in the 1980s and 1990s – which was more pronounced here than, for example, in other European countries where concrete is still the preferred material. Nevertheless, the ratio of steel to concrete framed buildings in the UK multi-story sector has remained roughly constant over the last 10 years.

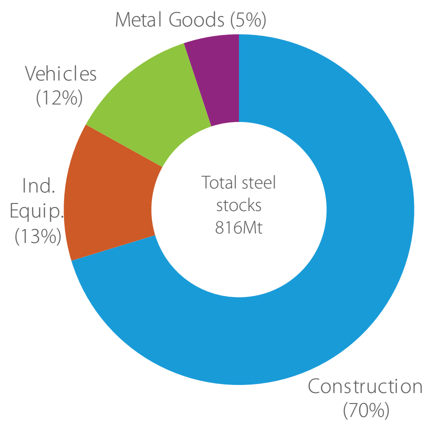


Fig 11: Estimated UK steel stocks by product category, 2007

The focus of this report so far has been on the flows of new material into the economy. However, the stock of materials in the economy, and the rate at which materials are discarded, are important determinants of new material flows. Goods are either purchased to replace existing ones or to expand the total stock, shown in Figure 11. So, using figures for material and product discards, and assuming that all retired goods are replaced by similar ones, the balance between these two drivers of purchasing has been estimated. Thus, 36% of the UK's total demand for steel arises from expanding rather than replacing stocks. In more detail, demand for expanding stocks is 38% for vehicles, -3% for industrial equipment, 63% in construction, and 36% in metal goods. Construction is therefore the only sector for which the majority of steel demand is for net additions to stock.

Growth and well-being

Conventional economic policy assumes that a key national goal is to increase 'Gross Domestic Product' (GDP, the rate of flow of money through the economy). This may not accurately reflect the modern concept of 'well-being' that is being taken up in UK policy making circles [for example, under the auspices of the Office of National Statistics (ONS)] to provide a fuller picture of societal welfare by supplementing existing economic, social and environmental measures. Nevertheless, as material demand for buildings, products, vehicles and equipment grows, so does GDP. It is important therefore to examine the extent to which it is actually the stock of goods in the country, rather than the annual demand for new materials, that relates to the well-being of the population. Box story 1 discusses how material demand is linked to economic development and well-being, and this is further discussed on pages 14 and 15.

Material demand, economic development and well-being — BOX STORY 1

The relationship between material demand, economic development and the well-being of the population has important implications for future levels of demand for energy intensive materials. This demand for materials or products has been an important goal of economic development, largely at the expense of other elements of welfare such as those related to the functions of communities, or the balance of work and leisure in individual lives. The question of whether developed economies should continue to pursue GDP growth is attracting increasing attention, but is far from resolved. The concept of 'dematerialisation' suggests that economic wealth in the industrial world might rise dramatically while resource use is reduced. Such a strategy requires a major change (or 'paradigm shift') to a manufacturing system that is focused on maximising resource efficiency, and minimising the embodied energy and GHG emissions in materials and products by way, for example, of reuse and recycling or lifetime extension. Figure 12 gives three contrasting views as a stimulus to future work, and the interpretation of these and similar data remains contested. Demand may reach a limit only for certain materials, mainly durables, while the demand for others continues to increase with income. And while rates of purchasing bulk materials may decrease in advanced economies, this may only lead to increased demand for other, novel and more energy intensive, materials.

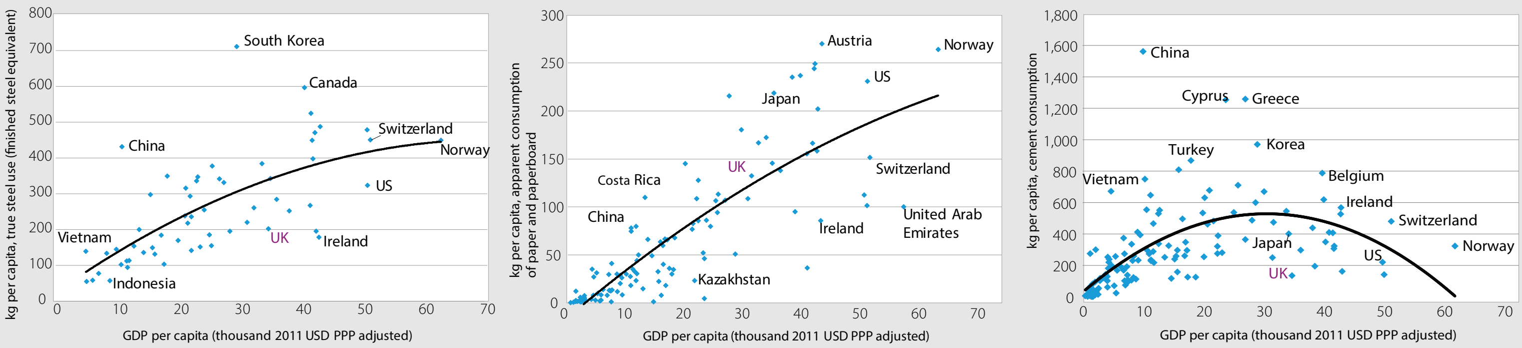


Fig 12: GDP per capita vs material consumption a) Steel, 2012; b) Paper and paperboard, 2012; and c) Cement, 2011

How will emission targets affect demand for materials?

To reduce the risks of climate change, the UK has set targets to reduce greenhouse gas emissions from its own territory. However, goods purchased in the UK are mainly imported, so if the same targets were applied wherever the goods are made, they could be met only if new material production was reduced.

Emissions targets

Global warming is driven by the accumulated stock of GHGs in the upper atmosphere. Climate scientists, using models of the interactions between atmosphere and planet, estimate how future increases in this stock will affect surface temperatures. In response, many developed countries have set quantified targets into policy aiming to limit warming to 2ºC above pre-industrial levels. The UK's target is to reduce emissions generated in its territory to 20% of 1990 levels by 2050. However, even if such targets are met, without reductions in other countries the average temperatures will likely rise by 4ºC by the end of the 21st century. Should the UK therefore apply its targets to emissions released by trade partners delivering goods to the UK?

Figure 13 illustrates the reductions required by the UK to meet its targets. Prior to the 2008 financial crisis, UK territorial emissions were reducing at approximately 1% per year, but this must increase to 3.4% to meet the target. Nevertheless, prior to 2008, emissions associated with UK imports were increasing at 1.1% per annum. If all other countries with emission reduction targets meet them and the UK's purchasing patterns remained unchanged, these emissions would reduce by 1.8% a year, consistent with a four degree temperature rise. Limiting the rise in global temperature to two degrees requires that this reduction rate associated with imports should be increased to 3.2%.

Emissions targets for steel and cement

The UK Government has developed the Carbon Plan, setting out a transition to a low carbon economy, including plans for the future structure of the UK energy sector and for future energy use across different industries. In reaching the UK's overall targets, the steel and cement industries have an important role to play. For example, in one scenario described in the Carbon Plan (created by the cost-optimisation model MARKAL), the direct final energy use of the UK steel and cement industries must be reduced significantly, as shown in Figure 14 (a). Because energy purchasing is a high fraction of the costs of producing steel and cement, these two industries are already extremely efficient in their use of energy. The estimates of future production levels shown in Figure 14 (b) are therefore made by assuming that energy demand can only be cut by reducing output. In this case, UK production of steel and cement in 2050 would be slightly below levels following the 2008 economic recession and far below pre-crisis levels.

Box Story 2 on page 12 discusses the absolute (and unachievable) thermodynamic limits to energy requirements for steel production and shows that

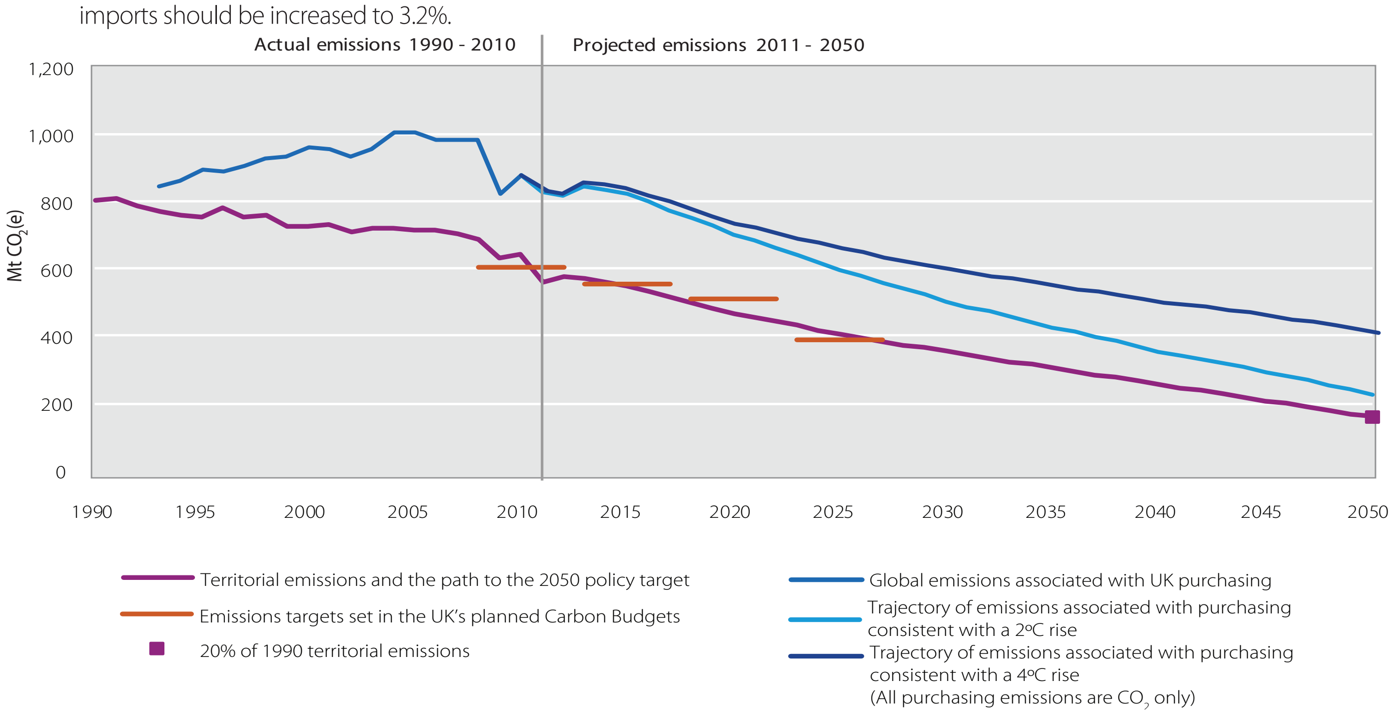


Fig 13: Greenhouse gas emissions trajectories for territorial emissions and those associated with UK purchasing, consistent with different forecast temperatures.

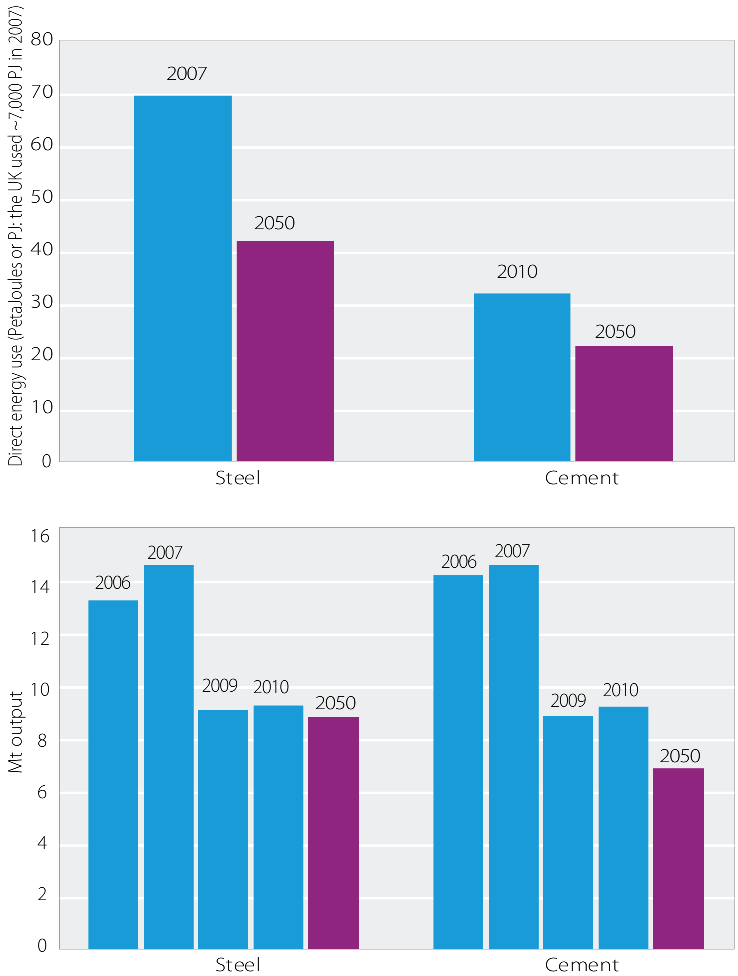


Fig 14: Historic and estimated a) direct energy use, and b) material production in the UK steel and cement sectors to contribute to a national 80% GHG emissions reduction target

this industry is close to reaching the practical limits of efficiency within the current processes. Planning for future material output within the UK depends strongly on the approach taken to the emissions caused by production in other countries. This is especially important for steel, where as discussed on pages 4 and 5, UK demand is largely met by imports.

Current projections indicate that the population of the UK will grow around 16% and GDP per capita approximately double from 2013 to 2050, it is then estimated that the UK would require approximately 25% more steel should historic trends linking steel demand and GDP continue (see Figure 15). A cut in steel production in the UK to the level required in Figure 14b, would necessitate an increase in imports by around one third. Alternatively, if imports are reduced to the level of UK steel exports (in order to avoid GHG emissions in other countries, but with the same level of UK production), final demand for steel in the UK would be cut to 9Mt. This represents a significant reduction from pre-recession levels of steel consumption, and would require significant change in the way steel is used and its value maintained in service.

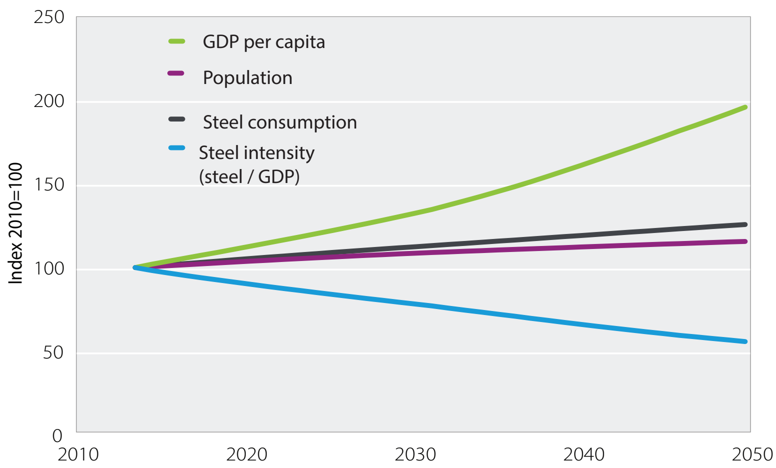


Fig 15: Steel consumption, steel intensity (steel consumption per unit of GDP), GDP per capita and population projections under a 'business as usual' scenario

How can we reduce our demand for new materials?

By examining economy-wide supply chains, leverage points for reducing emissions can be identified. Interventions that show high potential impacts should be prioritised, these include reducing material demand in business-to-business transactions and supplying final consumer demand with reduced material.

A framework to identify emission reduction opportunities across UK supply chains

An economy-wide supply chain framework has been developed, and this is represented schematically in Figure 16 (an expanded version of Figure 4).This will be adopted in order to investigate the emissions associated with money flows related to goods over which the UK has some level of influence. The framework identifies four different leverage points in the economy (described below) at which interventions could occur to reduce resource demand and GHG emissions. There is necessarily overlap in the emissions covered by each leverage point as there are multiple opportunities in the supply chain to reduce emissions. The absolute level of emissions at each leverage point, as indicated in Figure 16, can be used to identify possible high impact points along supply chains where mitigation efforts should be focussed. The leverage points are:

1. Production: Direct GHG emissions from the power sector, primary industries, manufacturing and construction. Improvements in the energy efficiency of production would lead to a reduction in emissions, whether for use in the UK or for export, as would any reduction in the emissions released by power stations or industrial processes. The majority of UK policies are aimed at this point, but it has limited leverage for the emissions associated with producing goods: the energy intensive primary material industries are already very efficient, the application of carbon capture and storage technologies has so far had little take up and many other sectors are competing for renewably generated electricity.

2. Business to Business transactions: GHG emissions embodied in products. Policies aimed at reducing demand for materials at this point in the supply chain can reduce emissions from UK production, and those embodied in imports. Opportunities that target this leverage point reduce the material demand of a product whilst retaining the service delivered to the final user.

3. Final purchasing: Total emissions attributed to the final consumer (i.e., households, government and lasting infrastructure). A reduction in the level of demand for goods, or a change in the composition of spending towards less carbon intensive products would reduce GHG emissions generated upstream, including emissions embodied in imports. The majority of final purchases are driven by UK households, but the same changes in spending – for example, reducing waste or maintaining rather than replacing goods – are part of the opportunity for businesses.

4. Direct household: GHG emissions generated directly by final purchasers. These are mostly associated with fuel combustion to heat homes and drive cars. Behaviour change can have some influence here, although these emissions are largely determined by the size and design of the homes and cars owned by the purchasers, so closely linked to the production of goods.

Meeting climate change targets will require action at all these leverage points, each of which involve different interest groups and the adoption of different policies. For example, the service industry (such as banks, consultancies or research organisations) directly emits a relatively small fraction of the UK's emissions (50 $MtCO_2e$). However, through its business-to-business spending it is a significant driver of upstream (manufacturing) activity (276 $MtCO_2e$), generating two thirds of its emissions overseas, this is highlighted in Figure 16.

Prioritising high impact interventions

Using a calculation based on the association of emissions to money flows between sectors in the UK economy, Figure 17 shows an estimate of the GHG emissions associated with the flows of selected inputs – mainly materials (the rows of the figure) – into the products made by key industries (the columns of the figure). The area of the outer circle is proportional to the global emissions of GHGs associated with the input and the area of the inner circle is proportional to the subset of these which occur within the UK.

The largest circles in the figure emphasise the emissions

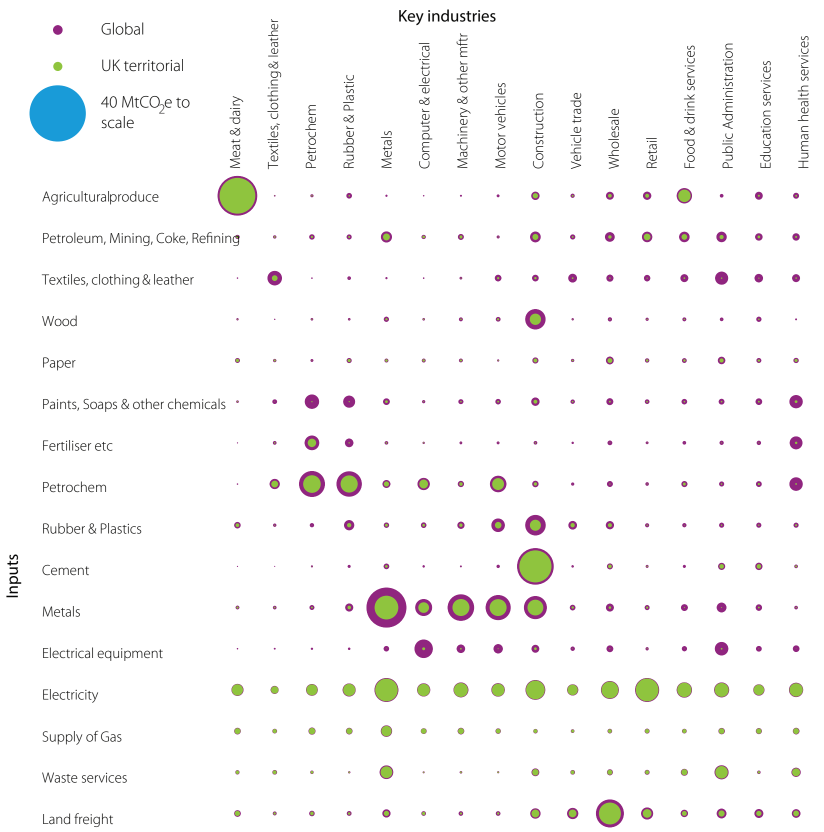


Fig 17: Estimated transfers of the greenhouse gas emissions associated with the flows of selected inputs – mainly materials (the rows of the figure) – into the products made by key UK industries (the columns of the figure) in 2007. [The area of the outer circle is proportional to the global emissions of greenhouse gases associated with the material input and the area of the inner circle is proportional to the subset of these which occur within the UK.]

associated with the supply of inputs from farms to the meat & dairy industries, the use of cement in construction, the use of metals in several industries, and the use of freight by the wholesale sector. The use of electricity contributes significantly to the emissions associated with each industry. Whilst decarbonisation of the power sector will be a very effective strategy (and one that is being pursued by existing government policy). Figure 17 clearly shows there are other leverage points in the economy where sizeable reductions can be achieved.

The emissions shown in Figure 17 relate to inputs used by industries in the UK, i.e. those that could be reduced by material efficiency measures applied only in the UK. The emissions which are embodied in flows into industries worldwide are much greater and so there is additional scope for the UK to reduce emissions through the transfer of knowledge and abatement technologies relating to such material efficiency.

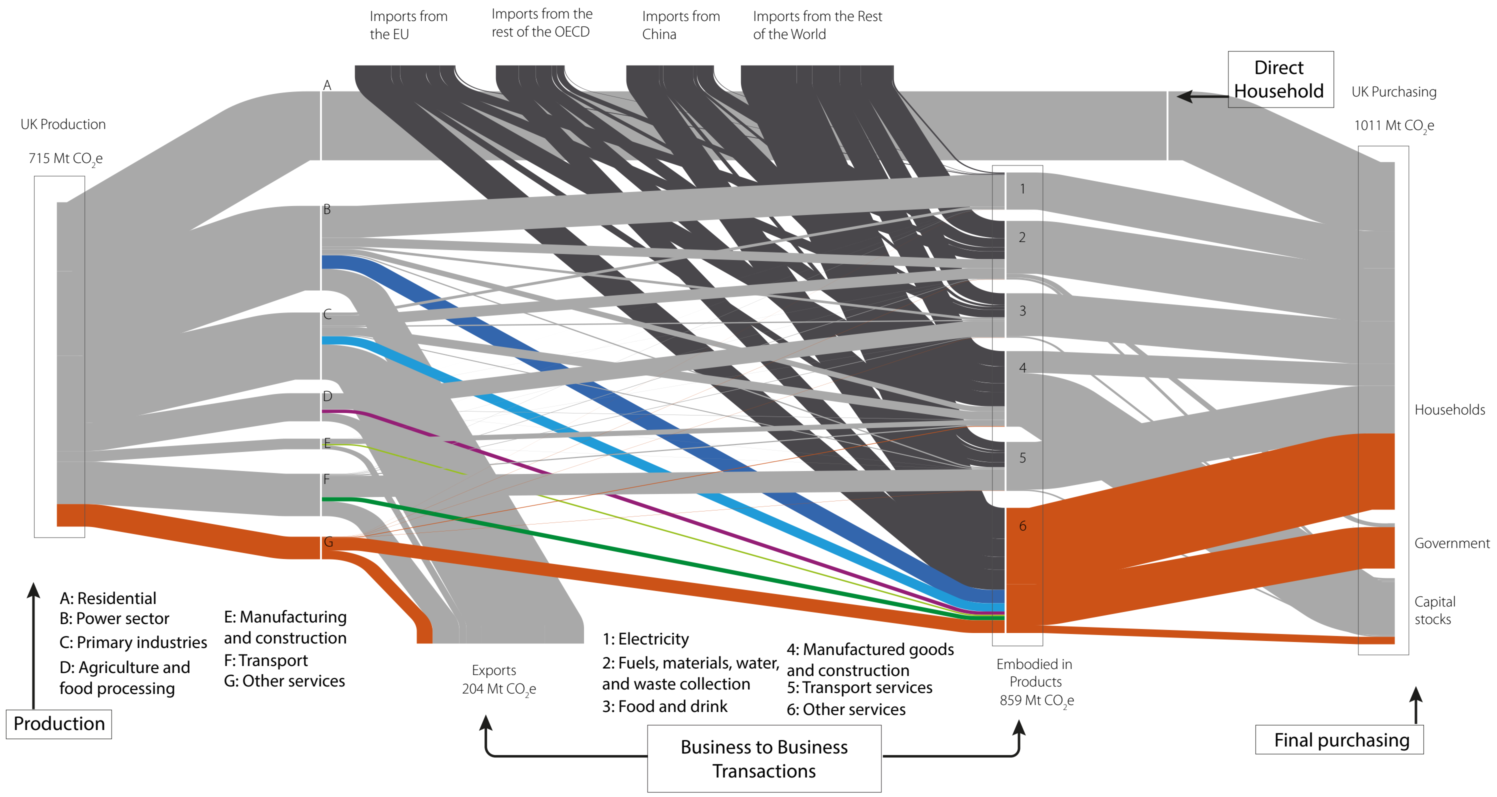


Fig 16: A framework to identify four leverage points for emissions reduction and high impact emission flows. Flows related to the service sector are highlighted. [This expands on Figure 4.]

Towards implementation

The framework developed here has shown that different strategies are required to support emissions reduction opportunities at different points along supply chains. Decarbonisation policy in the UK is well defined; yet changing the focus of policy further down the supply chain towards consumers introduces new opportunities for sizeable reductions. Taking the example of the automotive industry, the framework identifies four leverage points:

1. Cars can be manufactured with materials made by energy efficient processes powered by renewable energy supplies;
2. Cars can be made smaller and hence lighter, and with less scrap in production;
3. The demand for new cars to add to the stock of those which sit on driveways for the majority of their lifetime can be reduced if the existing stock is put to more intensive use through car sharing and is maintained in use for longer;
4. More efficient engines and smart driving practice can lead to less direct exhaust emissions.

Current policy sits within an energy framework and tackles (1) and (4), yet (2) and (3) identify additional resource efficiency options that can deliver comparable savings. The same approach can be applied to all goods and services produced and consumed in the economy. Box Story 3 and 4 represent case studies of two material efficiency options applying to leverage point 2.

Whilst the framework presented here provides a tool to assess the economy-wide potential of various strategies to reduce GHG emissions, further investigation is needed to identify the most appropriate mechanisms to govern such interventions, including evidence about implementation barriers and the economic and social consequences of these changes.

The thermodynamic limits of material production

BOX STORY 2

The minimum thermodynamic energy required for producing materials is determined by the necessary change in the chemical potential of the substances forming the material and by the work required to extract and concentrate them. This is a theoretical limit that cannot be reached in practice – for example, it assumes that fuel combustion is not required. Technological constraints on the efficiency of subsystems and on achievable levels of process integration further increase the energy requirements to the levels of current best practice. Figure 18 shows how the UK average energy requirement for steel production compares to world best practice and the thermodynamic limit.

For the key energy intensive materials, including steel, cement and aluminium, best practice is now approaching the achievable limits of energy efficiency, and there is limited scope for future improvement. In general, it is the industries which are not energy-intensive that have greater remaining potential for energy efficiency and which in recent years, have achieved greater relative improvements. However, their total energy requirements are lower.

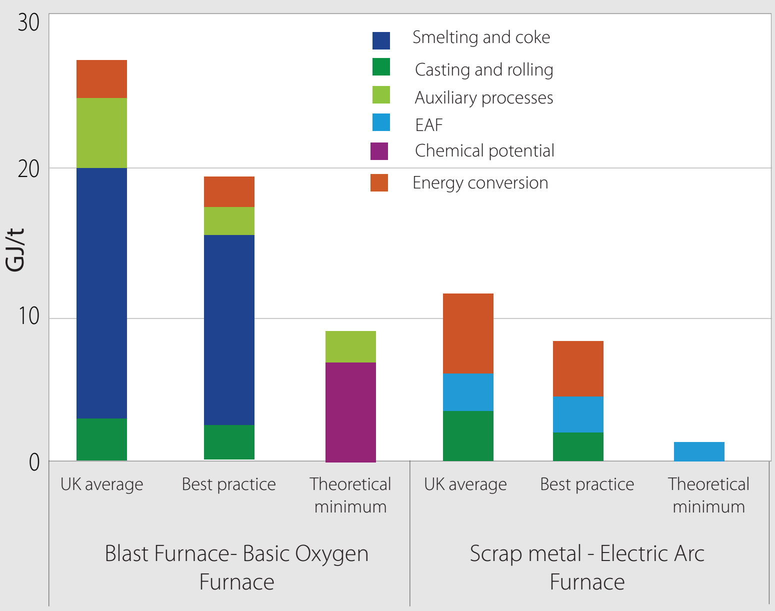


Fig 18: Specific energy requirements for steel production

Steel Savings in Offshore Wind Turbines

BOX STORY 3

The expected growth in the UK's offshore wind generation capacity could create demand for 1.4 Mt of steel by 2020, and a further 2.6 Mt by 2030. A 6MW offshore wind turbine will use approximately 300 tonnes of steel plate in the tower, and a further 350-500 tonnes in the foundations. Siemens have been assessing a number of opportunities for material efficiency in offshore wind towers:

- Substituting higher strength steels could reduce the mass by around 20%, although this would require a change in long established regulations that govern offshore turbines.
- Using a non-uniform wall thickness with less material where loads are lower (see Figure 19), allows amass saving of 10%. This design has been tested and proven, but commercial deployment now requires that plate manufacturers invest in new equipment.
- Manufacturing the tower from a single plate, would reduce yield losses and hence total steel requirements, but again requires investment in novel plate manufacturing techniques.

Additional savings could be achieved through the application of similar techniques to the foundations of offshore turbines, and in the construction of onshore turbine towers. Turbines that have a higher capacity or that share infrastructure with other renewable energy sources, such as marine turbines, could also reduce the total material requirement per unit of electricity generated.

Assuming a 10% saving in the mass of the tower under the projections above 177 kt of steel could be saved in the construction of offshore wind towers to 2030.

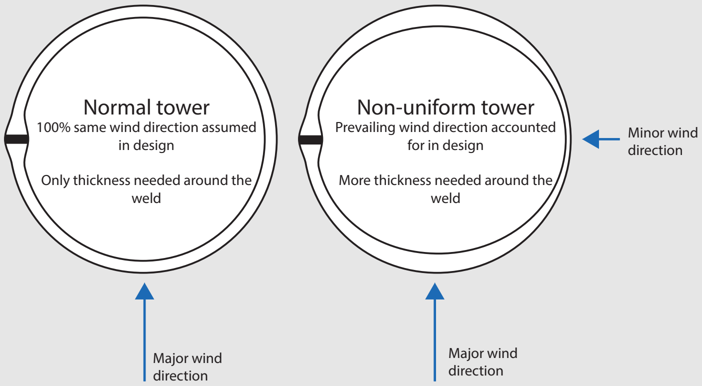


Fig 19: Cross sections of standard and non-uniform wind tower

Optimising concrete structures with fabric formwork

BOX STORY 4

Concrete elements are normally manufactured with uniform cross-sections in rigid moulds. In contrast, researchers at the Department of Architecture and Civil Engineering at the University of Bath are exploring a new technique in which conventional moulds are replaced by formwork created out of flexible, high strength, sheets of fabric. This fabric formwork capitalises on the fluidity of concrete to create optimised, geometrically complex shapes and can save up to 40% of previous material requirements. Fabric formwork is currently being tested and proven in research conditions and can be used in the construction of most steel reinforced concrete elements, including beams, columns, and flat slabs. It is low cost and relatively easy to adopt, and also offers new avenues for architectural expression.

Fabric formwork provides material efficiencies through geometry. Additional savings in the emissions associated with concrete construction can be achieved by reducing the clinker content of cements and by alternative reinforcement methods. Another opportunity being explored is how concrete components manufactured off-site can be mechanically joined and then disassembled for re-use.

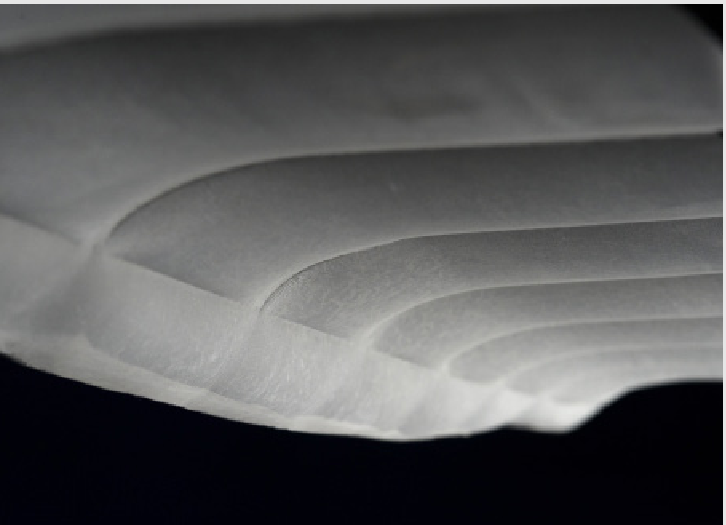


Fig 20: Optimised concrete T-beam cast using flexible formwork.

What are the social and economic implications of adopting material efficiency strategies?

Economic growth and jobs in the UK are becoming less dependent on domestic material production. However, reducing the overall requirement for materials production must affect employment – either in the UK or in the countries from which the UK imports goods. It is consequently desirable to understand the impact on well-being of pursing strategies to reduce future material demand.

Material demand and the economy

When viewed in isolation, the UK economy has apparently become increasingly efficient in producing more value per tonne of material produced within the country, as shown in Figure 21. Britain's GDP grew at twice the rate of its production for all minerals in the period 1998 to 2011. These apparent gains in material productivity have been accompanied by apparent improvements in labour productivity in manufacturing, construction and mining.

Figure 21could therefore suggest that the UK's economy is now sufficiently developed to be decoupled from its demand for materials – apparently its citizens can keep getting richer but not need more material. However, as clearly demonstrated earlier in this report, this is quite untrue. Many of the materials and goods required by UK purchasing are imported. The economic value of the country's trade in materials (steel in particular, because most cement production is used indigenously) and manufactured goods grew by more than 70% from 1993 to 2007. This is significantly faster than the industrial contribution to Britain's gross domestic product (as shown in Figure 22), so there is no evidence of material decoupling: the UK economy is growing because it can profit more from jobs in the service sector than in materials production.

UK industries have become more specialised in producing high-value and capital-intensive products. Nevertheless, the UK relies on foreign markets to acquire commodities and to undertake less complex manufacturing to meet its material demands. UK imports therefore create jobs and economic value abroad, and Figure 23shows the distribution of employment around the world created by Britain's purchases of goods and services. Only half of the employment created by this spending occurs in the UK; the remainder is in the EU, China, and the rest of the world. The graph shows that the global financial crisis in 2008 led to a reduction in UK purchases of imports, and hence the relative fraction of demand met by labour in the UK increased. Any initiatives to reduce material demand will therefore affect employment both in the UK and overseas.

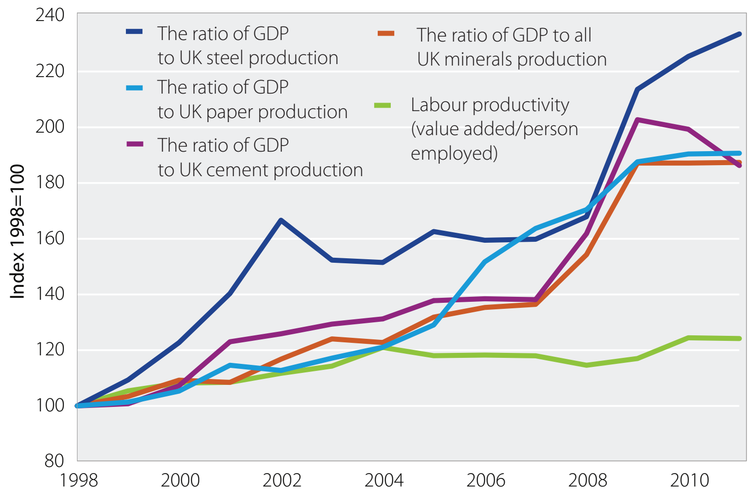


Fig 21: Material and labour productivity in the UK

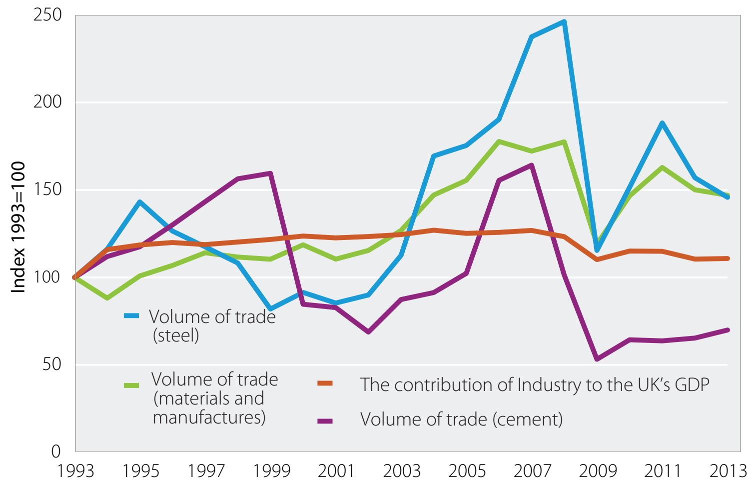


Fig 22: UK trade in materials

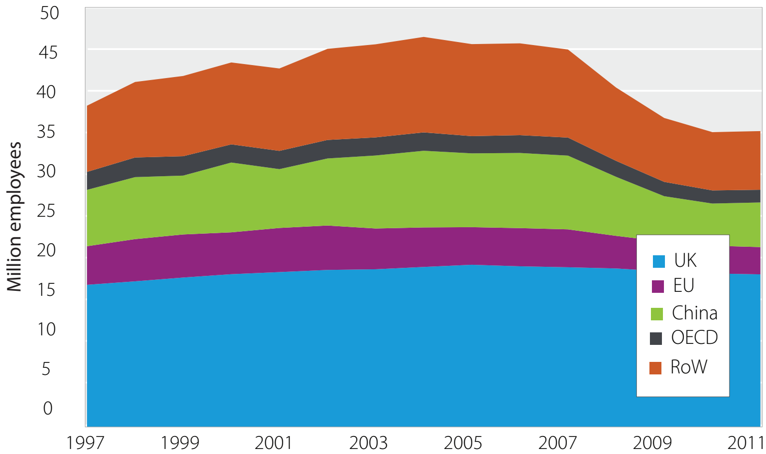


Fig 23:Employment driven by the purchasing of goods and services in the UK.

Material demand and social wellbeing

Materials are ultimately used in order to improve human well-being. When a house, school, hospital, or road is built it normally contributes to improving levels of comfort and, overall, to enhancing the living standards of individuals and of society. However, improvements in well-being may also drive material demand. Economic growth may result in more jobs and rising disposable income, thus increasing demand for more goods and services which necessitate more material inputs. A key question is to ask whether and how a material-constrained future will affect quality of life.

The United Nations Development Programme (UNDP) Human Development Index (HDI) is often used to define well-being. Although it is limited by its narrow focus (i.e. it is basically comprised of three indicators: life expectancy, education, and income per capita), HDI is useful to track a country's progress over time. From 2000 to 2012 all these measures registered improvements in the UK, especially income per capita which grew more than 15%. Over the same period material consumption per capita, illustrated in Figure 24 by steel and cement, registered a significant decline . This drop was to a major extent due to the global financial crisis in 2008-2010, when production and international trade observed a major decline. The consumption of steel and cement plunged, accompanied by a fall in real terms of income per capita. The fall in material consumption seen from 2008 was greater than the decline in any of the social well-being indicators however, with the HDI remaining relatively stable.

It is recognised that short-term changes in material consumption are not likely to significantly affect well-being however, and so to improve our understanding of the link between materials, income and well-being it is important to develop some key metrics of stock, possibly even of the 'demographics of stock', for a range of materials. It is this stock of materials, rather than the annual flows, with which people interact and which provide services that can contribute to well-being. The connection between materials and well-being is therefore markedly different to that between energy use and well-being (where there has been evidence of a decoupling) as it not the stock of energy that provides a service, but the flow. By determining the required levels of material stock in contributing to a full and satisfying life the future demand for materials and impacts of this production can be determined.

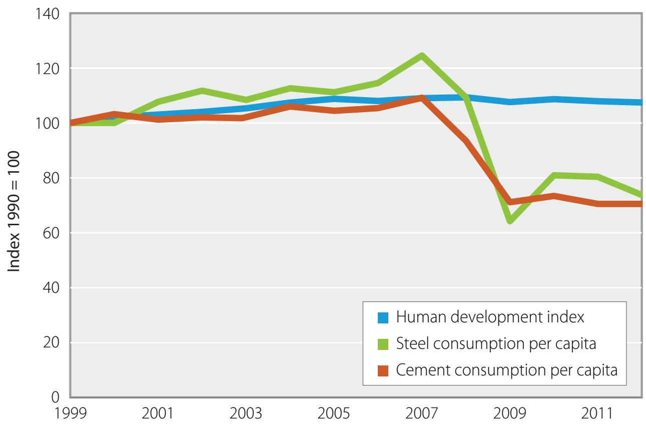


Fig 24: Relative changes in well-being and material consumption in the UK, 1999-2012

Opportunities for future research

This report has revealed some key features of the role of materials in driving energy demand and emissions in the UK:

- Industrial energy demand is strongly driven by production of a few key materials, in particular steel and cement, and because the industries that make these materials pay heavily for energy, they are already energy efficient.
- Most of the UK's purchasing of physical goods is met by imports, so most emissions and more than half of the jobs associated with their production occur outside its territory.
- It is recognised that many strategies exist aimed at living well with less new materials production. Consequently, there is a growing portfolio of case-studies of practical strategies illustrating how future flows of money and jobs are linked.
- Current UK emissions policy favour further cuts in UK industrial activity, but if it took responsibility for the emissions created by indigenous purchasing, then it could reduce emissions while still creating growth for UK manufacturing.

Opportunities for future research:

- Extending the analysis of material production driven by UK requirements for steel and cement to other materials. Then use this understanding of precisely which design and production choices could be modified, and by whom, to provide the services required with less new material.
- The work on how material flows and emissions are connected to money flows is constrained by the sectors used in the creation of national accounts. Further disaggregation of these sectors will enable the identification of interventions that reduce material inputs.
- Explore in detail the likely opportunities for renewable energy generation to power material production, both in the UK and elsewhere, and to refine understanding of remaining energy efficiency opportunities in industry, in order to clarify the extent to which material demand reduction is a pre-requisite for mitigating industrial emissions.
- Expand understanding of the links between material production and employment, to examine how re-deploying labour into industries which maintain rather than replace material goods will affect the wider economy.
- Develop techniques to map and characterise the stocks of key material goods in the UK, both to evaluate opportunities to maintain stocks in service for longer, and to examine the connections between stocks of goods and national well-being.
- Economic policy predicated on the growth of the Gross Domestic Product is likely to lead to growth in demand for materials, and hence emissions from industry. This link will be further developed to produce other metrics that reflect welfare in a broader sense, and which might support future policy aiming at living well with less new material.

Notes

Summary

1. CO_2e, or carbon dioxide equivalent is a measure of the global warming potential of greenhouse gases. The impact of different gases in converted into the amount of carbon dioxide (CO_2) that would have the same warming effect.

2. ONS(2014) Atmospheric Emissions: Greenhouse Gas Emissions: By Economic Sector and Gas, United Kingdom (Reference number 77-313900). Available: http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Environmental+Satellite+Accounts#tab-data-tables [Accessed 15 June 2014]. This figure and the consumption figure are for 2007. Figures post 2007 show effects of the recession and are discussed in the next section

3. IPCC (2014) Working Group III contribution to the IPCC's Fifth Assessment Report: Summary for Policy Makers. Intergovernmental Panel on Climate Change, Geneva, Switzerland. Note - we include CO_2 from fossil fuel and industrial processes, CH_4, N_2O and F-Gases but exclude emissions from land use, land use change and forestry

4. 106 sectors, by region, have been aggregated into 6 industries and 6 product groups and the figure includes an import and export sector. The technical appendix lists a full disaggregation of these groups. Including those classed here as "materials".

5. Allwood, J.M. and Cullen, J.M. (2011). Sustainable Materials - With Both Eyes Open: Future Buildings, Vehicles, Products and Equipment - Made Efficiently and Made with Less New Material. Cambridge: UIT Cambridge.

6. See Peters, G. P. and Hertwich, E. G. (2008) CO_2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science & Technology, 42(5), 1401-1407 and Davis, S. J. and Caldeira, K. (2010) Consumption-based accounting of CO_2 emissions. Proceedings of the National Academy of Sciences, 107(12), 5687-5692.

7. Full explanations of each of the drivers shown in Figure 8 are given in the technical appendix.

8. For more information, please refer to: De Bruyn S. M. and Opschoor J. B. (1997) Developments in the Throughput Income Relationship: Theoretical and Empirical Observations. Ecological Economics, 20, 255-68; Geyer, R., Davis, J., Ley, J., He, J., Clift, R., Kwan, A., Sansom, M. and Jackson, T. (2007) Time-dependent Material Flow Analysis of Iron and Steel in the UK Part 1: Production and Consumption Trends 1970–2000, Resources, Conservation and Recycling, 51, 101-117; and OECD (2013) Material Resources, Productivity and the Environment, Organisation for Economic Co-operation and Development. Available: http://www.oecd.org/env/waste/material-resources-productivity-and-environment.htm [Accessed 2 June 2014].

9. UNFCCC (2011) Report of the Conference of the Parties on its sixteenth session, Part Two: Action taken by the Conference of the Parties at its sixteenth session, held in Cancun from 29 November to 10 December 2010, United Nations Office at Geneva, Geneva, Switzerland.

10. Collins, M., Knutti, R. et al. (2013) Long-term Climate Change: Projections, Commitments and Irreversibility. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, UK and New York, USA.

11. Committee on Climate Change (2012) Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping. Committee on Climate Change, London, UK.

12. HM Government (2011) The Carbon Plan: Delivering our low carbon future. Department of Energy & Climate Change, London, UK.

1. For model details see: DECC (2013) 2050 Pathways, Department of Energy & Climate Change, London, UK.

2. According to projections by PWC (2013) World in 2050: The BRICs and Beyond: Prospects, Challenges and Opportunities. PricewaterhouseCoopers LLP; and United Nations (2014) World Population Prospects: The 2012 Revision. Department of Economic and Social Affairs, NY, USA. Available: http://esa.un.org/wpp [Accessed 30 August 2014].

3. For further discussion see: Suh, S. (2006) Are services better for climate change, Environmental Science and Technology, 40(21), 6555; and Scott, K. and Barrett, J. (2013) Investigation into the greenhouse gas emissions of the UK services industries, Report to the UK Department for Environment, Food and Rural Affairs by the University of Leeds.

4. For further discussion see: Barrett, J. and Scott, K. (2012) Link between climate change and resource efficiency. Global Environmental Change, 22, 299-307; and Girod, B., van Vuuren, D. P. and Hertwich, E. G. (2014) Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions. Global Environmental Change, 25, 5-15.

5. Hammond, G. P. and Norman, J. B. (2012) Decomposition analysis of energy-related carbon emissions from UK manufacturing. Energy, 41(1), 220-227.

6. For further information on flexible formwork see: Orr, J. J., Darby, A. P., Ibell, T. J. and Evernden, M. (2014) Forthcoming. Design methods for flexibly formed concrete beams. Proceedings of the Institution of Civil Engineers: Structures and Buildings.

7. Steinberger, J. K. and Roberts, J. T. (2010) From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecological Economics, 70(2), 425-433.

Images

Earth image courtesy of NASA

Bricks (http://goo.gl/d29eD3)

Steel beams (http://goo.gl/GJJHO3)

People by Bel Fegore (http://goo.gl/vPjB0g)

Plane (http://goo.gl/odge3k) (edited by Fran Sergent)

Cars (http://goo.gl/6dJANr)

Scrap products (http://goo.gl/Fj51x5)

Concrete by Clive Darra (http://goo.gl/GWhFWh)

Steel manufacture by Jake Trussel (http://goo.gl/LIkQLj)

Offshore wind farm by Leo Reynolds (http://goo.gl/Whvzbd)

English terrace (http://goo.gl/iaFhJA)

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