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Analysis of energy embodied in the international trade of UK

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HIGHLIGHTS

- Model is established to examine UK's energy imports embodied in trade.
- UK's embodied energy imports have exceeded its exports every year since 1997.
- UK's net embodied energy imports from China are the largest accounting for 43%.
- UK needs to reconsider its energy utilization and efficiency in the light of trade.

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ABSTRACT

Interest in the role embodied energy plays in international trade and its subsequent impact on energy security has grown. As a developed nation, the UK's economic structure has changed from that of a primary producer to that of a primary consumer. Although the UK's energy consumption appears to have peaked, it imports a lot of energy embodied in international trade alongside the more obvious direct energy imports. The UK has seen increasing dependency on imported fossil energy since the UK became a net energy importer in 2005. In this paper an energy input–output model is established to calculate not only the amount of fossil energy embodied in UK's imports and exports, but also the sector and country distributions of those embodied fossil energy. The research results suggest the following: UK's embodied fossil energy imports have exceeded embodied fossil energy exports every year since 1997, UK embodied energy imports through the so-called 'Made in China' phenomena are the largest accounting for 43% of total net fossil energy imports. If net embodied fossil energy imports are considered, the gap between energy consumption and production in UK is much larger than commonly perceived, with subsequent implications to the UK's energy security.

1. Introduction

The UK has consistently ranked as one of the top ten wealthiest states by GDP (Table 1). It is a member of those select countries known as the 'developed' nations. This privileged global position is reflected in the UK's change in economic structure from a primary producer, to a primary consumer, with an economy dominated by the service sector. The UK is a primary consumer of energy and, although for a number of years at the end of the 20th century it was a net exporter of energy, the first decade of the 21st century has seen it transform into a net importer of energy.

The UK economy, when examined by turnover, displays a service sector bias representing nearly 70% of business transacted (Fig. 1). Yet the largest consumers of energy – within this service/industry split – tend to be those industries involved in the production of physical goods (the relative weighting of which is illustrated in Fig. 2), but both of these sectors lag Transport and Domestic energy use when looked at the economy as a whole (see Fig. 3).

High oil prices, and a general upward shift in energy costs have provided fresh impetus to examine energy security (Augutis et al., in press; Chester, 2010; Hughes, 2012; Mulligan, 2010) with the IEA expressing unprecedented concern in their 2008 World Energy Outlook (IEA, 2008). Energy security is often seen as a national (Farah and Rossi, 2011; Kim et al., 2011, Sovacool et al., 2011; Takase and Suzuki, 2011) or regional (Doukas et al., 2011) issue where the nation state must act to protect the energy supply of the country, although some would argue the economy will look after itself (Markandya and Pemberton, 2010). There is some discussion linking energy security to global carbon emissions controls (Gang et al., 2012; Mulligan, 2011), however, there is

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Table 1
Top ten states by GDP in the world (*Unit*: Billion US$).
Source: International Monetary Fund, 2012.

Country	2010	2011
United States	14,527	15,065
China	5878	6988
Japan	5459	5855
Germany	3286	3629
France	2563	2808
Brazil	2090	2518
United Kingdom	2250	2481
Italy	2055	2246
Russia	1480	1885
India	1632	1843

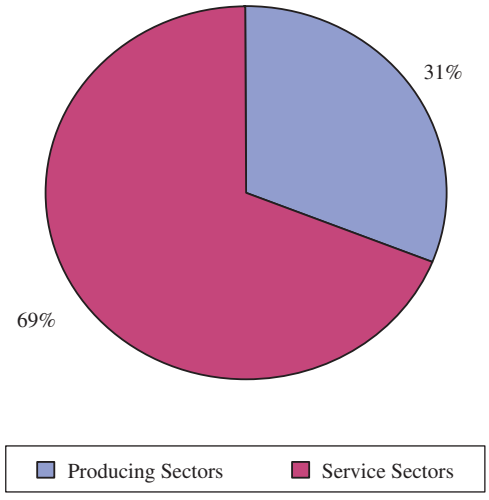

Fig. 1. UK economy split between service and producing sectors.
Source: Department for Business Innovation and Skills (2012) (Data from 2011 based upon turnover—value of sales, work done, and services rendered).

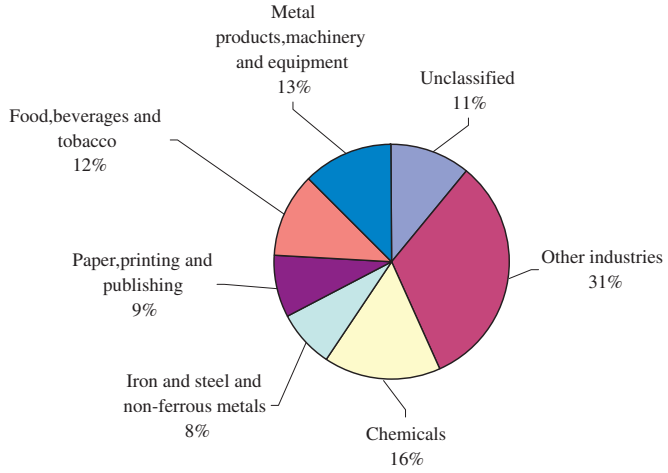

Fig. 2. UK's energy consumption by main industrial group in 2010.
Source: MacLeay et al. (2011).

growing recognition that in a globally integrated trade environment, focusing on the national aspect of energy security may prove short sighted (Qi, 2011). Interest in the role of international trade in environmental impacts (Liu et al., 2010; Peters and Hertwich, 2006) has grown and there is a clear, focus on embodied energy (Atkinson and Hamilton, 2002; Bullard and Herendeen, 1975; Chen et al., 2011; Jiang et al., 2011; Li et al., 2007; Machado et al., 2001; Tang et al., 2011; Wyckoff and Roop, 1994), and carbon emissions (Chen and Chen, 2011; Hetherington, 1996; Liu and Ma, 2011). It has been argued that the differences in energy consumption between different energy models can be accounted for by the way they handle embodied energy in imported goods (Wiedmann, 2009). Input/Output models have proven useful in defining the impact of both direct and indirect (embodied) energy use (Machado et al., 2001) and the potential impact on policy (Bordigoni et al., 2012; Liu et al., 2010).

This paper will examine the impact of embodied energy from trade on the UK energy imports. The paper will first examine the economic and energy structures of the UK providing the context for a discussion of embodied energy in a developed state. There will then be a section examining the Input/Output methodology employed followed by a section on the results of this analysis. Discussion of these results will complete the paper drawing out some of the key findings and pointing out impacts on policy direction.

1.1. UK energy context

To better understand the impact of embodied energy, the current economic and energy structures reported in official UK statistics is outlined. There are many data sets available publicly, compiled by government departments on a yearly basis, that provide a good view of trends within the UK economy. These statistics range from transport data, through to the current account status of the UK (the so called pink book). Here data from energy and business have been utilized to provide context to understanding the impact of embodied energy.

As a developed nation it appears that energy consumption appears to have peaked at around 160 million tonnes of oil equivalent per annum (Fig. 3). It has been suggested that whilst energy consumption appears to have flat-lined, GDP growth has continued (not withstanding the present economic situation), and that may suggest to some emerging patterns of sustainable growth, an upward trend on the so called Kuznets curve (Chowdhury and Moran, 2012; Spangenberg et al., 2002; Spangenberg, 2010; Turner and Hanley, 2011).

UK production of the key forms of fossil energy (oil, gas, coal) all appear to be in decline (Fig. 4).

Between the 1980s to mid 2000s the UK was a net exporter of energy (except for a dip generated by the Piper Alpha disaster – an explosion on an off shore gas rig in the North Sea leading to the deaths of 167 workers), but is now on a steady upward gradient of energy imports (Fig. 5). Energy import dependency is defined as net energy imports divided by final energy consumption, expressed as a percentage. A negative dependency rate indicates a net export of energy. Since energy loss – including losses in process – through energy conversion is not the focus of this paper, all energy consumption in this paper means primary energy consumption.

Energy consumption intensity can be calculated as energy consumption per GDP, a widely used indicator to measure the efficiency of energy use. UK's energy consumption intensity which is given as GDP at 2006 prices has been decreasing over the past 40 years (Fig. 6). Furthermore, the energy efficiency narrative shows the greatest gains are in the industrial and service sectors, but transport and domestic use have seen little in terms of efficiency gains (Fig. 7).

1.2. UK trade context

Overall the 2000s witnessed a declining balance of trade for the UK as a total, with 2004–2006 showed a reverse trend (Fig. 8). The monetary figures in Figs. 8–10 are nominal.

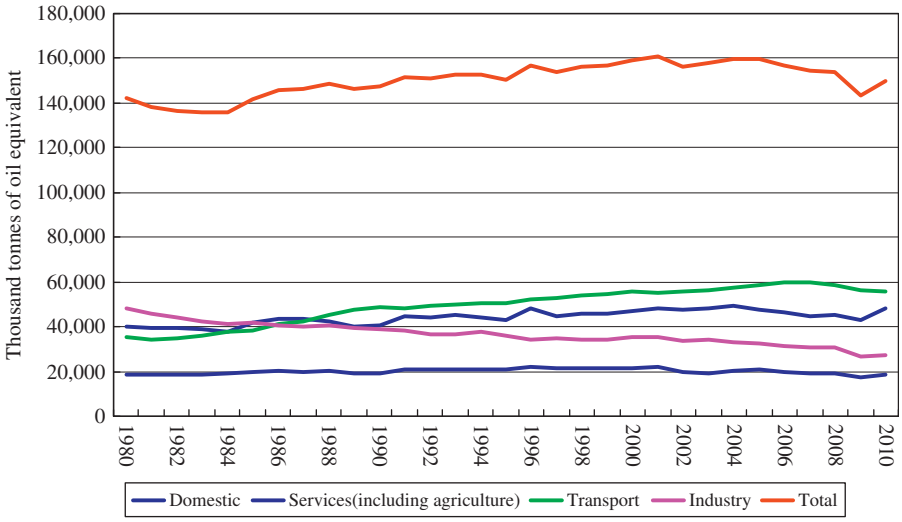

Fig. 3. UK's final energy consumption since 1980.
Source: Department of Energy and Climate Change (2011).

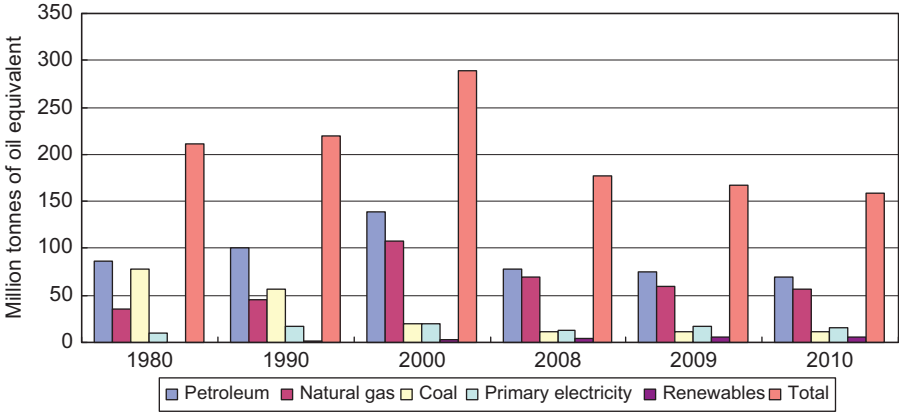

Fig. 4. Production of primary fuels in UK.
Source: Department of Energy and Climate Change (2011).

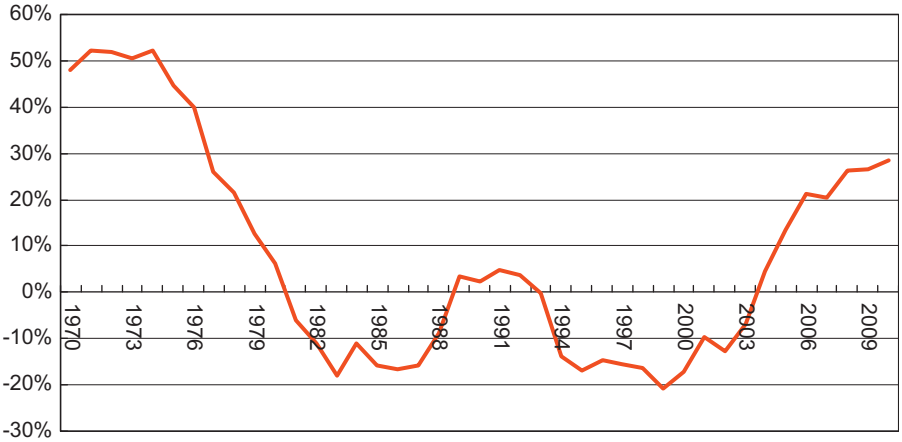

Fig. 5. UK's energy import dependency since 1970.
Source: Department of Energy and Climate Change (2011).

When examining the top three trade partners (USA, Germany, China, respectively), we can see that the UK has managed to maintain a positive balance of trade with the USA, but that China has grown as a major source of imports (Fig. 9).

From Fig. 10 it is clear that the balance of trade has worsened, and over the same period the increase in the balance of trade is marked, most pronounced in 'Food, Beverages, and Tobacco', and in 'Manufactured Finished Goods'. Oil trade, a significant proportion of current energy imports, went from a positive to a negative balance in 2005.

The official figures provide a picture of the UK as a wealthy country with high energy efficiency, gas displaying the highest

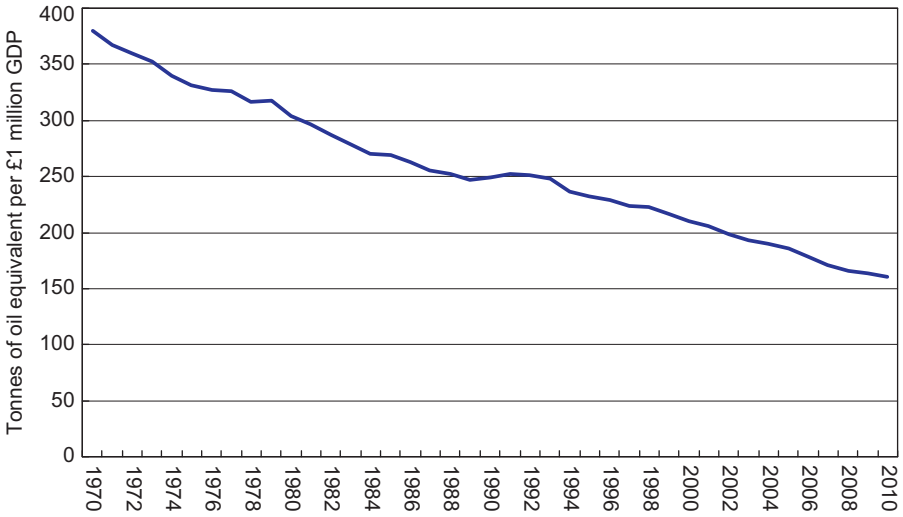

Fig. 6. Energy consumption intensity in UK since 1970.
Source: Department of Energy and Climate Change (2011).

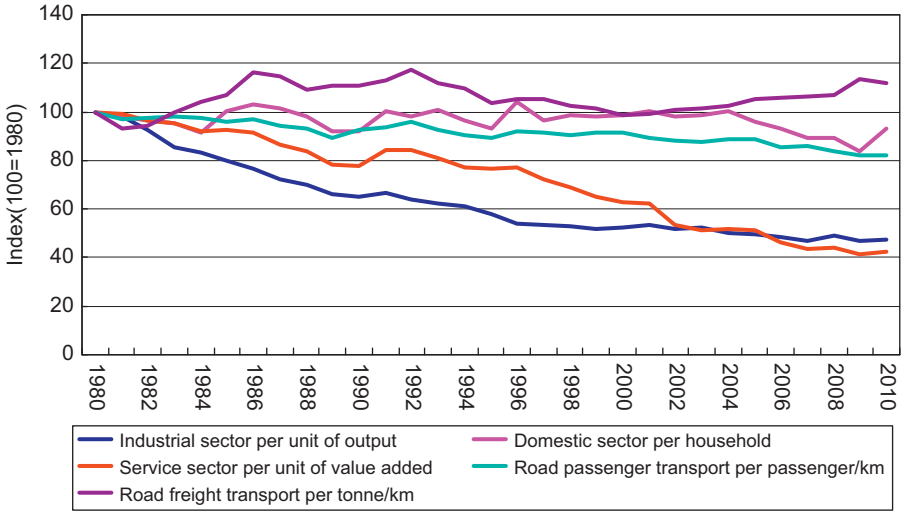

Fig. 7. UK's energy efficiency since 1980.
Source: Department of Energy and Climate Change (2011).

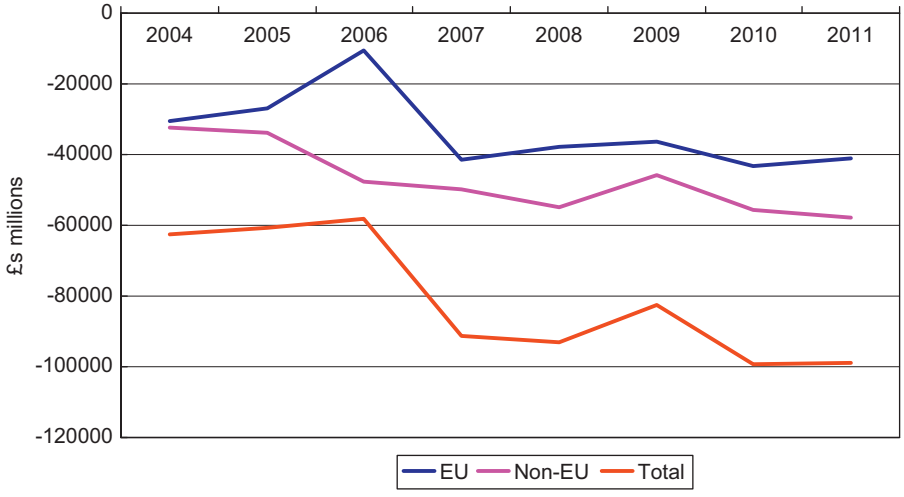

Fig. 8. Balance of trade in UK.
Source: HMRC Overseas Trade Statistics.

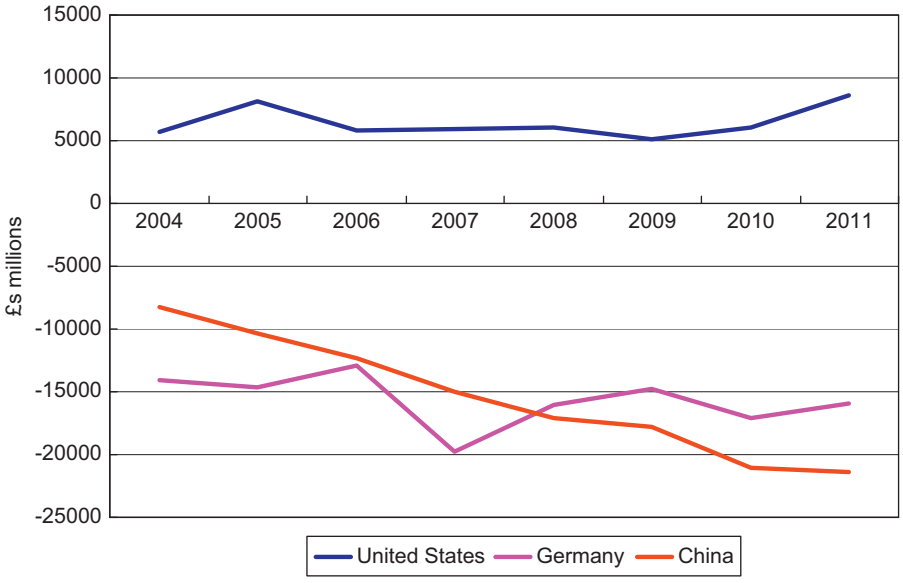

Fig. 9. Balance of trade for leading importers in UK.
Source: HMRC Overseas Trade Statistics.

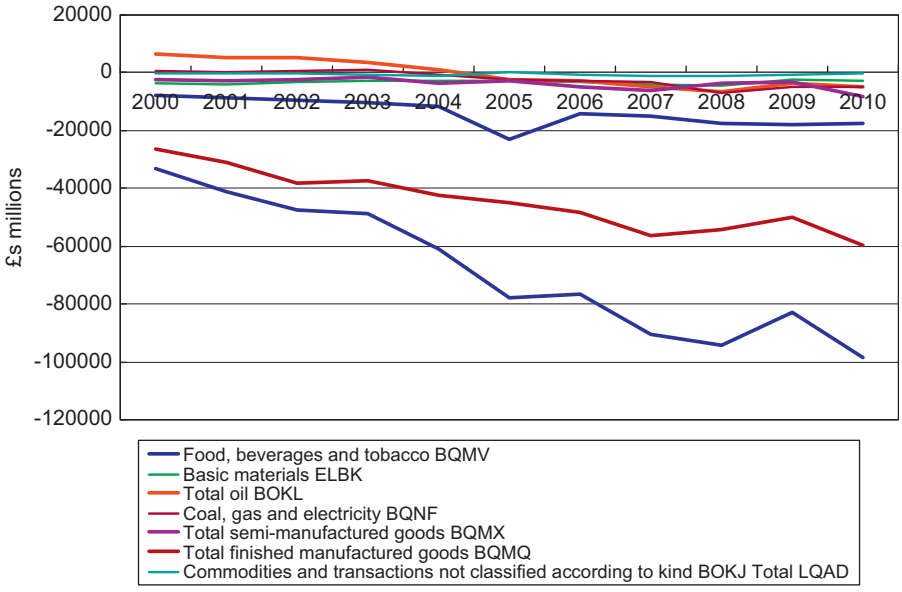

Fig. 10. Balance of trade by goods in UK.
Source: Office for National Statistics (2011).

consumption intensity, but a nation that has recently moved from a net exporter of energy to a net importer. There is an increasing balance of trade deficit, especially in the manufactured finished goods sector, and China is an increasingly important trade partner.

2. Methodology and data

2.1. Methodology

The input–output (IO) model, useful for analyzing the economic relationship of linkages among sectors of an economy, was developed by (Leontief, 1936). In the basic IO model, X which stands for the total output of an economy can be expressed as the sum of intermediate consumption (AX) and final consumption (Y) as follows:

$$AX+Y=X \tag{1}$$

where, A is the technical coefficient matrix, expressed as follows:

$$A=\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2j} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ a_{i1} & a_{i2} & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nj} & \dots & a_{nn} \end{bmatrix} \tag{2}$$

a_{ij} is the technical coefficient, which can be calculated using:

$$a_{ij}=\frac{x_{ij}}{X_j} \tag{3}$$

where, x_{ij} are the purchases by sector j of the goods produced by sector i, y_i are the sales from sector i to final demand, and X_j is the total output of sector j.

The solution of Eq. (1) can be expressed as follows:

$$X=(I-A)^{-1}Y \tag{4}$$

where, I is identity matrix, and the matrix $(I-A)^{-1}$ is called the Leontief inverse matrix (the key matrix).

Besides the technical coefficient a_{ij}, a complete consumption coefficient b_{ij} is also widely used in IO modeling. The parameter b_{ij} measures how much direct and indirect output from sector i will be used given each output increase in sector j. Matrix notation can be used as follows to give a reformulation of the relations:

$$B=\begin{bmatrix} b_{11} & b_{12} & \dots & b_{1j} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2j} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ b_{i1} & b_{i2} & \dots & b_{ij} & \dots & b_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ b_{n1} & b_{n2} & \dots & b_{nj} & \dots & b_{nn} \end{bmatrix} \tag{5}$$

where, B is the complete consumption coefficient matrix and can be calculated as follows:

$$B=(I-A)^{-1}-I. \tag{6}$$

2.1.1. Calculation of energy embodied in UK's exports

Suppose the UK exports a total of n kinds of commodities and has k export trading partners. Energy embodied in the UK's exports E, can be theoretically expressed as follows:

$$E=\sum_{i=1}^{k}\sum_{j=1}^{n}M_{ij}\times\gamma_j \tag{7}$$

where, M_{ij}, the data of customs statistics, is the value of commodity j exported by UK to country i; and γ_j is the embodied energy contained in a unit value of commodity j.

So, the calculation of the UK's embodied energy exports lies in the embodied energy contained in unit value of export commodities. The full life-cycle approach is the usual approach to calculating embodied energy (Chapman, 1974; Venkatarama-Reddy and Jagadish, 2003; Chen and Chen, 2006), but energy consumption in all areas of the production chain must be traced, meaning a laborious, subjective methodology. The input–output method is therefore an expedient and operable choice when investigating this aspect of energy consumption. The model to calculate E which is energy exports embodied in international trade is established as follows:

$$E=\frac{C}{Y+Y^I-Y^E}\sum_{j=1}^{n}M_j\times b_{ij} \tag{8}$$

where, C is UK's energy consumption; Y is the output of energy sector; Y^I is energy sector's imports from other countries; Y^E is the energy sector's exports to other countries. Y is monetary unit, $(C/Y+Y^I-Y^E)$ measuring the energy content of the energy sector's total output for domestic use. Due to the unit measurement of IO tables being monetary, the economic relationship between energy sectors and other sectors can be transferred into material connection via the $(C/Y+Y^I-Y^E)$ ratio. M_j is exports in sector j, b_{ij} is sector j's complete consumption coefficient from the energy sector (sector i).

2.1.2. Calculation of energy embodied in UK's imports

The calculation method for energy embodied in imports is more complicated. In theory, energy consumption coefficients of imported commodities from different countries should be calculated based on each country's input–output table respectively. However, UK has more than one hundred trade countries, and it would prove difficult to calculate energy consumption coefficients for each commodity according to the each countries' input–output tables.

For the sake of simplification, this paper adopts the method of "substitution effect" (Liu, 2007; Qi et al., 2008) with improvement. The "substitution effect" method refers to the calculation of embodied energy in UK's imports based on the complete energy consumption coefficients of the UK's industrial sectors because imported commodities avoid domestic energy consumption in the production process.

However, the implied basic assumption of the "substitution effect" is that the technical level of commodity processing in exporting countries is the same as the importing country. It therefore does not reflect the actual situation from a point of view of energy consumption. Usually there is a significant difference in energy consumption efficiency among countries at different levels of development. For commodities of equal value, energy consumption in developing countries is much higher than it is in developed countries. However, there are problems in obtaining the energy consumption efficiency differences for each commodity produced in the UK and that of its import trade partners. Limitations in the available data leaves measuring the differences of embodied energy in unit of UK's imported and exported commodities according to the ratio of the world average energy consumption intensity to UK's energy consumption intensity discussed in this paper. The UK is excluded when calculating the world average energy consumption intensity. The calculation results show that in 2011 the world average oil and gas consumption intensity except UK is 1.172t per 10000$, and it is 0.614 for coal. UK's energy consumption intensity is much lower compared with the world average, oil and gas, coal consumption intensities of UK are 60.1% and 22.6% of the world average level respectively.

The model to calculate UK's energy imports embodied in international trade I is established as follows:

$$I=\frac{C}{Y+Y^I-Y^E}\sum_{j=1}^{n}I_j\times b_{ij}\times\frac{Q_w}{Q_c} \tag{9}$$

where, $(C/Y+Y^I-Y^E)$ measures the energy contents of each output of energy sector for UK's domestic use; I_j is UK's imports in sector j; Q_W is the average energy consumption intensity in the world except UK; Q_C is UK's energy consumption intensity.

2.1.3. Calculation of net energy exports embodied in UK's international trade

Based on Eqs. (8) and (9), UK's net energy exports embodied in international trade E_{net} can be calculated as follows:

$$E_{net}=E-I=\frac{C}{Y+Y^I-Y^E}\sum_{j=1}^{n}\left(M_j\times b_{ij}-I_j\times b_{ij}\times\frac{Q_w}{Q_c}\right) \tag{10}$$

Eq. (10) can be revised further to calculate the net energy exports embodied in international trade from the UK to country A as follows:

$$E_A=\frac{C}{Y+Y^I-Y^E}\left\{\sum_{j=1}^{n}(b_{ij}\times w_j)\times\left(M_A-I_A\times\frac{Q_A}{Q_c}\right)\right\} \tag{11}$$

where, E_A is the net energy export embodied in international trade from UK to country A; w_j is the weight of sector j's output in national output; M_A is UK's exports to country A; I_A is UK's imports from country A.

Table 2
UK's fossil energy imports and exports embodied in international trade. (*Unit*: Million tones oil equivalent).

Year	Embodied coal imports	Embodied coal exports	Embodied oil and gas imports	Embodied oil and gas exports	Net embodied fossil energy imports
1997	15.4	6.5	28.6	21.9	15.6
1998	16.0	5.8	30.0	20.4	19.8
1999	16.6	5.2	31.6	21.0	22.0
2000	18.7	6.3	35.1	24.1	23.4
2001	19.8	6.9	37.4	24.7	25.5
2002	20.1	5.9	37.7	22.6	29.3
2003	19.9	5.6	35.3	20.4	29.1
2004	20.1	4.8	34.7	18.6	31.4
2005	21.7	5.1	36.3	19.5	33.5
2006	23.7	6.0	38.3	20.2	35.7
2007	21.9	4.8	34.6	17.1	34.6
2008	22.5	5.3	35.5	20.4	32.2
2009	20.8	5.1	32.4	22.1	26.0
2010	24.3	5.7	36.9	24.5	31.0
2011	26.3	6.4	39.9	27.3	32.5

Table 3
Reason analysis for UK's embodied fossil energy imports change.

Year	Change rate of embodied fossil energy imports (%)	Change rate of trade imports (%)	Change rate of fossil energy consumption intensity (%)
1998	4.5	3.0	1.5
1999	4.8	6.7	−1.7
2000	11.7	12.3	−0.7
2001	6.2	4.5	1.6
2002	1.2	2.6	−1.4
2003	−4.6	2.6	−7.3
2004	−0.8	6.2	−6.7
2005	6.1	11.2	−4.7
2006	6.6	12.3	−5.2
2007	−8.7	−0.7	−8.1
2008	2.5	10.9	−7.6
2009	−8.2	−8.8	0.6
2010	15.1	13.1	1.6
2011	8.1	8.3	−1.1

2.2. Data

The data used in this study are mainly based on the United Kingdom Input–Output Analytical Tables 2005 (Detailed Version) released by the UK Office for National Statistics on August 2011. The data from the Input–Output Analytical Tables are consistent with UK National Accounts (the Blue Book) 2009 and the UK Balance of Payments (the Pink Book) 2009.

To calculate and compare energy including oil, gas and coal consumption intensity in the same caliber, energy consumption and GDP data are taken from the (BP, 2011) and (World Bank, 2011) respectively.

3. Results

3.1. Trend of UK's embodied fossil energy imports and exports

The Office for National Statistics in the UK publishes Input–output supply and use tables every year. It also publishes Input–output (I–O) Analytical Tables, derived from the annual Input–output supply and use tables. The latest I–O Analytical Tables are from 2005 released in August 2011. According to Eqs. (8) and (9), UK's fossil energy imports and exports embodied in international trade can be calculated (Table 2).

It can be found from Table 2 that both the UK's coal and 'oil and gas' embodied fossil energy imports exceed embodied fossil energy exports in every year of the period covered. So the UK is a net embodied fossil energy importer. Table 2 also shows that the UK imports, by volume, more embodied 'oil and gas' than embodied coal, however, from the perspective of *net* imports, the UK imports more embodied coal than embodied 'oil & gas', because the UK's coal consumption intensity is much lower than the world average, and the gap of 'oil and gas' consumption intensity between the UK and the world is not as large (see above).

Table 3 shows the reason analysis for UK's embodied fossil energy imports change. It can be found from Table 3 that the reasons for UK's embodied fossil energy imports increase or decline can be divided into two parts. One is the amount of trade imports change, and the other is the fossil energy consumption

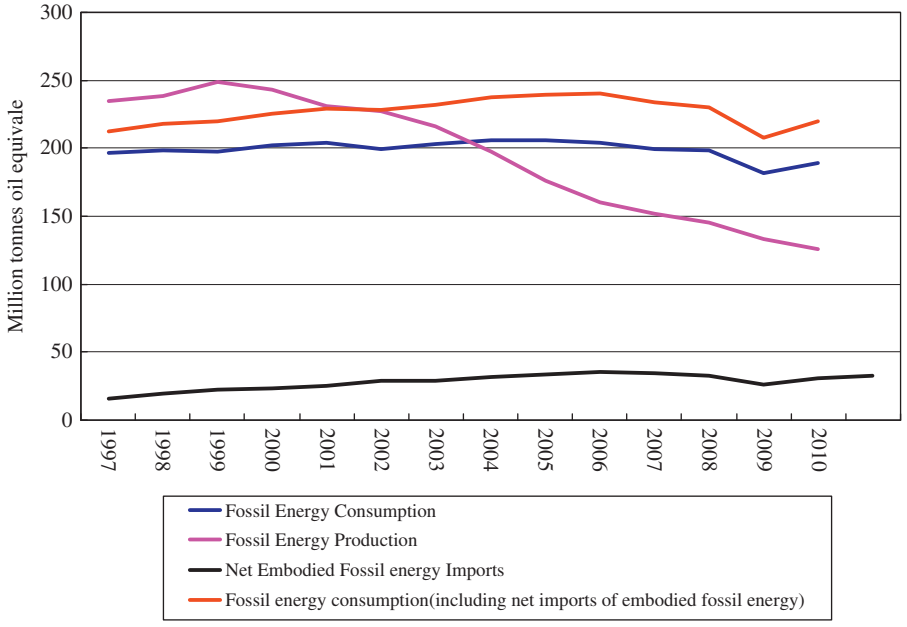

Fig. 11. UK's fossil energy consumption and production if considering net embodied fossil energy imports.

Table 4
Top 10 sectors in UK to import net embodied coal in 2011.

Rank	Sector	Net embodied coal imports (Thousand tones oil equivalent)	Percentage of net embodied coal imports (%)
1	Electricity production and distribution	5581	33.2
2	Structural clay products, cement, lime and plaster	1168	6.9
3	Iron and steel, non-ferrous metals, metal castings	738	4.4
4	Motor vehicles	652	3.9
5	Paper and paperboard products	623	3.7
6	Sugar	500	3.0
7	Coke ovens, refined petroleum and nuclear fuel	444	2.6
8	Construction	399	2.4
9	Gas distribution	388	2.3
10	Hotels, catering, pubs etc	357	2.1

Table 5
Top 10 sectors in UK to import net embodied oil and gas in 2011.

Rank	Sector	Net embodied oil and gas imports (Thousand tones)	Percentage of net embodied oil and gas imports (%)
1	Coke ovens, refined petroleum and nuclear fuel	7137	34.9
2	Electricity production aaaand distribution	4287	20.9
3	Gas distribution	1152	5.6
4	Hotels, catering, pubs etc	510	2.5
5	Iron and steel, non-ferrous metals, metal castings	496	2.4
6	Health and veterinary services non-market	486	2.4
7	Public administration and defence non-market	476	2.3
8	Air transport	435	2.1
9	Paper and paperboard products	424	2.1
10	Motor vehicles	391	1.9

Table 6
Top 10 sectors in UK to import net embodied fossil energy in 2011.

Rank	Sector	Net embodied fossil energy imports (Thousand tones oil equivalent)	Percentage of net embodied fossil energy imports (%)
1	Electricity production and distribution	9867	26.9
2	Coke ovens, refined petroleum and nuclear fuel	7580	20.7
3	Gas distribution	1541	4.2
4	Structural clay products, cement, lime and plaster	1244	3.4
5	Iron and steel, non-ferrous metals, metal castings	1234	3.4
6	Paper and paperboard products	1047	2.9
7	Motor vehicles	1043	2.8
8	Hotels, catering, pubs etc	867	2.4
9	Health and veterinary services non-market	767	2.1
10	Construction	740	2.0

Table 7
Top 10 sectors in UK to export net embodied fossil energy in 2011.

Rank	Sector	Net embodied fossil energy Exports (Thousand tones oil equivalent)	Percentage of net embodied fossil energy exports (%)
1	Water transport	472	14.9
2	Auxiliary financial services	379	12.0
3	Banking and finance	358	11.3
4	Other business services	253	8.0
5	General purpose machinery	179	5.6
6	Medical and precision instruments	170	5.4
7	Pharmaceuticals	169	5.3
8	Mechanical power equipment	139	4.4
9	Wearing apparel and fur products	102	3.2
10	Research and development	96	3.0

intensity change. In 2007, the rapid decline of fossil energy consumption intensity made the embodied fossil energy imports decline a lot. During the global economy crisis in 2009, the reason for embodied fossil energy imports decline changed to the rapid decline of trade imports.

Fig. 11 shows the gap between UK's fossil energy consumption and production. In the 21st century, the obvious gap between the UK's fossil energy consumption and production starts in 2004, if net embodied fossil energy imports are considered, this gap appears earlier, starting in 2002. It can also be easily found from Fig. 11 that the gap between fossil energy consumption and production in UK is much larger if net embodied fossil energy imports are considered.

3.2. Distributions of UK's embodied fossil energy imports and exports

The results from Table 2 are total fossil energy exports and imports embodied in UK's international trade. In order to analyze

the UK's net embodied fossil energy imports further, distributions including sector and country distributions can be analyzed (Tables 4–6).

There is a distinct difference between those sectors that are net importers of embodied fossil; energy, and those that are net exporters reflecting the economic structure of the UK. Tables 4–6 show the top 10 sectors in UK to import net embodied coal, 'oil and gas', and total embodied fossil energy respectively and it can be seen that most of the net importers of embodied fossil energy belong to the heavier industries. Table 7, in contrast, shows the top 10 sectors in UK to export net embodied fossil energy. From this it can be seen that the top net exporters of embodied fossil energy belong to light and tertiary industries.

Tables 8 and 9 show intensity of embodied fossil energy exporting and importing by top 10 sectors in UK in 2011. It can be easily found that the average intensity of embodied fossil energy importing is higher than that of embodied fossil energy exporting obviously.

Country distribution of UK's embodied fossil energy exports, imports and net imports are shown in Figs. 12–14, respectively as follows:

Fig. 14 shows that China accounts for 43% of UK's total net embodied fossil energy imports becoming the UK's biggest net importer since 2008 (Fig. 9). As a "world factory", China's foreign trade is trapped in a series of 'comparative advantages'. China's trade surplus is at the cost of exporting low-tech, low value-

Table 8
Intensity of embodied fossil energy exporting by sectors in UK in 2011.

Rank	Sector	Intensity of embodied fossil energy exporting (ton per 1000£)
1	Electricity production and distribution	1.9639
2	Gas distribution	1.9238
3	Structural clay products, cement, lime and plaster	1.5614
4	Sugar	0.5600
5	Fishing	0.4452
6	Coke ovens, refined petroleum and nuclear fuel	0.4255
7	Pulp, paper and paperboard	0.3517
8	Industrial gases and dyes	0.3183
9	Other land transport	0.2503
10	Metal ores extraction, other mining and quarrying	0.2498

Table 9
Intensity of embodied fossil energy importing by sectors in UK in 2011.

Rank	Sector	Intensity of embodied fossil energy importing (ton per 1000£)
1	Structural clay products, cement, lime and plaster	6.1867
2	Electricity production and distribution	5.5810
3	Gas distribution	4.4177
4	Sugar	2.0887
5	Pulp, paper and paperboard	1.0607
6	Industrial gases and dyes	0.9774
7	Fishing	0.9721
8	Coke ovens, refined petroleum and nuclear fuel	0.8703
9	Articles of concrete, stone etc	0.7263
10	Metal ores extraction, other mining and quarrying	0.6619

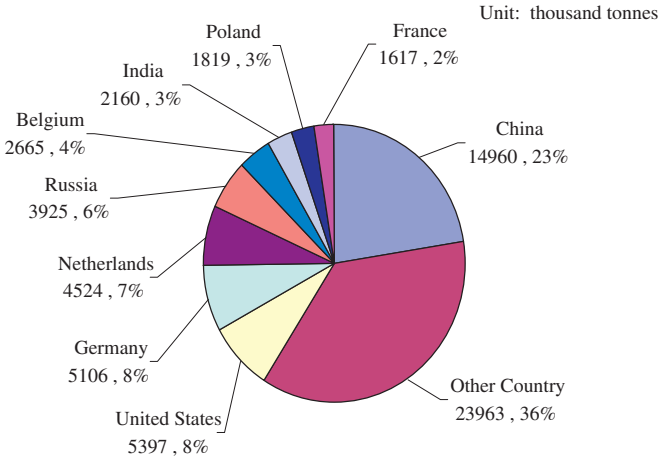

Fig. 13. Country distribution of UK's embodied fossil energy imports in 2011.

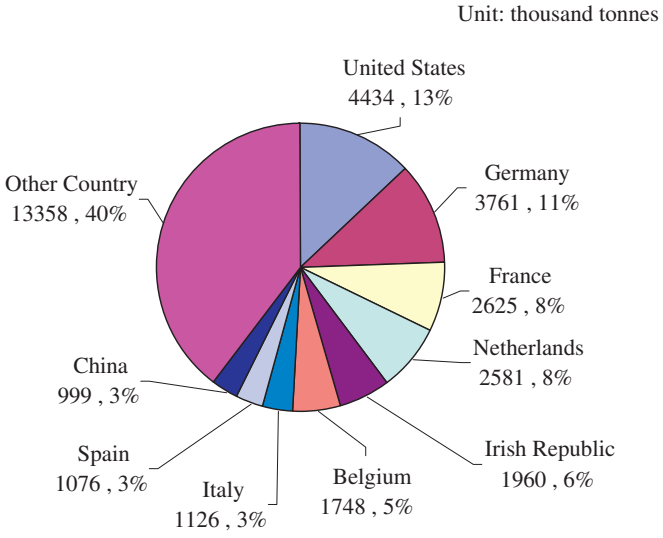

Fig. 12. Country distribution of UK's embodied fossil energy exports in 2011.

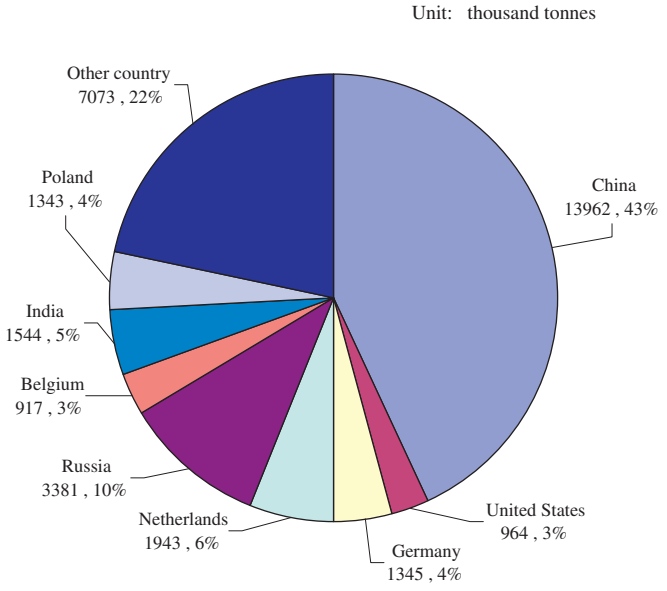

Fig. 14. Country distribution of UK's net embodied fossil energy imports in 2011.

Table 10
Intensity of embodied fossil energy exporting by countries in 2011.

Rank	Country	Intensity of embodied fossil energy exporting (ton per 1000£)
1	Russia	0.5403
2	China	0.4961
3	India	0.3680
4	Poland	0.2586
5	United States	0.1782
6	Canada	0.1738
7	Turkey	0.1738
8	Netherlands	0.1611
9	Hong Kong	0.1479
10	Belgium	0.1426
11	UK	0.1138
12	Spain	0.1052
13	Germany	0.1042
14	Italy	0.0985
15	Japan	0.0970
16	Irish Republic	0.0881
17	Denmark	0.0712
18	France	0.0700
19	Sweden	0.0512
20	Norway	0.0465

added products. At the same time, China also exports a lot of embodied resources, including fossil energy, reducing the economic development costs of other countries.

The UK also exports net fossil energy embodied in trade to other countries and regions. Those countries mainly belong to the EU, countries such as France, the Irish Republic, Switzerland and Sweden. The net embodied fossil energy from UK to those countries are 1007, 819, 339 and 317 thousand tonnes of oil equivalent respectively.

Table 10 shows intensity of embodied fossil energy exporting by countries in 2011. Russia, China and India rank top three in UK's trade partners.

4. Conclusion and discussions

4.1. Conclusion

Brown et al. (2010) and Warr and Ayres (2010) showed that economic growth and the quantity/quality of energy consumption are linked. Consequently, the UK economy cannot grow without continued support from the required energy inputs. The model established in this paper aims to analyze the interdependence of different types of energy imports, those indirect energy imports embodied in globally traded goods. The basic conclusions obtained from the analysis are as follows.

There is an inverse relationship between the UK's balance of trade, and the UK's net embodied fossil energy imports, so as the balance of trade worsens, the UK imports increasing amounts of embodied fossil energy through international trade. The UK's embodied fossil energy imports have exceed embodied fossil energy exports every year since at least 1997, leaving the UK a net embodied fossil energy importer.

Energy security as a nationally bounded imperative is questionable at the very least in the light of these findings. If net embodied fossil energy imports are considered, the gap between fossil energy consumption and production in the UK is larger than commonly believed, and so the problem of energy security is greater than generally accepted. The size of the problem is not the main consideration though, as much as the scope of the potential problem; that is to say, the increase in the gap between consumed and produced (one traditional measure of energy security), although significant is not substantial. The interesting point is that direct energy imports are not the only point of vulnerability, but indirect energy imports through the energy embodied in traded goods is shown here to be another variable that should be considered in the complex equation of energy security.

If we examine those UK domestic industries most impacted by embodied energy imports, the picture of increased energy vulnerability becomes starker. The top three sectors all relate to what could be broadly termed the energy sector. Not only is this sector vulnerable from the standpoint of the necessary direct energy inputs required, but there appears to be an additional vulnerability based upon the energy embodied in the goods imported for the functioning of this sector. The next 4 sectors in this list all relate to the production of key material goods for the UK economy. Although there is a service sector bias in the economy, there is still an important element of manufacturing, and embodied energy vulnerabilities may prove as much a concern as direct energy imports to this area of the UK economy. From the perspective of net embodied fossil energy imports, the UK needs to reconsider its energy utilization, efficiency and consumption in the light of global trade, and hence the UK should reconsider its approach to energy security policy.

To extend this analysis further, beyond the purely national perspective to the global distribution of net embodied fossil energy imports, the UK is most dependent on the 'Made in China' phenomena. 'Made in China' accounts for 43% of the total net fossil energy imports. As 'factory to the world', China has become the biggest net embodied energy importer to the UK since 2008. Energy security then is both a major focus for the global economy, but is also of considerable interest at the level of international political relations.

4.2. Discussions

Over the last decade the consumption of direct fossil energy in the UK economy has remained stable (not increasing with economic growth). However, this phenomena cannot be simply ascribed to success in the arena of energy conservation and the increasingly efficient use of energy in the UK, but must take into account the export of energy use in the UK economy to other economies through the mechanism of global trade, and furthermore, must take into account which countries play a key role in the UK's continued energy security beyond those states that supply the more obvious direct energy inputs. If China (or any other trade partner) cannot provide energy security for themselves, can the UK really have energy security without disconnecting from the global economy? This displacement of energy consumption through international trade also raises questions about the applicability of Kuznets curve, but this requires more in depth study than detailed here.

The UK has seen an increasing dependency on imported fossil energy since it became a net energy importer in 2004 and a constant increase in global energy demand has seen energy security develop as one of the 'grand challenges' facing the UK drawing scrutiny of the UK government. As the UK's trade deficit and recessionary pressures grow, the UK looks to access the markets of developing countries such as China, India and Brazil in order to address these issues through the expansion of exports. Although this may promote the UK's economic recovery, one point cannot be ignored: The UK's net embodied fossil energy balance of trade will probably increase, but this will not mean that there is an increase in energy security, in fact increasing interdependence within the global economic infrastructure will make energy security less achievable, even less desirable if the environment for energy security proves, as is likely, to be highly competitive.

There are a number of areas for continued investigation to help develop a more complete picture of the impact of embodied energy on the UK economy. They include better identification of a country by country impact of imports on each of the identified industry sectors. Better estimation of embodied energy on a country by country basis for imported goods into the UK. A full lifecycle case study of a specific industry would prove a useful tool to validate the data from this approach. The model developed would also prove useful when analyzing the total carbon footprint of UK consumption patterns, and beyond that the resource footprint of the UK. These national footprints may prove useful when developing global responses to resource consumption. This is not necessarily as a Malthusian response to resource depletion, but part of an adaptive perspective to changes in resource use patterns.

The research results presented here show that the UK is a net embodied fossil energy importer. The amount of net embodied fossil energy imported is smaller than direct energy imports, but still significant, and plays an important role in key UK industries. Therefore the notion of a bounded energy security - a national imperative - is, at best, flawed, and national discussions of energy security must take into account global trade and the interdependence of the UK with the many nation states that comprise the world economy.

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