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Outsourcing or efficiency? Investigating the decline in final energy consumption in the UK productive sectors

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Abstract

Over the past two decades reductions in the final energy consumption of the productive sectors (industry, public administration, commercial services and agriculture), have made important contributions to overall reductions in UK final energy consumption. This study investigates the drivers of the reductions in final energy consumption in the UK productive sectors between 1997 and 2013 using a decomposition analysis that incorporates two novel approaches. Firstly, it uses results from a multi-regional input-output model to investigate how much of the structural change in the economy has been driven by outsourcing production overseas. Secondly, it utilises energy conversion chain analysis to determine how much increases in the conversion efficiency from final energy to useful exergy have contributed to improvements in final energy intensity. In aggregate all energy savings from structural change are attributed to outsourcing. Improvements in the conversion efficiency produced savings of a similar size. However energy savings from both factors have stalled since 2009. Improvements in useful exergy intensity, the useful exergy used per unit of monetary output, provided the biggest share of energy savings, but these savings are concentrated in a few sectors and rarely lead to absolute reductions in final energy use. All of this suggests that a return to the rates of energy reduction seen between 2001 and 2009 should not be taken for granted and that active policy interventions might be required to achieve further reductions.

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Keywords: Energy demand; Decomposition; UK; Exergy; Multiregional input-output databases; Outsourcing;

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1. Introduction

Reducing final energy consumption is an important part of the UK and EU strategies to reduce carbon emissions [1,2]. UK final energy consumption has been in decline since 2004, being 7% below the 2004-level in 2013. This trend is even stronger when energy consumption is corrected for temperature [3]. This study focuses on final energy consumption in the 'productive' sectors (sectors producing economic output) and excludes energy consumption for transport and domestic purposes. Reduced consumption of final energy in the productive sectors accounts for about half the change in overall UK final energy consumption since 2004. While progress in these sectors is encouraging, further reductions are needed to meet climate change targets. To assess the need for further policy interventions it is important to consider what has been driving the reduction in energy consumption of the productive sectors and whether the trends are likely to continue into the future. This study contributes to answering these questions by providing a novel decomposition analysis of UK final energy consumption in the productive sectors between 1997 and 2013.

Currently, there is no comprehensive analysis of the drivers that have influenced UK final energy consumption in the UK over the past two decades. Hammond & Norman [4] decompose trends in CO_2 emissions in the UK but focus exclusively on the manufacturing sector between 1990 and 2006. Reports from the ODYSEE-MURE project present detailed analyses of the ODEX efficiency indicator but do not investigate drivers of structural change [5].

Decomposition analysis is a widely-used tool to identify the drivers of change in energy use and carbon emissions [6]. Commonly energy consumption is decomposed according to three factors, namely energy intensity, economic structure and aggregate economic output [7]. However, this leaves unanswered important questions about the drivers of changes in energy intensity and economic structure. The current study presents a novel and important contribution to our understanding of UK energy consumption because it provides the first comprehensive analysis of energy use in the productive sectors in the UK. It also incorporates two novel approaches into the decomposition analysis that allow additional insights into the underlying drivers of changes in economic structure and sectoral energy intensity. Firstly, it employs data from a multi-regional input-output model to further break down the structural change effect to identify how much it has been driven by outsourcing of energy-intensive production to other countries. Secondly, it draws on energy conversion chain analysis (ECC) [8] that allows the estimation of the conversion efficiencies from final energy to useful exergy to further break down changes in final energy intensity. While ECC analysis has been applied to energy consumption at a national level [9,10] this is the first study to study energy consumption at the sector level.

2. Method

This study employs the Logarithmic Mean Divisia Index (LMDI), which has been identified as one of the most suitable methods for energy decomposition [6,11]. The subject of this study is the decomposition of the total final energy consumption in the productive sectors of the UK (E). For this purpose E is expressed as a product of 6 factors:

$$E = \sum_i CE_i\, EI_i\, OS_i\, CN_i\, DM\, P = \sum_i \frac{E_i}{UE_i} \frac{UE_i}{X_i} \frac{X_i}{XG_i} \frac{XG_i}{Y} \frac{Y}{P} P$$

The subscript *i* denotes the subsectors used in the analysis. Explanation of the factors are provided in table 1. The overall difference in energy consumption (ΔE) over a time period is allocated to the factors using the additive LMDI I formula provided in [6]. For each factor this provides an estimate of how much final energy consumption would have changed if all other factors had stayed the same. This estimated change will be referred to as the "energy savings" associated with a specific factor, if the change in energy consumption is negative. A chained decomposition method is used so that the change of energy consumption is always decomposed for two consecutive years.

This study focuses on final energy consumption in the productive sectors, excluding energy use for transport or domestic purposes. The productive sectors are disaggregated into fifteen categories, including twelve industrial and three non-industrial sectors (Table 2). Data describing the final energy consumption in the sectors was obtained from *Energy Consumption in the UK* [3]. The monetary output of sectors in constant prices was obtained by applying the double deflation method to the UK multi-regional input-output (UKMRIO) model [12]. In this study the term 'output' always refers to the monetary measure of output as it is conventionally used in input-output analysis. This means that output is measured as the total volume of sales, rather than value added.

Table 1: Description of decomposition factors used in the analysis

Decomposition factor		Description
Conversion efficiency	CE_i	Final energy used in each UK sector (E_i) divided by the useful exergy obtained from it (UE_i)
Exergy intensity	EI_i	Useful exergy used in each UK sector (UE_i) divided by monetary output of the sector (X_i)
Outsourcing	OS_i	Monetary output of each UK sector (X_i) divided by the monetary output of the global sector that is needed for producing UK final demand (XG_i)
Changed need	CN_i	Monetary output of the global sector needed for producing UK final demand (XG_i) divided by the total amount of UK final demand (Y)
Demand per person	DM	Total amount of UK final demand (Y) divided by UK population (P)
Population	P	UK population (P)

Of the six decomposition factors the first two factors subdivide the commonly used factor of final energy intensity (final energy per sector output) into two separate factors. The first factor describes the conversion efficiency with which final energy is transformed into useful exergy as obtained from ECC analysis. ECC analysis tracks the energy use at each stage of the conversion chain from primary to final to useful energy. At each stage energy consumption can be described either in conventional energy terms or in terms of exergy, which captures the ability of the energy to deliver physical work before reaching equilibrium with the environment [13]. Useful exergy describes the useful work that is delivered at the last stage that can still be measured in energy units, for example in terms of useful heat, mechanical drive or light. Useful exergy can therefore be considered to be most closely related to the energy services delivered [13]. To decompose final energy consumption this analysis employs a conversion efficiency calculated as final energy per unit of useful exergy. This factor is useful because it presents a physical measure of energy efficiency that can be consistently applied across all the sectors used in the analysis. For brevity it will hereafter be referred to as 'conversion efficiency'. The second factor, useful exergy intensity (hereafter exergy intensity), captures the changes in the monetary output that is produced for each unit of useful exergy. This factor is influenced by several variables. These include changes in the physical efficiency of the production process that are not captured by the conversion efficiency factor, but also changes in the monetary value of production, imperfect deflation and structural change within sectors. Data on the energy and exergy conversion efficiencies for each sector were produced by the authors, following the methodology in [8,10].

The third and fourth decomposition factors allow further examination of the drivers of structural change. They utilize data from the UKMRIO model [12]. Using standard methods for input-output analysis the model provides a time series of the global output from each sector that is embodied in the goods and services supplied for UK final demand. The factors of 'outsourcing' and 'changed need' determine whether structural changes in the UK have been matched in the supply-chains of UK final demand (Table 2). For example, the factors determine whether a shrinking steel sector in the UK is matched by a shrinking amount of steel sector output needed globally to satisfy UK final demand. If the structural change in the UK is not matched by changes in the global supply chains of UK demand it is considered to constitute a type of outsourcing. In contrast, if the structural change in the UK is a reflection of broader changes to the structure of global output needed for UK final demand, it can be considered a case of 'changed need'.

The fifth and sixth decomposition factors describe the effect of overall economic activity on final energy consumption. To be consistent with the treatment of structural change described above, the total final demand for goods and services in the UK is used as a measure of overall economic activity, rather than total output. It is split up into demand per capita and population (Table 1).

Table 2: Sector split used in decomposition analysis, corresponds to sectors reported in *Energy Consumption in the UK* [3].

Sector category	Sector name
Industrial Sectors	Iron & Steel; Non-ferrous metals; Mineral products; Chemicals; Mechanical engineering and metal products; Electrical and instrument engineering; Vehicles; Food, beverages & tobacco; Textiles, clothing, leather & footwear; Paper, printing & publishing; Construction; Other industries (includes unclassified industrial energy use)
Non-industrial sectors	Public administration; Commercial services; Agriculture, Forestry, Fishing

3. Results and Discussion

3.1. Industrial and non-industrial sectors show distinctly different patterns

The reductions in final energy consumption in the productive sectors were mostly achieved between 2001 and 2009 (Fig 1a). However, this pattern is produced by a combination of very different trends in the industrial and non-industrial sectors. All the reductions in energy consumptions have been achieved in the industrial sectors. Output in the industrial sectors grew very little over the entire time period as increases in per capita demand and population were largely cancelled out by outsourcing and changed need. Hence improvements in conversion efficiency and exergy intensity have led to absolute reductions in final energy consumption (Fig 1b). In contrast the non-industrial sectors show a largely constant level of energy use over the whole time period (Fig 1c). Savings from improvements in the conversion efficiency and exergy intensity are cancelled out by increased output driven by increases from demand, population and changed need. The different trends in final energy consumption have led to a convergence of energy use in industrial and non-industrial sectors. While non-industrial energy use was only 62 % of industrial energy use in 1997 this figure had risen to 87% by 2013.

3.2. The structural change effect is dominated by outsourcing

Overall the savings allocated to improved final energy intensity, which includes the conversion efficiency and exergy intensity factors, are considerably larger than the energy savings from structural change, which includes the outsourcing and changed need effects (Fig. 1a). This result is largely in line with those from other studies [4,7]. However, in aggregate almost all savings from structural change can be contributed to outsourcing. This makes outsourcing a significant factor producing energy savings of a similar size to those from the improvements in conversion efficiency. The savings from outsourcing are all realized in the industrial sectors (Fig 1b) with no savings from outsourcing in the non-industrial sectors (Fig. 1c). The lack of energy savings from changed need is produced by reductions in the industrial sectors being cancelled out by increases in the non-industrial sectors.

Most notably energy savings from outsourcing in industrial sectors largely occurred before 2010 and the trend has even slightly reversed after 2010. This trend should be welcomed as it indicates that the UK is not outsourcing any more of its responsibility for the energy and emissions associated with its demand. However, while the level of outsourcing is no longer increasing, it is still high as outsourcing in the past has not been reversed. The recent announcement of an industrial strategy indicates that the UK government wants to pursue an active strategy for

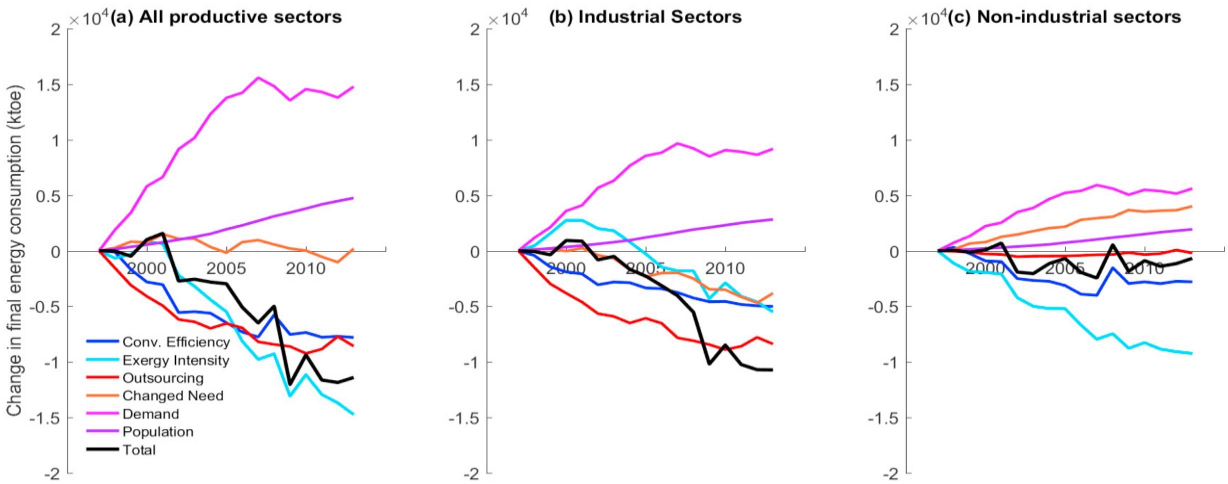

Figure 1: Results of the decomposition analysis for (a) all productive sectors, (b) the industrial sectors subset and (c) the non-industrial sectors subset. The black line shows the total change in final energy consumption for each year compared to 1997. Coloured lines show the allocation of the change to the different decomposition factors.

strengthening the industrial sectors in the UK [14]. This suggests that further energy savings from outsourcing are both undesirable and unlikely.

3.3. Energy savings from improved conversion efficiency are levelling off

The conversion efficiency factor has made a significant contribution to the reductions in final energy consumption in the productive sectors, although the contribution is significantly smaller than the one from exergy intensity improvements (Fig 1a). About two thirds of the overall savings attributed to conversion efficiency improvements can be attributed to the industrial sectors (Fig. 1b), with conversion efficiency improvements playing only a minor role in the non-industrial sectors (Fig 1c).

Similar to the outsourcing effect the rate of energy savings from improved conversion efficiency is clearly slowing down, with no further energy savings after 2007. This effect of levelling off is evident for both the industrial and non-industrial sectors, even though it is more pronounced for the non-industrial sector. This raises questions about how trends in the conversion efficiency will continue into the future. Brockway et al. [10] suggest that the reduction in the rate of UK primary-to-final exergy efficiency improvements could either be a sign that the UK is reaching the physical potential of exergy efficiency or it could be related to the outsourcing of exergy-efficient but energy-intensive activities to other countries. While using a slightly different measure for the conversion efficiency this study presents some support for the latter hypothesis, as it shows a very close relationship between the aggregate trends in conversion efficiency and outsourcing (Fig 1a).

3.4. Exergy intensity is the only factor reducing energy use over the past years

Overall improvements in the exergy intensity of production have contributed most to the reduction in final energy consumption in the productive sectors (Fig. 1a). It is the only factor that has acted to reduce energy use after 2010, keeping final energy consumption stable despite growing demand and population. In contrast to the other factors the majority of energy savings are realized in the non-industrial sectors. Improvements in exergy intensity constitute by far the biggest drivers to reduce energy consumption in the non-industrial sectors (Fig 1c). In the industrial sectors the effect of exergy intensity is less important (Fig. 1b). It is also characterized by very different trends in the different sub-sectors. Over the whole time period the reductions in energy use allocated to exergy intensity improvements are dominated by only two sectors, namely the steel sector (before 2001) and the chemicals sector (2001-2009). Of the overall savings of 5501 *ktoe* assigned to exergy intensity in the industrial sectors these two sectors contribute a reduction of 4261 *ktoe*. However, after 2009 exergy intensities in these sectors have been stagnant with smaller amounts of energy savings from exergy intensity improvements contributed by other sectors, such as ‘other industries’.

The factor of exergy intensity combines a range of different effects and the results are therefore not straightforward to interpret. Due to data limitations the disaggregation of sectors in this study is very coarse, hence the exergy intensity effect could be influenced by structural changes within the sectors studied here [15]. Given the large savings attributed to exergy intensity in the chemicals sector, it might be particularly interesting to further investigate this sector, as it consists of a very heterogeneous group of sub-sectors. The exergy intensity factor could also be influenced by improvements in the physical efficiency of the production process not captured in the conversion efficiency factor, for example if process improvements allow more cars being built using the same amount of useful exergy. In addition changes in the monetary value of output or imperfect inflation can impact the value of exergy intensity.

Overall the findings indicate that improvements in the exergy intensity (useful exergy per output) are largely driven by increases in output rather than reductions in the use of useful exergy. Hence the improvements rarely lead to absolute reductions in energy consumption but contribute to keeping final energy use stable. This is particularly evident in the non-industrial sectors. This poses the question whether improvements in exergy intensity alone will be able to deliver the reductions in energy consumption that are needed, given that contributions from outsourcing and improved conversion efficiency are currently stalling.

4. Conclusion

This study has presented two novel features in a decomposition analysis of final energy consumption in the UK productive sectors. These features have allowed the analysis go beyond the commonly used factors of energy intensity and structural change. The results suggest that a return to the rates of reduction of final energy consumption seen between 2001 and 2009 should not be taken for granted. Hence there is a need for more active policy interventions to secure further reductions in final energy consumption in the productive sectors. This study highlights different angles from which to address the issue. While further outsourcing should not be considered a preferred option (as it is unlikely to be consistent with reducing global carbon emissions), it could be worth investigating how conversion efficiencies can be further improved in different sectors. While a change in the global production structure of UK consumption and investment has not led to reductions in energy consumption in the UK so far, this would open another range of opportunities to target and reduce energy-intensive consumption. Finally there is a need for more research and a better understanding of the drivers behind improvements in exergy intensity and how they can be harnessed to produce absolute reductions in energy demand.

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References

[1] DECC, The Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK, Dep. Energy Clim. Chang. (2012).

[2] European Commision, A policy framework for climate and energy in the period from 2020 to 2030, Commun. FROM Comm. TO Eur. Parliam. Counc. Eur. Econ. Soc. Comm. Comm. Reg. (2014). doi:10.1007/s13398-014-0173-7.2.

[3] BEIS, Energy Consumption in the UK, Dep. Bussiness Energy Ind. Strat. (2016). www.gov.uk/beis.

[4] G.P. Hammond, J.B. Norman, Decomposition analysis of energy-related carbon emissions from UK manufacturing, Energy. 41 (2012) 220–227. doi:10.1016/j.energy.2011.06.035.

[5] Ricardo Energy & Environment, Energy Efficiency Trends and Policies in the United Kingdom, 2015.

[6] B.W. Ang, Decomposition analysis for policymaking in energy: Which is the preferred method?, Energy Policy. 32 (2004) 1131–1139. doi:10.1016/S0301-4215(03)00076-4.

[7] N. Liu, B.W. Ang, Factors shaping aggregate energy intensity trend for industry: Energy intensity versus product mix, Energy Econ. 29 (2007) 609–635. doi:10.1016/j.eneco.2006.12.004.

[8] M.K. Heun, Energy conversion chain (ECC) analysis: A proposed unifying physical supply-use table framework, Present. to Eng. Dep. Semin. Ser. Calvin Coll. Gd. Rapids, MI, USA. April (2017).

[9] R. Ayres, L.W. Ayres, B. Warr, Exergy, power and work in the US economy, 1900 - 1998, Energy. 28 (2003) 219–273. doi:10.1016/S0360-5442(02)00089-0.

[10] P.E. Brockway, J.R. Barrett, T.J. Foxon, J.K. Steinberger, Divergence of trends in US and UK Aggregate Exergy Efficiencies 1960-2010, Environ. Sci. Technol. 48 (2014) 9874–9881. doi:http://dx.doi.org/10.1021/es501217t.

[11] R. Hoekstra, J.C.J.M. van den Bergh, Comparing structural and index decomposition analysis, Energy Econ. 25 (2003) 39–64. doi:10.1016/S0140-9883(02)00059-2.

[12] T. Wiedmann, J. Barrett, Policy-Relevant Applications of Environmentally Extended Mrio Databases – Experiences From the Uk, Econ. Syst. Res. 25 (2013) 143–156. doi:10.1080/09535314.2012.761596.

[13] T. Sousa, P.E. Brockway, J.M. Cullen, S.T. Henriques, J. Miller, A.C. Serrenho, T. Domingos, The Need for Robust, Consistent Methods in Societal Exergy Accounting, Ecol. Econ. 141 (2017) 11–21. doi:10.1016/j.ecolecon.2017.05.020.

[14] UK Government, Building our Industrial Strategy, Green Pap. (2017).

[15] C.L. Weber, Measuring structural change and energy use: Decomposition of the US economy from 1997 to 2002, Energy Policy. 37 (2009) 1561–1570. doi:10.1016/j.enpol.2008.12.027.