EU energy trends and macroeconomic performance

Case study – Energy Resilience and Vulnerability in the EU and Other Global Regions

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Executive Summary

This case study examines the resilience of the EU economy to energy supply shocks and provides comparisons with six other global regions: Brazil, China, India, Japan, Russia and the US.

We begin by reviewing trends in the EU and other global regions in key indicators that measure aspects of resilience to energy supply shocks: energy intensity; dependence on energy imports; the share of production costs in energy-intensive sectors; the export performance of energy-intensive sectors; and shares of fuel expenditures in total household consumption. Since indicators based on the cost share of energy do not shed light on the extent to which energy is an essential (rather than, say, large) input to production, we proceed to present the results of new econometric analysis carried out for this study of the degree of *substitutability* between energy and other production factors across EU sectors.

Findings

The key findings are as follows:

- The macroeconomic impact of energy price shocks depends on the extent to which an economy is a net energy importer and the scale of this in relation to the size of the economy. These depend in turn on the availability of domestic energy sources (which, in the EU, mostly means renewable sources) and on the energy intensity of the economy.
- Energy intensity is falling in the major global regions, and falling more rapidly in the countries with the highest intensity (Russia and China). This is partly due to structural changes (a smaller share in the economy of the most energy-intensive activities), and partly due to greater energy efficiency within each sector. In the EU, energy efficiency improvements accounted for just over half of the reduction over the 15 years from 1995, a similar performance to that found for the US. In China, very substantial improvements in energy efficiency occurred in this period; in Russia, structural changes (a reduction in the importance of the most energy-intensive industries) were the most important factor.
- The most energy-intensive sectors are in mineral extraction, the process industries in manufacturing (for example, metals, chemicals and paper), and transport. In the manufacturing sectors that are most energy-intensive, in the first half of the 2000s the share of energy in input costs was relatively low in the EU28 and similar in magnitude to the same sectors in the US; but since 2009 (as shale gas has been developed in the US) a gap compared with the US has opened up. Japan also saw a marked upward trend in the share of energy costs since 2009; in the other countries reviewed here the shares were broadly unchanged over 2009-14. This is also the period during which the export performance of the EU's energy-intensive manufacturing industries was relatively weak: the decline in the EU's share of world trade in energy-intensive products was more pronounced than those for the US and Japan (despite the increase in energy costs in the latter).
- Of the countries studied here[1], Japan has by far the highest energy import dependence (over 90% in 2014) followed by the EU (53%). The EU's sources of imports are geographically concentrated: some 32% of energy imports were sourced from Russia in 2014.

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[1] Brazil, China, the EU, India, Japan, Russia and the US.

- High energy import dependence in the EU leaves energy-intensive sectors particularly vulnerable to energy supply shocks. Europe's energy-intensive sectors are increasingly more reliant on imports than other sectors, reflecting the EU's increasing energy import dependence and the reliance of these sectors on oil and gas.
- On the other hand, energy-intensive industry plays a smaller role in the EU economy than it did 20 years ago. Restructuring away from energy-intensive activity has made EU production less exposed directly[2] to energy supply shocks, even while exposure has increased in the energy-intensive sectors.
- Lower income households spend proportionately more on fuel, and so are more exposed to energy price shocks. On average, across the EU in 2014, fuel accounted for 8.6% of total expenditure for households in the lowest income quintile and just 4.3% for those in the highest income quintile. Likewise, households in poorer countries (with a cold winter) tend to spend proportionately more on fuel.
- The share of household spending on energy tends to rise and fall in response to global energy prices: these prices are more volatile than most consumer prices. In almost all EU countries, the share spent on energy fell over 2010-15, largely driven by a sharp fall in oil prices in 2015.
- High energy import dependence might be less of a concern if there was significant scope for producers to adapt quickly to higher energy prices or supply shortages. However, our estimates suggest very weak substitutability between energy and capital-labour production factors. In other words, as the relative price of energy increases, only limited opportunities exist in most sectors to replace energy inputs with other production factors (capital or labour). This holds true for the majority of EU sectors, and it does not appear to have changed much over time. Similarly, the fact that the share of household spending moves in the same direction as the price of energy shows that household energy spending is quite price inelastic, indicating limited opportunities to curb energy use in the short term. Both of these results point to the need to develop indigenous renewable energy sources (both large and small-scale) and to improve energy efficiency in both business and households so as to curb exposure to global energy price shocks and supply dependence.

Data sources

- The main data sources used, and their limitations, are as follows. The WIOD database[3] is used for the analysis at the sector/product level. The 2016 release is used for the analysis of sector energy costs by sector. The main limitation of the 2016 data is that, at the time of writing, they do not include energy use data in physical units. Hence, for the analysis of energy-intensity by sector we used the WIOD 2013 release. Using the older WIOD release limits us to coverage of the years 1995-2009 for the analysis of sector-level energy intensity, but these are the only data available at the required level of detail and consistency across countries.
- For the analysis of energy intensity and energy import dependence at the country level, the World Bank development indicators database[4] is used. The advantage of this database is that it allows analysis of energy intensity

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[2] There remains indirect dependence on the energy embodied in energy-intensive products.

[3] http://www.wiod.org/home.

[4] http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators.

in more recent years, covering years up to 2014 for some countries. For the energy import dependence analysis, data from the Eurostat simplified energy balances[5] are used to cover an extra year of data for the EU28. Comtrade data[6] are used for the analysis of energy imports by source, as these provide detailed coverage of countries and products. Lastly, the analysis of household expenditure of fuel uses data from the Household Budget Surveys[7] and national accounts[8]. These data cover recent years up to 2014/15, but do not cover the global regions other than the EU28, and are missing data for several Member States.

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[5] http://ec.europa.eu/eurostat/web/energy/data/database.
[6] https://comtrade.un.org/data/.
[7] http://ec.europa.eu/eurostat/web/household-budget-surveys/database
[8] http://ec.europa.eu/eurostat/web/national-accounts/data/database

Part I. Introduction

This case study examines the resilience of the EU economy to energy supply shocks, and provides comparisons with six other global regions: Brazil, China, India, Japan, Russia and the US.

The structure of the study is as follows. Part II presents trends in energy intensity in and import dependence in the global regions and EU sectors. Part III considers trends in the share of production costs in energy-intensive sectors and the trends in those sectors' exports, output and employment. Part IV looks at the the shares of fuel expenditures in total household consumption to show the exposure of households to price changes. Part V presents an econometric analysis of the degree of substitutability between energy and other production factors across sectors in twelve Member States[9], to examine the extent to which business can readily respond to energy price changes by cutting back on energy use in the short term.

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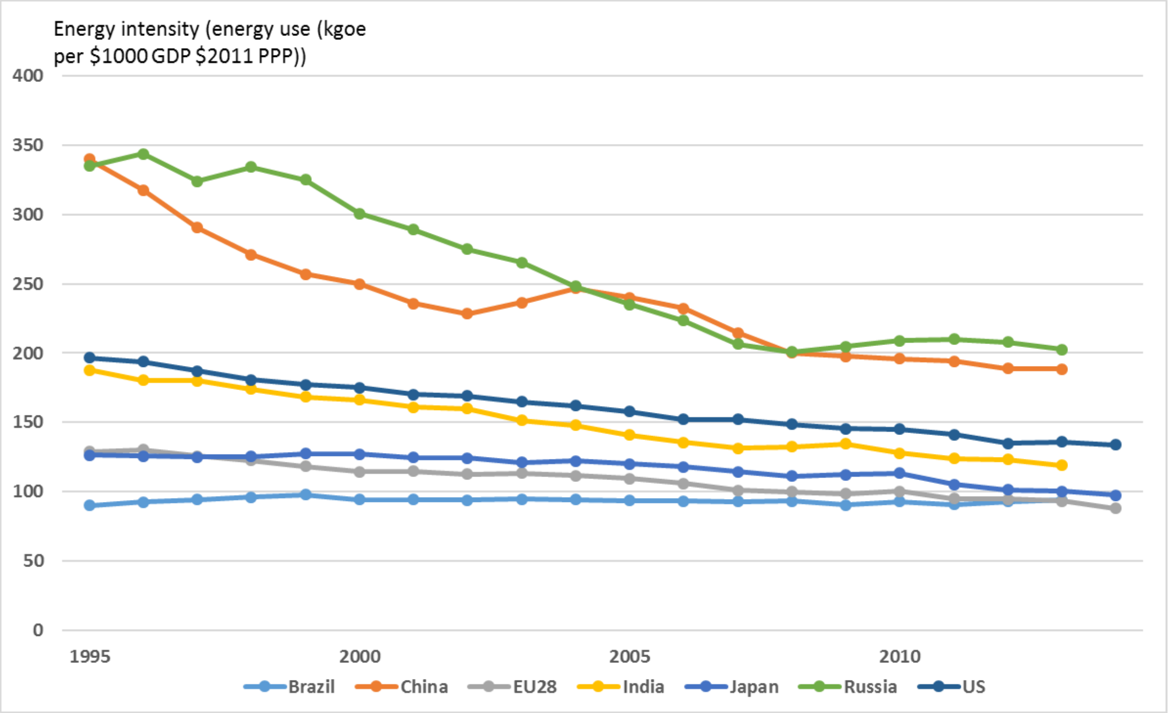
[9] Twelve Member States were chosen to provide a manageable number for analysis. The twelve were selected so as to provide contrasts in terms of level of economic development, structural composition of sectoral value added, and variations in the scale of energy consumption.

Part II. Energy intensity and import dependence in the EU and global regions

Energy intensity is falling in the major global regions

Figure II.1 shows trends in the energy intensity of the EU28 and six other world regions over 1995 - 2014. Clearly, energy intensity in the EU is relatively low compared to other major economies, and after Brazil it is the lowest of all the world regions in this analysis.

Figure II.1: Energy intensity in the EU28 and other global regions, 1995-2014



Source: World Bank World Development Indicators.

Note: Data for Brazil, China, India and Russia is unavailable for 2014.

Energy intensity has declined in all countries (except Brazil where it has broadly stayed at a low level). Energy intensity has declined more rapidly in the regions with the highest energy intensity. Energy intensity is highest in China and Russia, but fell by around 45% and 40% in each country respectively over 1995-2013. Energy intensity fell by around 28% in the EU28 and 31% in the US.

Figure II.2 confirms that there has been some catch-up in the energy efficiency performance of the worst-performing countries: the countries with the highest energy intensity in 1995 saw the largest reduction over 1995-2013[10].

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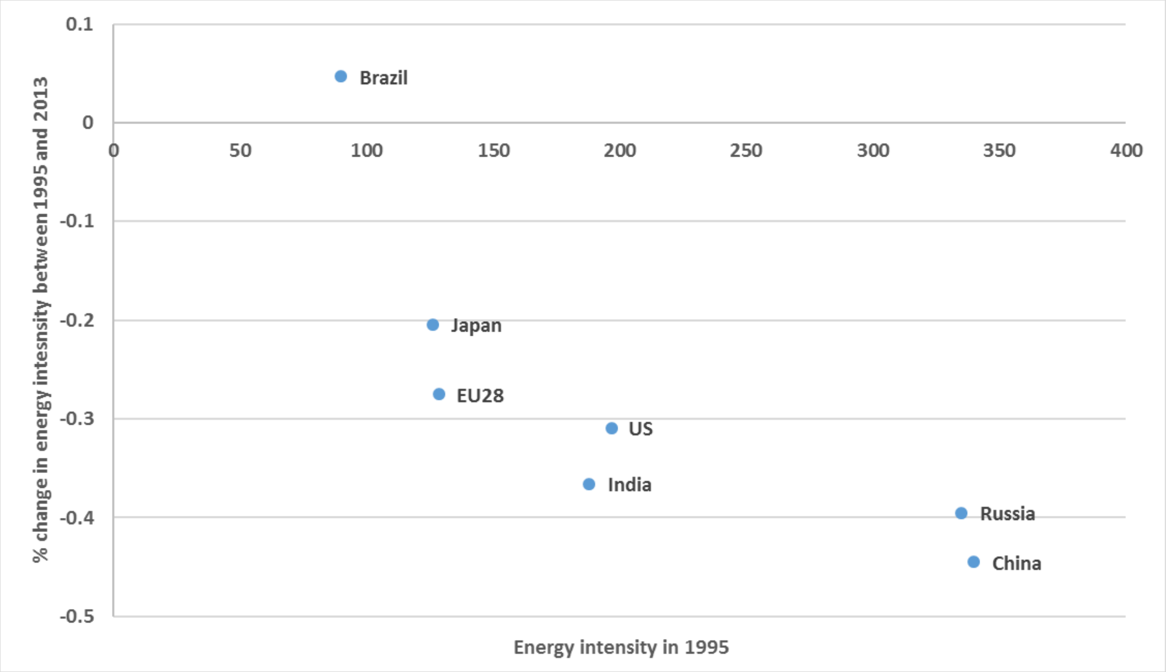
[10] For Figure II.2, 2013 is used as the last year because later data were not available for Brazil, China, India or Russia.

Figure II.2: Level of energy intensity in 1995 and percentage change over 1995-2013



Source: World Bank World Development Indicators.

High energy-intensive sectors in the EU are in the primary sector, manufacturing and transport

Energy intensity varies greatly between a small number of highly energy-intensive sectors and a larger number of sectors with much lower intensity. Table II.1 shows the top ten energy-intensive sectors in the EU in 2009 defined at the 1/2 digit NACE Rev1.1 level, and their shares of the energy used by the whole group.

The energy transformation sectors are, of course, by far the most energy-intensive sectors in the EU. Together, these two sectors (coke, refined petroleum and nuclear fuel and electricity, gas and water supply) account for over 60% of EU energy use in the top ten sectors. Outside of those sectors, air transport is by far the most energy intensive. After water transport, the other most energy-intensive sectors are those that extract or process raw materials.

Table II.1: Top ten energy-intensive sectors in the EU27 and their shares of energy use, 2009

	Energy intensity (energy use (mJ) per € of GVA)	**Share of total energy use by the top ten sectors (%)**
Coke, Refined Petroleum and Nuclear Fuel	924	31.3
Electricity, Gas and Water Supply	146	31.3
Air Transport	137	30.7
Water Transport	42	2.4
Chemicals and Chemical Products	37	1.8
Other Non-Metallic Minerals	25	6.6
Basic Metals and Fabricated Metals	18	1.7
Mining and Quarrying	15	3.6
Wood and Products of Wood and Cork	14	1.2
Pulp, Paper, Printing and Publishing	12	0.4
Energy intensity across all sectors	10	(not applicable)

Source: WIOD Environmental Accounts and Eurostat National Accounts.

Globalisation increased the share of energy-intensive sectors in China, but this effect was outweighed by strong gains in energy efficiency

Changes in energy intensity can be decomposed into two components: an energy efficiency component and a structural component that reflects changes in the sectoral mix (notably the changing share of energy-intensive activities in the economy). Figure II.3 shows the results of a decomposition analysis[11] for each global region (Brazil was omitted due to data limitations). The data distinguished 34 sectors covering the whole economy over the years 1995-2009[12].

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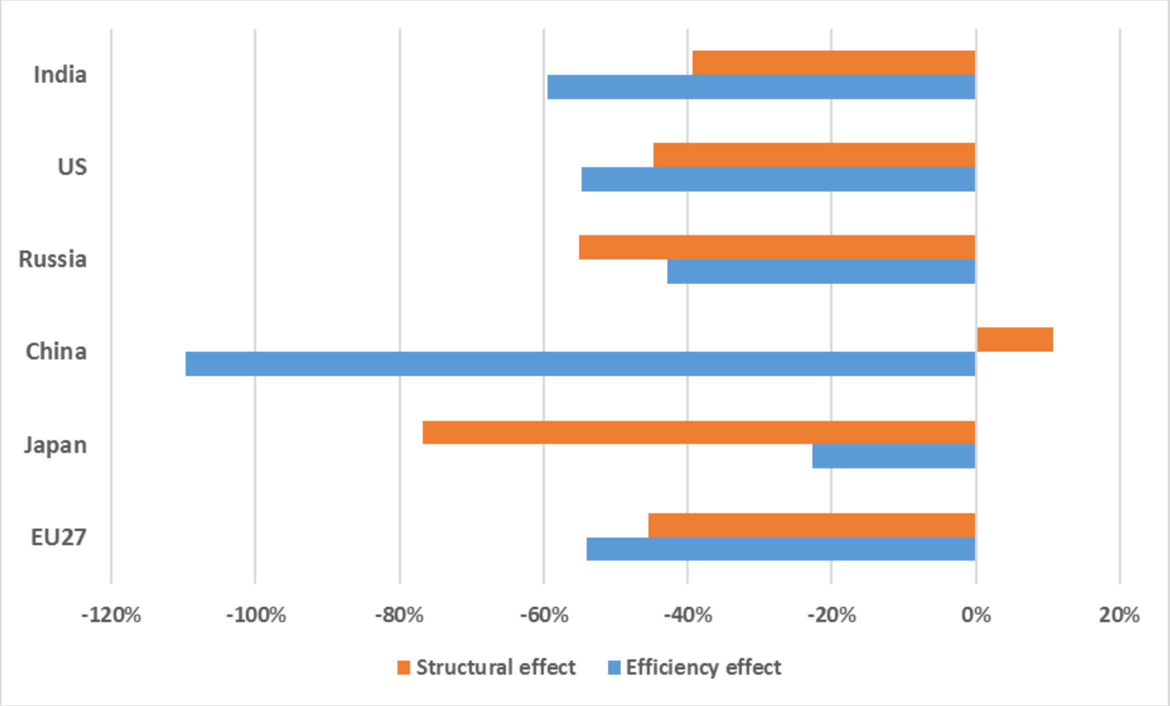
[11] See Appendix II for the decomposition analysis methodology used in this report.

[12] The sectoral decomposition period of study ends in 2009, because this is the latest year for which WIOD Environmental Accounts data were available for the 6 global regions included in the analysis.

Figure II.3: Decomposition analysis of changes in energy intensity over 1995-2009



Source: WIOD Environmental Accounts and Socio Economic Accounts.

Note: The Coke, refined petroleum and products and nuclear fuel sector and the Electricity, gas and water supply sector have been excluded from the decomposition analysis. This is because the very large scale of energy intensity in these energy transformation sectors relative to all other sectors means that changes in its energy intensity (which could be due to a change in the mix of activities within the sector itself as well as changes in energy efficiency) can dominate the results. 2009 is the latest year for which WIOD Environmental Accounts data were available for the 6 global regions included in the analysis.

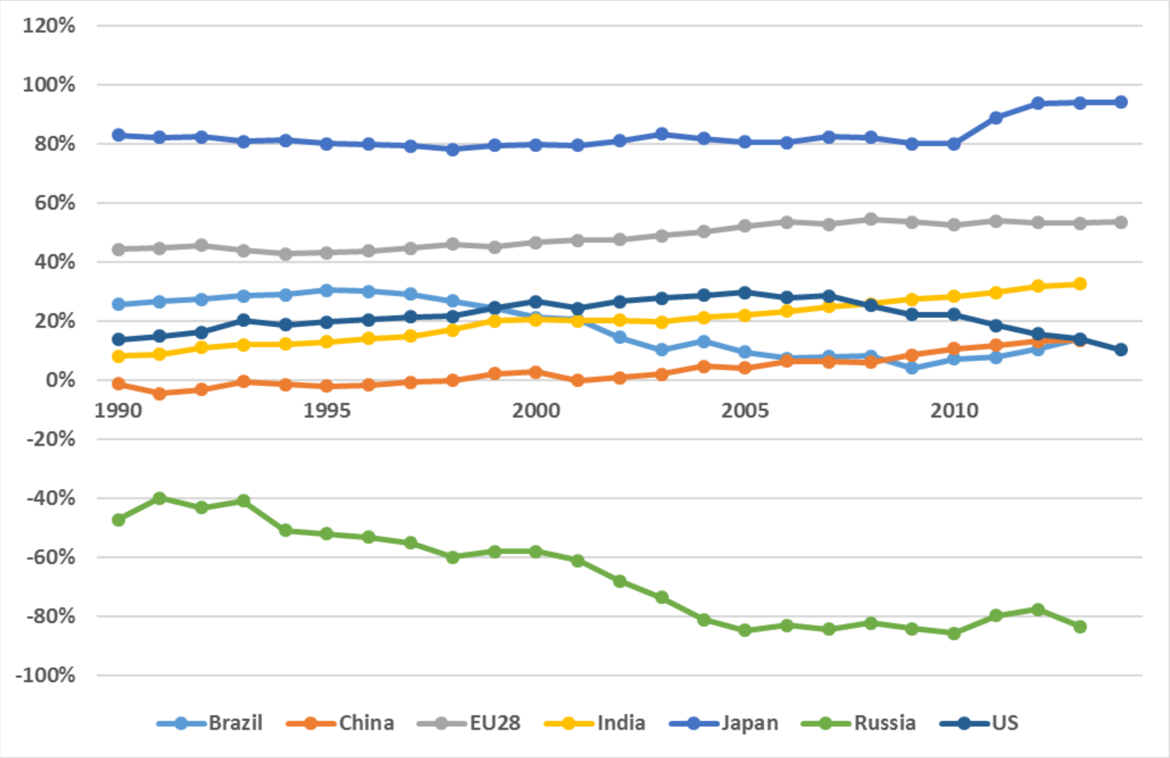
The results of the decomposition analysis reveal differences in the way in which different global regions have achieved lower energy intensity over 1995-2009. All regions saw improvements in energy efficiency, though to varying extents. In China, improvements in energy efficiency accounted for almost 110% of the total energy intensity reduction, offsetting a shift in the sectoral mix towards (i.e. strong growth in) more energy-intensive sectors. In contrast, Japan and Russia experienced particularly strong structural effects: energy efficiency improvements were also important (especially in Russia), but less so than the rebalancing of its sectoral mix towards less energy-intensive sectors. In the EU, US and India, energy efficiency improvements had the largest impact, but there was also a clear shift towards less energy-intensive sectors in their economies. However, the decomposition analysis does not shed light on the *drivers* of energy efficiency in each sector: it simply isolates the effect of changes in *structure*.

Japan is the most import-dependent global region for energy products, followed by the EU

The resilience and vulnerability of an economy to energy supply shocks depends greatly on its energy import dependence: high import dependence, particularly when the sources of supply are geographically concentrated, raises risks about the security of energy supplies, and increases the macroeconomic impact of a rise in energy prices (because the implied transfer of income from energy consumers to energy producers is lost to the domestic economy).

Figure II.4 plots energy import dependence in the EU and the selected global regions over 1990-2014.

Figure II.4: Energy import dependence in the EU and other global regions, 1990-2014



Source: World Bank World Development Indicators and Eurostat Simplified Energy Balances.

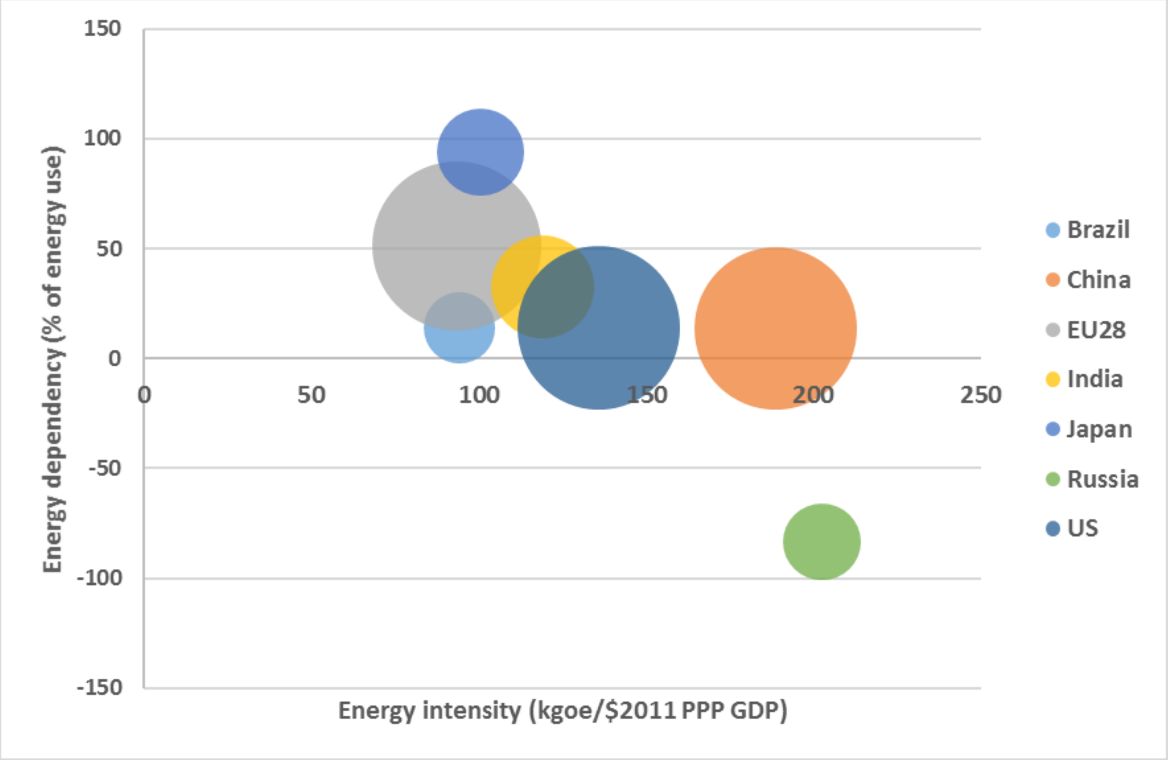
Note: Energy import dependence is calculated as the share of imported energy in total energy use. Data for 2013 and 2014 is unavailable for Brazil, China, India and Russia.

Japan has by far the highest energy import dependence followed by the EU. Energy import dependence increased in the EU by nine percentage points over 1990-2014. India saw the largest increase in energy dependence over the period, at over 24 percentage points. Russia and Brazil both saw reductions in energy import dependence at 36 percentage points and 11 percentage points respectively, reflecting development of energy sources in those countries.

In the US, energy dependence increased slightly by just over three percentage points over 1990-2014. However, energy dependence has been falling since 2005, reflecting growth in the US energy industry following the shale gas revolution.

There is some evidence that regions with fossil fuel sources tend to have a greater share of energy-intensive industries and/or lower energy efficiency: Figure II.5 shows that the level of energy import dependency in the economy is inversely related to its level of energy intensity.

Figure II.5: Energy dependence, energy intensity and GDP, 2013



Source: World Bank Development Indicators.

Note: The size of each bubble is proportional to each country's GDP (constant PPP $2011).

The EU and Japan have the highest energy dependence and the lowest energy intensity (apart from Brazil), while Russia and China have the lowest energy dependence and the highest energy intensity.

The EU is heavily reliant on Russia for its energy imports

Aside from energy import dependence, it is also important to consider the sources of imports and the diversity of suppliers in order to gauge a country's exposure to energy supply shocks. Obviously there is less risk of supply interruption if sources are diversified.

Figure II.6 shows the sources of EU energy extra-EU imports[13]. It is evident that the EU is heavily reliant on Russia for its energy imports with around 32% of energy imports sourced from the region. This reliance on Russia applies to both imports of natural gas, at 26% of extra-EU imports, and crude oil, at 30% of extra-EU imports. Aside from Russia, Norway supplies around 12% of energy imports, while Algeria accounts for 6.8%. These three countries are the top extra-EU suppliers of both crude oil and natural gas. Most of the remaining suppliers of energy to the EU are members of OPEC. Hence, the EU's energy import supply is highly concentrated, and some of the suppliers are subject to geopolitical risk.

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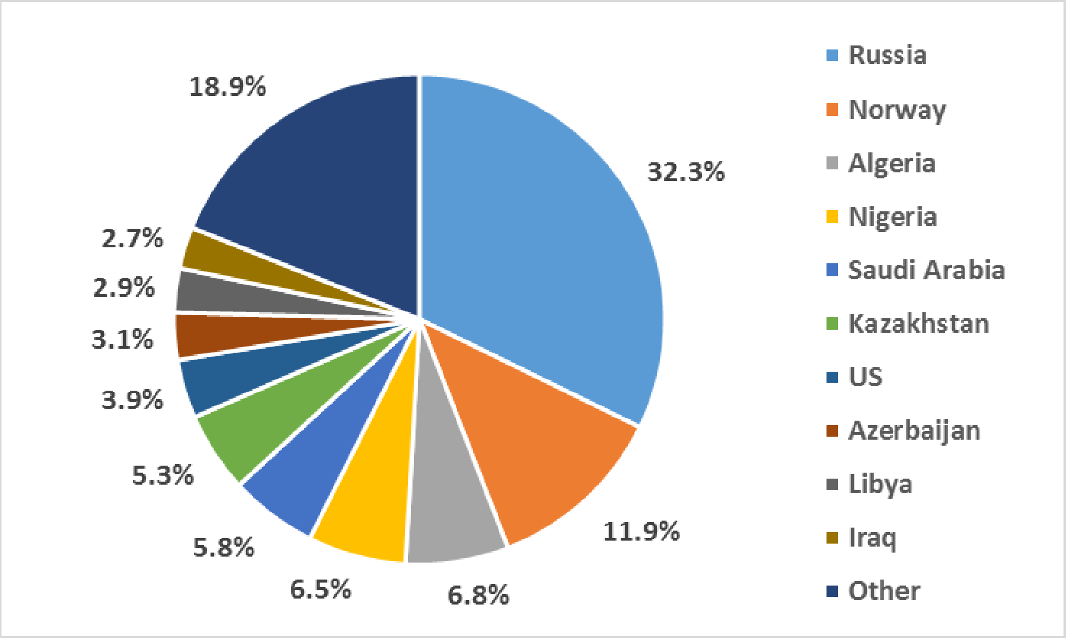
[13] Energy products are defined by SITC Rev3. Section 3 – Mineral fuels, lubricants and related materials.

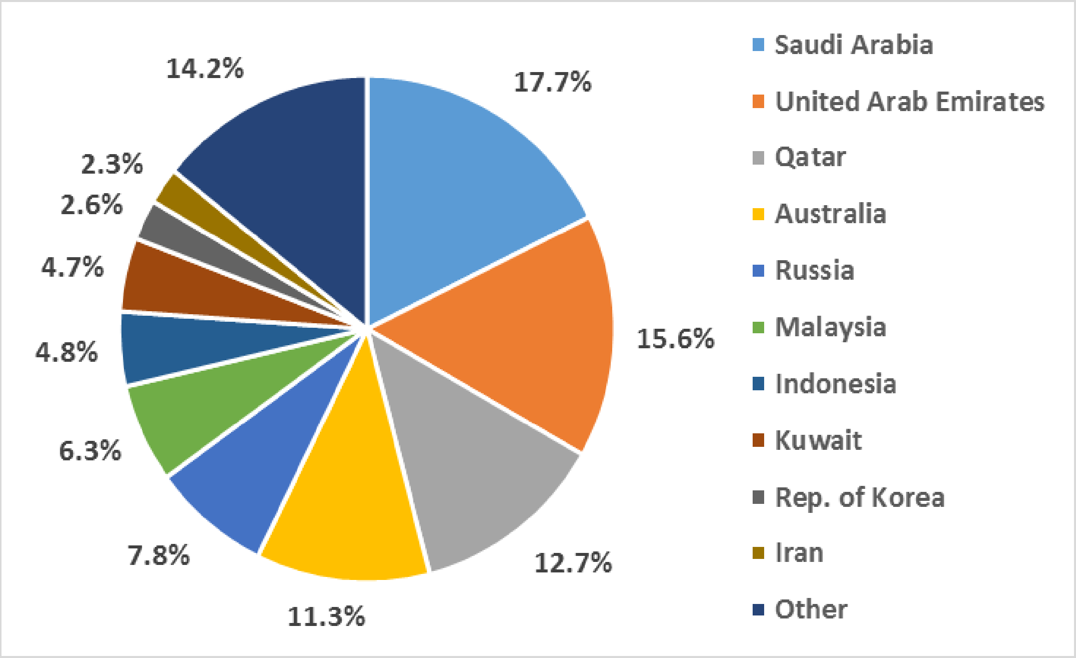
Figure II.6: Shares of energy imports by source to the EU in 2014



Source: Comtrade.

Japan, which is the most energy import-dependent region in this analysis, is also reliant on a concentrated number of suppliers, as is shown in Figure II.7. Japan's energy imports mainly come from the Middle East, with Australia also a major supplier providing over 11% of total energy imports.

Figure II.7: Shares of energy imports by source to Japan in 2014



Source: Comtrade.

Amongst the other global regions considered here, sources of imports tend to vary according to the geographical location of the regions. In India, which has the third-highest energy import dependence, imports are largely sourced from the Middle East, though Venezuela and Nigeria are also major suppliers of crude oil to the country. The US sourced over a third of its energy products from Canada in 2014, and over half from Canada, Venezuela and Mexico taken together.

***The EU's energy import sources* are less diversified than those of other global regions that depend heavily on imports for energy**

One way to measure the degree of concentration of import sources by country is to construct a Herfindahl- Hirschman Index (HHI). Table II.2 presents HHIs for all energy products, crude oil, and gas, for each global region. Countries with higher degrees of import source concentration have HHI numbers closer to one, while countries with lower degrees of import source concentration have HHI numbers closer to zero.

Table II.2: Herfindahl-Hirschman index showing the concentration of import sources of global regions in 2014

	Brazil	China	EU	India	Japan	Russia	US
All energy products	0.099	0.057	0.139	0.075	0.101	0.161	0.154
Crude oil	0.348	0.090	0.135	0.099	0.198	1.000	0.179
Gas	0.241	0.168	0.188	0.463	0.123	0.506	0.810

Source: Comtrade.

Focusing on the regions with high energy import dependence, the EU and Japan, the EU's oil import concentration is lower than Japan's but for gas imports the EU's sources of supply are more concentrated than in Japan. India, the region with the next highest overall import dependence, is well diversified in terms of its crude oil import sources, but has a very highly concentrated profile of gas suppliers.

Turning to the other regions analysed, Russia's energy import sources are highly concentrated, but Russia's overall energy import dependence is low and so the concentration among its sources of imports does not pose much risk. Likewise, the US, which has the second-highest concentration of energy import sources is also one of the regions that is less dependent on energy imports.

Part III. The share of energy in production costs, and the economic performance of energy-intensive manufacturing

The share of energy in all purchased inputs in the EU was lower in 2014 than in most other global regions

Figure III.1 shows the share of energy in all purchased inputs in 2014 in the EU28 and other global regions for five sectors: Energy-intensive manufacturing, Other manufacturing, Mining and quarrying, Transport, and Other sectors[14]. Among the world regions, in energy-intensive manufacturing the share of energy in purchases was highest in Russia at around 24%, followed by Japan at around 22%, and China at around 21%. In the EU28 the share was a little under 15%, similar to that of Brazil and India. The US has the lowest share of energy in purchases in energy-intensive manufacturing, at around 10%.

In mining and quarrying, Japan has the highest energy share of energy in purchases, at around 61%. Russia and the US have the next highest shares, at around 32% each, followed by China at around 30%. Brazil and India have much lower shares of energy in purchases in mining and quarrying.

In the transport sector, the EU28 has a relatively low share of energy in purchases. Russia has the highest share of energy in purchases in this sector, followed by India.

The differences between energy shares in purchases are much smaller in the remaining two sectors, but Russia has the largest shares of energy in purchases in both cases.

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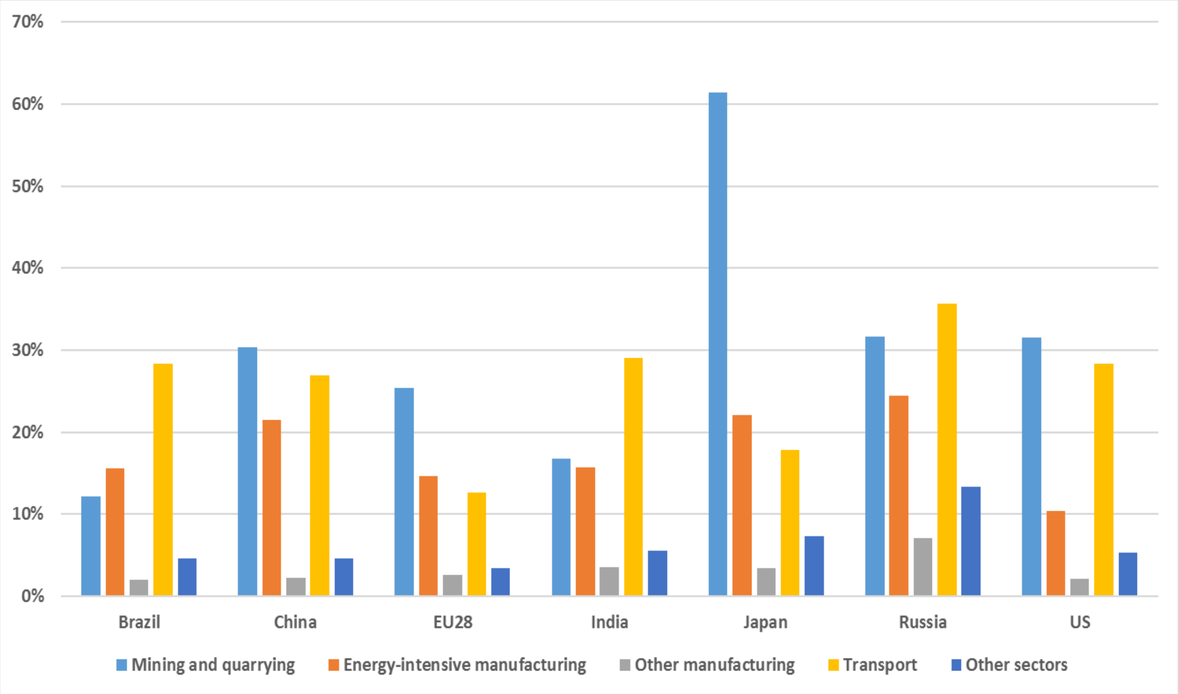
[14] The five sectors are defined as follows. Mining and quarrying is defined as NACE Rev 2. Section B (Mining and Quarrying). Energy-intensive manufacturing comprises five energy-intensive subsectors of NACE Rev 2. Section C (Manufacturing) – C16, C17, C20, C23 and C24. Other manufacturing comprises the rest of NACE Rev 2. Section C. The transport sector is defined as NACE Rev 2. Section H (Transport), and Other sectors comprise NACE Rev2. A, E, F, G, I, J, K, L, M, N, O, P, Q, R, S, T and U. Lastly, the energy transformation subsectors NACE Rev 2. C19 (Manufacture of coke and refined petroleum products) and D35 (Electricity, gas, steam and air conditioning supply) are excluded from these sector groupings.

Figure III.1: The share of energy in production costs in the EU28 and global regions in 2014



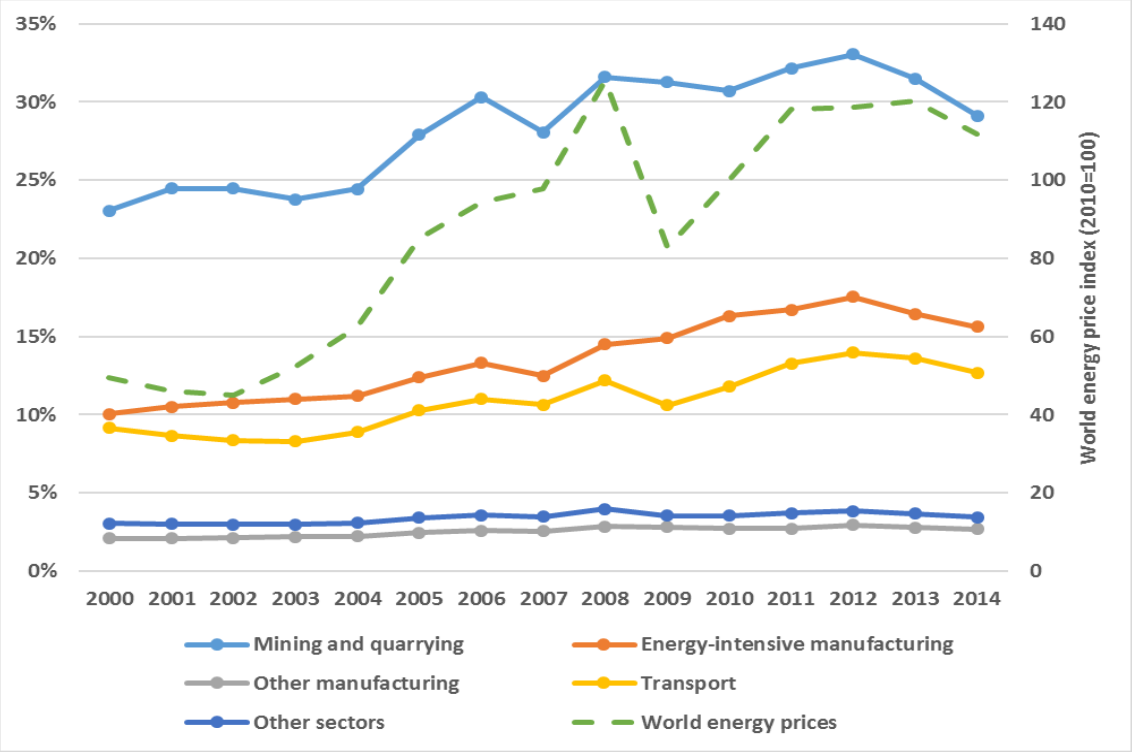
Source: WIOD (2016) use tables and WIOD (2013) use tables.

Note: The shares are calculated as the current dollar value of intermediate consumption of the following energy products: mining and quarrying energy products; coke and refined petroleum products; and electricity, gas, steam and air conditioning products.

Energy costs in the energy-intensive sectors are particularly sensitive to changes in world energy prices

The share of energy costs in all purchased inputs is closely linked to the world price of energy. Not only do energy-intensive sectors have higher energy costs than other sectors; their energy costs are *more sensitive* to world energy price changes than those of other sectors. Thus as world prices increased over 2000-2014, so did the share of energy in the three energy intensive sectors – mining and quarrying, energy-intensive manufacturing, and transport – in the EU28 as shown in Figure III.2 below. The share of energy in all purchases stayed relatively stable in the two other sectors. This is consistent with the fact that energy-intensive sectors make greater use of relatively unprocessed energy inputs (for example, gas rather than electricity) and face lower taxes on energy inputs than, for example, transport: consequently, their costs are more sensitive to the price of fossil fuels.

Figure III.2: Share of energy in production costs in the EU28, and world energy price index (real $2010), 2000-14



Source: WIOD (2016) Use tables.

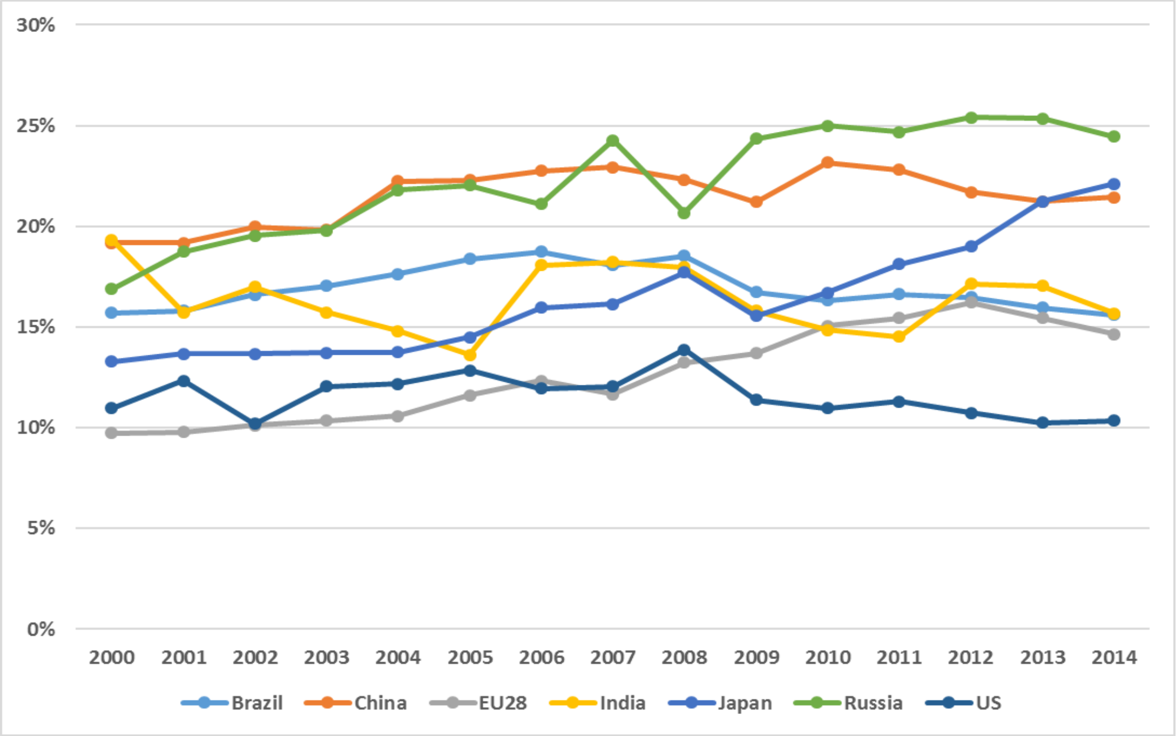
In energy-intensive manufacturing, the share of energy in all purchased inputs has risen in the EU28, opening up a gap compared with the US. In Japan, the share has risen strongly and it is now as high as in China.

The share of energy in purchases in energy-intensive manufacturing is an important driver of competitiveness. In interpreting the data, it should be remembered that cross-country differences in these shares reflect

- differences in energy prices between countries (including the effects of each country’s policies on prices)
- differences in the energy efficiency of plant
- differences in the mix of sectors and products and the position of the industry within the value chain (energy costs are higher in upstream processes)

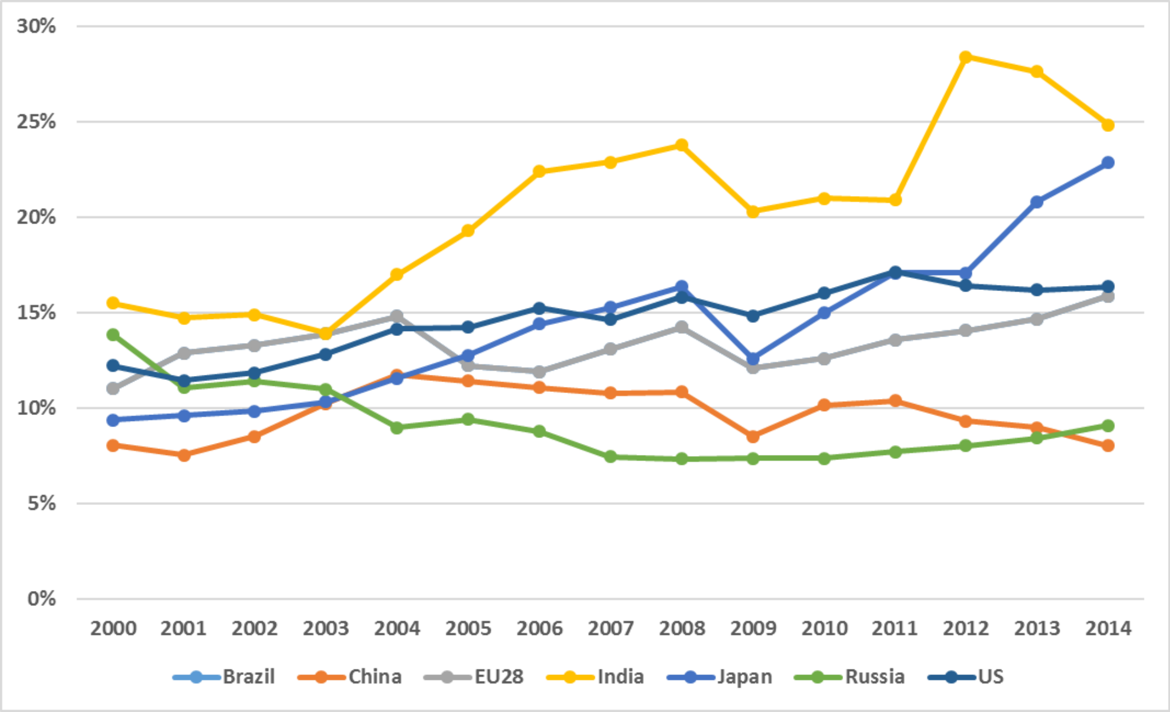
Figure III.3 shows that, among the more developed countries, the EU28’s energy-intensive manufacturing sector had a similar, relatively low, share of energy in purchases as in the US in the first half of the 2000s, but since 2008 a gap has opened up with the EU28 figure consistently higher since then. This is also the period during which the export performance of the EU’s energy-intensive manufacturing industries was relatively weak (see Figure III.6 below). At the other extreme, the shares in China and Russia rose in the 2000s as global energy prices rose and have remained high, although in China the increase was curbed after 2005. In Japan, the share increased by around ten percentage points overall, and rose sharply over 2009-14. During this period, Japan became more dependent on energy imports, increasing its exposure global energy prices.

Figure III.3: Share of energy in all purchased inputs to energy-intensive manufacturing in the EU28 and global regions, 2000-14



Source: WIOD (2016) Use tables.

Figure III.4: Import shares of intermediate consumption in energy-intensive manufacturing, 2000-14



Source: WIOD (2016) World Input-Output tables.

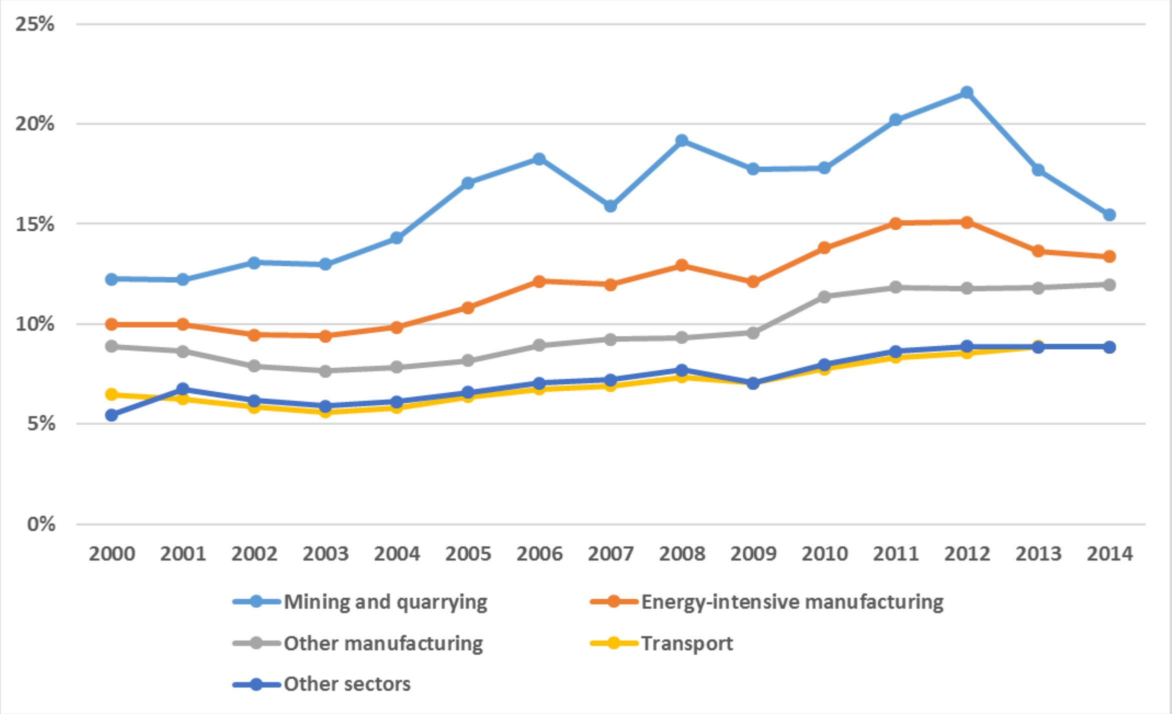
Energy-intensive manufacturing in global regions has become more dependent on imports

In several of the global regions considered here, but not Russia and China, there has been a trend towards greater dependence on imports for intermediate inputs to energy-intensive manufacturing (measured in current prices). Figure III.4 shows the import shares of intermediate consumption in energy-intensive manufacturing of each global region over 2000-14. The trends partly reflect the energy price movements already discussed: when energy prices rise faster than other prices, countries that are large net importers of energy (for example, Japan), see the (current-price) share of imports in all inputs rise, while net exporters (for example, Russia) do not.

The EU's dependence on imported energy makes energy-intensive manufacturing more reliant on imports than other manufacturing sectors

In the EU, the share of extra-EU imports in intermediate consumption has risen in all sectors of the economy over 2000-14, showing a growing trend towards import dependence that is not confined to the energy-intensive sectors. But the EU's dependence on imported energy is reflected in the higher shares of imports for mining & quarrying and energy-intensive manufacturing than for other sectors as shown in Figure III.5.

Figure III.5: Import shares of intermediate consumption in the EU28, 2000-14

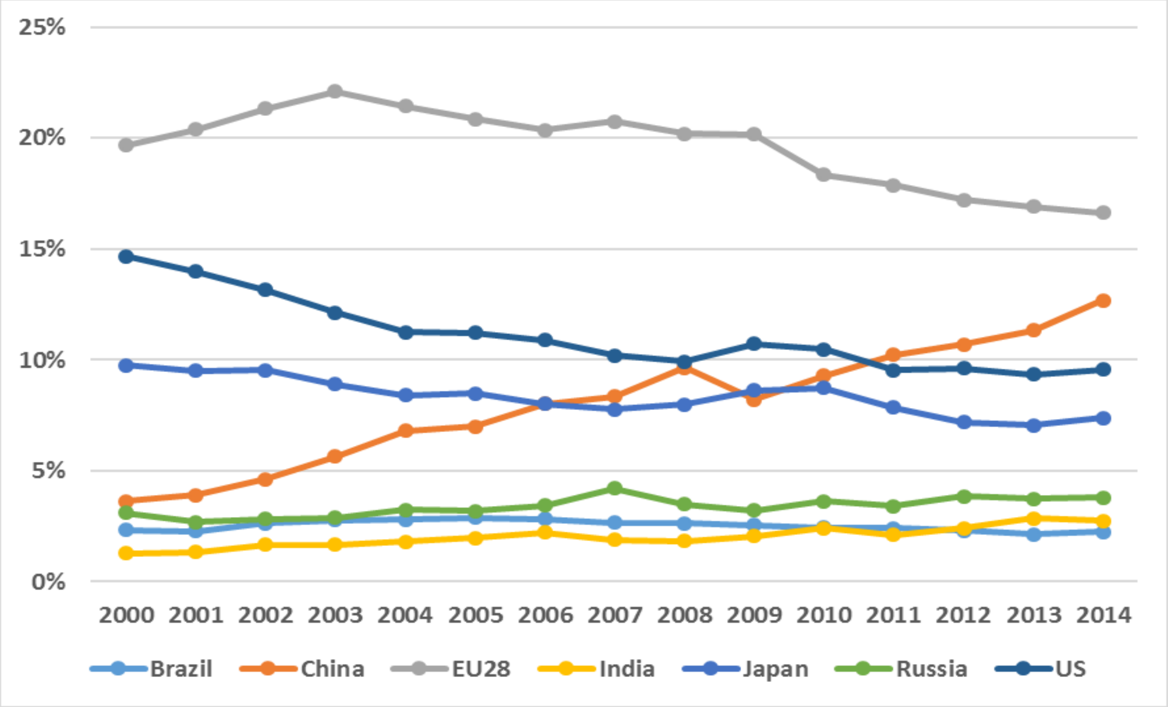


Source: WIOD (2016) World Input-output tables.

Energy-intensive manufacturing in the EU, US and Japan has seen a reduction in its share of world trade, with a larger fall in the EU since 2009

Turning to exports, the EU, US and Japan's energy-intensive manufacturing sectors all experienced a reduction in their share of world trade over 2000-14, as is shown in Figure III.6. The largest reduction was in the EU, particularly after 2009, which coincides with the period when the share of energy in all purchased inputs was rising relative to the US, but not Japan (see Figure III.3 above). China in particular increased its share over the same period, while in the other countries the (smaller) export market shares were broadly stable.

Figure III.6: Share of world exports of energy-intensive manufacturing in the EU28 and global regions, 2000-14



Source: WIOD (2016) World input-output tables.

Energy-intensive manufacturing in the EU has seen stagnating GVA and falling employment, a worse outcome than other manufacturing sectors

While the energy-intensive manufacturing sector in the EU has seen energy costs rise and its share of the world market has fallen, GVA growth has stagnated since 2011 and employment has fallen substantially. A similar trend was seen in other manufacturing saw a similar trend, but it was more pronounced in energy-intensive sectors. This restructuring away from energy-intensive manufacturing has made EU production less directly[15] exposed to energy supply shocks. Figure III.8 and Figure III.7 plot GVA and employment indices in energy-intensive manufacturing and other sectors. Clearly, energy-intensive manufacturing plays a smaller role in the EU economy than it did 15 years ago. In contrast, employment in other sectors grew by 11% over 2000-14. However, the transport sector has also grown since 2000 in terms

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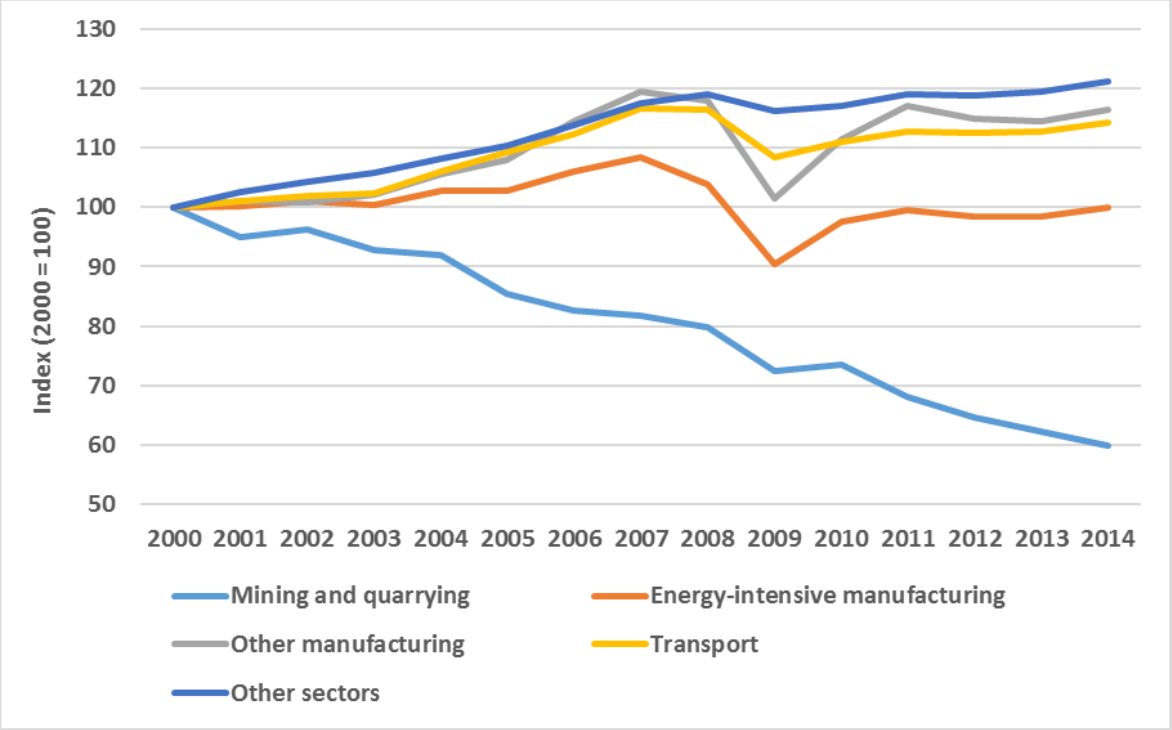
[15] Downstream producers that rely on imported products of energy-intensive sectors are, of course, still vulnerable to the impacts of higher energy prices passed through the prices of those products.

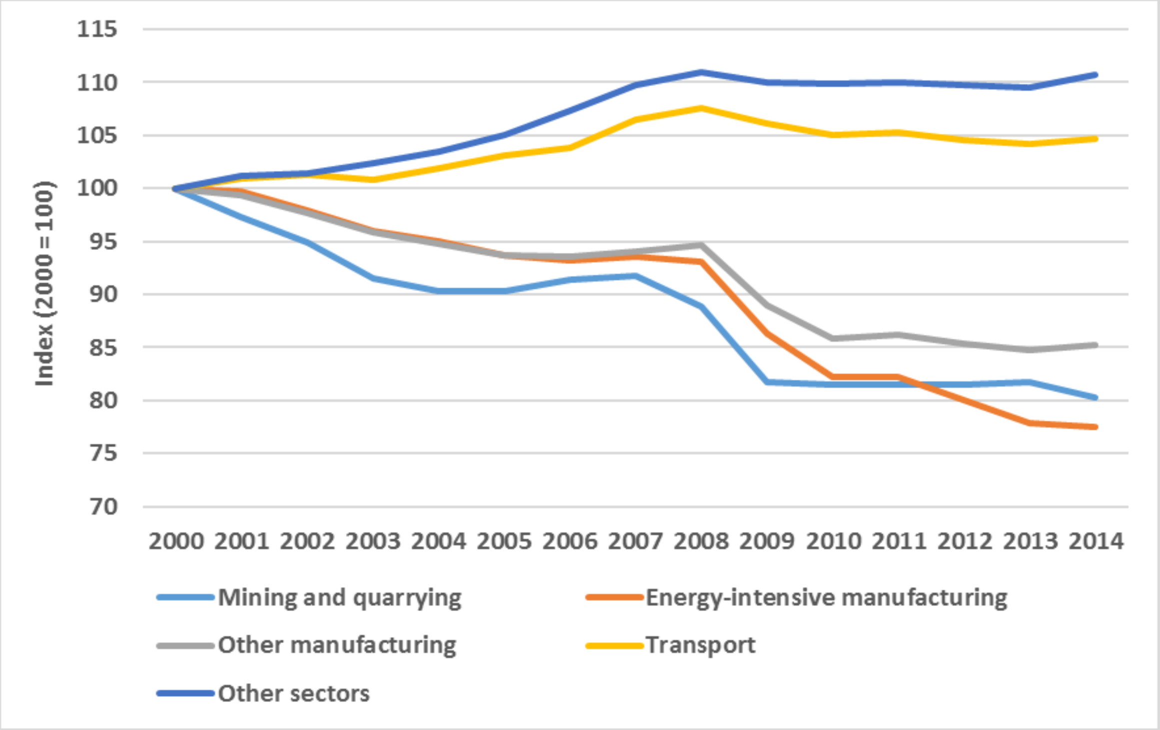
of GVA and employment, so is an example of a growing sector that remains exposed to energy price increases.

Figure III.8 – Real gross value added in energy-intensive manufacturing and other sectors in the EU28, 2000-14



Source: Eurostat National Accounts and CE estimates.

Figure III.7: Employment in energy-intensive manufacturing and other sectors in the EU28, 2000-14



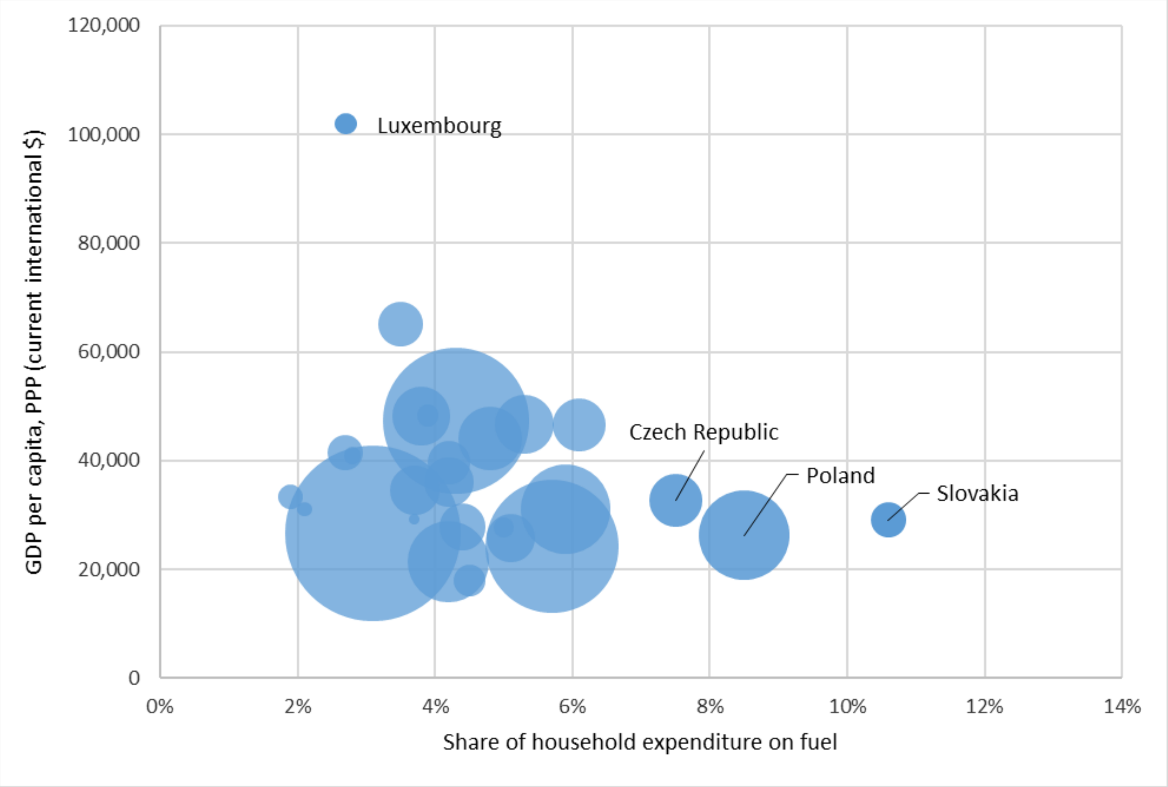
Source: Eurostat National Accounts.

Part IV. The share of energy products in household consumption

Energy products account for a higher proportion of spending for households in central eastern Europe, and notably in the Czech Republic, Hungary and Slovakia

There is a great deal of variation in household exposure to energy supply shocks between the EU Member States. On average, households in the EU spend around 4% of total expenditure on fuel. Richer countries tend to have a lower share of average household expenditure on fuel[16], and as such consumers are less exposed to a price increase. On the other hand, households in many of the newer Member States spend more of their total household expenditure on fuel. In particular, households in the Czech Republic, Poland and Slovakia spent around 7.5%, 8.5% and 10.6% of total expenditure on fuel in 2015 – considerably more than the EU average of 4.1%. Figure IV.1 plots the relationship between GDP, GDP per capita in the Member States and their shares of household expenditure on fuel in 2015.

Figure IV.1: GDP, GDP per capita and household expenditure on fuel in the EU28, 2015



Source: Eurostat National Accounts and World Bank Development Indicators.

Note: The size of each bubble is proportional to each country's GDP (current international $). Household fuel expenditure data is unavailable for Croatia,

Households in almost all EU countries saw their fuel expenditure shares fall as energy prices decreased between 2010 and 2015 (largely driven by a sharp fall in energy prices in 2015). There were some exceptions, such as in France and Slovakia, where household fuel expenditure shares rose slightly. Figure IV.2 plots average household expenditures on fuel for the EU28 and each Member State in 2010 and 2015. In

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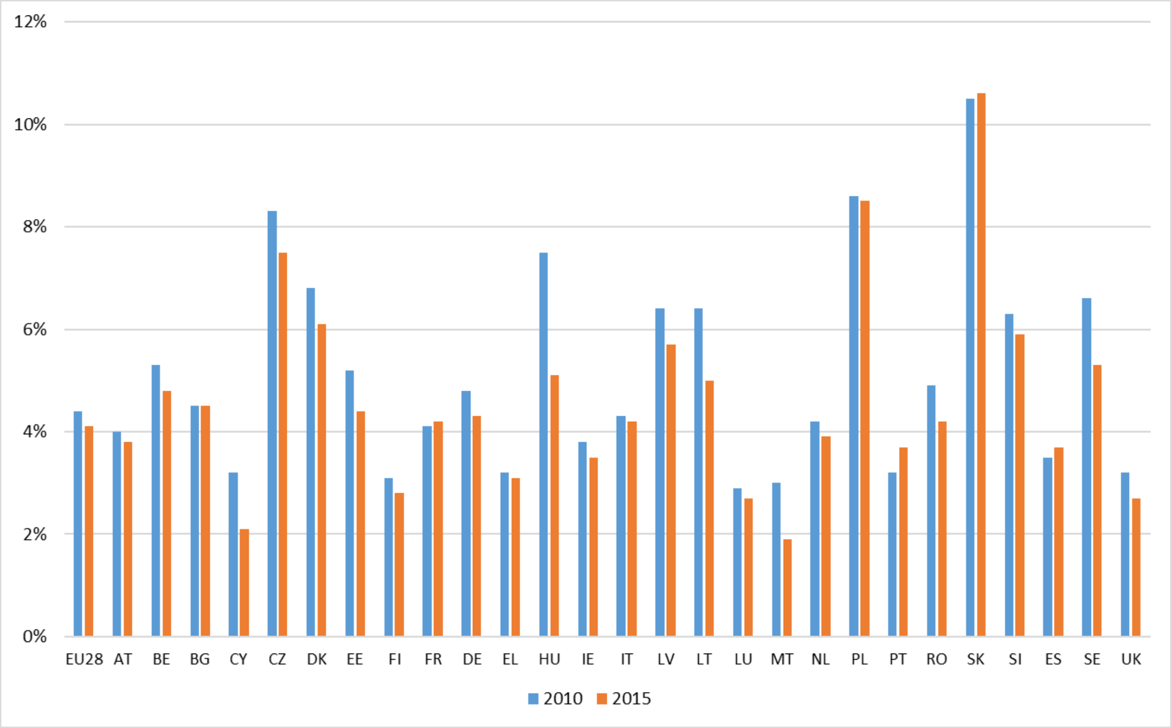
[16] Fuel comprises COIPCOP 04.5 – Electricity, gas and other fuels.

general, the shares of spending on energy tend to move in the same direction as price changes, indicating that the price elasticity of energy spending is low (so that households do not have much opportunity to curb energy use when the price rises).

Figure IV.2: Shares of household expenditure on fuel in the EU28 and each Member State in 2010 and 2015

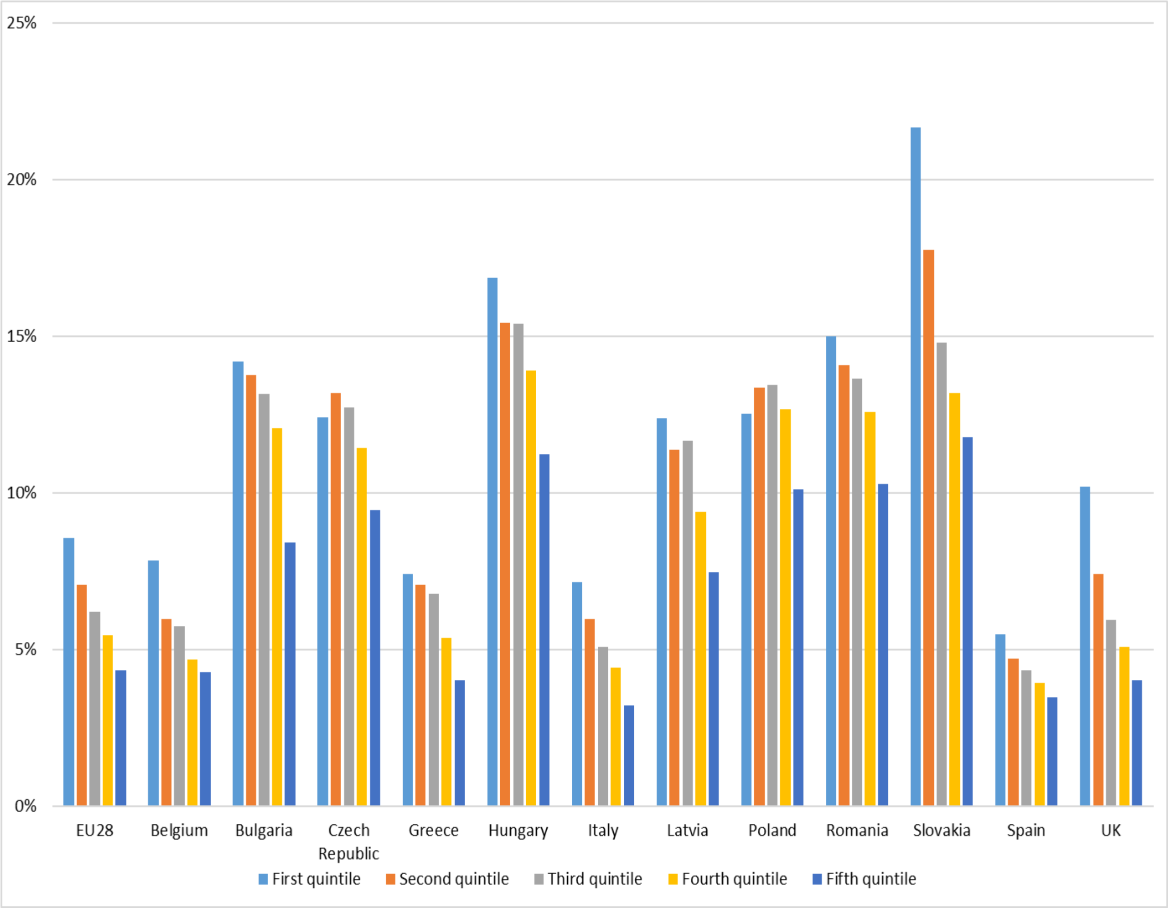


Source: Eurostat National Accounts.

Low income households spend proportionately more on energy, and much more in some Member States

Low-income households are more exposed to energy price increases than high-income households. For the EU as a whole, households in the lowest income quintile spent 8.6% of their total household expenditure on fuel in 2014, whereas households in the uppermost quintile spent 4.4%. The same pattern is evident in each Member State, but the proportions are generally higher in those poorer Member States that experience cold winters. Figure IV.3 plots household fuel expenditures as a share of total expenditure for Member States for which data are available for 2014

Figure IV.3: Share of household expenditure on fuel by income quintile, 2014



Source: Eurostat, Structure of consumption expenditure by income quintile (COICOP level 2).

Note: Data unavailable for Austria, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Ireland, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovenia and Sweden.

Part V. A multi-country estimation of the elasticity of substitution of energy with other production factors

The degree of substitutability between energy and other production factors is a key issue with regard to energy resilience, since low substitutability would indicate that there is little scope for the economy to adapt to higher energy prices by reducing energy inputs.

The elasticity of substitution between two factor inputs measures the percentage response of the relative marginal products of the two factors to a percentage change in the ratio of their quantities. In competitive markets it essentially measures how the ratio of two factor inputs changes when their relative price changes. It can be interpreted as indicating how "easy" it is to substitute one production factor with another. The potential for substitution depends by the technology used in the production process. Theoretically the elasticity value can range from zero (no substitution) to infinity (perfect substitution). The degree of substitutability is of significant importance as it indicates how effective policies or regulations that increase energy prices are in driving reductions in energy consumption for a given output.

Our analysis focuses on the size of the substitution elasticity and whether this varies across countries, sectors and over time.

This section presents an assessment of the elasticity of substitution between energy and other production factors for different products and countries. The analysis is made in three subsections: a brief literature review; presentation of new econometric estimates using the WIOD time series data set; and a comparison between the estimated elasticities with those used in macroeconomic models and how these can be used in applied modelling.

1 Literature review

The literature is inconclusive as to whether capital and energy are substitutes or complements

Since the first studies on energy-capital substitution, when Berndt and Wood (1975) found that energy and capital are complements and Griffin and Gregorys (1976) found substitutability, there has been no consensus regarding the degree and nature of energy – capital substitutability.

Table V.1 presents the conclusions of some early studies for the US and the UK.

Recent estimations based on 17 econometric studies of aggregate substitution elasticities of energy with other production factors are presented in Table V.2 and Figure V.1. On average the elasticity for energy to capital is found to be 0.45 whereas for energy to a capital-labour bundle the elasticity is slightly larger at 0.49.

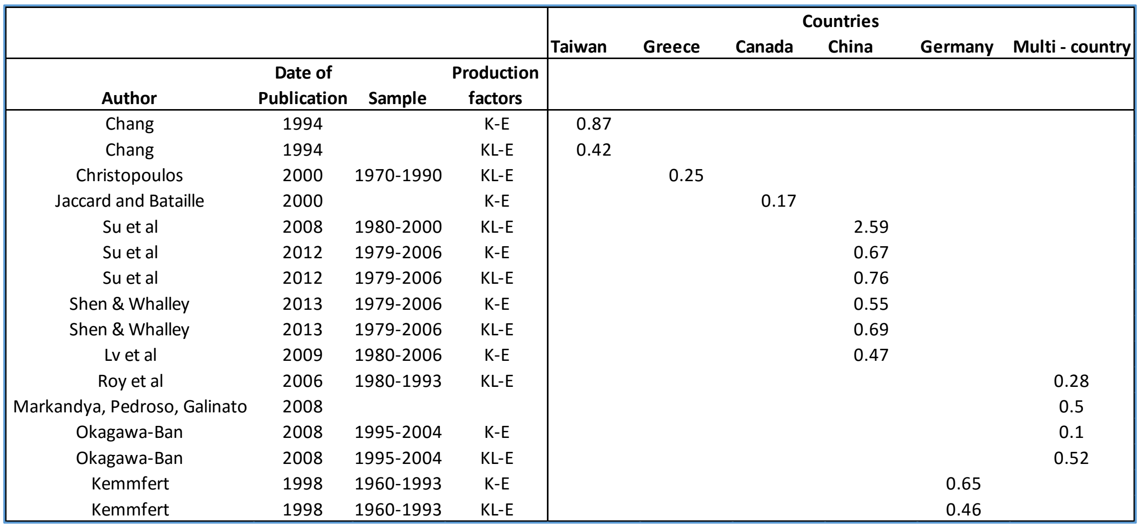
Table V.1: Early empirical studies on K-E substitution or complementarity

Authors	**Model**	**Type of elasticity**	**Data type**	**Regions**	**Time Period**	**Complementarity / Substitutability**
Berndt - Wood (1975)	Translog (KE)(LM)	AES	TS	USA	1947-71	C
Griffin - Gregory (1976)	Translog (KLE)(M)	AES	CS	9 industrialized countries	1955,60,65,70, 1961-71	S
Fuss (1977)	KLEM	AES	CS	Canada manufacturing	1961-71	C
Berndt - Wood (1979)	Translog (KE)(LM)	AES	TS	Canada, USA	1947-71	C
Pindyck (1979)	Translog KL(E)[1]	AES	CS	10 industrialized countries [2]	1963-1973	S
Hunt (1984)	Translog KLE	AES, CPE	TS	UK	1960-1980	C
Hunt (1986)	Translog KLE (3)	AES. CPE	TS	UK	1960-1980	S
Nguyen - Streitweiser (1997)	Translog KLE	AES, CPE, MES	CS	USA	1991	S

Notes: AES: Allen Elasticity of Substitution, CPE: Cross Price Elasticity, MES: Morishima Elasticity of Substitution, TS: Time Series, CS: Cross Section. [1] The nest E includes 4 types of fuels, [2] Canada, France, West Germany, Italy, Japan, Netherlands, Norway, Sweden, UK, USA. [3] Non-neutral technical change.

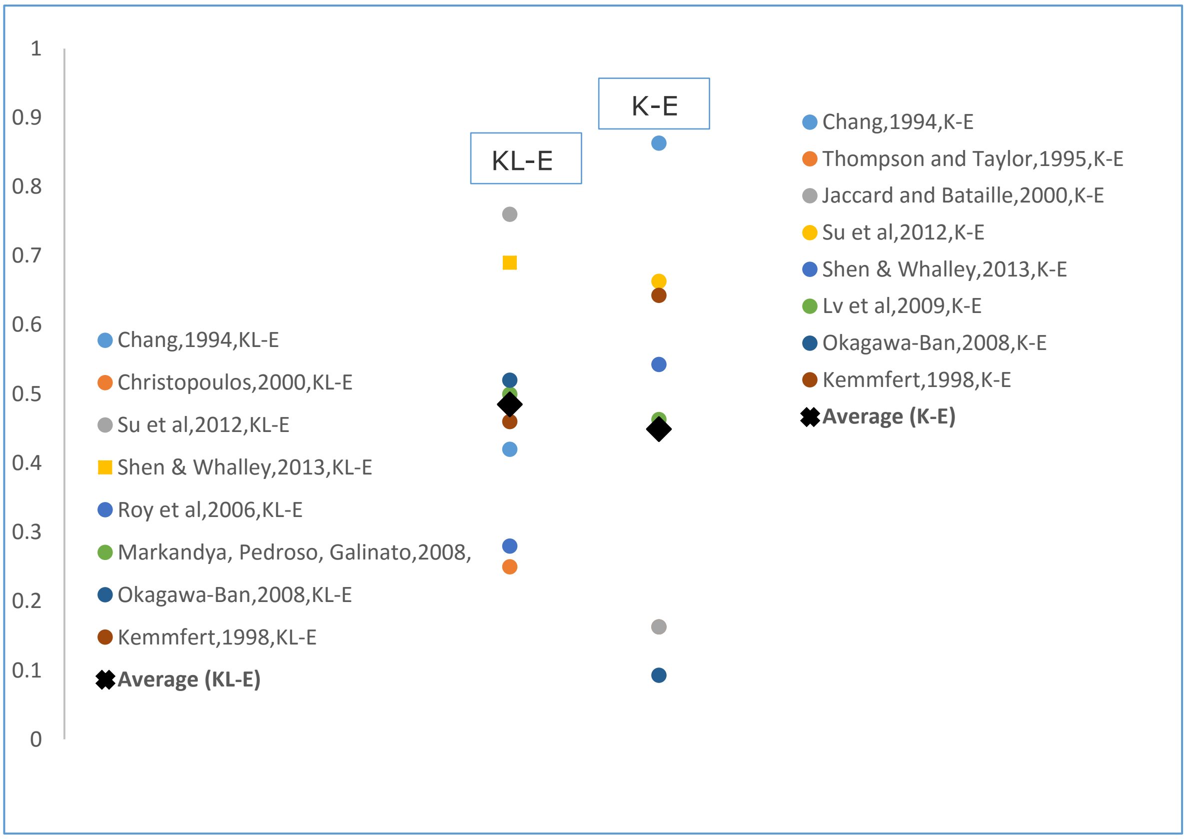
Source: Constantini & Paglialunga, 2014

Table V.2 Energy elasticity of substitution with other production factors



				Countries					
				Taiwan	Greece	Canada	China	Germany	Multi - country
Author	Date of Publication	Sample	Production factors						
Chang	1994		K-E	0.87					
Chang	1994		KL-E	0.42					
Christopoulos	2000	1970-1990	KL-E		0.25				
Jaccard and Bataille	2000		K-E			0.17			
Su et al	2008	1980-2000	KL-E				2.59		
Su et al	2012	1979-2006	K-E				0.67		
Su et al	2012	1979-2006	KL-E				0.76		
Shen & Whalley	2013	1979-2006	K-E				0.55		
Shen & Whalley	2013	1979-2006	KL-E				0.69		
Lv et al	2009	1980-2006	K-E				0.47		
Roy et al	2006	1980-1993	KL-E						0.28
Markandya, Pedroso, Galinato	2008								0.5
Okagawa-Ban	2008	1995-2004	K-E						0.1
Okagawa-Ban	2008	1995-2004	KL-E						0.52
Kemmfert	1998	1960-1993	K-E					0.65	
Kemmfert	1998	1960-1993	KL-E					0.46	

Figure V.1: Energy and other production factors substitution elasticity



The conclusion as to whether energy and capital are substitutes or complements varies across sectors

Many studies argue that the extent to which energy and capital are substitutes or complements varies according to the sector. Table V.3 shows the energy–capital substitution elasticity of recent econometric estimates for key economic sectors.

Table V.3: Energy – Capital substitution at sectoral level

Author	**Kemfert**	**Kemfert**	**Okagawa Ban**	**Dissou et al**	**Christopher G.F. Bataille**	**Constantini et al**
Date of Publication	**(1998)**	**(1998)**	**(2008)**			
Sample & Country	**1960-1993s, Germany**	**1960-1993s, Germany**		**Canada**	**1995-2015, Canada**	
Production factors	**K-E**	**KL-E**		**KL-E**	**K-E**	**K-E**
Sectors						
Chemical	0.49	0.96	0.04	0.48	0.11	0.29
Electric goods			0.25	0.2	0.06	0.32
Food		0.64	0.39	0.74		0.45
Machinery			0.12			0.32
Non-Ferrous	0.23	0.77		0.24	0.1	
Iron	0.17	0.98	0.29	0.1	0.07	0.24
Non-Metallic minerals	0.98	0.91	0.35	0.31	0.09	0.12
Pulp and paper	0.91	0.96	0.37	0.15	0.34	0.38
Textile			0.17	0.33		
Transport	0.31	0.88		0.54		
Transportation equipment			0.09	0.35		0.28
Wood			0.05			0.13

According to Thompson (2006) "The time period chosen and the dynamic model of substitution are critical". Yi (2000) finds different estimates of substitution with dynamic translog and generalized Leontief production functions across Swedish manufacturing industries. Urga and Walters (2003) show that the specification of dynamic translog functions has an effect on estimates of substitution, and find coal and oil substitutes in US industry. Kuper and van Soest (2003) show that the time period affects estimates of substitution due to path dependencies that arise given fixed costs of input adjustments".

Constantini and Paglialunga (2014) perform an estimation of K-E substitution elasticities for four time periods starting 1990 with a four-year time interval. The results are summarised in Table V.4. The elasticity estimated is relatively constant over time for some sectors (food, transport equipment, pulp and paper), increasing for textiles and decreasing for metals. Elasticities across sectors and over time range roughly from 0.2 to 0.6 (excluding few outliers).

Koetse et al (2008) estimated the short-run and long-run Morishima elasticities for North America and Europe for three time periods (pre -1973, post-1973 and post-1979). They found (Table V.5) that capital and energy are substitutes in the long-run with long-run Morishima elasticities to be almost double the short-run Morishima elasticities. Hence, in the long-run, high energy prices may drive energy-saving investments.

Table V.4: K-E substitution by sector and over time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1990-1994	1995-1999	2000-2004	2004-2008	Mean	BE 1990-2008	Distance from mean in (6)	(6)-(5)
Food	0.44	0.45	0.46	0.44	0.45	1.00	0.58	0.55
Textile	0.30		0.46	0.64	0.47	0.44	0.02	-0.03
Wood	0.03	0.14		0.32	0.16	0.13	-0.29	-0.03
Pulp and Paper			0.37	0.29	0.33	0.38	-0.04	0.05
Chemical	0.46		0.04	0.36	0.29	0.29	-0.13	0.00
Minerals	0.61	0.01		0.69	0.44	0.12	-0.30	-0.32
Basic Metals	0.61	0.12		0.32	0.35	0.24	-0.18	-0.11
Machinery eq.	0.51	0.07	0.09	0.43	0.27	0.32	-0.10	0.05
Transport eq.	0.28	0.35	0.32		0.32	0.28	-0.13	-0.04
Other manufacturing	0.30		0.15	0.35	0.27	0.98	0.56	0.71
Mean	0.39	0.19	0.27	0.43	0.33	0.42		
Variance	0.035	0.029	0.031	0.021	0.009	0.066		

Source: Constantini & Paglialunga, 2014

Table V.5: K-E short and long run Morishima elasticities

	North America		Europe	
	Short - Run (time series)	Long - run (cross -section)	Short - Run (time series)	
Pre-1973	.414**	1.046**	.142**	.775**
	(.091)	(.198)	(.100)	(.211)
Post-1973	.442**	1.074**	.171**	.803**
	(.089)	(.205)	(.095)	(.217)
Post-1979	.429**	1.062**	.158**	.790**
	(.111)	(.194)	(.106)	(.201)
**,* = statistically significant at 1% and 5%, repsectively				

Source: Koetse et al, 2008

The main reasons for divergent results in the literature are: i) the level of industrial aggregation adopted (sectoral aggregation masks crucial sub-sector differences), ii) differences between data sets, iii) differences in the measure of substitution used, iv) whether or not technical progress is accounted for, and v) the extent of aggregation of fuels adopted.

Bataille (2000) suggests that, in Canada, capital and energy are weak long-run substitutes with a national cross-price elasticity of substitution of 0.24 (which could range up to 0.4 if technical progress were accounted for). When looking at fuel-specific elasticities they found quite varied results. In particular, capital for oil exhibits the most substitutability, with an elasticity of 0.60. The capital for electricity substitution elasticity was 0.29 and that for capital for gas was 0.07.

Shen (2013) estimated the elasticity of substitution for China under various two-level CES nested structures and with or without human-capital-induced productivity. Most of the estimates (Table V.6) are quite uncertain (as indicated by high standard errors) apart from the pair of (energy, human capital) - capital nested scheme.

Table V.6: Two-level CES estimates of elasticities of substitution for China with and without human capital induced productivity

Nest Structure	Estimate of σ with v=1	Std. Error of σ	R^2	Estimate of σ without v=1	Std. Error of σ	Est. of v	Std. Error of v	R^2
K, HL	0.5565	0.6095	0.9989	0.5562	0.4968	1.0828	0.2626	0.9989
(K, HL)E	0.6648	1.1727		0.967	2.6916			
K,E	0.5829	0.4099	0.9989	0.6553	0.6044	1.0655	0.2943	0.9989
(K,E)HL	0.6091	0.7827		0.598	0.635			
E,HL	0.9113	2.4950	0.9989	0.8113	1.9676	1.0367	0.3037	0.9989
(E,HL)K	0.5755	0.1578		0.6014	0.2713			
K,L	0.7418	1.1275	0.9989	0.7072	1.4294	1.0238	1.0121	0.9989
(K,L)E	0.5059	1.0382		0.6373	1.5392			
K,E	0.5312	0.5756	0.9989	0.4356	0.619	0.8635	0.9174	0.9989
(K,E)L	0.8691	1.544		0.7833	7.0084			
E,L	2.8637	22.2009	0.9989	1.6949	9.5032	0.9577	0.9077	0.9989
(E,L)K	0.6057	0.1819		0.568	0.9647			

Source: Shen, 2013

Choosing between time series and cross-section analysis to estimate the elasticity of substitution between capital-labour and energy

The empirical literature is inconclusive regarding the capital and energy substitutability or complementarity. Apostolakis (1990) argues that time-series based estimations lead to results supportive of capital-energy complementarity as they capture short term effects (as the length of time series is usually 10-15 years long) whereas cross-section based estimations (that support substitutability between energy and capital) capture long-term effects.

However, in the present study it was decided not to perform a cross-section analysis based on the WIOD[17] dataset as the sectoral aggregation of the database masks important differences in sectoral composition. For example, the chemical sector[18] in UK is mainly composed of the pharmaceuticals industry whereas in Germany this sector is mainly composed of petrochemicals. Sectoral composition can be substantially different among countries. Estimates of the degree of substitution between capital-labour and energy using cross-section analysis could therefore be misleading in these circumstances. A panel data approach was considered but not implemented. The panel data approach could control for unobserved heterogeneity that is constant over time, but this would have other disadvantages as explained below.

The panel data estimator provides a central estimate of the elasticity of substitution between capital-labor and energy. This estimate will lie in the interval between the minimum and maximum value of the already estimated substitution elasticities (based on time series analysis). Measurement errors, and possible outliers, which in time series analysis only affect specific countries and sectors, would affect the central estimate represented by the panel data estimator. The central panel data estimate may hide many theoretical and econometric problems that may exist in individual analysis (either time series or cross-section analysis). Perhaps for these reasons the literature on substitution elasticities it is either based on cross section (bottom-up) data or time series: there are very few cases using panel data.

In addition to the sectoral homogeneity issue mentioned above a consistent cross-section analysis should take into account the following key differences across countries: (i) fuel scarcity, (ii) energy policies (taxes and subsidies), (iii) restrictions or benefits in capital or/and labour markets, and (iv) growth characteristics such as potential growth, the per capita income, speed of convergence and technical productivities. Addressing all the issues above at same time increases the complexity and data requirements of the task considerably. For this reason, in the present study we chose to use time series analysis so as to achieve the highest level of sectoral homogeneity.

The main reasons for divergent results in the literature are: i) the level of industrial aggregation adopted (sectoral aggregation masks crucial sub-sector differences), ii) differences between data sets, iii) differences in the measure of substitution used, iv) whether or not technical progress is accounted for, and v) the extent of aggregation of fuels adopted.

Limitations of the WIOD data

The advantage of using the WIOD database is that the data belong to the same industrial classification and therefore there are no compatibility issues (e.g. energy

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[17] The aggregation issue is not relevant only to WIOD dataset but to any dataset that is available only for 2-digit detail

[18] Data available from Structural Business Statistics (SBS), Eurostat Database.

volumes and value added refer to exactly the same industrial classification). However, there are a number of issues with the dataset which we discuss here.

The WIOD data are constructed by imposing accounting constraints, which implies dependence between variables. This endogeneity issue is commonly present in supply – demand analysis as a result of simultaneous causality. In our case, we have focused only on the supply function and the CES production function. It seems reasonable to assume that there is not simultaneous causality between (a) the ratio of volumes of value-added with energy and (b) the ratio of prices of value-added with energy. That is, for given output, the choice of the producer, which is the ratio of value-added and energy volumes that minimize its production cost, does not affect the relative prices between value-added and energy. This assumption is in line with the assumption of competitive markets used in the GEM-E3 model. As a check, we selected a few cases and tested the correlation between the independent variable and the error term. The null hypothesis of no correlation was not rejected; that is, we did not find high correlation that could arise from the constraints imposed in constructing the dataset.

Although the WIOD tables are published for each year, they are based on underlying data that are only available infrequently. The data for intervening years are constructed by an updating process that implies high dependence over time. However, the time series we have used are updated annually from the national accounts with the exception on energy expenditures of the national input-output tables. Even if the energy expenditure data involve some extrapolation, we have assumed that this would have been carried out with a methodology that minimizes the error between the real (energy) data and the WIOD data.

A possible alternative is to use data from a different database (i.e. energy volumes and energy prices from International Energy Agency (IEA)). But this alternative may have serious drawbacks regarding the consistency/comparability of sectoral aggregation. Since the national accounts data would still be drawn from the WIOD, it would be necessary to attempt match the WIOD sectoral classification with the classification used in the IEA Energy Balances: only a small number of sectors are defined on exactly the same classification.

2 Econometric results

Our econometric estimation results suggest very limited substitutability of energy for other factor inputs, a key finding for resilience

In this section, we report new econometric estimates using the WIOD time series data set. The substitution between energy and capital-labour production factors have been estimated for 12 EU countries and all economic sectors. The aim is to establish econometrically some benchmark values for the constant elasticities of substitution that characterize Computable General Equilibrium models and constitute important elements in controlling their simulation properties. A time series analysis was carried out to examine the non-stationarity and the autocorrelation of the data series and identify possible long-run equilibrium relations (cointegration). Two estimation methods are used: i) OLS applied to the first differences of the demand functions (these functions are derived from the firm's profit maximization problem), and ii) estimation of a single cointegrating relationship using the fully-modified OLS (FMOLS) method.

In summary, the estimates suggest very weak substitutability between energy and capital-labour production factors[19]. This holds true for the majority of EU sectors.

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[19] The detailed econometrics results and methodology are presented in Part XI. Appendix C

Comparing our estimations with older studies that have used older datasets we conclude that the low elasticity of substitution of energy with other production factors is a feature that is relatively stable over time.

The new estimates are based on WIOD data and use a CES production function

The estimates are based on the WIOD release 2013 database which includes a time-series of input-output tables, socio-economic accounts and on environmental accounts for twelve EU countries covering the period from 1995 to 2011.

The CES production function is selected for the estimation of the elasticity of substitution between a capital–labour bundle and energy.

The parametric form which is used is specified as follows:

$$QKLE_t = \gamma\left(\delta \cdot \left(e^{\lambda_1 \cdot t} \cdot QKL_t\right)^{-\rho} + (1-\delta) \cdot \left(e^{\lambda_2 \cdot t} \cdot QE_t\right)^{-\rho}\right)^{-1/\rho} \quad (1)$$

where:

$QKLE_t$: Composite good of capital-labour and energy, volume index, 1995 = 100
QKL_t: Gross value added, volume index, 1995 = 100
QE_t: Total Energy, volume index, 1995 = 100
$\sigma = 1/(1+\rho)$: Elasticity of substitution

The CES production function is used extensively in CGE models as it is well behaved and is flexible enough to to reflect quite different production technologies. Its general parametric form incorporates many special cases, and so the evidence for these can be econometrically tested. These include:

- Factor Substitutability - Complementarity:
  1. Cobb-Douglas special case: $\rho \to 0$ and $\sigma \to 1$
  2. Leontief special case: $\rho \to \infty$ and $\sigma \to 0$
  3. Linear function special case: $\rho \to -1$ and $\sigma \to \infty$
- Technological Change:
  1. Factor augmented (non – neutral) technological change: $\lambda_1 \neq \lambda_2$
  2. Hicks (neutral) technological change: $\lambda_1 = \lambda_2 = \lambda$
  3. Nonexistence of factor embedded technological change: $\lambda_1 = \lambda_2 = 0$
  4. Exogenous rate of growth: γ

A linear estimation approach was selected in preference to a non-linear estimation approach

Two main approaches are found in the literature for estimates of the elasticity of substitution (σ) under the CES parametric form: (i) the direct approach and (ii) the general approach. We have adopted the general approach, and discuss below the advantages and disadvantages of each approach.

Direct Approach

The direct approach to estimate the CES parameters is to employ nonlinear techniques. Henningsen and Henningsen (2012) developed a user-friendly R-package, the "micEconCES", in the R statistical language, where the user can estimate the parameters of a CES production function or a nested CES production function by employing non-linear optimization algorithms such as the Levenberg-Marquardt, Quasi-Newton, Simulated Annealing, etc. This approach is less vulnerable to measurement errors than the general approach (described below) because the method only requires the series in volumes and not data for factor prices, The use of the direct approach ensures that misspecification errors related to a different (i.e. non-rational) demand behavior of individual producers are avoided. However, the direct approach is not problem-free: as issues such as nonstationarity, endogeneity bias or serial correlation in the time series cannot be handled (they are masked under the non-linear form representation). Data for the composite good of capital-labour and energy $(QKLE_t)$ are not directly available and have to be constructed.

General Approach

This method is based on the derived factor demand functions which are obtained by solving the producer profit maximization problem (which under the assumption of perfect competition reduces to a cost minimization problem). This approach offers two critical advantages over the direct approach: i) the estimator of the elasticity of substitution takes account of information from the variation in prices and the economic behavior of the individual producers, and ii) the derived factor demand functions are estimated via a linear regression which takes into account possible time series problems like nonstationarity and autocorrelation. The main drawbacks of the approach relate to (i) the possible misspecification errors (market imperfections) and (ii) its vulnerability to measurement errors in prices and volumes.

As most of the time series in economics are nonstationary and are characterized by autocorrelation, the general approach has been preferred.

The objective function of the firm is formulated mathematically as follows:

$$\max \Pi = PKLE_t \cdot QKLE_t - PKL_t \cdot QKL_t - PE_t \cdot QE_t$$
$$s.t.\ QKLE_t = \gamma\left(\delta \cdot \left(e^{\lambda_1 \cdot t} \cdot QKL_t\right)^{\rho} + (1-\delta) \cdot \left(e^{\lambda_2 \cdot t} \cdot QE_t\right)^{\rho}\right)^{1/\rho} \tag{2}$$

where:

$PKLE_t$: composite good of capital-labour and energy, price index, 1995 =100

PKL_t: gross value added, price index, 1995 = 100

PE_t: total Energy, price index, 1995 = 100

The optimal factors demand (in a steady state) equations are:

$$\frac{QKL_t}{QKLE_t} = \delta^{\sigma} \cdot \gamma^{\sigma-1} \cdot e^{(\sigma-1)\cdot\lambda_1 t} \cdot \left(\frac{PKL_t}{PKLE_t}\right)^{-\sigma} \tag{3}$$

$$\frac{QE_t}{QKLE_t} = (1-\delta)^{\sigma} \cdot \gamma^{\sigma-1} \cdot e^{(\sigma-1)\cdot\lambda_2 t} \cdot \left(\frac{PE_t}{PKLE_t}\right)^{-\sigma} \tag{4}$$

Equations (3), (4) can be estimated either independently or as a system with a common parameter σ. Alternatively, by combining equations (3) and (4) we end up with a single equation to estimate the substitution of elasticity.

$$\frac{QE_t}{QKL_t} = \left(\frac{1-\delta}{\delta}\right)^{\sigma} \cdot e^{(\sigma-1)\cdot(\lambda_2-\lambda_1)t} \cdot \left(\frac{PE_t}{PKL_t}\right)^{-\sigma} \tag{5}$$

Equation (5) has the advantage that it does not require data for the composite good of capital – labour and energy.

In logarithmic form:

$$\ln\frac{QE_t}{QKL_t} = a + \varphi \cdot t + \beta \cdot \ln\frac{PE_t}{PKL_t} \tag{6}$$

where: $\beta = -\sigma$, $a = \sigma \cdot ln\left(\frac{1-\delta}{\delta}\right)$ and $\varphi = (\sigma-1)\cdot(\lambda_2 - \lambda_1)$.

To estimate equation (6) we first need to examine the time series properties of the variables to find their order of integration.

Many economic time series are difference-stationary

The Augmented Dickey–Fuller (ADF) unit root test (1979) is used to determine the order of integration for each sector of activity. The following variables are tested: i) the quantity ratio of energy to value-added inputs and ii) the price ratio of energy to value-added inputs. An appropriate number of lags is chosen, according to the minimum Schwarz criterion, to handle autocorrelation. Three cases in the deterministic part are examined: i) with a constant, ii) with a constant and trend and iii) without a constant or trend. Although the number of observations are limited, the test results provide strong evidence that most of the time series are integrated of order one[20], I(1).

Two estimators have been used to estimate the elasticity of substitution (OLS, FMOLS)

Due to the shortage of degrees of freedom, two alternative estimators are selected for the estimation of the elasticity of substitution. The first method uses a simple econometric technique which can handle stationarity, heteroscedasticity and autocorrelation problems of the economic time series. The second method uses an econometric technique which is based on an active area of research, the study of cointegrating relationships.

The first specification we used is based on the first differences (FD) of the variables and is appropriate when just one of the two ratios is I(1) or both are I(1) or I(0):

$$\Delta\left(\ln\frac{QE_t}{QKL_t}\right) = \varphi + \beta\cdot\Delta\left(\ln\frac{PE_t}{PKL_t}\right) + \varepsilon_t \tag{7}$$

Similarly, if just one of the two ratios are I(2), differences of first differences (second order differences) of the variables are used. We apply the Newey and West (1987) covariance estimator that is consistent in the presence of both heteroscedasticity and autocorrelation of unknown form.

The second specification we used is to estimate the single cointegrating equation (6) with the Fully Modified Ordinary Least Square (FMOLS) estimator proposed by Phillips and Hansen (1990). Depending on the deterministic part (i.e. constant, linear or quadratic trend) of the cointegrating equation, we estimate the three corresponding forms of the equation (6). The Park’s added variables test, Park (1992), has been used to select among these three forms. The test is computed by testing for the significance of spurious time trends in a cointegrating equation estimated by using the FMOLS method. We follow a specific to general approach[21]. In each regression, the Bartlett kernel nonparametric method and the Newey – West fixed bandwidth method are used to handle heteroscedasticity and autocorrelation.

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[20] All results on different lag structures for the stationarity test are available upon request from the authors.

[21] Initially we estimate the specification with a constant in the deterministic part and test if there are spurious linear and quadratic trend in the deterministic part. If the null hypothesis of this test is rejected, we estimate the specification with a constant and linear trend in the deterministic part and test if there are spurious quadratic and cubic trend in the deterministic part. Similarly, if the null hypothesis of the latter test is rejected, we estimate the specification with a constant, a linear and a quadratic trend in the deterministic part and test if there are cubic and quartic trend in the deterministic part. In the above steps we stop the process if the null hypothesis of the test for the spurious trends is accepted, and choose the respective specification.

Having selected the preferred cointegrating equation on the basis of Park's added variables test, we apply two additional tests[22]: (i) the Hansen instability test (1992) of the null hypothesis of cointegration against the alternative of no cointegration and (ii) the Engle–Granger (1987) cointegration test of the null hypothesis of no cointegration against the alternative of cointegration.

The estimation results strongly support the weak substitutability[23] of energy with the composite good of capital and labour

The elasticity of substitution was estimated for the 34 sectors[24] and 12 regions[25], a total of 408 cases. A qualitative overview of the estimation results is presented in Table V.7. There are relatively few cases (8 cases when the OLS estimator is used in first differences of the time series and 37 cases when the FMOLS estimator is used) where the sign of the estimated elasticity of substitution is statistically significant and negative, which contradicts the theory of the CES function[26]. Despite the rather low number of freedom, in many cases the estimated elasticity of substitution is positive and statistically significant (188 cases when the OLS estimator is used in first differences of the time series and 166 cases when the FMOLS estimator is used).

Table V.7: Qualitative overview of the estimations

Total number	OLS (FD)	FMOLS
Estimated equations	408	408
Cases with no data available	1	1
Cases with positive sign in σ	350	292
Cases with positive sign in σ and insignificant results*	162	126
Cases with negative sign in σ	57	115
Cases with negative sign in σ and insignificant results*	49	78

* Results are based on a two – tailed t – test for the elasticity of substitution

To examine whether energy and other production factors are complements or substitutes, two hypothesis tests are applied to the estimator of the substitution of elasticity in equations (6) and (7). The first hypothesis test is: $H_0\colon \sigma = 0\ \ vs\ \ H_1\colon\ \sigma > 0$, which examines whether the composite good of capital and labour is a complement with energy, and the second hypothesis test is: $H_0\colon \sigma = 1\ \ vs\ \ H_1\colon\ \sigma < 1$, which examines whether the composite good of capital and labour is a strong substitute to energy.

Table V.8 presents the number of occasions in which each null hypothesis was accepted, for each of the OLS and FMOLS estimators. The **results strongly support the hypothesis that energy is not a strong substitute with respect to the composite good of capital and labour**. Under the second specification, the OLS estimator, the null hypothesis, that energy and capital-labour are substitutes, is

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[22] Both tests verify that a cointegration relationship exists confirming Park's added variable test (test results are available upon request)

[23] A low positive level of the elasticity of substitution towards zero.

[24] See Appendix C.

[25] Austria, Belgium, France, Germany, Great Britain, Greece, Italy, Netherlands, Poland, Portugal, Romania, and Spain.

[26] A negative sign of the elasticity of substitution corresponds to a non-canonical producer behaviour (i.e. an increase in the price of a factor implies an increase of its use in the production process).

rejected in the 84% of the total of 407 cases examined. This number increases to 91% if the FMOLS estimator is used.

Table V.8: Number of acceptances of the null hypothesis

Activity		OLS (FD)		FMOLS	
		H_0: $\sigma = 0$	H_0: $\sigma = 1$	H_0: $\sigma = 0$	H_0: $\sigma = 1$
AtB	Agriculture etc	8	2	8	0
C	Mining and Quarrying	5	2	9	0
15t16	Food, Beverages and Tobacco	6	0	5	0
17t18	Textiles and Textile Products	3	2	5	0
19	Leather, Leather and Footwear	3	4	3	3
20	Wood and Products of Wood and Cork	4	5	4	1
21t22	Pulp, Paper, Paper , Printing and Publishing	7	0	10	0
23	Coke, Refined Petroleum and Nuclear Fuel	8	0	8	1
24	Chemicals and Chemical Products	8	0	8	0
25	Rubber and Plastics	5	8	4	2
26	Other Non-Metallic Mineral	9	0	8	0
27t28	Basic Metals and Fabricated Metal	7	2	6	2
29	Machinery, Nec	5	2	5	2
30t33	Electrical and Optical Equipment	5	2	6	2
34t35	Transport Equipment	8	0	8	3
36t37	Manufacturing, Nec; Recycling	4	7	6	4
E	Electricity, Gas and Water Supply	9	0	7	0
F	Construction	7	0	8	0
50	Sale of motor vehicles and fuel, etc.	9	2	9	2
51	Wholesale trade	6	1	11	1
52	Retail trade	10	2	7	1
H	Hotels and Restaurants	10	2	10	3
60	Inland Transport	11	0	9	0
61	Water Transport	8	1	8	0
62	Air Transport	6	3	8	3
63	Other transport activities	10	1	8	0
64	Post and Telecommunications	7	3	9	1
J	Financial Intermediation	11	2	10	3
70	Real Estate Activities	9	4	10	2
71t74	Renting of M&Eq and Oth Business Activities	9	3	9	0
L	Public Admin and Defence; etc	8	2	7	1
M	Education	8	1	11	0
N	Health and Social Work	8	1	9	1
O	Other Community, Social, Personal Services	10	3	10	0
	Total	251	67	263	38

There are only a few sectors where energy appears to be a substitute and these are: (19) Leather, and (36t37) Manufacture of furniture, waste recycling etc. These sectors are selected as the H0:σ=1 null hypothesis is accepted sufficient times in both estimators. Our results indicate that energy is an essential input with very limited scope for substitution.

The elasticity of substitution (E, KL) in 85% of cases is less than 0.7

Focusing on the elasticity of substitution by sector and by region we present in

Table V.9 the results only for those cases that are both significant and have a positive sign (consistent with economic theory that underlies the CES function).
The two estimators give similar results. In most of the cases the elasticity of substitution is lower than 0.7 supporting the weak substitutability hypothesis. Sectors such as Coke, Refined Petroleum and Nuclear Fuel (23), Inland Transport (60), and Construction (F) have limited substitution possibilities (as expected) between the energy and the composite good of capital and labour.

Analytical results for each sector and region are presented in

Table V.10 and Table V.11. Sectors such as Textiles and Textile Products (17t18), Wood and Products of Wood and Cork (20), and Post and Telecommunications (64) have similar estimates across countries.

Table V.9: Energy substitution elasticities: results from the OLS and FMOLS estimators

Activity	OLS (FD)				FMOLS			
Abbr.	max	min	median	number of cases*	max	min	median	number of cases*
AtB	0.72	0.30	0.41	5	0.68	0.33	0.38	5
C	0.83	0.23	0.44	7	0.72	0.22	0.29	3
15t16	0.55	0.18	0.34	7	0.55	0.12	0.32	7
17t18	0.65	0.24	0.52	9	0.67	0.28	0.48	7
19	1.19	0.37	0.50	11	1.36	0.30	0.50	9
20	0.72	0.41	0.62	9	0.63	0.37	0.46	9
21t22	0.44	0.31	0.37	5	0.38	0.15	0.16	3
23	0.76	0.10	0.17	5	0.76	0.15	0.20	5
24	0.41	0.20	0.32	4	0.50	0.13	0.29	4
25	0.88	0.48	0.72	8	0.92	0.27	0.48	9
26	0.34	0.26	0.28	4	0.38	0.16	0.19	4
27t28	0.77	0.11	0.36	5	0.95	0.12	0.48	6
29	0.59	0.15	0.32	9	0.68	0.15	0.38	7
30t33	0.80	0.21	0.42	8	1.04	0.22	0.45	7
34t35	0.70	0.18	0.37	7	0.54	0.22	0.43	8
36t37	0.99	0.25	0.65	9	0.80	0.32	0.59	6
E	0.51	0.18	0.41	4	0.53	0.04	0.22	5
F	0.44	0.14	0.29	7	0.31	0.15	0.20	4
50	0.87	0.23	0.46	4	0.73	0.15	0.52	3
51	0.85	0.11	0.24	6	0.79	0.16	0.18	3
52	0.76	0.20	0.41	3	0.46	0.14	0.28	5
H	0.72	0.42	0.57	2	1.11	0.69	0.90	2
60	0.13	0.10	0.11	2	0.32	0.13	0.26	4
61	0.84	0.08	0.26	3	0.53	0.10	0.18	5
62	1.02	0.36	0.48	6	1.08	0.12	0.55	6
63	0.56	0.21	0.23	5	0.55	0.21	0.38	4
64	0.68	0.32	0.47	7	0.69	0.40	0.48	3
J	0.68	0.23	0.30	3	0.70	0.19	0.41	4
70	0.86	0.67	0.69	3	1.18	0.82	1.00	2
71t74	0.70	0.21	0.57	4	0.61	0.11	0.28	4
L	0.70	0.11	0.30	4	0.81	0.19	0.25	6
M	0.56	0.21	0.28	5	0.67	0.67	0.67	1
N	0.80	0.21	0.54	4	0.65	0.27	0.49	4
O	0.75	0.23	0.58	4	0.66	0.27	0.47	2

*Cases that are both significant and have a positive sign.

Table V.10: Analytical results for each sector and region of the OLS estimator

Activity	Austria	Belgium	France	Germany	Great Britain	Greece	Italy	Netherlands	Poland	Portugal	Romania	Spain
AtB	0.30	0.41			0.72					0.51		0.38
C	0.43		0.59	0.44		0.23	0.83				0.41	0.50
15t16	0.46	0.34		0.37	0.19	0.55				0.26		0.18
17t18	0.32	0.53	0.64	0.57		0.65	0.29	0.52		0.24	0.29	
19	0.49	0.67	0.40	0.70	0.47	1.19	0.37	0.60		0.51	0.47	0.50
20	0.56	0.62		0.71	0.72		0.42	0.66		0.41	0.49	0.62
21t22				0.44		0.35			0.31		0.42	0.37
23	0.24	0.10		0.76	0.13			0.17				
24				0.41	0.40						0.23	0.20
25		0.71		0.81	0.58	0.73			0.62	0.48	0.85	0.88
26		0.26			0.29						0.34	0.28
27t28		0.11				0.36	0.77			0.70		0.18
29	0.27	0.26			0.15	0.59	0.32	0.56		0.49	0.29	0.36
30t33	0.32	0.45		0.72		0.80	0.21			0.29	0.39	0.77
34t35	0.53				0.18		0.31	0.70		0.37	0.49	0.28
36t37		0.71		0.99	0.62		0.38	0.25	0.65	0.77	0.56	0.90
E			0.51		0.51	0.18				0.31		
F					0.14		0.22	0.19	0.41	0.29	0.31	0.44
50	0.87	0.23		0.66				0.27				
51	0.85	0.19			0.19			0.36	0.11		0.29	
52	0.76				0.20						0.41	
H	0.72										0.42	
60				0.13							0.10	
61				0.84						0.26		0.08
62			0.60	0.37		1.02				0.36	0.56	0.40
63	0.56			0.23	0.21			0.47			0.21	
64	0.63	0.47		0.32	0.45			0.50	0.68		0.36	
J	0.68							0.30		0.23		
70	0.69			0.86							0.67	
71t74	0.60	0.21		0.54					0.70			
L			0.11					0.70		0.34		0.25
M		0.24						0.43		0.56	0.28	0.21
N	0.80	0.21						0.41		0.66		
O	0.65	0.23								0.75	0.52	

Table V.11: Analytical results for each sector and region of the FMOLS estimator

Activity	Austria	Belgium	France	Germany	Great Britain	Greece	Italy	Netherlands	Poland	Portugal	Romania	Spain
AtB		0.35			0.68			0.55		0.38		0.33
C	0.72					0.22			0.29			
15t16	0.55	0.32			0.12		0.40		0.54	0.14		0.15
17t18	0.28	0.29	0.50	0.58			0.45	0.48	0.67			
19	0.72	0.50	0.30	0.72		1.36	0.50	0.77		0.46		0.40
20	0.37	0.63		0.48		0.46	0.40	0.57		0.39	0.41	0.60
21t22						0.15					0.38	0.16
23	0.58		0.18	0.76	0.15			0.20				
24				0.50	0.35			0.13				0.24
25	0.92			0.33	0.27	0.69	0.33		0.48	0.58	0.33	0.75
26		0.16			0.16						0.21	0.38
27t28		0.12				0.61	0.95	0.34		0.78		0.13
29		0.31		0.68	0.15	0.68	0.38	0.59				0.35
30t33		0.46		1.04	0.22	0.85	0.32			0.26		0.45
34t35	0.48			0.49	0.33		0.28	0.52		0.22	0.38	0.54
36t37	0.58	0.40		0.80		0.60	0.32					0.80
E			0.40	0.04	0.53			0.22		0.20		
F			0.15				0.19			0.31	0.22	
50	0.73	0.15		0.52								
51	0.79				0.16					0.18		
52	0.29			0.28	0.20			0.14			0.46	
H	1.11										0.69	
60					0.20	0.31				0.13	0.32	
61				0.53	0.10		0.18			0.34		0.12
62	0.56		0.54			0.40			1.08	0.12	0.93	
63	0.55	0.21	0.36	0.40								
64				0.40				0.69	0.48			
J	0.59			0.70				0.19	0.24			
70				1.18							0.82	
71t74	0.61	0.21	0.11	0.35								
L	0.19	0.25			0.23		0.44	0.81		0.26		
M										0.67		
N	0.65	0.27						0.47		0.51		
O		0.27								0.66		

The elasticity of substitution of energy with respect to other factors of production is relatively stable over time

Our estimates are in line with the findings of the literature surveyed (Table V.12) and suggest weak substitution among energy and capital-labour production factors. This holds true for the majority of the EU sectors. Comparing our estimations with older studies that have used older datasets we conclude that the low elasticity of substitution between energy and other production factors is relatively stable over time.

Table V.12: Energy substitution elasticities: Comparison with empirical literature

	Empirical Literature			OLS (FD)			FMOLS		
	max	min	median	max	min	median	max	min	median
Chemical	0.96	0.04	0.39	0.41	0.20	0.32	0.50	0.13	0.29
Electric goods	0.32	0.06	0.23	0.80	0.21	0.42	1.04	0.22	0.45
Food	0.74	0.39	0.55	0.55	0.18	0.34	0.55	0.12	0.32
Machinery	0.32	0.12	0.22	0.59	0.15	0.32	0.68	0.15	0.38
Non-Ferrous	0.77	0.10	0.24	0.77	0.11	0.36	0.95	0.12	0.48
Iron	0.98	0.07	0.21	0.77	0.11	0.36	0.95	0.12	0.48
Non-Metallic minerals	0.98	0.09	0.33	0.34	0.26	0.28	0.38	0.16	0.19
Pulp and paper	0.96	0.15	0.38	0.44	0.31	0.37	0.38	0.15	0.16
Textile	0.33	0.17	0.25	0.65	0.24	0.52	0.67	0.28	0.48
Transport	0.88	0.31	0.54	1.02	0.36	0.48	1.08	0.12	0.55
Transportation equipment	0.35	0.09	0.28	0.70	0.18	0.37	0.54	0.22	0.43
Wood	0.13	0.05	0.09	0.72	0.41	0.62	0.63	0.37	0.46

We performed the Hansen[27] instability test to examine the parameters instability. In our case the Hansen test confirmed that parameters were stable, supporting the hypothesis that a cointegrating relationships exists.

3 Comparison with macroeconomic models

The elasticities estimated in the previous section not only serve as a benchmark to evaluate the degree of substitutability between energy and the other production factors but can be directly used to parameterize the CES production functions of CGE models.

Both the GEME3 and E3ME macro models will benefit from the new estimates.

In the GEME3 model there is a direct correspondence to its nested CES production function.

GEME3 uses a central value of 0.25 for the elasticity of substitution between capital-labour and energy (all countries and sectors). The econometric findings of this study suggest that GEME3 model could vary this central value across sectors and regions. Under a climate policy scenario this change will have distributional and scale effects on the resulting impacts across sectors and regions. But it should be noted that the median value of the elasticity of substitution for each sector is not very different from the GEME3 central value. In some sectors the GEME3 central value of the elasticity

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[27] Hansen (1992) proposed a Lagrange Multiplier type test to evaluate the stability of the parameters and utilized these stability evidences to test the null hypothesis if a cointegration relationship exists under the alternative of no cointegration. He notes that the parameters instability is present when no cointegration relationship exists.

of substitution is lower than the values suggested through the econometric analysis. In these cases adoption of the new estimates would make substitution between energy and capital/labour less costly than in the present model.

E3ME uses time series analysis separately for each fuel user category, country and sector to estimate cointegrating[28] equations for aggregate energy demand. The main difference compared with GEME3 is the estimated functional form: E3ME relates the use of energy to each sector's output, whereas in GEME3 (and the estimates presented above) the relationship is between energy and value added. Even so, the values of the elasticity are similar to the econometric findings presented above, as indicated by Table V.13.

Table V.13: Comparison of E3ME elasticities and the elasticities estimated in this study

	E3ME	OLS (FD)	FMOLS
Power own use & trans.	NA	NA	NA
Energy own use & transformation	-0.21	NA	NA
Hydrogen production	NA	NA	NA
Iron & steel	-0.27	-0.36(1)	-0.48(1)
Non-ferrous metals	-0.44	-0.36(1)	-0.48(1)
Chemicals	-0.75	-0.32	-0.29
Rubber and Plastics		-0.72	-0.48
Non-metallics nes	-0.31	-0.28	-0.19
Ore-extra.(non-energy)	-0.24	-0.44(2)	-0.29(2)
Food, drink & tob.	-0.50	-0.34	-0.32
Tex., cloth. & footw.	-0.44	-0.52	-0.48
Paper & pulp	-0.64	-0.37(3)	-0.16(3)
Engineering etc	-0.43	-0.32	-0.38
Other industry	-0.35	-0.37	-0.43
Construction	-0.33	-0.29	-0.20
Rail transport	-0.24	-0.11(4)	-0.26(4)
Road transport	NA	-0.11(4)	-0.26(4)
Air transport	-0.40	-0.48	-0.55
Other transp. serv.	-0.23	-0.23	-0.38
Households	-0.22	NA	NA
Agriculture, forestry	-0.21	-0.41(5)	-0.38(5)
Fishing	-0.34	-0.41(5)	-0.38(5)
Commerce	-0.27	-0.30(6)	-0.41(6)
Non-energy use	-0.20	NA	NA

Notes: Corresponds to: (1) Basic Metals, (2) Mining and Quarrying (3) Pulp, paper and printing, (4) Inland Transport, (5) Agriculture, forestry and fishing, (6) Financial Intermediation

Our estimations on capital-energy elasticity of substitution indicates that the two production factors are weak substitutes. This finding is consistent with the stream of econometric analysis that bases its estimates on time series. A direct implication of the weak substitutability character of capital & energy is that a rise in energy prices will not increase investments as expected if it is not accompanied by a change in technology (i.e. the use of a more efficient and expensive capital).

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[28] See Appendix C for more details of the specification in E3ME.

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Appendix B: Decomposition analysis methodology

The energy intensity decomposition analysis in Part II of this report uses the following methodology.

Energy intensity (EI) is the ratio of total energy use (E) to value added (Y). This ratio can be expressed as a combination of within-sector energy intensities (EIi) and sector shares of total value-added (Si), where i denotes the sectors of the economy:

$$EI = \frac{E}{Y} = \sum_i \frac{E_i}{Y_i}\frac{Y_i}{Y} = \sum_i EI_i\, S_i$$

From this equation, changes in energy intensity between period 0 and period T can be decomposed into an efficiency effect and a structural effect:

$$\Delta EI_{eff} = \sum_i w_i \,\ln\left(\frac{EI_i^T}{EI_i^0}\right)$$

$$\Delta EI_{str} = \sum_i w_i \,\ln\left(\frac{S_i^T}{S_i^0}\right)$$

where each sector effect is weighted by the logarithmic average of their share of total energy use between period 0 and period T:

$$w_i = \frac{\left(\frac{E_i^0}{\sum_i E_i^0}\right) - \left(\frac{E_i^T}{\sum_i E_i^T}\right)}{\ln\left(\left(\frac{E_i^0}{\sum_i E_i^0}\right) \Big/ \left(\frac{E_i^T}{\sum_i E_i^T}\right)\right)}$$

Appendix C: Detailed econometric methods and results (for Part V)

Table 0.1: Sector definitions for abbreviations used in Part VIII

Abbr.	Description
AtB	Agriculture, Hunting, Forestry and Fishing
C	Mining and Quarrying
15t16	Food, Beverages and Tobacco
17t18	Textiles and Textile Products
19	Leather, Leather and Footwear
20	Wood and Products of Wood and Cork
21t22	Pulp, Paper, Paper , Printing and Publishing
23	Coke, Refined Petroleum and Nuclear Fuel
24	Chemicals and Chemical Products
25	Rubber and Plastics
26	Other Non-Metallic Mineral
27t28	Basic Metals and Fabricated Metal
29	Machinery, Nec
30t33	Electrical and Optical Equipment
34t35	Transport Equipment
36t37	Manufacturing, Nec; Recycling
E	Electricity, Gas and Water Supply
F	Construction
50	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
51	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
52	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
H	Hotels and Restaurants
60	Inland Transport
61	Water Transport
62	Air Transport
63	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
64	Post and Telecommunications
J	Financial Intermediation
70	Real Estate Activities
71t74	Renting of M&Eq and Other Business Activities
L	Public Admin and Defence; Compulsory Social Security
M	Education
N	Health and Social Work
O	Other Community, Social and Personal Services

Table 0.2: E3ME aggregate energy demand equations

Co-integrating long-term equation:

LN(FR0(.)) [total energy used by energy user]
= BFR0(.,10)
+ BFR0(,.11) * LN(FRY(.)) [activity measure]
+ BFR0(.,12) * LN(PREN(.)) [average price ratio]
+ BFR0(.,13) * LN(FRTD(.)) [R&D by energy user]
+ BFR0(.,14) * LN(ZRDM) [global R&D in machinery]
+ BFR0(.,15) * LN(ZRDT) [global R&D in transport]
+ BFR0(.,16) * LN(FRK(.)) [investment by energy user]
+ ECM [error]

Dynamic equation:

DLN(FR0(.)) [total energy used by energy user]
= BFR0(.,1)
+ BFR0(.,2) * DLN(FRY(.)) [activity measure]
+ BFR0(.,3) * DLN(PREN(.)) [average price ratio]
+ BFR0(.,4) * DLN(FRTD(.)) [R&D by energy user]
+ BFR0(.,5) * DLN(ZRDM) [global R&D in machinery]
+ BFR0(.,6) * DLN(ZRDT) [global R&D in transport]
+ BFR0(.,7) * DLN(FRK(.)) [investment by energy user]
+ BFR0(.,8) * DLN(FR0(-1)) [lagged change in energy use]
+ BFR0(.,9) * ECM(-1) [lagged error correction]

Identity:

PREN = PFR0(.) / PRYR [relative price ratio]

Restrictions:

BFR0(.,3 .,4 .,5 .,6 .,7 .,12 .,13 .,14 .,15 .,16) <= 0 [‘right sign’]
BFR0(.,2 .,11) >= 0 [‘right sign’]
0 > BFR0(.,9) > -1 [‘right sign’]

Definitions:

BFR0	is a matrix of parameters
FR0	is a matrix of total energy used by 22 energy users for 53 regions, th toe
PFR0	is a matrix of average energy prices for 22 energy users and 53 regions, euro/toe
PRYR	is a matrix of average producer prices in the economy as a whole (2005 = 1.0, local currency)
FRY	is a matrix of activity for 22 energy users and 53 regions, m euro at 2005 prices
FRTD	is a matrix of R&D by 22 energy users for 53 regions, m euro at 2005 prices
ZRDM	is global R&D in machinery, m euro at 2005 prices
ZRDT	is global R&D in transport, m euro at 2005 prices
FRK	is a matrix of investment by 22 energy users for 53 regions, m euro at 2005 prices