European Commission

EU energy trends and macroeconomic performance

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Study on the Macroeconomics of Energy and Climate Policies

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Executive Summary

This report highlights the main historical trends in the EU's energy demand and supply, setting them in the context of wider global trends, summarises views on the key drivers of those trends, and discusses the macroeconomic importance of energy. It then draws lessons for priorities for macro-energy model development to improve analytical support for energy-related policy-makers.

Trends in energy consumption and intensity

- Global **primary energy consumption** has increased by 2% pa since the early-1970s, reflecting strong growth in Asia and much slower growth in the US and the EU.
- There have been different trends in the **mix of fuels** in EU28 and rest of the world. In the EU28 over 1990-2007, demand for coal (and other solid fuels) fell and that for petroleum products was little-changed, while demand for gas rose substantially. Since 2007 EU28 demand for all fuels has fallen with the exception of renewables, which have seen a strong growth. Non-EU OECD saw demand for all fuels increase over 1990-2007, but has since seen trends similar to the EU28. In non-OECD countries, growth in fossil fuel consumption has accelerated in recent years, whereas renewables consumption has kept a steady pace largely due to traditional biomass use in heating and cooking.
- Growth in **final energy consumption** has varied across the globe depending on **structural changes** in the economy. In the EU28 and the US, final energy consumption has been driven, over the last three decades, by transport and services. In Asia and China, strong growth in manufacturing output has more than trebled energy demand by industry. In the EU's wealthier countries, increases in final energy demand have been led by residential, transport and tertiary users. In the newer Member States of Central and Eastern Europe, post-Communist structural change in industry and sharply reduced energy-intensity have driven a fall in overall final energy demand.
- **Electricity** is accounting for a growing share of final energy consumption in EU28, and within this the share of **renewable electricity** has risen, particularly since 2000.
- At an aggregate level, **energy intensity** in the EU has been declining steadily since the 1990s, with the more recent EU member states, on average, experiencing faster declines in energy intensity than their "older" counterparts.
- **Drivers of EU energy intensity decline** are varied, and include economic growth dynamics, structural economic changes, market-driven and policy-induced energy efficiency improvements, global energy prices, and trend temperature changes. The 2008 recession was unusual in that GDP fell by more than energy consumption, reflecting the fact that the sectoral impact was led by the decline in (low energy-intensive) banking.
- The **greenhouse gas intensity** of EU energy consumption has fallen by 19% over 1990-2013, driven partly by a shift towards less carbon-intensive fuels. The same trends that are reducing energy dependency and vulnerability to global fossil fuel energy price shocks (lower energy intensity, increased share of non-fossil fuel energy sources) are also driving reductions in greenhouse gas intensity. Differences between Member States in the extent to which power

generation is based on low-carbon and renewable energy are an important driver of their differences in greenhouse gas intensity of (overall) energy consumption.

- The EU28 as a whole experienced a steady rise in **energy import dependency** over 1990-2008, reaching a peak in 2008 of almost 55%. Since 2008 the decline in energy demand and the development of renewable energy power generation capacity have been associated with a flattening-off of the upward trend in import dependency.
- **Sources of energy imports** are concentrated among a small number of countries, increasing the EU's exposure to supply shocks. In other words, high energy dependency exposes the EU economy to global energy price fluctuations.

Trends in investment in power generation and energy innovation spending

- There has been a rapid expansion of **renewable generation capacity in Europe** over the last decade. The growth has been predominantly in **wind** and **solar** capacity.
- However, this is part of a global trend, with data showing the strongest growth in **renewable capacity** installed happening in **China**, whereas more modest renewable expansion is registered in the US and Japan. Net installed renewable capacity in China now exceeds that installed in EU28.
- **Global public budgets for RD&D in energy technology** are high historically and the shares of renewables and energy efficiency have increased in the past decade so that they each now broadly match the budget for nuclear.
- In the **EU** that trend has been more pronounced: Public RD&D budgets in Europe are more focused on **spending on energy efficiency** and **renewable energy sources.**

Understanding the drivers of energy consumption

- The relatively fast reduction in energy intensity observed for the **US and EU** in the last decade could be partly attributed to structural reasons. Faster growth in less energy-intensive sectors in the economy, such as the production of electronic consumer goods or improvements in energy efficiency were made possible by **the high rate of investment in new capital equipment**.
- In the **US and Europe**, studies suggest that **structural change has a less important role in influencing energy intensity than does energy efficiency**.
- While analyses that have sought to account for the change in energy intensity attribute a substantial part of the change to improvements in technological efficiency, such improvements are themselves the outcome of **decisions** on the part of suppliers **to innovate** in order to provide more efficient equipment, and on the part of energy users **to invest** in this equipment. The key question for policy, and for policy modelling, is what drives these decisions. **Relevant drivers include the price of energy, regulation and policy, financing conditions, incentives for R&D, and the availability of knowledge spillovers**.

The macroeconomic importance of energy

- Energy contributes to the macro-economy in terms of the **value added, income and employment** that it generates from its production, transformation and distribution (and associated equipment); the **functioning of the economy**, firms and households that are dependent on cheap and reliable energy use; and the **waves of innovation** that it generates on both the supply and demand side and which are often inextricably linked to major transformations in society and economic performance.
- Over 2000-14, output by the EU energy sector fell as a share of overall economic activity and in absolute value, led by a decline in extraction of primary energy sources. **The energy sector accounts for a smaller share of the EU economy than it does in the US, Japan or China** (the share of the energy sector in overall value added is currently estimated at just above 2% for the EU, almost 3% for Japan, almost 4% for US, and around 7% for China). This is partly to do with the geographical distribution of fossil fuel resources, but it also reflects the structure and relative energy efficiency/intensity of the rest of the economy.
- Employment in the EU energy sector has fallen at a similar rate to the decline in output, so **EU28 has seen little change in levels of value-added per worker** in the sector. The energy sector accounts for a smaller share of jobs in the US than in the EU, but a larger share of value added, reflecting higher labour productivity in the sector in the US.
- **The majority of EU energy sector jobs are in the production and supply of electricity, gas and steam**; the loss of employment in this sub-sector has been less rapid than in mining or fuel processing activities.
- Regardless of whether it is produced domestically or imported, energy is an essential input to production. In the neoclassical tradition, this is recognised in those production functions that include energy as an explicit factor. However, estimating the contribution of energy to production is distinct from the question of the **necessity of energy as an input**; an input can be absolutely essential for production to continue, but its value contribution to production and growth can nevertheless be small. In the production function tradition, the necessity issue is treated by considering the scope for substitution between energy and other inputs (notably capital).
- Some, but not all, empirical literature suggests that capital and energy are complements, or only weak substitutes. However, despite the large number of studies carried out, no clear conclusion has been reached either in terms of sign or magnitude. This has important implications for the choice of policy design. **If energy and capital are complements**, they will respond to price changes moving in the same direction. In this case, for example, **the promotion of innovation in, and the diffusion of, energy-efficient technologies will be effective** in reducing energy consumption. **If energy and capital are substitutes, a carbon tax could be preferred**, bringing about a change in relative prices and a shift in the relative shares of energy and capital.
- Some studies suggest that energy 'causes' growth, rather than the other way round, but there is **no clear consensus on the direction of causality between energy and GDP**, suggesting circular causation or bi-directional causality.

- Renewable power generation plants are more capital-intensive than fossil fuel plants. **The substitution of renewable energy capital for fossil fuel inputs** offers the opportunity to **reduce exposure to volatile global energy prices**. If the capital equipment is produced within Europe, it also offers the possibility of **reducing Europe's energy trade deficit**, and, potentially through first-mover advantages, **establish an industry that can serve leading global markets**.
- **Europe's strength is in the production of components for wind generation rather than for solar generation** (where China is dominant). In 2013 there were an estimated 300,000 direct and indirect (i.e. in the supply chain) jobs in the EU's wind power sector and 160,000 direct and indirect jobs in its photovoltaic industry.
- In the majority of studies investigating the impact of energy efficiency and low carbon technological improvement on labour, the **likely net employment effects tend to be positive, irrespective of the modelling approach** used. For instance, investment in energy efficiency can improve the competitive position of sectors (where energy-efficiency options are cost-effective), boost employment in more labour-intensive sectors providing energy efficient goods and services (e.g. buildings and construction sector), and release household spending on energy and make it available to purchase other goods and services.
- **Energy is essential for household wellbeing and for helping lift people out of poverty.** In 2014, around 10% of households in the EU were not able to keep their home adequately warm, a figure that rises above 25% in Bulgaria, Greece, Portugal, Cyprus and Lithuania. The incidence of fuel poverty in the EU as a whole has broadly followed the economic cycle, with rates falling as the pre-recession peak was reached and rising in periods of recession or weak growth such as 2009-12. In most countries poorer households spend a higher proportion of their income on energy services.
- **Energy costs may affect industrial competitiveness, particularly that of energy-intensive sectors**. The EU has seen a reduction in the share of energy-intensive industries in its GDP in the past decade, whereas in the US the share has increased a little, perhaps reflecting the impact of the shale gas revolution on energy costs in the US. While EU's higher energy costs may be associated with weaker export performance, it is difficult to identify the impact of energy costs on the output and investment decisions of energy-intensive industries.

Drawing lessons for the future: How the drivers of energy demand and greenhouse gas emissions might be different in the future than in the past

- Because energy-intensive sectors now account for a smaller share in the overall economy, **future reductions in energy intensity need to be more focused on buildings**, both residential and non-residential.
- **Cuts in carbon emissions will depend on transport electrification and decarbonisation of power generation**. Future cuts will require greater take-up of renewable sources in power generation, a trend that has already been evident in the most recent years.
- **In the longer term**, **emissions sources that** are not the first priorities for the next decade and **are currently more costly to reduce**, including process emissions and aviation **will need to be addressed**.

Drawing lessons for the future: How the macro-energy models can be adapted to better address key issues in the future

- There would be substantial benefit in **more detailed modelling** (including behavioural issues) **of household energy use** and uptake by consumers of innovations that promote energy efficiency and low-carbon use. Making the macroeconomic link to the impacts on household spending of (1) the financing of expenditure on the technologies, and (2) the spending of the income released by lower spending on energy would benefit macro-energy modelling.
- The scale of investment required to decarbonise Europe's power generation sector is very large and will require the mobilisation of private finance. The **factors that may hinder or promote the flow of funds into decarbonising energy supply** are not yet well represented in the models.
- Furthermore, the macroeconomic impact depends critically on whether such mobilisation would divert investment away not only from the fossil-fuel power plants that would otherwise be built but also from other sectors in the economy. **Crowding out of investments** should be further **empirically assessed** and **explicitly represented in the modelling**, where necessary.

Drawing lessons for future: Key energy-related policy messages

- Because future reductions in energy intensity are likely to be more focused on buildings, this suggests an important role for policies that work alongside energy prices to promote those reductions. In other words, there is the need for a greater role for **energy-related policies that tackle non-price barriers** and support the incentives given by energy prices.
- There has been a recovery in the **scale of public RD&D budgets in energy technologies** in recent years, and a growing share of spending on renewables and energy efficiency. This effort **needs to be sustained and accelerated** to maintain the 'upstream' flow of new technologies.
- A greater emphasis would need to be given to **policies that address obstacles to private finance** for investment in renewables in power generation.
- The energy transition to a low carbon economy can also yield benefits in terms of lower energy dependence and more jobs, but the net losers and winners are geographically concentrated. The fossil-fuel extraction industry is associated with skills that are not readily transferred to other sectors. As such, EU-wide and national-level **policy support** will be needed **to facilitate the transition to sustainable energy** systems and avoid the deterioration of human and social capital associated with the loss of major local employers (including skill reorientation and formation).
- **Policies promoting the energy transition need to keep in view the wider land-use and environmental impacts**, both complementary (as in the case of fossil-fuel local air pollutants) and competing (as in the case of some aspects of the energy-water-food nexus).

Part I. Introduction

This report has been prepared as the first deliverable within a wider project intended to improve the way that the relationship between changes in the energy system and in the wider macroeconomy are understood and modelled (with an emphasis on EU energy innovation and finance issues), so as to better support EU policy-makers.[1]

This report begins by highlighting the main historical trends in the EU's energy demand and supply, setting them in the context of wider global trends, and summarises views on the key drivers of those trends. It then draws lessons for priorities for the macro-energy model development to be carried out in the rest of the project. The work underpinning this report is motivated both by what is needed to better capture the expected drivers of energy-related trends in the future and by what is needed to better represent the kinds of energy-related policies whose potential impacts are likely to require assessment.

[1] European Commission, DG ENER funded project "Study on the macroeconomics of energy and climate policies". The Terms of Reference are available at: https://ec.europa.eu/energy/en/content/study-macroeconomics-energy-and-climate-policies , and the contract notice published in the TED (Tenders Electronic Daily) system, the online version of the 'Supplement to the Official Journal' of the EU is available at: http://ted.europa.eu/udl?uri=TED:NOTICE:159373-2015:TEXT:EN:HTML

Part II. Trends in key energy indicators

This section reviews the historical long-term trends in key indicators of EU energy-related developments and compares them where possible to trends in various non-EU regions. Key differences in the trends by Member State are also distinguished where appropriate.

1 Primary energy consumption

Global primary energy consumption has increased by 2.2% pa over 1971-2013, reflecting strong growth in Asia (4.6% pa) and much slower growth in the US and the EU (0.8% pa)

Between 1971 and 2013, global primary energy consumption more than doubled (equivalent to a 2% pa average rate of growth over that period). As shown in Figure II.1, there has been considerable variation in energy consumption trends between global regions.

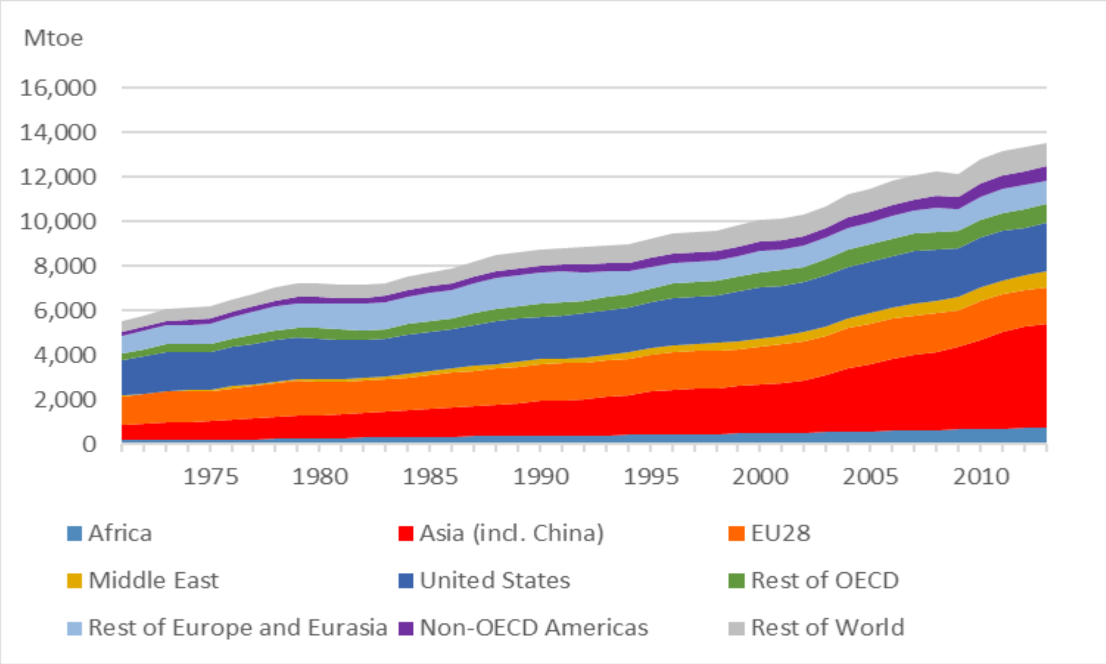
In the early 1970s, energy consumption in the EU28 and the US together accounted for around 50% of global primary energy consumption. Modest income and GDP growth in these countries, together with a structural transition away from more energy-intensive manufacturing industries towards service sectors, have meant that, since 1971, energy demand in the EU28 and the US has increased at a relatively slow rate of 0.8% pa. By 2013, the EU28 and the US accounted for a 12% and 16% share, respectively, of global primary energy consumption. In addition to structural change, industries themselves have become more energy efficient since the 1970s as a result of technical advances in part stimulated by legislation and increasing and erratic fuel prices[2].

By contrast, in Asia, strong economic growth, rising incomes and export-driven demand for products from heavy-industry sectors have led to a 4.6% pa annual increase in primary energy consumption over the same period. By 2013, Asia consumed around 35% of the global primary energy supply, up from 13% in 1971.

In Africa and the non-OECD Americas, economic growth and development has been slower. These countries continue to consume a small share (around 5% each) of global primary energy. The Middle East also accounts for a small share of global primary energy consumption but, as shown in Figure II.1, this region has seen strong growth in primary energy consumption over the past 40 years, as output in the extraction and refining industries has increased substantially, population and real incomes have grown rapidly, while domestic energy prices have remained relatively low.

[2] See Part III.1 for further discussion on economic activity and energy intensity.

Figure II.1 Primary energy consumption by global region

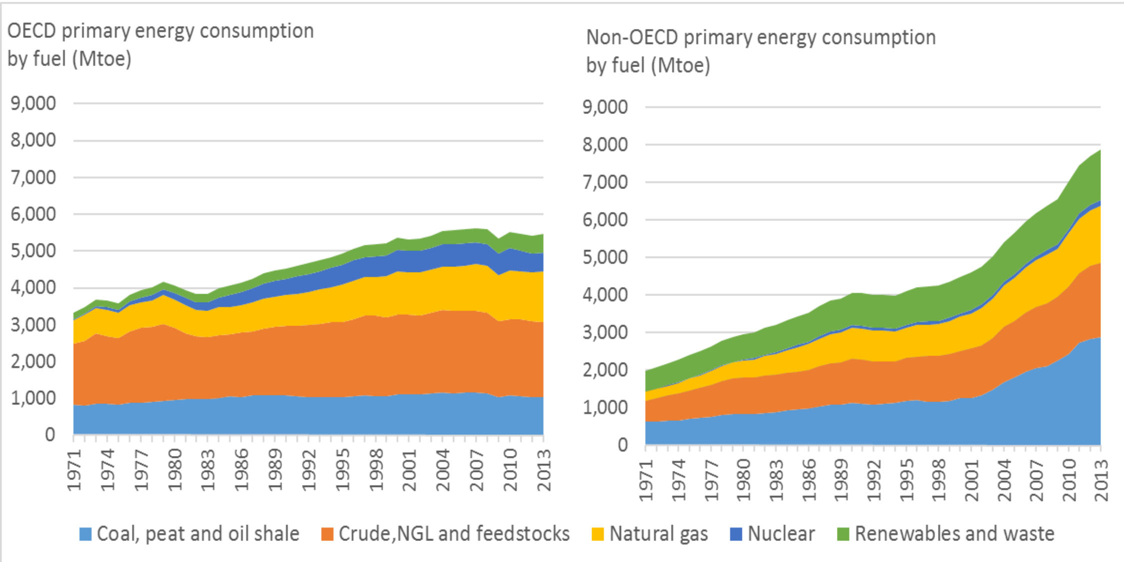


Sources: IEA Energy Balances (2015), Eurostat Energy Statistics

There have been different trends in the mix of fuels in EU28, rest of OECD and rest of the world.

Figure II.2 shows the profile for demand for energy by fuel among the OECD and non-OECD countries back to 1971 and Figure II.3 shows a similar breakdown distinguishing the EU28 and the rest of OECD for the period from 1990[3]. It is clear from both figures that there have been different trends in mix of fuels in the three blocks.

Figure II.2 Primary energy consumption by fuel in OECD and Non-OECD countries



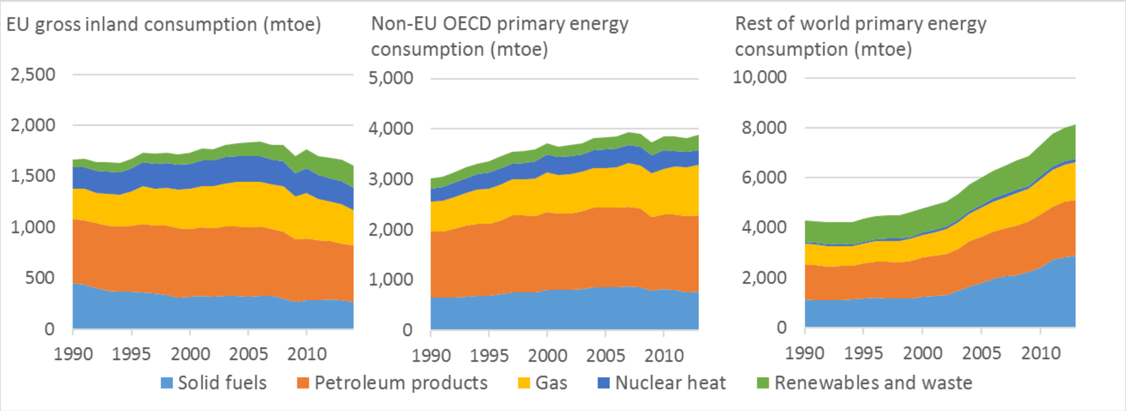
Sources: IEA Energy Balances (2015), Eurostat Energy Statistics

[3] Data for EU28 are only available from 1990

In the EU28 over 1990-2007, demand for coal (and other solid fuels) fell and that for petroleum products was little-changed, while demand for gas rose substantially.

In the EU (proxied here in data prior to 1990 by OECD Europe[4]) total primary energy consumption rose steadily from the mid-1970s before falling back in the late 1980s. Over the 1970s and 1980s demand for coal in OECD countries as a whole remained at a fairly constant level of around 1,000 Mtoe. Over 1990-2007 demand for solid fuels in the EU28 fell back sharply, by 28% as its role in power generation declined and the use of gas increased. As a result, demand for gas in the EU rose by almost 50% over this period. There was also an increase in nuclear energy during the period. It was also the period when renewables began to increase in scale. The demand for petroleum products in the EU28 remained little-changed over the period, despite the increase in demand for road transport stimulated by economic growth and rising real incomes.

Figure II.3 Primary energy consumption by fuel



Sources: Cambridge Econometrics calculations using IEA Energy Balances (2015) and Eurostat.

EU28 demand for all fuels has fallen since 2007 with the exception of renewables, which have seen a strong growth

Since 2007 EU28 demand for coal has continued to fall and the structural change in the power generation sector continues. In 2013 coal accounted for just 17% of overall energy demand compared with 27% in 1990. The structural change in the power sector has also resulted in continued strong growth for renewables. Renewables now account for a similar share of primary energy use as nuclear (13-15%). Demand for other fuels have fallen since 2007, with the sharpest fall in demand for petroleum products (15%) as demands from transport in particular have been affected by both the economic slowdown and improved technology trends in fuel efficiency.

[4] Compared with EU28, OECD Europe includes Iceland, Norway, Switzerland, Turkey and excludes Bulgaria, Croatia, Cyprus, Latvia, Lithuania, Malta, Romania.

Non-EU OECD saw demand for all fuels increase over 1990-2007 but has since seen trends similar to the EU28

In the rest of the OECD as a whole demand increased for all fuels over 1990-2007. The strongest increases were for natural gas and nuclear power (40-45%) though demand for coal increase by 30% and petroleum products by 20-25%.

Since 2007 the trends within the non-EU OECD have been more in line with EU28: demand for coal and petroleum products have fallen and there has been increasing use of renewables. However, demand for natural gas has continued to increase, though at a much slower rate than in the period before the 2007 recession. The non-EU OECD is now more reliant on coal to meet its primary energy needs than is the EU28.

In non-OECD countries, growth in fossil fuel consumption has accelerated in recent years. The consumption of renewables has also increased, though the rate of growth has been more measured.

In non-OECD countries, growth in primary energy consumption has been much stronger, particularly over the most recent 10-15 years. Demand for fossil fuels has grown considerably in recent years, due to strong growth in economic activity (particularly in Asia) and increases in demand from the power sector, as electricity use in the residential and industry sectors has increased. Renewables (including generation from waste) accounted for about 20% of primary energy consumption in the early 1990s. Demand has increased, mostly due to the use of traditional biomass for heating and cooking by increasing populations, though the rate of growth has been more measured than for other fuels.

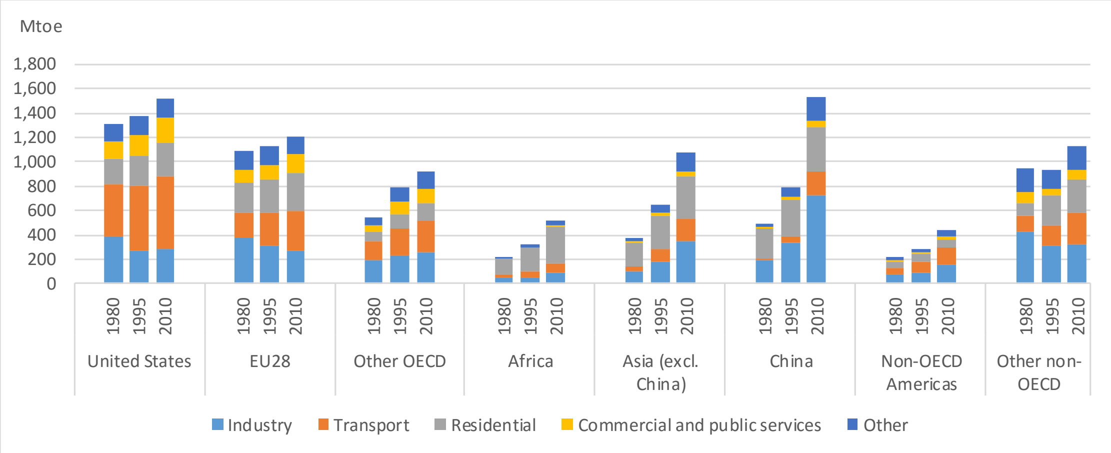
2 Final energy consumption

Growth in final energy consumption in the EU28 and the US over the three decades from 1980 has been led by transport and services. In Asia and China, strong growth in manufacturing output has more than trebled energy demand by industry over 1980-2010.

Figure II.4 shows final energy consumption by global region and sector in 1980, 1995 and 2010. In the EU28, small increases in final energy consumption were primarily a result of increases in demand in the transport and service sectors. Consumption by industry has fallen. The trend for increases in demand by transport and services sectors are also seen in the US and in the other OECD countries as a whole. However, while the US saw consumption by industry fall between 1980 and 1995, there has subsequently been some increase. Among the other OECD countries as a whole, consumption by industry has been steadily increasing since 1980. Of all the major economies, final energy demand drew most rapidly in Asia and China: strong growth in manufacturing production meant that industry energy demand more than trebled over 1980-2010. In Africa, smaller increases in final energy consumption were driven by increases in demand in the residential sectors as incomes grew and energy infrastructure developed.

In the EU's wealthier countries, increases in final energy demand have been led by residential, transport and tertiary users. In the newer Member States of central and eastern Europe, structural change in industry and sharply reduced energy intensity have driven a fall in overall final energy demand.

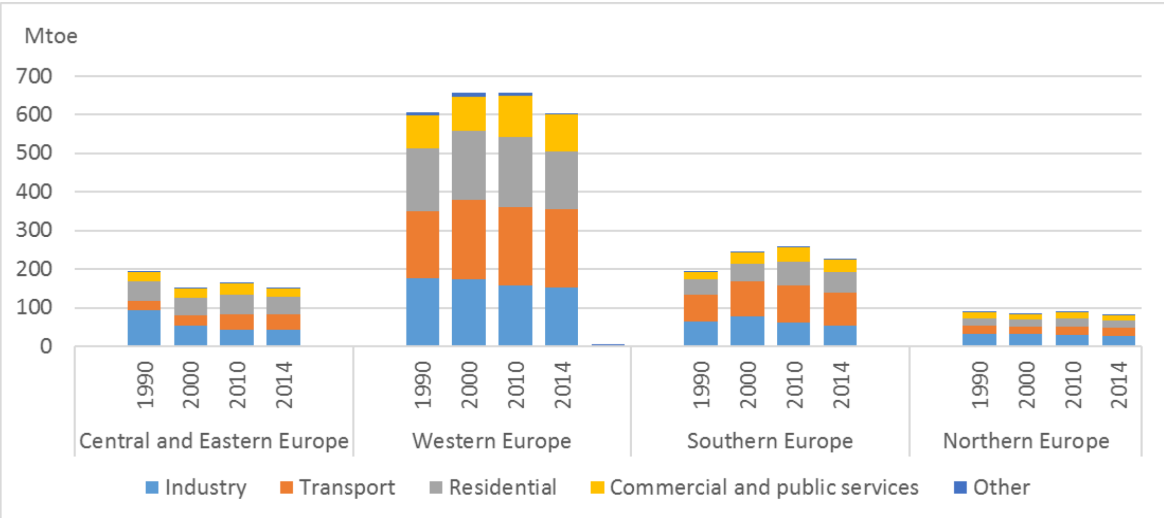
Figure II.4 Final energy consumption by global region and sector



Source: IEA Energy Balances (2015)

There are differences in final energy consumption trends within the EU28, as shown in Figure II.5. Peak energy demand in the EU28 as a whole was in 2006. Over 1990-2006 energy consumption was broadly flat in northern Europe while demand in southern Europe increased by around 40%, with strong growth in all sectors. Demand in western Europe increased by 10%. Over the same period energy consumption in central and eastern Europe fell by 15% primarily due to structural change and improvements in the energy intensity of industry. Since 2006 energy demand in the EU28 has fallen by 10%. Generally, demand has fallen in each sector within each region. The sharpest fall has been southern Europe, where industry demand has been particularly weak due to the economic challenges since the mid-2000s recession. Even where current consumption is higher than it was in 2006, as is the case for energy consumption by transport in central and eastern Europe, the recent trend is for falling consumption.

Figure II.5 Final energy consumption by EU28 region and sector

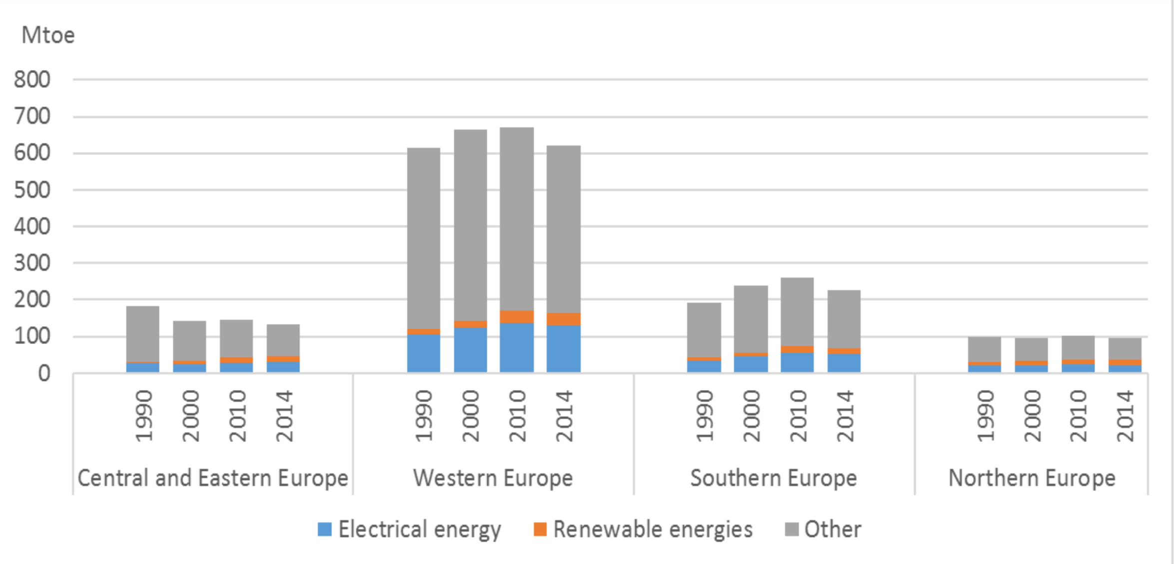


Note: 'Central and Eastern Europe' includes the Czech Republic, Hungary, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia; 'Western Europe' includes Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands and the UK; 'Southern Europe includes Greece, Italy, Portugal, Spain, Cyprus and Malta; 'Northern Europe' includes Denmark, Finland, Sweden, Latvia, Lithuania, Estonia.

Source: Eurostat

Final energy consumption has fallen in all European regions since 2010, most noticeably in Western Europe. Here there have been sharp reductions in consumption by industry (-9%) and services (a fall of almost 20%).

Figure II.6 Final energy consumption by EU28 region and fuel



Note: 'Central Europe' includes the Czech Republic, Hungary, Poland, Slovakia, Slovenia, Bulgaria, Romania and Croatia; 'Western Europe' includes Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands and the UK; 'Southern Europe includes Greece, Italy, Portugal, Spain, Cyprus and Malta; 'Northern Europe' includes Denmark, Finland, Sweden, Latvia, Lithuania, Estonia.

Source: Eurostat

Electricity is accounting for a growing share of final energy consumption in EU28, and within this the share of renewable electricity has risen, particularly since 2000.

Figure II.6 shows the trends within Europe for final energy consumption by fuel. Overall consumption increased through the 1990s in Western and Southern Europe. It then remained little-changed over 2000-10 and has since fallen back. In Central Europe demand fell through the 1990s with the restructuring of industry in the region. Since then there has been little change in overall demand in the region. Overall consumption in Northern Europe has seen little noticeable change since 1990.

Electricity consumption now accounts for 20-23% of overall final energy consumption across the EU. It increased steadily over 1990-2010 in all regions but while it has fallen back across most of the EU, it has continued to increase in Central Europe. There is a clear difference in the role of renewables in meeting energy consumption. In northern Europe this is the source of around 15% of final energy consumption, compared to just 5.6% in Western Europe. Nevertheless, all regions have seen strong growth in the consumption of renewables since 1990, with much of it occurring over 2000-10.

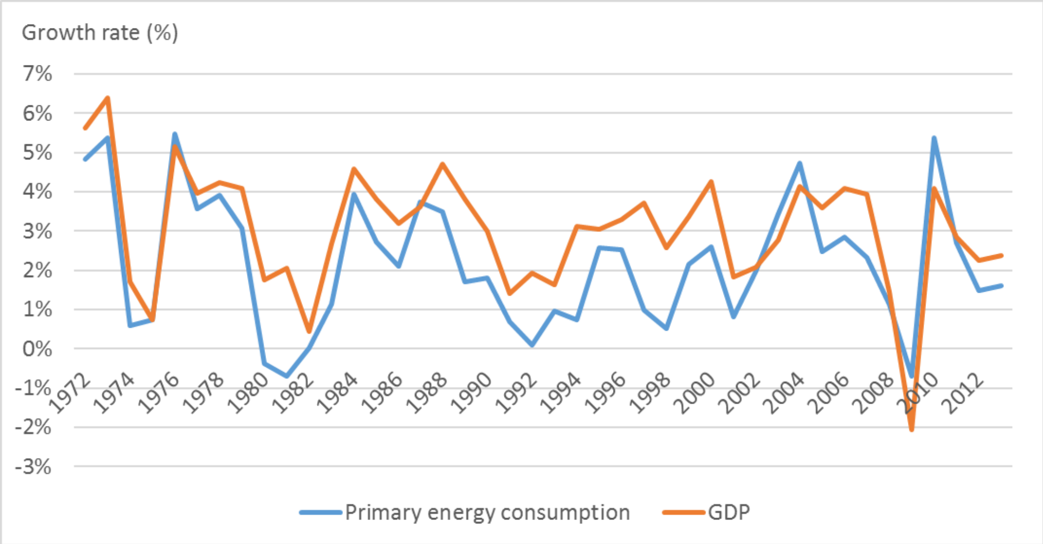
Renewables have an increasing role in electricity generation, but with electricity consumption accounting for a relatively low share of total final energy consumption, the vast majority of the EU's energy needs continues to be met by other (non-renewable) fuels. However, consumption of non-renewable fuels as a whole has steadily fallen since 1990 through most of Europe; this trend has only been evident in southern Europe in recent years (consumption had risen by 25% over 1990-2010).

3 Energy intensity

Energy demand is driven by changes in economic activity, mitigated by long-term trend improvements in energy efficiency (reductions in energy intensity). Over 1990-2013 the energy intensity of the EU28 fell by around 30%.

The short-term relationship between GDP and energy consumption globally is highlighted in Figure II.7, which shows annual growth in global GDP and annual growth in global primary energy consumption over the period 1972-2013.

Figure II.7 Growth in world GDP and primary energy consumption



Source: IEA Energy Balances (2015), World Bank (2015) GDP data in 2005 constant prices.

The chart shows broad correspondence between periods of faster/slower economic growth and faster/slower energy consumption, while the rate of growth of energy consumption has generally been lower than GDP growth, consistent with the decline in energy intensity noted earlier. Comparison of the impact of past world recessions on energy demand shows a difference in the most recent experience. In the mid-1970s and early 1980s, high oil prices drove a simultaneous reduction in demand for energy and a contraction of the economy. In 2008-09, the global economic downturn and decline in industry output also led to a reduction in demand for energy, but GDP fell by more. This is surprising given that investment always falls sharply in any recession, and the production of investment goods is more energy-intensive than the rest of the economy.[5] It may reflect the fact that the 2008-09 recession was led by a financial crisis (unlike the two other major recessions in the period covered by the chart) and

[5] Lower investment also weakens the trend in energy efficiency because it slows growth in the share of newer plant and buildings in the stock of capital. But the impact on energy demand in the short term is modest because investment in any given year accounts for only a small proportion of the capital stock.

the associated collapse in banking activity (a sector that is not energy-intensive) would have had a more marked impact on GDP than on energy consumption.

Figure II.8 shows comparable data[6] for the EU28 for the last two decades, and the same broad trends are visible here. Growth in gross inland energy consumption has generally been weaker than growth in GDP and GDP growth slowed more sharply in the recession than did growth in energy consumption. The sustained period of weak economic growth since 2010 has been accompanied by a decline in energy consumption. The outturn will also have been influenced by EU energy and climate policy introduced before and during this period.

Figure II.8 Growth in EU28 GDP and gross inland energy consumption

Source: Eurostat.

Over the longer term, changes in energy intensity reflect technical energy efficiency improvements which can be influenced by both market development and energy and climate policies (less energy required per unit of output), structural changes (a greater share of less energy-intensive activities in GDP), trend temperature changes (warmer winters, but hotter summers) and other behavioural changes (for example, more travel and the balance of private versus public transport). Over 1990-2013, the energy intensity of the EU28 fell by around 30%.

Within the EU, energy intensity in most newer Member States is higher than, but has converged towards, the levels that prevail in most of the pre-2004 EU15.

Figure II.9 and Figure II.10 show the energy intensity of countries in the pre-2004 EU15 and in the newer Member States that joined the EU since 2004. It is immediately clear that, at an aggregate level, energy intensity in the EU has been on a steady rate of decline since the 1990s.

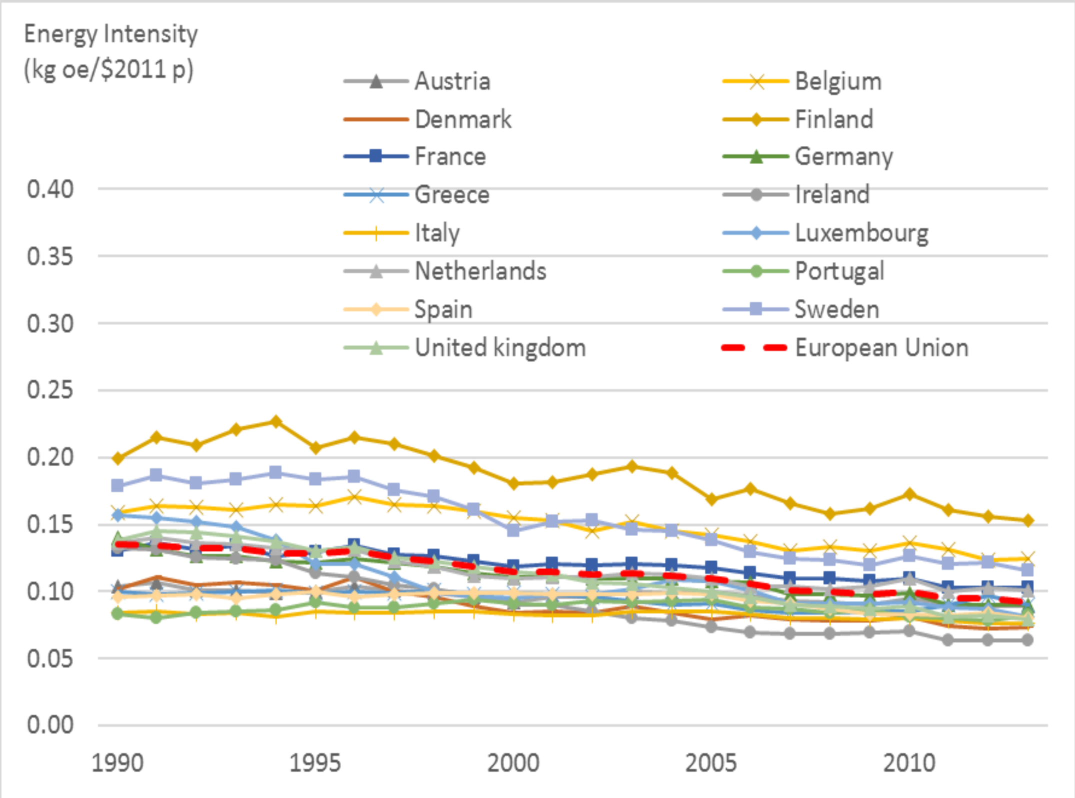
In the EU15, Finland and Sweden have consistently had a higher energy intensity than the EU average, reflecting the colder climates and greater energy requirements for space heating in these countries. The energy intensity of the Irish economy has been

[6] The EU28 data are for 'gross inland energy consumption', which differs from 'primary energy consumption' in that it includes non-energy uses of energy products.

the lowest in the EU15 since the early 2000s, mainly attributable to a restructuring of the economy towards sectors with low energy intensity and high value added coupled with efficiency improvements in electricity generation. The rate of decline in energy intensity over the period 1990-2013 is fairly consistent among all EU15 countries and has been driven by both structural change (as heavy industry output declined and service sector output increased) and market-driven and EU policy-induced technological energy efficiency improvements.

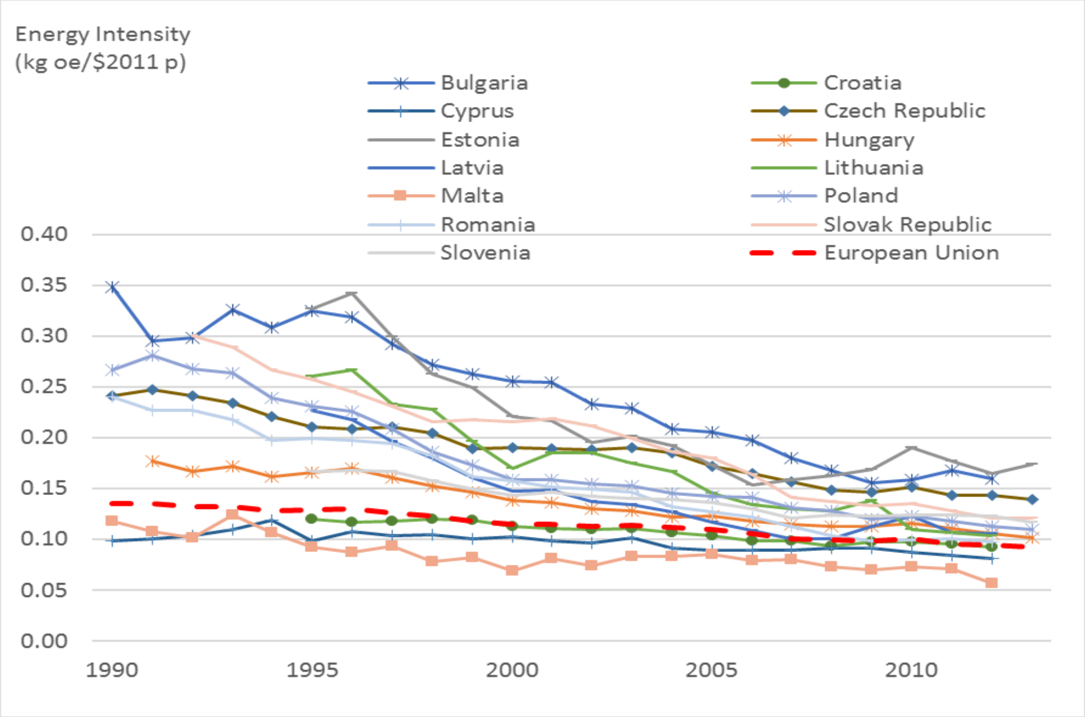
In the newer Member States, there is much greater variation in energy intensity among countries. The rate of decline in energy intensity has been much stronger with the result that energy intensity in most countries has converged toward the EU average over the past 20 years. Of the Member States that have joined the EU since 2004, only three (Malta, Cyprus and Croatia) have an energy intensity that is lower than the EU average, consistent with the view that there is substantial scope for energy efficiency improvements in the newer Member States. The relatively low energy intensity in Malta, Cyprus and Croatia is likely to be due to the warmer climates and lower space heating requirements.

Figure II.9 Energy intensity in the EU15



Source: World Bank (2016), World Development Indicators, primary energy intensity per unit of GDP at purchasing power parities ($ 2011 prices) with climatic corrections.

Figure II.10 Energy intensity in newer Member States



Source: World Bank (2016), World Development Indicators primary energy intensity per unit of GDP at purchasing power parities ($ 2011 prices) with climatic corrections.

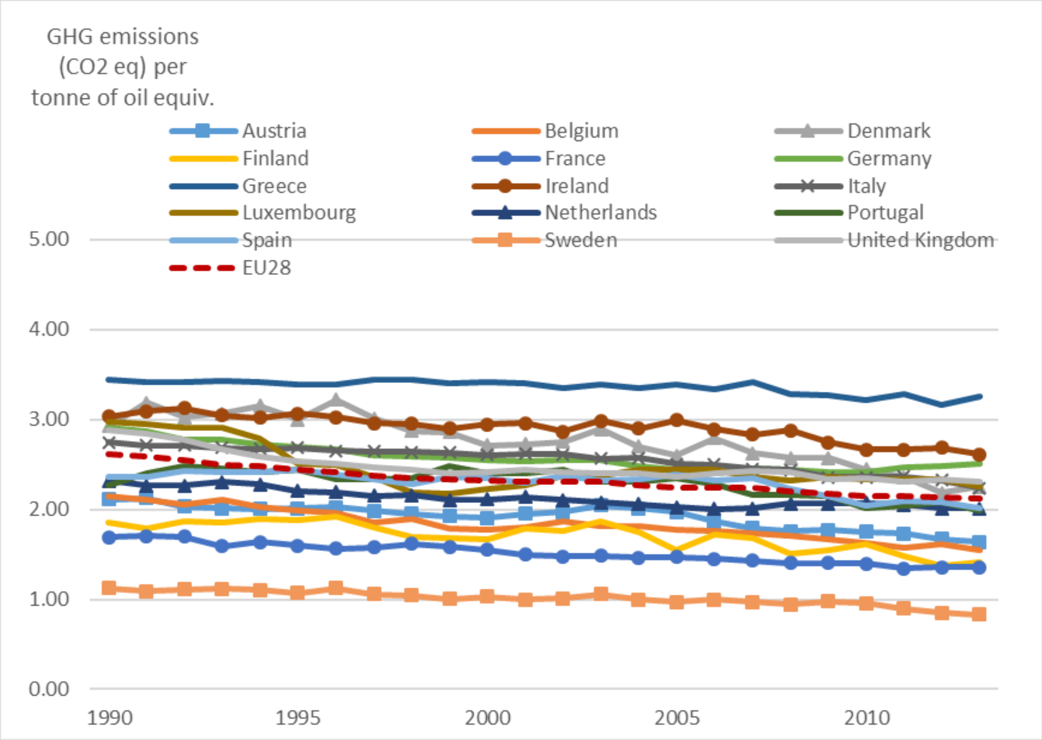
4 Greenhouse gas intensity

The greenhouse gas intensity of EU energy consumption has fallen by 19% over 1990-2013, contributing to a reduction in energy-related greenhouse gas emissions per unit of GDP of some 44%.

The trends presented in Section 3 have shown that the energy intensity of EU Member States has fallen. Other things being equal, this would imply a reduction in the greenhouse gas intensity of the economy. But changes in the composition of the fuels used have brought about still larger reductions in (energy-related[7]) greenhouse gas intensity. The greenhouse gas intensity *of EU energy consumption* fell by some 19% over the period 1990-2013, contributing to a reduction in energy-related greenhouse gas emissions per unit of GDP of some 44%. Hence, the same trends that are reducing energy dependency and vulnerability to global fossil fuel energy price shocks (lower energy intensity, increased share of non-fossil fuel energy sources) are also driving reductions in greenhouse gas intensity. These trends are not universal outside the EU28.

[7] 'Energy-related' is used here to exclude those greenhouse gas emissions that are not associated with energy consumption.

Figure II.11 Greenhouse gas intensity of energy consumption in the EU15

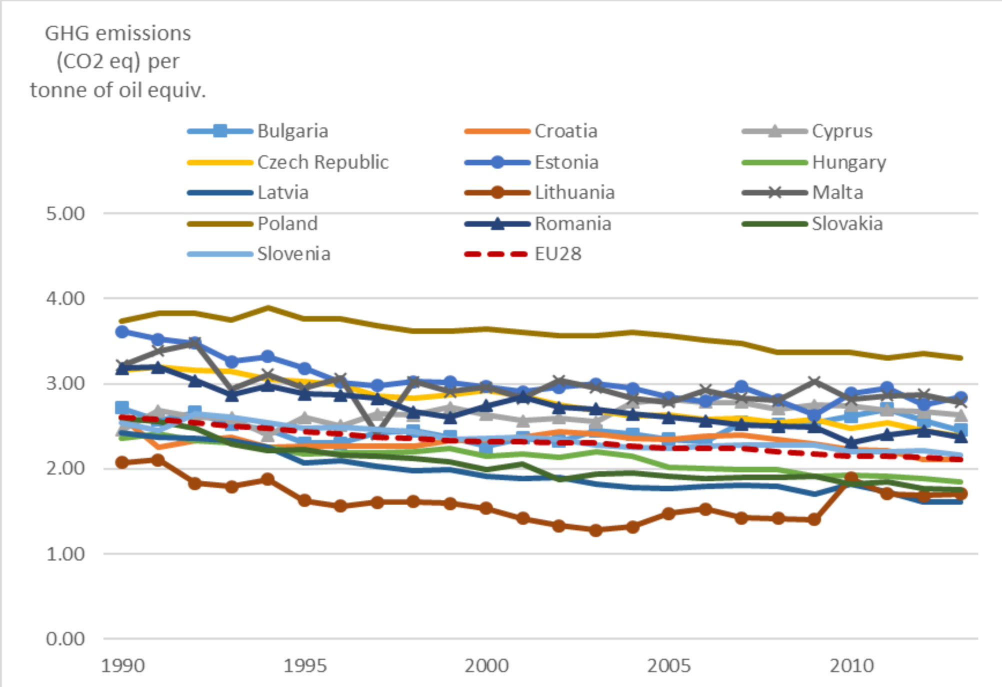


Source: Eurostat.
Note: Greenhouse gas emissions (tonnes of CO_2 equivalent) associated with energy consumption per tonne of oil equivalent of gross inland energy consumption.

Figure II.11 and Figure II.12 show the greenhouse gas intensity *of energy consumption* in the pre-2004 EU15 and in newer Member States that have joined the EU since 2004. The reduction in the greenhouse gas intensity of EU energy consumption was driven by an increase in the share of renewables in the energy mix and fuel switching from more emissions-intensive fossil fuels to cleaner energy sources, notably gas.

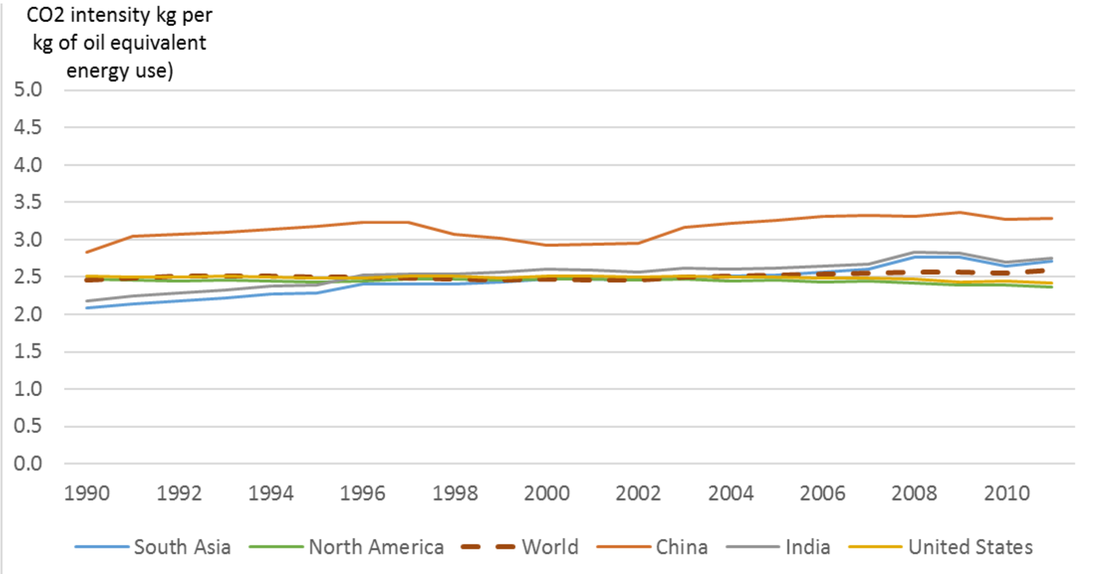
When comparing the carbon intensity of Member States, the importance of the mix of technologies deployed in the power sector becomes apparent. In Sweden and Finland, a large share of electricity is generated by hydropower. In France, around 75% of electricity is produced using nuclear. The use of low-carbon and renewable energy for power generation in these countries means that the carbon intensity of primary energy consumption is 30-50% lower than the EU average. By contrast, in Poland, Estonia and Ireland, the power sector's dependence on carbon-intensive fuels such as coal (and, in the case of Ireland, peat) means that the greenhouse gas intensity of the energy supply in these countries is 25%-50% higher than the EU average.

Figure II.12 Greenhouse gas intensity of energy consumption in newer Member States



Source: Eurostat.
Note: Greenhouse gas emissions (tonnes of CO2 equivalent) associated with energy consumption per tonne of oil equivalent of gross inland energy consumption.

Figure II.13: CO2 intensity of energy use in selected world regions



Source: World Bank

The downward trend in greenhouse gas intensity seen across in the EU28 are not repeated everywhere. As Figure II.13 shows, other world regions have seen the CO2-intensity of energy consumption increase over the period.

5 Energy import dependency

There are several dimensions to 'energy dependency': the importance of energy to facilitate economic growth and the potential exposure to volatile movements in global fossil fuel prices (both related to the energy/carbon-intensity of activity); the security of energy supply, and the contribution energy and energy products make to trade. The first two topics have been discussed in their own right in earlier sections, and so this section approaches the issue from the perspective of security of energy supply.

Security of energy supply relates to having reliable access to sufficient energy to meet the economy's needs. The geographical distribution of primary energy supplies globally results in considerable variation in the dependency of countries on imports to meet their needs. The risk associated with import dependency is influenced by the scale of imports and by the origin and diversity of sources of imports, given the geopolitical risk associated with particular countries as sources of energy imports or transit countries and routes through which energy flows are transported.

Import dependency can be reduced by: meeting more of an economy's needs from domestic sources (e.g. moving from fossil-fuels towards renewable generation, which has the associated benefit of reducing exposure to fossil fuel price movements); having more balance in the share of particular fuels being imported (so less reliant on any one fuel), and sourcing imports from a number of exporting countries.

Indicators for security of energy supply include[8]:

- energy import dependency, commonly defined as net imports as a share of total energy consumption
- Herfindahl index (HHI) to measure of the degree of concentration of import sources, by country; it is more appropriate to calculate the index for a particular energy product (fuel), but it can be calculated for total energy imports, and an equivalent indicator can be constructed to measure the degree of concentration of the energy mix
- share of gross inland energy consumption by fuel
- HHI for energy mix (built up from the shares of gross inland energy consumption by fuel)

Measures to promote alternative low-carbon energy sources and energy efficiency both have a role to play in helping to reduce the EU's energy import dependency.

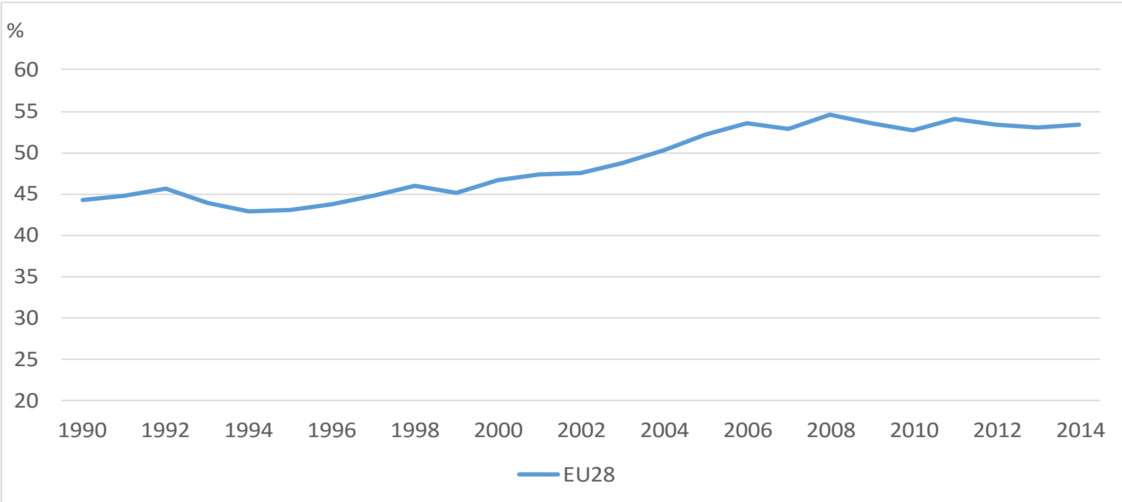
The energy-intensity of economies is an important dimension to energy dependency. To the extent that any reduction in energy-intensity is brought about in the types of use for which petroleum products and gas are the dominant sources (for example, in transport and space heating), this will reduce the EU's imports of those products. Given that nuclear and renewable energy sources tend to act as base load in power generation, a reduction in demand for electricity in the short term will typically result in a reduction in the demand for fossil fuels (mainly coal and gas), for which extra-EU imports are an importance source for most Member States. The impact of longer-term reductions or slower growth in electricity demand is less clear, since it depends on which fuel power generation companies would have chosen for new investment that is now foregone or postponed.

[8] For examples see Member States' Energy Dependence: An Indicator-Based Assessment, European Economy Occasional Papers 145, April 2013. European Commission Directorate-General for Economic and Financial Affairs.

EU energy import dependency peaked at the onset of the 2008 recession

The EU28 as a whole experienced a steady rise in energy import dependency from 1990 to the recession of 2008 (see Figure II.14), reaching a peak of almost 55% of gross inland energy consumption. Since 2008 the decline in energy demand and the development of renewable energy power generation capacity have been associated with a flattening-off of the upward trend in import dependency.

Figure II.14 Energy import dependency of the EU28



Note(s): Energy dependency is calculated as net imports divided by the sum of gross inland energy consumption plus bunkers.

Source: Eurostat Energy Statistics (2015).

The degree of energy dependency varies greatly across the EU. The most-dependent countries are Malta, Luxembourg and Cyprus (with dependency rates of around 95% or more), followed by Ireland (85%), Belgium, Italy, Lithuania, Spain and Portugal (with dependency rates of 70-80%). The less-dependent countries include

- Poland, Romania and Estonia where the domestic power generation sector uses domestically-produced coal and other fuels
- Sweden and Denmark where renewables have a large share of electricity production.

The EU is heavily dependent on fossil fuel imports due to its low and declining oil and gas production

The majority of energy imports to the EU are imports of crude oil and natural gas. The EU's domestic proven oil and gas reserves are low compared with its demand and crude oil production in the EU has been in steady decline over the past decade. The EU's oil reserves in 2014 were just 5.9 bbl, compared to around 1,656 bbl proven oil reserves globally[9]. The EU's gas production has also seen a trend of steady decline. Imports accounted for over 87% of the region's total consumption of oil and 67% of the region's total consumption of gas in 2014[10], and oil and gas together accounted for around 59% of the EU's primary energy consumption in that year[11].

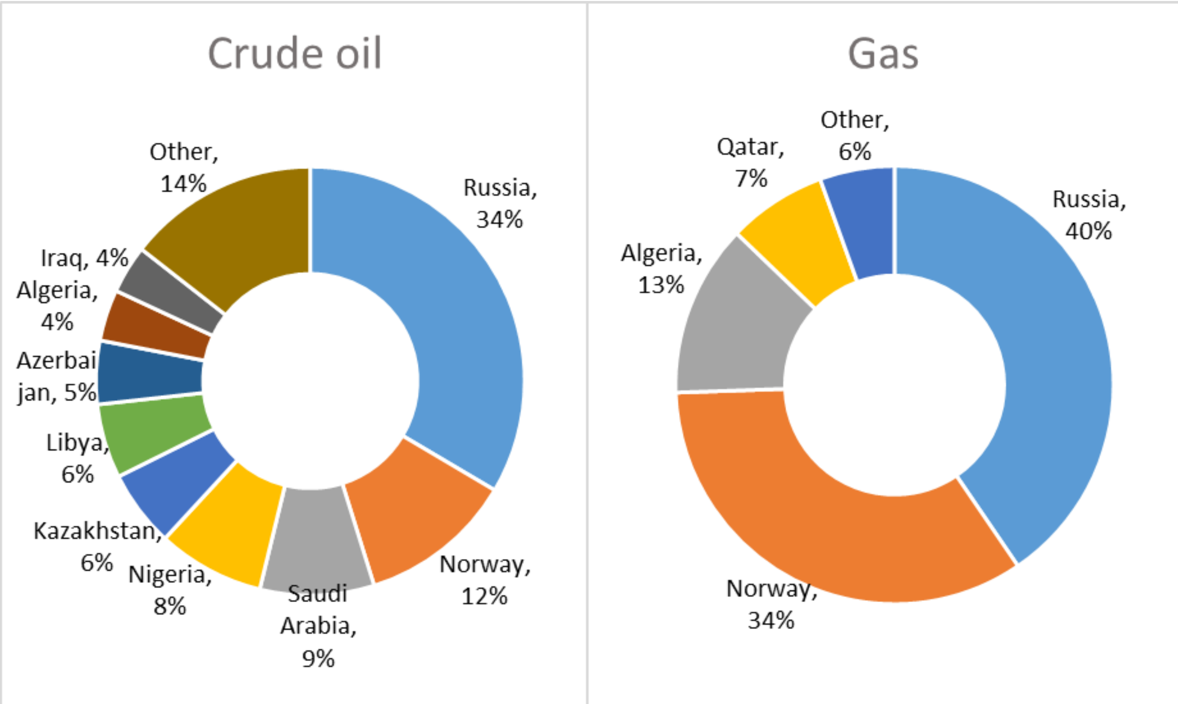
[9] US Energy Information Administration (2016), 'International Energy Statistics: Proved Reserves of Crude Oil', data for 2014.
[10] Eurostat (2016), 'Energy Dependence', data for 2014.
[11] IEA Energy Balances (2015)

Sources of energy imports are concentrated among a small number of countries, increasing the EU's exposure to supply shocks

Figure II.15 shows the source of EU oil and gas extra-EU imports. Almost 50% of crude oil and some 74% of natural gas extra-EU imports come from just two countries, Russia and Norway, and most of the remainder is sourced from members of OPEC. The EU's oil and gas supply is therefore highly concentrated, and some of the supplying countries are subject to the risk of political instability.

There is considerable variation in the concentration of imports for particular Member States. Various northern European countries, including Bulgaria, Estonia, Finland, Sweden, Latvia and Latvia are wholly reliant on Russia as a single source of imports of gas. They are also heavily reliant on a small number of suppliers for oil imports.

Figure II.15 Sources of EU oil and gas imports in 2014



Note(s): Oil energy import shares are calculated as imports divided by the sum of gross inland energy consumption plus bunkers.

Source: Eurostat.

High energy dependency exposes the EU economy to global energy price fluctuations

High energy dependency exacerbates the economic impact of global energy price instability and fluctuations: not only does a sharp increase in energy prices result in higher general inflation and a sudden redistribution of real income from consumers to producers, with all the associated adjustment costs, but high energy dependency means that the majority of producer income flows out of the EU. Oil price shocks in the 1970s and early 1980s prompted two deep recessions, high inflation[12] and large trade deficits. Household incomes were squeezed due to rising prices and high unemployment. The price spike in 2008 also raised price inflation in much of the EU, not least because of its impact on the cost of mobility for which short-term price elasticities are typically low. Recent events show how supply shocks can also lead to considerable price fluctuations, as the shale gas boom in the US and a decision by OPEC to refrain from withholding supply led to a sharp fall in the oil price in the second half of 2014. Of course, a fall in energy prices provides a real-income boost to energy importers, but currently the unexpected depressing effect on consumer prices adds to the macroeconomic challenges posed by a very low-inflation environment in Europe.

6 Energy investment

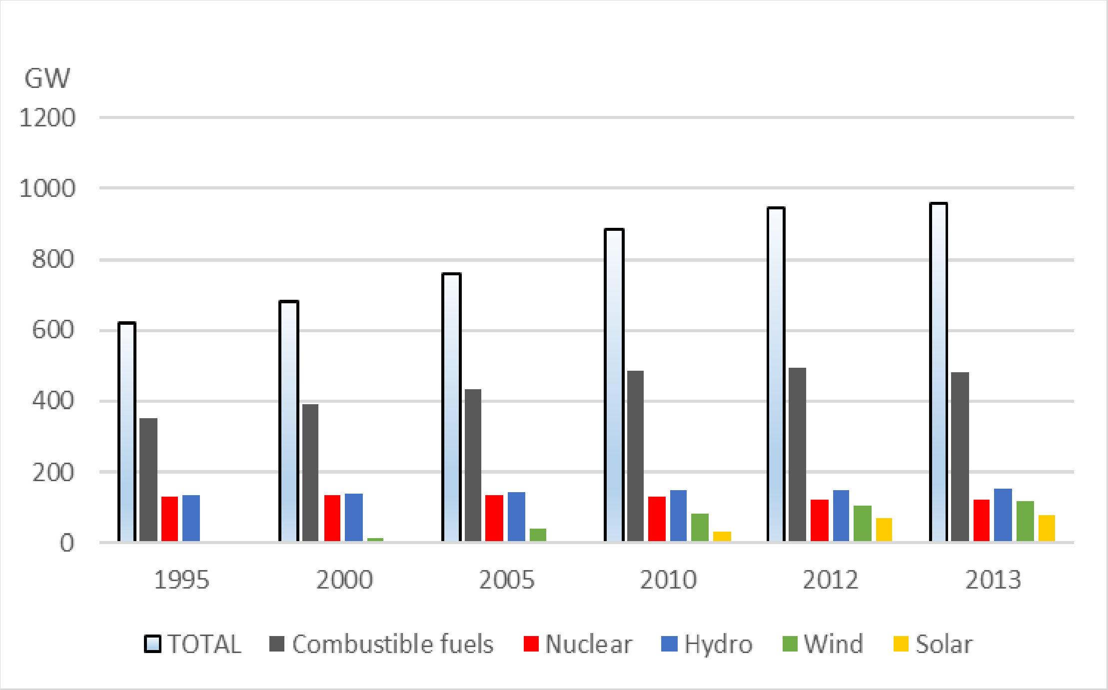
Figure II.16 shows investment in EU28 power generation capacity. Overall capacity has increased by 55% (340 GW) since 1995. The capacity powered by combustible fuels grew steadily through to 2010 and has since fallen back slightly, as any new investment has not been sufficient to replace decommissioned capacity. Over the same period renewable capacity (the other sources shown the chart, including nuclear) has grown by around 80% (210 GW) and now accounts for 50% of total installed electricity capacity. This net growth has been predominantly in wind and solar. There has been only a modest increase in hydro capacity (16.6GW), while nuclear capacity has been falling since mid-2000s and is now slightly below its 1995 level.

The rapid expansion of renewable generation in Europe is part of a global trend. Data from IRENA (see Figure II.17) indicate global renewable generation capacity almost doubled over 2006-15. The strongest growth has come in China, where current capacity is almost three times what it was a decade earlier. In contrast, renewable capacity installed in the US and Japan increased by 65-75%.

These data show the net generating capacity in the EU28 has kept pace with that globally and continues to account for 20-25% of global capacity. Installed capacity in China now exceeds that in the EU28.

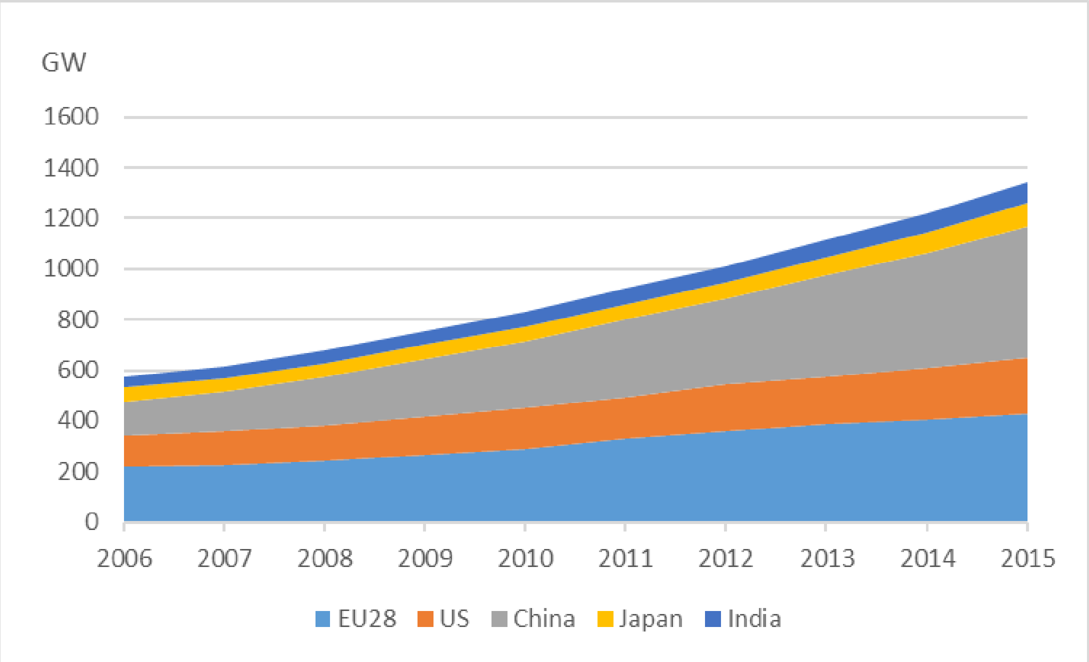
[12] The average inflation rate in the ECD was around 13% over the period 1974-1975 and around 12% over the period 1979-1983.

Figure II.16 Trends in installed electricity capacity in the EU28



Source: European Commission, EU Energy in Figures, 2016.

Figure II.17 Net Renewable Power Capacity in Key World regions



Source: IRENA, Renewable Capacity Statistics, 2016.

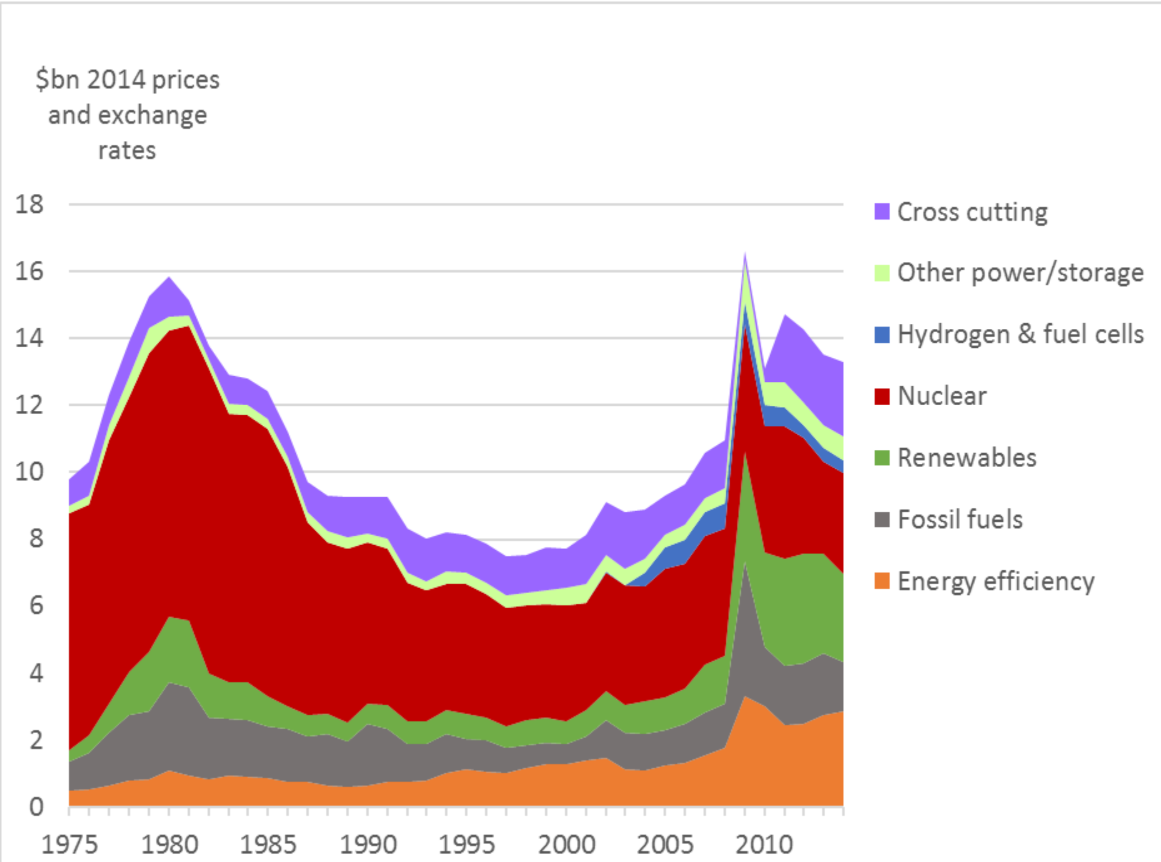
7 Energy innovation

Global public budgets for RD&D in energy technology are high historically and the shares of renewables and energy efficiency have increased in the past decade so that they each now broadly match the budget for nuclear.

Analysis by the IEA indicates that public spending on research, development and demonstrations of energy technology has fallen back a little in recent years, but it remains above levels seen through most of the 30 years since the oil-shocks inspired peak of 1980. However, as a share of global GDP levels of public R&D spending in the area are little different from the low rates seen in the mid-1990s.

In the 1970s global R&D was heavily weighted towards nuclear technology. By the 1980s the scale of spending fell back, the brunt of which was borne by spending on nuclear. In the past decade, spending on renewables and energy efficiency have increased markedly so that by 2014 the budgets for each of these was similar to the budget for nuclear.

Figure II.18 Global public energy research, development and demonstration (RD&D) budgets

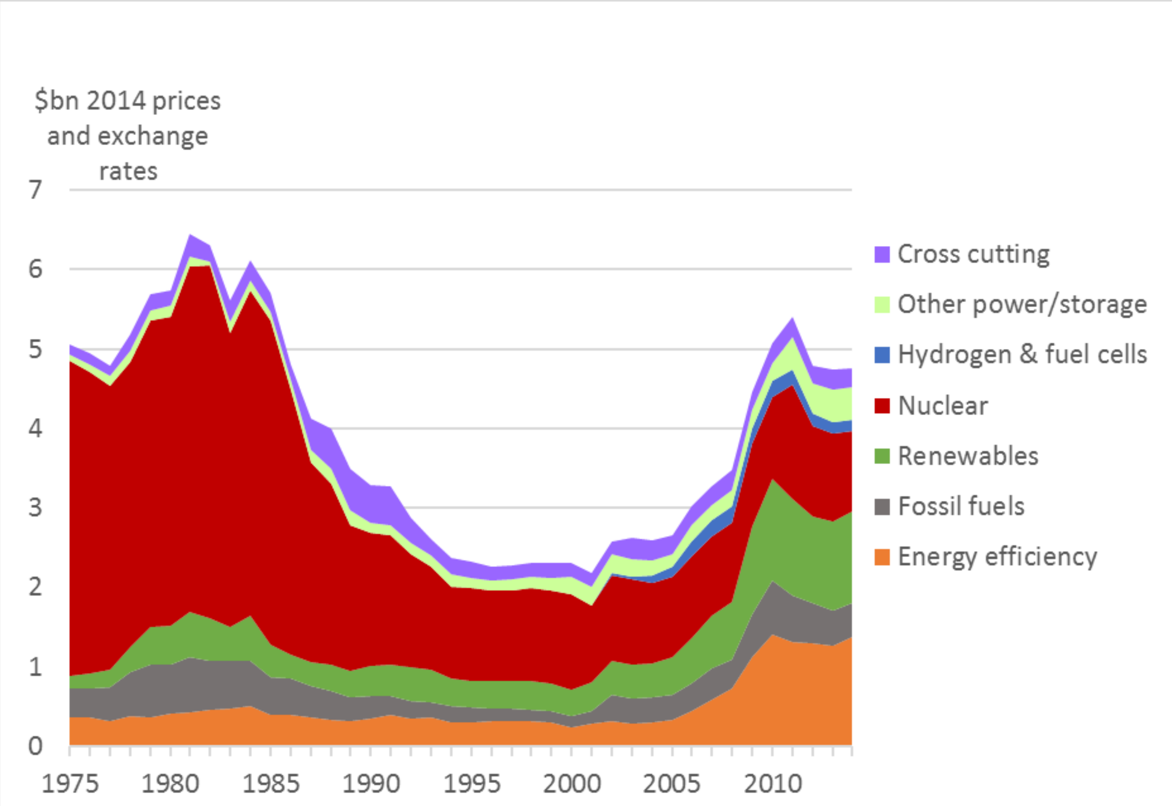


Source: Energy Technology RD&D, IEA (2015).

Public RD&D budgets in Europe are more focused on energy efficiency and renewable energy sources

The trends in public RD&D energy technology budgets shown in Figure II.19 are similar to the global trends noted above, but with a more pronounced long-term shift from nuclear and a sharper increase in the shares of renewables and energy efficiency in the past decade. Almost a third of the budget for Europe is now focused on energy efficiency (compared to just over 20% globally) and a further 25% is on renewable energy sources (compared with 20% globally). The public RD&D budget for fossil fuels is still 9% of the total (11% globally), three times the budget for hydrogen and fuel cells.

Figure II.19 Estimated European public energy research, development and demonstration (RD&D) budgets



Source: Energy Technology RD&D, IEA (2015).

Part III. Understanding the drivers of energy consumption

1 Economic activity and energy intensity

Decomposition analysis seeks to distinguish the contribution of different factors to overall changes in energy demand over a specific period of time.

At the simplest level, energy demand can be defined as the product of economic activity and energy use per unit of activity, as shown in the equation below.

$$Energy\ Demand = Economic\ Activity \times \frac{Energy\ Demand}{Economic\ Activity}$$

Changes in energy demand are divided into an 'activity effect' and an 'energy intensity effect', where the activity effect reflects changes in energy demand due to changes in economic output, population or real income growth, while the energy intensity effect encompasses all other factors that affect energy demand. The latter includes the effect of structural changes that reduce the weight of energy-intensive industries in the economy and energy efficiency improvements driven, for example, by price increases, policy measures and the opportunities made available by innovation [13]. This decomposition is, of course, an accounting identity rather than a behavioural explanation: the question as to what underlying factors are driving changes in energy intensity is explored in the next section.

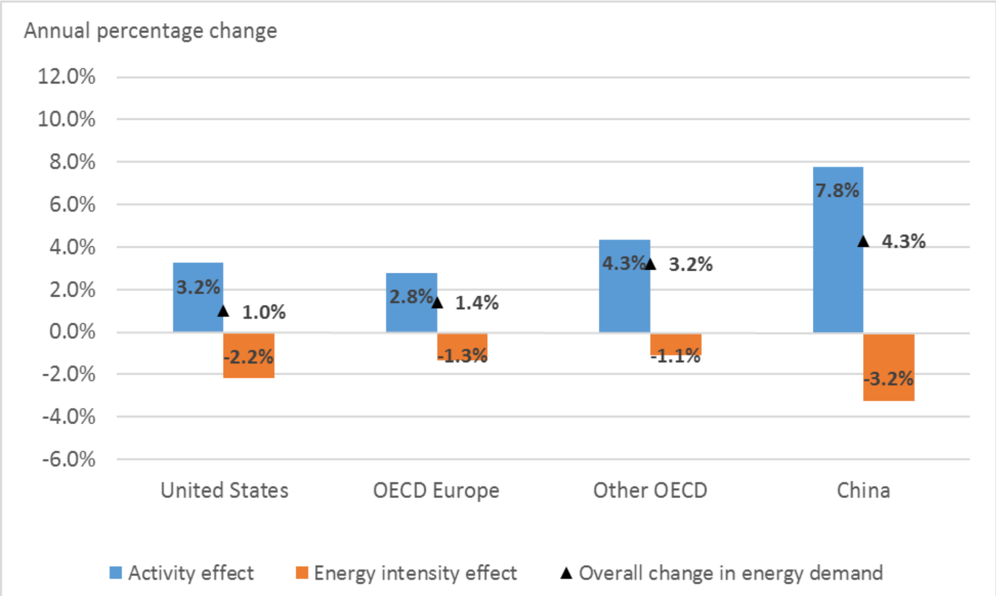
Figure III.1 and Figure III.2 show the effect of changes in economic activity and energy intensity on overall primary energy consumption in two periods[14] each covering 20 years. In these examples, GDP is used as the measure of economic activity.

In the US and OECD Europe, economic growth modestly outpaced the rate of decline in the energy intensity of these economies in both periods. Primary energy demand increased by 1.0% pa and 1.4% pa respectively over 1970-90, but by about half those rates over 1990-2010 as economic growth was slower while the rate of decline in energy intensity continued at about the same rate as in the earlier period. Data available for EU28 from 1995 show a similar trend to OECD Europe but a somewhat stronger decline in energy intensity (but not as strong as in the US) and hence slower overall growth in energy demand.

Unsurprisingly, much stronger economic growth in China in both periods was associated with much stronger growth in primary energy demand, particularly in the second period. In the case of China, the period in which GDP growth was faster was also the period in which the decline in energy intensity was faster. This could be for structural reasons (faster growth in less energy-intensive sectors in the economy, such as the production of electronic consumer goods) or improvements in energy efficiency made possible by the high rate of investment in new capital equipment.

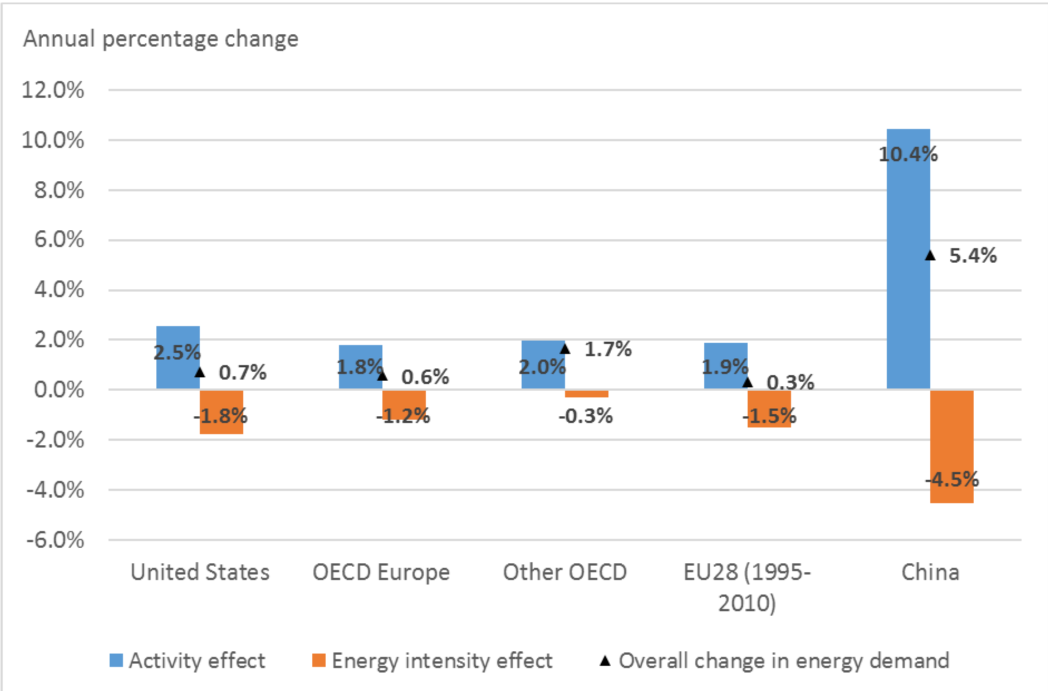
[13] The relative effects of these alternative factors are discussed in a later section.
[14] Eurostat data to distinguish the EU separately are only available from 1995.

Figure III.1 Annual percentage change in economic activity, energy intensity and total primary energy demand over the period 1970-1990



Source: IEA Energy Balances (2015), OECD GDP data (2016).

Figure III.2: Annual percentage change in economic activity, energy intensity and total primary energy demand over the period 1990-2010



Source: IEA Energy Balances (2015), OECD GDP data (2016), Eurostat.

2 Unpacking the factors driving energy intensity

Energy intensity, defined in the simple decomposition equation as energy demand per unit of activity, is influenced by a wide range of factors.

The composition of growth

While the overall level of activity is important, so too is the structural composition of that activity because the energy intensity of different energy users varies. Economic growth that comes through greater use of business services will have a different impact on energy use than of growth coming from, say, increased growth in exports of investment machinery.

While the compositional effect is normally considered at the level of (broad) fuel users (e.g. manufacturing, services, households, transport), the effect also occurs within each broad group. Clearly, energy use by manufacturing will depend on whether the sector comprises energy-intensive activities like steel production. But as another example, there could be a compositional effect on household energy use coming from the trend towards an aging population if the use of energy differs greatly between different age groups.

A study of the US (Metcalf (2008)) showed the importance that composition can have on overall energy use. Over 1970-2003, overall energy intensity fell by almost 50%. The changing composition of economic activity accounted for between one quarter and one third of this fall.

Analysis of the EU experience (European Commission ODYSSEE-MURE) over the 2000s also shows structural change in the economy has had the effect of reducing the overall energy-intensity of the economy, but the scale reported there is much less pronounced (see further discussion below).

Energy prices

The price of energy faced by the end user could be expected to affect energy demand in several ways. In the short term, increases in price encourage users to be more efficient by reducing 'wasteful' energy consumption. In the longer term, higher prices can stimulate investment in new, more energy-efficient technologies and processes. This relationship is demonstrated by Metcalf (2008) who found a 10% increase in energy prices led to a 1.1% fall in energy intensity when looking at the impact of short-term price changes, while the impact increased by almost 50% when looking at longer term price changes. There is also some evidence (Grubb, 2014) that price effects are asymmetric: price rises lead to investment in more energy-efficient capital and faster turnover of the stock, but price falls of similar magnitude do not reverse these changes (although they may slow down the uptake of available energy-efficient technologies). This could be because capital is long-lived, because actors behave differently when faced with a sharp increase in costs compared with a sharp reduction, or because price-driven innovations that take users closer to the technological frontier are not 'unlearned' when prices fall.

Technological change

Technological change typically reduces energy intensity even when it is not prompted by higher energy prices, through its impact on the quality of the capital stock. This is because new capital equipment tends to be more energy-efficient that the equipment it is replacing (e.g. greater fuel efficiency of engines). When assessing China's energy intensity, Ma and Stern (2008) found that technological improvements played a "dominant role in decreasing energy intensity". In fact, by Ma and Stern (2008) cite a decrease in 'technological effects' as the reason for a reversal to increasing energy intensity in China after 2000, stating that "technological effect dominates all the changes in energy intensity: dramatic decrease, slow-down of the decrease, and reversal" rather than structural change.

Wilson et al. (2013) argue that energy conservation is driven by *reductions in the cost of energy-efficient equipment*.

Ma and Stern (2008) also found that the choice of fuel mix influences overall energy intensity because some fuels deliver a higher level of useful energy per unit of embodied energy. They illustrate this with the case of households in China: coal accounted for 54% of household energy consumption in 1994 but only 31% in 2000. Substitution towards petroleum, natural gas and electricity is argued to have reduced energy intensity.

Lifestyle choices

Lifestyle choices also have an impact on the intensity of energy use. Some of these effects are income-related while others are social or psychological in nature. As populations become richer they increase their level of material comfort, and if the income elasticity of energy use is greater than unity then the simple decomposition analysis noted earlier will identify this as something above and beyond the activity effect. It could affect energy use directly, for example, by increasing the level of heating (or cooling) of the home, or indirectly by acquiring/consuming more goods/services or 'better' services. Lenzen et al (2004) found that while the direct energy requirements (energy per capita) of a household were relatively inelastic to income changes, the indirect energy requirement through increased consumption of goods and services increased more strongly with income. However, the positive relationship between energy intensity (energy per household asset) and income weakened for higher income groups as "wealthier households purchase proportionally more services, which are characterised by lower energy requirements". Additionally, Lenzen et al (2004) found that larger households required less energy per capita than smaller ones, reflecting economies of scale in the direct energy requirement (e.g. heating/cooling the house) which were not outweighed by the indirect effect. Regarding transport, Lenzen et al (2004) found that age has the largest impact on automotive energy requirement, indicating that an aging population may lead to higher energy intensity due to increased automotive use.

Other lifestyle effects could include the trend toward single-person households, partly but not only due to aging (the average energy use per person is higher for two people living separately); preferences for apartments over individual properties, or the use of private versus public transport.

Darby (2006) suggests that the provision of feedback about energy consumption to users, which is becoming more common thanks to the greater availability of cheap monitors, affect the quantity of energy used: households with informative energy billing have adapted their energy use and curbed consumption.

Regulation

Energy demand can clearly be influenced by regulation that limits the availability of products with poor energy efficiency characteristics. Gupta (2011) discusses the "Energy Conservation Law" and the "Top Runner Program" in Japan which were implemented to influence Japanese energy consumption habits. These laws included advice and fines for manufacturers whose products did not meet energy efficiency thresholds. These laws are credited by Gupta with helping to bring about significant improvements in the energy efficiency of electronic appliances. These measures were supported by a number of publicity campaigns to inform households of how to be less energy intensive, such as encouraging lower air conditioning use, efficient driving and wise use of electricity. Hence the effects of regulation may appear in the form of technological change, faster uptake of more energy-efficient technologies, or lifestyle changes.

Firm-level drivers of energy use

Firm-level analysis further backs up the role of investment and improvements in technical capacity in determining energy demand. For example, Sahu and Narayanan (2010) found a strong positive relationship between capital intensity and energy intensity while at the same time noting that older capital (with reliance on repairs to extend the lifetime of equipment) was less efficient. They also found that greater use of imported technologies was associated with lower energy intensity, on the grounds that the technological standard (and energy-efficiency) of imported equipment was higher than that produced in India.

When looking at the organisation of firms in India, Sahu and Narayanan (2010) found a U-shaped relationship between size of firm and energy intensity, suggesting that economies of scale help to improve energy efficiency up to a point, but the largest firms are more likely to be in energy-intensive sectors. They also found that younger firms were generally somewhat more energy-efficient than older firms, either because their capital equipment was newer or because there are more young firms in less energy-intensive activities (if these activities are the faster-growing segments of the economy).

Further disaggregation shows energy efficiency improvements were the dominant factor behind the fall in energy intensity in the EU over 2000-2012

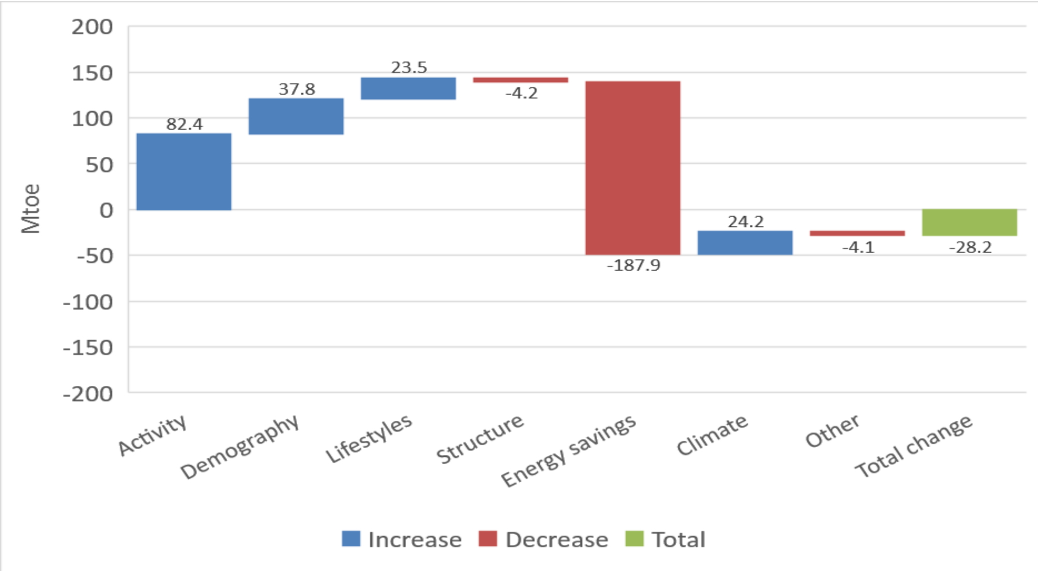
The ODYSSEE-MURE[15] project provides a more detailed decomposition of the factors affecting final energy consumption in the EU. Figure III.3, Figure III.4, Figure III.5 and Figure III.6 show the ODYSSEE decomposition analyses for total final energy consumption, industry final energy consumption, residential final energy consumption and tertiary final energy consumption, respectively, in the EU over the period 2000-2012. The decomposition analysis comprises an activity effect (defined as the change in value added by sector and changes in traffic in the case of transport) and disaggregates the energy intensity effect into various contributory factors, including

- demography effects (due to changes in the number of dwellings)
- lifestyle effects (due to changes in the number of appliances and changes to the size of dwellings)
- structural effects (due to structural change in industry/service sectors and modal shift in transport)
- climate effects and other effects (which encompass changes in household behaviours, changes in the value of products in industry, changes in labour productivity in services and "negative" savings due to inefficient operations)
- technical energy savings (i.e. excluding the impact of operating inefficiencies). which can be interpreted as an estimate of energy efficiency improvements due to technological progress (whatever may have prompted this)

Total final energy consumption in the EU fell by 28 Mtoe over 2000-2012. The activity, demography, lifestyles and climate indicators all acted to increase energy consumption over the period, but this was more than offset by an estimated 188Mtoe energy efficiency improvement (Figure III.3).

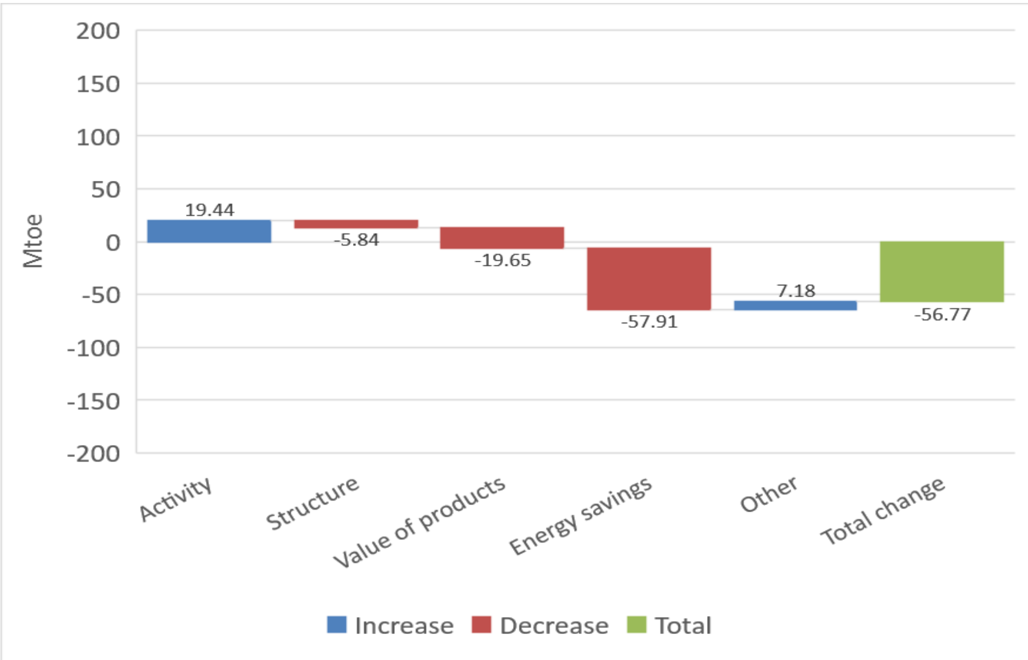
[15] See http://www.odyssee-mure.eu/ for more information.

Figure III.3: Decomposition of change in final energy consumption in the EU over 2000-2012



Source: European Commission ODYSSEE indicators.

Figure III.4:Decomposition of change in industry energy consumption in the EU over 2000-2012

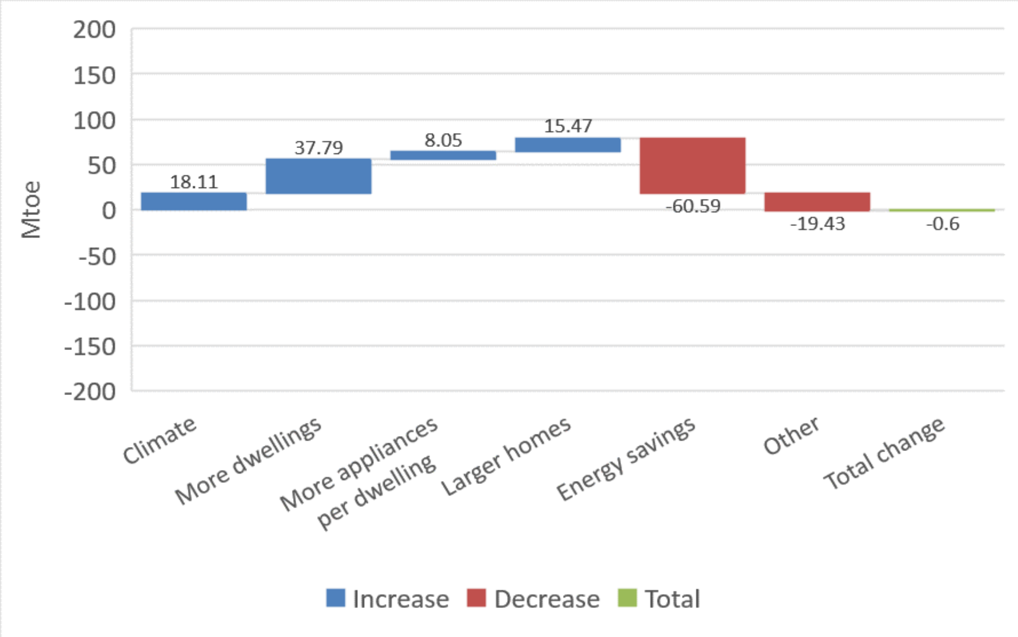


Source: European Commission ODYSSEE indicators.

The scale of the technical efficiency savings dwarfs the changes in energy intensity attributed to structural change in the economy towards less energy-intensive sectors. However, from this analysis it is not possible to say more about the relative importance of factors, such as policy initiatives, driving the increases in efficiency or the extent to which this outturn represented a stronger outturn (relative to other influences on consumption) than was seen in preceding periods.

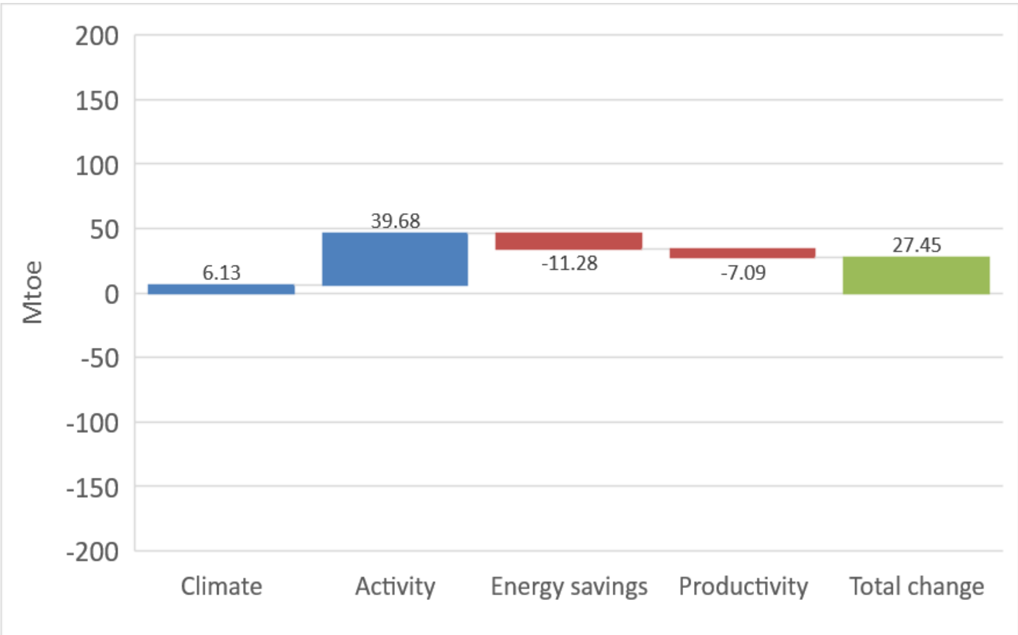
Around 58 Mtoe of this saving is attributable to energy efficiency savings in industry (Figure III.4); 61 Mtoe was attributable to energy efficiency improvements in the residential sector (Figure III.5) and only 11 Mtoe attributable to energy savings in the tertiary sector (Figure III.6).

Figure III.6: Decomposition of change in residential energy consumption in the EU over 2000-2012



Source: European Commission ODYSSEE indicators.

Figure III.5: Decomposition of change in tertiary energy consumption in the EU over 2000-2012



Source: European Commission ODYSSEE indicators.

The analysis clearly indicates that technical efficiency has had relatively little impact in the tertiary sector (technical savings were equivalent to a third the increase due to higher levels of activity). It also shows that the growing population (resulting in more dwellings) is a relatively more important factor behind demand in energy by the residential sector than is the level of economic activity to the industrial sector. This could be a result of the period of analysis with almost a third of the period covered by recession or very slow growth. The analysis also shows that lifestyle factors of increased household appliances and the move to larger properties (a trend as population become more affluent on average) increases the energy-intensity of the residential sector.

Part IV. The macroeconomic importance of energy in the EU

There are a number of different ways in which energy can be understood as contributing to macroeconomic performance:

- the production of energy (and associated equipment) generates incomes
  - firms engaged in energy production, transformation and distribution generate value added and sustain employment: an increase in energy production is reflected in an increase in GDP, and substitution of domestic energy production for imported energy products boosts value added in the domestic economy (at the expense of production in the exporting country)
  - firms in other sectors that form part of the energy sector’s supply chain (both current and capital inputs to production) also generate value added and sustain employment
  - exports of the engineering services and equipment associated with energy production (and energy products, for countries that have the energy resources) sustain output and incomes in production, and the markets are fast-growing in countries that are industrialising rapidly
- cheap and reliable energy (whether produced domestically or imported) is indispensable for economic activity and helps to keep households’ cost of living and firms’ production costs low
- the use of energy is so pervasive throughout the economy that major transformations in society and economic performance have been driven by waves of innovation in energy supply interacting with innovations in the use of energy
  - for example, water power and factory machinery; coal, coke and metallurgy; steam power and rail transport; electricity and machine power; petroleum and road and air transport; electricity and information and communications technology; the construction industry and non-metallic products and industries
- emissions associated with energy use have harmful effects on human health and climate change; innovations that curb or eliminate these emissions, or promote energy efficiency, support the decoupling of economic growth from damage to health and the environment and hence relax an important long-term constraint on growth

1 The traditional contribution of energy production to the macro-economy

The data presented in this section follow the traditional approach in measuring the contribution of sectors to whole-economy activity by the size of the value added (and, in a similar way, the employment) in the firms that produce energy. The attraction of this approach is that when it is applied consistently across all sectors in the economy, there is no double-counting and the sum across sectors gives whole-economy value added.

However, this way of measuring the contribution of a sector ignores the value added associated with its upstream and downstream linkages (since, by definition, these are counted as the value added of other sectors). A capital-intensive sector such as energy production generates substantial demand for the sectors that produce the equipment that it uses, and this sustains value added and employment in these sectors (which may or may not be captured within Europe, depending on whether the equipment is produced there or imported). Furthermore, as noted below, the stimulus given to equipment producers by a large domestic market for a technology that is not yet mature (such as for some renewables) can provide the first-mover advantages that improve the industry's competitive position for exports to the rest of the world. Similarly, a reliable and competitively-priced supply of energy to the rest of the economy supports the competitive position of energy users, notably the energy-intensive industries. Rapid technological progress in, for example, renewable energy production, may (depending on the regulatory and competitive environment) be reflected in lower energy prices to users (and, as important, in greater assurance that future prices will be insulated from changes in global fossil fuel prices or from policies that penalise carbon emissions). This would be reflected in economic statistics not as an increase in the value added of the energy production sectors but in the scale of production and value added of the energy users that would gain market share against competitors in the rest of the world.

The scale of the value added associated with such upstream and downstream linkages is not directly reported in economic statistics. Even the calculation of so-called 'multipliers' from input-output tables, which is intended to estimate upstream linkages, focuses on intermediate rather than capital inputs and so does not capture the full scale of linkages for capital-intensive sectors. Furthermore, this kind of analysis would have to be applied consistently to every sector to provide the comparative statistics to gauge the relative importance of the energy sector. A full analysis of that kind is a larger undertaking than can be carried out in the present report; this section presents data on the conventional measure while the next section explores further some of the wider contributions of energy to the economy.

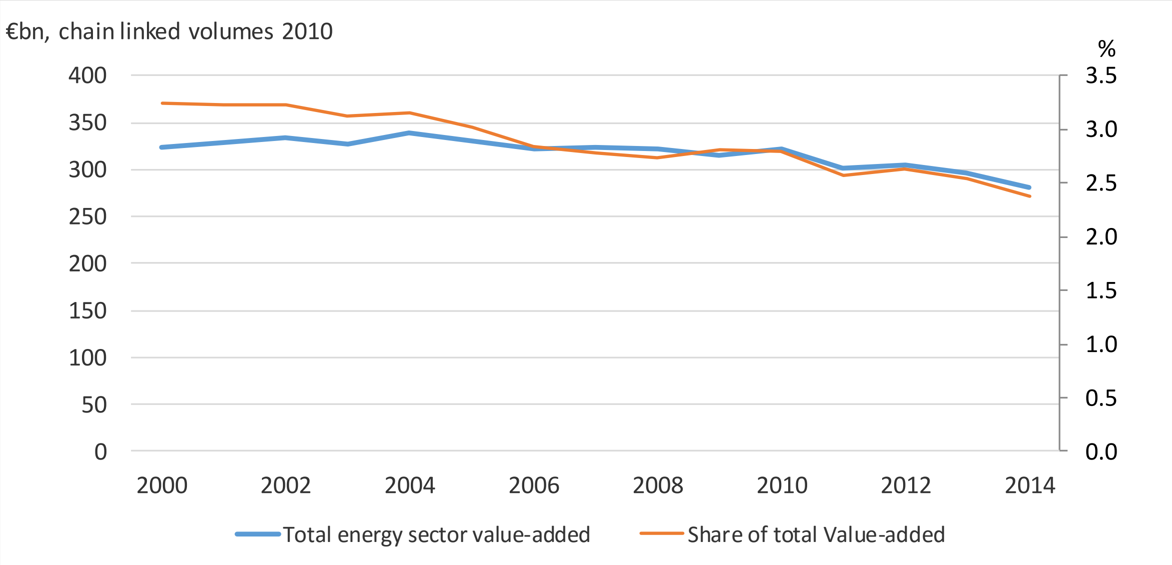
1.1 Value added

Output by the EU energy sector has been falling as a share of overall economic activity and in absolute value, led by a decline in extraction of primary energy sources

Figure IV.1 shows that the EU energy sector has been declining in both absolute terms and as a share of whole-economy GVA over the past decade. Value-added by the sector has fallen by around 13% in real terms since 2000, during which time the EU28 economy as a whole has grown by almost 20%. Section II.3 showed that the energy-intensity of the EU economy has fallen steadily over time and the decline in the relative importance of EU energy production is consistent with this. Its value added is estimated at around 2½% of overall EU value-added[16].

[16] In 2010 prices; because global energy prices fluctuate substantially, value added measured in current prices also fluctuates.

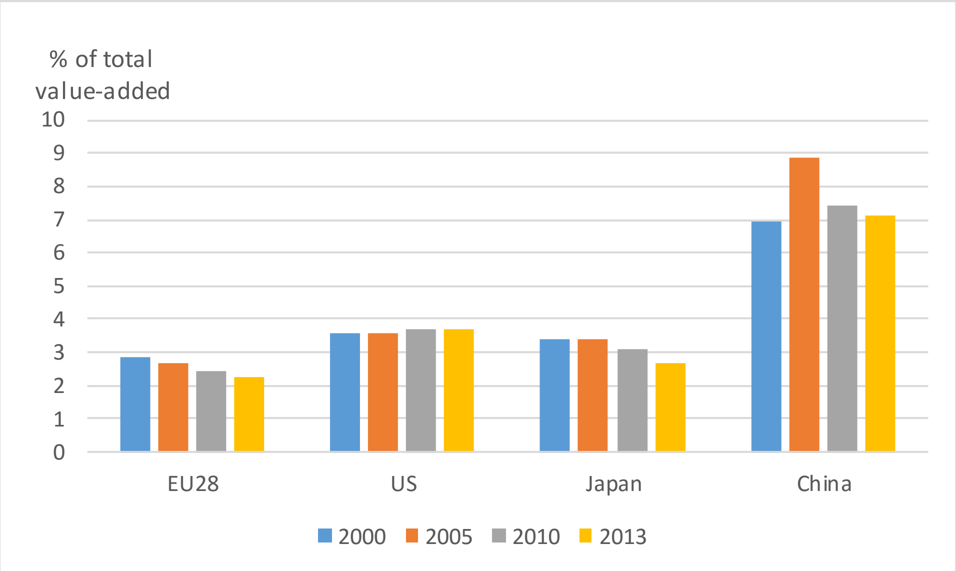
Figure IV.2 Energy Sector GVA, EU28



Note(s): Energy sector defined as Mining of coal and lignite, Extraction of crude petroleum and natural gas, Manufacture of coke and refined petroleum products and Electricity, gas, steam and air conditioning supply.

Source: Cambridge Econometrics calculations using data from Eurostat National Accounts, Structural Business Statistics databases.

Figure IV.1 Share of Energy Sector in Total GVA



Note(s): Energy sector defined as Mining of coal and lignite, Extraction of crude petroleum and natural gas, Manufacture of coke and refined petroleum products and Electricity, gas, steam and air conditioning supply.

Source: Cambridge Econometrics calculations using data from Eurostat National Accounts, Structural Business Statistics databases and E3ME data.

Within the sector, the rate of decline has been greatest in the extractive sector. Output of the supply sector Electricity, gas, steam and air conditioning supply was little changed in 2014 from the value in 2000.

The sector makes a much larger direct contribution in those states that joined the EU more recently, where there are large fossil fuel deposits to mine and the extractive industries and the power generation sector are still going through structural change. It accounts for 4½% of total value-added in the Czech Republic, 6¾% in Estonia over 6% in Poland and more than 5% in Romania. In contrast, the sector accounts for just 1½% of economic activity in France and just over 2% in Belgium.

The relative size of the EU energy sector is smaller than in other major economies

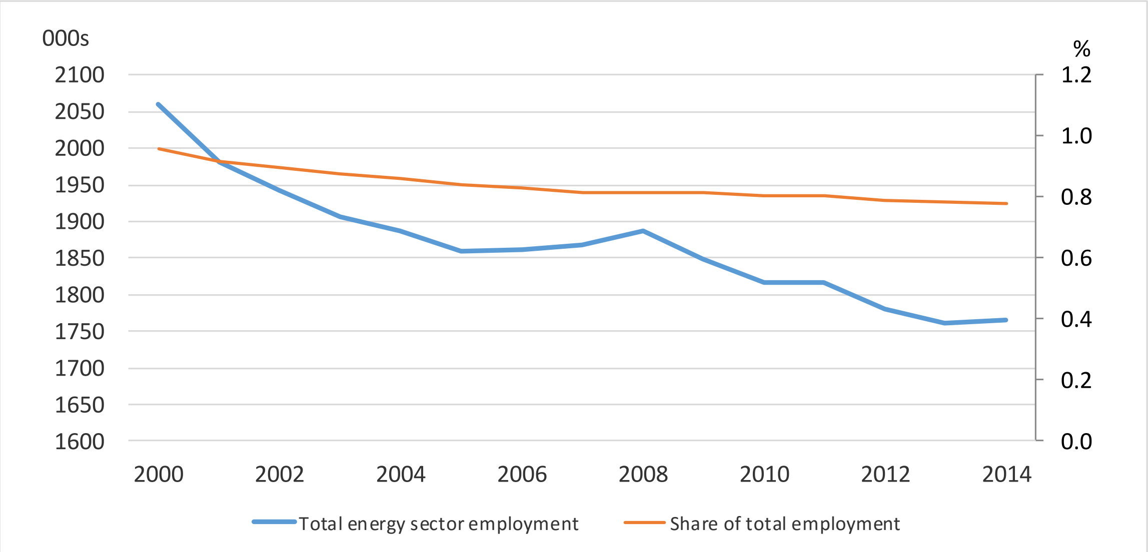
Figure IV.2 shows the energy sector's share of total economic activity in a number of key countries. The sector accounts for a smaller share of the EU economy than it does in the US, Japan or China. This is partly to do with the geographical distribution of fossil fuel resources, but it also reflects the structure and relative energy efficiency/intensity of the rest of the economy. In Japan, the sector's share of overall economic activity has been falling, as it has in the EU28. This trend has not occurred in the US; indeed, the sector's relative contribution to the economy has increased over time, reflecting in recent years the expansion of the shale gas sector.

1.2 Employment

Employment in energy sectors has fallen at a similar rate to output. Most jobs are now in energy supply (including electricity generation) rather than extractive sectors

Figure IV.3 shows the fall in employment in the energy sector in the past decade or so. Employment has fallen by almost 300,000 jobs since 2000 (around 15%). This rate of decline is similar to that in the sector's value-added, so the EU28 has seen little change in levels of value-added per worker over this period. The energy sector currently accounts for about ¾% of all jobs (a lower share than for value added, reflecting the capital-intensive nature of energy production).

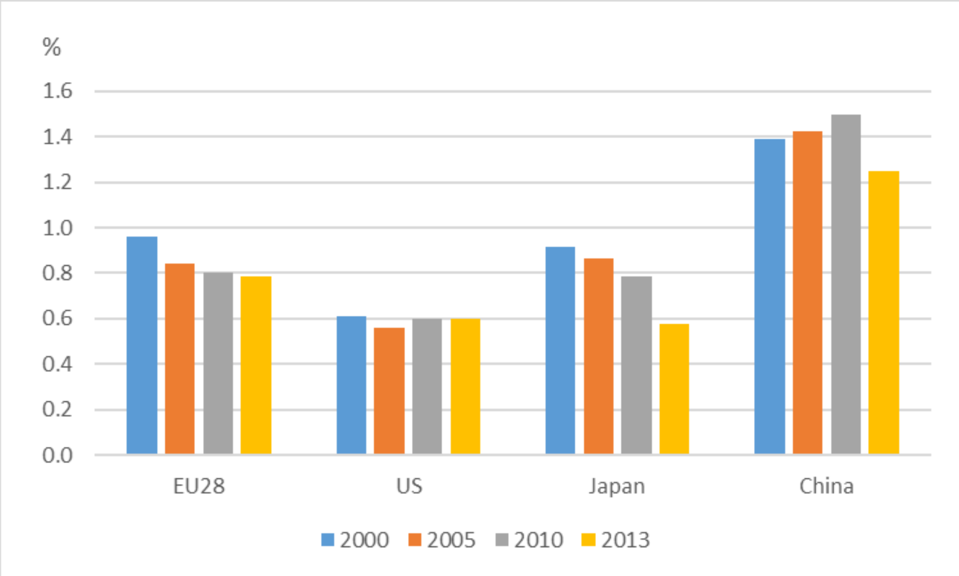
Figure IV.3 Energy Sector Employment, EU28



Note(s): Energy sector defined as Mining of coal and lignite, Extraction of crude petroleum and natural gas, Manufacture of coke and refined petroleum products and Electricity, gas, steam and air conditioning supply.

Source: Cambridge Econometrics calculations using data from Eurostat National Accounts, Structural Business Statistics databases.

Figure IV.4 Share of Energy Sector in Total Employment



Note(s): Energy sector defined as Mining of coal and lignite, Extraction of crude petroleum and natural gas, Manufacture of coke and refined petroleum products and Electricity, gas, steam and air conditioning supply.

Source: Cambridge Econometrics calculations using data from Eurostat National Accounts, Structural Business Statistics databases and E3ME data.

Within the energy sector, the majority of jobs are in the production and supply of electricity, gas and steam. The loss of employment in this sub-sector has been less rapid than in mining or fuel processing activities.

The distribution of energy sector employment within the EU28 generally follows that of overall employment and of the sector's value-added. The Member States that are much more dependent on the sector for employment are Poland (which has 20% of EU28 employment in the sector, but only 7% of all EU28 employment), Romania, Estonia, Latvia and Croatia. The relative importance of the energy sector for jobs has been falling since 2005 in Romania, Estonia and Croatia, but not in Poland or Latvia.

Figure IV.4 shows the trend in the sector's share of overall employment in the EU and a number of other economies. The sector accounts for a smaller share of jobs in the US than in the EU, but a larger share of value added (reflecting higher labour productivity in the sector in the US).

1.3 Energy as a factor in the production function

Regardless of whether it is produced domestically or imported, energy is an essential input to production. In the neoclassical tradition, this is recognised in those production functions that include energy as an explicit factor (rather than those that, for example, represent value added as a function of labour and capital inputs and exclude 'intermediate' inputs such as energy and materials). Typically, such functions have the property that the contribution to growth of any given factor reflects both the size of the change in the use of the factor and the value share of the factor in production costs; in the case of energy, because the value share is small, the estimated contribution to growth is also small. This method of estimating the contribution is distinct from the question of the *necessity* of energy as an input; an input can be absolutely essential for production to continue, but its value contribution to production and growth can nevertheless be small. In the production function tradition, the necessity issue is treated by considering the scope for substitution between energy and other inputs (notably capital): low substitutability or complementarity, especially in the short run, is an indication of the essential nature of energy as an input. In a related strand of literature, studies have also sought to identify the direction of causality between energy consumption and economic growth.

The rest of this section provides a short review of theoretical and empirical literature on this subject.

Growth theory production functions initially focused on capital and labour, but were later extended to incorporate natural resources and energy inputs

Based on the Solow (1956) model, growth theory initially developed with a focus on only two factors of production: capital and labour. The origins of this approach can be traced back to the income allocation theorem, according to which GDP is defined as the sum total of payments to capital (interest, dividends, rents and royalties) and payments to labour (wages, salaries). According to this, the output elasticity of the inputs to production must be proportional to their cost share. In extensions of the approach that make energy an explicit input, since primary energy accounts for a very small fraction of total factor cost, theorists have argued that energy cannot be an important source of growth (Denison, 1979). All modern neoclassical approaches to economic growth assume that growth in GDP per capita is driven by technological progress and capital investment, including knowledge investment (Romer, 1994; Aghion and Howitt 1998; Barro and Sala-i-Martin 2003). Recognition of the potential constraint on growth posed by the availability and prices of natural resources has motivated a branch of growth theory that includes environmental and resource variables (see Smulders 2005 for a review), but it has not yet affected the core of the growth theory and the associated policy debate.

Ayers et al. (2013) show that there is good reason to doubt that past GDP growth per capita is entirely explained by capital accumulation or non-specific knowledge accumulation. The authors note that neither labour nor capital can function without inputs of energy, either as food or animal feed, or as fuel for engines, or electric power for light, communication and appliances of all sorts. In other words, a flow of energy capable of doing work, in some form, is just as essential for economic output (production) as capital or labour. Thus energy should be included as a separate factor of production next to labour and capital. Yet energy has been largely ignored by economic theory. The first attempts to treat energy as an explicit factor of production next to capital and labour in quantitative analysis were made only after the energy crises in the 1970s and the 1980s (see Hudson and Jorgenson 1974; Allen and et al., 1976 and Jorgenson 1978) when oil price spikes triggered deep recessions. In response to this apparent relationship, several economists introduced the KLEM production function, where K refers to capital, L to labour, E to energy and M to materials (see Hudson and Jorgenson 1974; Jorgenson 1978 & 1984 and Berndt and Wood, 1979).

The inclusion of natural resources and energy in growth models poses issues of measurement difficulties and the finiteness and exhaustibility of resources that render problematic the notion that economic growth can proceed indefinitely (Stern, 2011). The growth path in the presence of resources is affected by the institutional arrangements assumed. Studies look at both (1) optimal growth models, which attempt to maximize the total discounted social welfare over some relevant time horizon (often an infinite horizon) or achieve sustainability (non-declining social welfare), and (2) models intended to represent real economies assuming perfectly competitive markets or other arrangements. In these efforts, the substitution elasticity between capital and resources has been identified as a critical factor that indicates by how much one of the inputs must be increased to maintain the same level of production when the use of the other input is altered.

Solow (1974) discusses the cases in which the substitution elasticity for non-renewable resources and capital is greater or less than unity. In the first case, where substitution possibilities are large, the possibility of non-renewable resources acting as a constraint on growth does not arise. In the second case non-renewable resource inputs are essential: that is, given positive non-resource inputs, output will be zero when the resource input is zero and strictly positive otherwise.[17]

The question of substitutability of inputs has been taken further to address the possibility that more than one type of substitution may be involved and that there may be several factors that lead to limited substitutability. Substitution may be possible between similar production inputs (for example, different fuels) and/or between different categories of inputs (like energy and machinery). A distinction should also be made between micro- and macro-level substitutions; in the first case substitution may occur in a single process or firm, while in the second case substitution may occur at the economy-wide level. Solow (1997) argues that within-category substitution (for instance within renewable and non-renewable resources) is of particular importance and has played an important part in shaping patterns of natural resources and energy use in economies[18].

Some, but not all, empirical literature suggests that capital and energy are complements, or only weak substitutes, but no clear conclusion has been reached either in terms of sign or magnitude.

There is an increasing amount of empirical evidence that energy is subject to limited substitutability, and this can shape the process of economic growth, though some forms of energy can be replaced by others (e.g. wind power for nuclear power). Stern (2011) shows that substitution between energy carriers has been an important driver of growth in the past, but that such substitution has now reached its limit. Econometric studies of aggregate production functions find complementarity or weak substitutability between energy and capital for OECD countries (see Berndt and Wood 1979; Koetse et al., 2008 and Fiorito and van den Bergh, 2011). Most growth models with resources exclude realistic constraints on the substitution possibilities between energy and capital. Exceptions to this approach include the works of D'Arge and Kogiku (1973), Kümmel (1982), Gross and Veendorp (1990), van den Bergh and Nijkamp (1994), Kümmel et al. (2002) and Lindenberger and Kümmel (2011).

In the overwhelming majority of growth models, labour and capital are assumed to be easily substitutable, i.e. output can be produced with labour with very little capital, or with capital with very little labour. In reality, the range of short-term factor substitutability is fairly narrow and there exists an optimal operating point for the economy and an optimal combination of capital and labour with which under-utilization of labour or capital is avoided. This also holds in the case of three factors of production where energy is included. For instance, capital would be unproductive without a flow of energy. On the other hand, for given output there is a certain

[17] The Cobb-Douglas production function, frequently used in growth models entails the essentiality condition: some amount of energy and materials is required to produce goods and services.

[18] For instance, consider the long-run pattern of energy use in industrial economies dominated by the substitutions from wood to coal, oil, natural gas and primary electricity (Hall et al., 1986).

potential of substituting capital for energy by increasing energy efficiency, and so some degree of limited substitutability should be considered[19].

Motivated by the policy objective of reducing dependence on energy use, studies that forecast future energy demand and seek to understand the potential impact of energy taxation on energy use have, in the last decades, concentrated on whether energy and capital are complementary or substitutes. This has important implications for the choice of policy design. If energy and capital are complements, they will respond to price changes moving in the same direction. In this case, for example, the promotion of innovation in and the diffusion of energy-efficient technologies will be effective in reducing energy consumption. If energy and capital are substitutes, a carbon tax could be preferred, bringing about a change in relative prices and a shift in the relative shares of energy and capital (Tovar and Iglesias, 2013)[20].

Among early literature, Berndt and Wood (1975) found that capital and energy were complements, while Griffin and Gregory (1976) concluded that they were substitutes. Since then many studies have investigated the elasticity of substitution or complementarity between energy and capital. Examples include Hudson and Jorgenson (1974), Pindyck (1979), Hunt (1984), Thompson and Taylor (1995), Nguyen and Streitweiser (1997). Despite the large number of studies carried out, no clear conclusion has been reached, either in terms of sign or magnitude (see Apostolakis, 1990 and Thompson, 2006 for a detailed review of existing studies).

In a literature review, Apostolakis (1990) argues that most studies based on time-series data classify the two inputs as complements, while studies based on a pooled cross-section of countries or regions find that they are substitutes. The conclusion drawn is that time-series reflect short-term relationships (how the relationship between the two inputs changes from year to year in a given country), while cross-section analyses capture long-term effects (by comparing countries with quite different capital to energy ratios)[21]. More recent studies of Woodland (1993) and Nguyen and Streitwieser (1999) provide evidence based on micro data. Woodland (1993) uses repeated cross-section data for about 10,000 industrial establishments located in the Australian state of New South Wales for the period 1977-85. Nguyen and Streitwieser (1999) used cross-section data for 10,412 U.S. manufacturing plants for the year 1991. Both studies concluded that energy and capital were substitutes in production.

An additional difference among the studies that have been carried out is whether energy and material are both distinguished (KLE versus KLEM models where K is capital, L is labour, E is Energy and M is materials). The choice of including or excluding materials in the production function (M) implies different assumptions about the separability of the factors within production processes and this results in differences in cost shares (Costantini and Paglialunga, 2014). The magnitude of cost shares is crucial in determining the sign for the energy price elasticity. Higher cost

[19] A core challenge in explicitly modelling the role of energy to production is the specification of an appropriate production function. Kümmel (1982), Kümmel et al. (1985) and Kümmel et al. (2002) provide a production function that does not presume equality of output elasticities and cost shares and considers the substitution possibilities between energy, capital and labor. Applying a similar methodology based on the specification of output elasticities that satisfy appropriate asymptotic technological boundary conditions, production functions for the service sector have been derived by Lindenberger (2003).

[20] As noted in Golub (2013), the elasticity of substitution between energy and capital measures the degree of technological flexibility.

[21] The vast majority of the empirical studies have been carried out on the basis of aggregate data including macro time series or cross-country data. Solow (1987) emphasizes that studies based on macro data cannot capture the technical substitution between energy and capital, and that data at a more disaggregated level should be used instead.

shares are more likely to show substitutability whereas for small cost shares it is easier to have smaller or negative elasticities (factors may be complements).

Recent contributions to the investigation of the relationship between energy and capital have moved on from the issue of identifying complementarity or substitutability to the development of better econometric specifications to obtain more realistic estimated values to include as inputs to energy models. In these models, elasticity parameters represent the sensitivity of economic agents to price changes and determine subsequent demand adjustments[22]. Despite the extensive research on this matter, the literature has again not reached a conclusion on the sign or the magnitude of the substitution elasticity between energy and capital. Differences in the results reflect different specifications, different data sets and different estimation methods (Tovar and Iglesias, 2013).

Some studies suggest that energy 'causes' growth, rather than the other way round, but there is no general conclusion on the direction of causality: the findings vary according to the particular data set that is examined.

One related strand of literature has investigated the nature of the causal relation between energy and economic output in the long run[23]. In this strand, the causal direction, magnitude, sign and significance of the parameters of interest are investigated (see Ozturk 2010 and Payne 2010). The direction of causality has policy implications for the potential impact of energy and environment regulations on economic performance. Four possible hypotheses are explored in the literature. The 'neutrality' hypothesis holds if no causal relationship is found between energy and economic output, which would imply that energy policies have no impact on economic growth. The 'feedback' hypothesis has causality flowing in both directions between energy and economic output. In the 'conservation', the level of economic activity Granger-causes energy consumption. Fourthly, the 'growth' hypothesis has causality running from energy consumption to economic output.

The analysis has been supported by advances in time-series econometrics that test for non-stationarity and cointegration in a multivariate setting and control better for omitted variables bias. Panel cointegration techniques and Vector Error Correction Models (VECM) have allowed analysis to control for cross-country heterogeneity and cross-sectional interdependency. However, once again, no clear conclusion has been drawn on which of the hypotheses are supported by the data and how large the relationships are.

Table IV.1 provides a summary of the key studies on the relationship between energy, capital and growth.

The pioneering work of Kraft and Kraft (1978) which applied a standard Granger test (see Granger, 1969) found a uni-directional long-run relationship running from GDP to energy consumption in the USA for the period 1947-1974. Yu and Hwang (1984) used the same methodology and find no causality in the case of the USA for the period 1947-1979. Yu and Choi (1985) employ the standard Granger test for the period 1954-1976 for a set of countries finding that: causality runs from GDP to energy consumption for Korea, in the opposite direction for the Philippines, while no causality

[22] For a discussion and evidence on the importance of substitution elasticity see: Saunders (2000, 2008), Jacoby et al. (2004), Broadstock et al. (2007), Okagawa and Ban (2008), Lecca et al. (2011), Burniaux and Martin (2012) and Antimiani et al. (2013).

[23] Besides the impact it has if combined with capital, energy also has a direct contribution on output and the energy-output elasticity has therefore also been widely investigated, both in the CGE literature and in terms of causality relationships (Costantini and Paglialunga, 2014).

at all was identified in the case of USA, Poland and UK. Erol and Yu (1987) found a uni-directional relationship running from energy consumption to growth for Japan for the period 1950-1982. Hwang and Gum (1992) and Yang (2000) used the same test for Taiwan, for the period 1955-1993 and for the period 1954-1997, and found a bi-directional causal relationship between energy consumption and economic growth. Cheng (1997) and Wolde-Rufael (2004) found a long-run causal relationship running from energy consumption to GDP in the case of Brazil for the period 1963-1993 and the case of Shanghai for the period 1952-1999.

Lee (2006) examined the causal linkages between energy consumption and economic growth for 11 developed countries for the period 1960-2001 and found mixed results on the nature and the direction of causality. Cheng and Lai (1997) used Hsiao’s (1981) Granger causality test for Taiwan for the period 1995-1993 and, in contrast to the work of Hwang and Gum (1992) and Yang (2000), found the causal relationship being uni-directional running form GDP to energy consumption. Chiou-Wei et al. (2008) used both linear and non-linear Granger causality tests for a sample of Asian newly industrialized countries as well as for the USA for the period 1954-2006 and found evidence in support of the neutrality hypothesis for the USA, Thailand, and South Korea. The authors also found uni-directional causality running from economic growth to energy consumption for the Philippines and Singapore while energy consumption may have affected economic growth for Taiwan, Hong Kong, Malaysia and Indonesia. Chontanawat et al. (2008) test for causality between energy and GDP using a consistent data set and Granger test methodology for 30 OECD countries and 78 non-OECD countries. Their findings show that causality from energy to GDP is more prevalent in the developed OECD countries as compared to the developing non-OECD countries.

Tsani (2010) investigates the causal relationship between aggregated and disaggregated levels of energy consumption and economic growth for Greece for the period 1960-2006 employing the Toda-Yamamoto (1995) methodology. For aggregated energy consumption, Tsani found a uni-directional causal relationship running from energy consumption to output. With disaggregated data, Tsani found a bi-directional causal relationship between (1) industrial and (2) residential energy consumption and GDP. No causal relationship was found for transport.

Menegaki (2010) examined the relationship between economic growth and renewable energy for 27 European countries in a multivariate panel framework for the period 1997-2007. The results supported the neutrality hypothesis. In a subsequent paper Menegaki and Ozturk (2013) analysed the relationship from a political economy perspective and found bi-directional causality (supporting the feedback hypothesis) between growth and political stability as well as capital and political stability. Ucan et al. (2014) examined the relationship between renewable and non-renewable energy consumption and economic growth for a panel of 15 European Union countries for the years 1990-2011 using heterogeneous panel integration tests. Their findings show unidirectional causality between non-renewable energy consumption and economic growth.

Table IV.1 Key studies on the energy, capital and growth nexus

Author	Region	Time	Findings	Notes
Energy-capital relationship				
Berndt and Wood (1975)	USA	1947-1971	Complementary	Data employed: Time series
Griffin and Gregory (1976)	Industrialized countries	1955-1970[24]	Substitutes	Data employed: Cross-section
Fuss (1977)	Canada	1961-1971	Complementary	Data employed: Time-series
Pindyck (1979)	Industrialized countries	1963-1973	Substitutes	Data employed: Cross-section
Hunt (1984)	UK	1960-1980	Complementary	Data employed: Time series
Nguyen and Streitweiser (1997)	USA	1991	Substitutes	Data employed: Cross section
Energy-growth causality				
Kraft and Kraft (1978)	USA	1947-1974	Causality runs from growth to energy consumption	Method employed: Granger causality test
Yu and Hwang (1984)	USA	1947-1979	No causality	Method employed: Sim's test
Oh and Lee (2004)	Korea	1970-1999	Causality runs from energy consumption to growth	Method employed: Granger test and Error Correction Model
Wolde-Rufael (2004)	Shanghai	1952-1999	Causality runs from energy consumption to growth	Method employed: Toda-Yamamoto causality test
Soytas and Sari (2009)	Turkey	1960-2000	No causality	Method employed: Toda-Yamamoto causality test
Yang (2000)	Taiwan	1954-1997	Bi-directional causality	Method employed: Granger causality-VAR
Tsani (2010)	Greece	1960-2006	Uni-directional causality from aggregate energy consumption to output	Method employed: Toda-Yamamoto causality test
Menegaki (2011)	27 EU countries	1997-2007	No causality	Method employed: Panel causality test and one-way random effect model
Menegaki and Oztruk (2013)	26 EU countries	1975-2009	Causality runs from energy consumption (fossil) to growth	Method employed: Dynamic error correction model
Ukan et al. (2014)	15 EU countries	1990-2011	Causality runs between non-renewable energy consumption and economic growth	Method employed: Panel integration test

Studies focused on EU countries have also produced mixed and inconclusive results.

No consistent findings have therefore emerged: studies with different econometric techniques, different time periods and different countries have produced varying

[24] In 5-year steps.

results. Differences may reflect the fact that countries differ in terms of structural and development characteristics. Studies also differ according to the selection of variables, particularly in multivariate models (Gross, 2012). For example, studies differ in the measures used for energy consumption. In some cases, (aggregate) primary energy consumption is used (see Bowden and Payne, 2009) while other studies examine particular energy resources, especially electricity, or distinguish between renewable and non-renewable energy sources (see Stern, 2000; Oh and Lee, 2004; Warr and Ayres, 2010 and Tugcu et al., 2012). In the energy-GDP cointegration analysis literature, attention has mainly focused at the macroeconomic level (see Soytas and Sari, 2007; Bowden and Payne, 2009; Ziramba, 2009; Ewing et al., 2009 and Zhang and Xu, 2013) while only a few disaggregate to sectoral level (see for instance Tsani, 2010 and Liddle, 2012).

2 The new role of energy in driving macroeconomic performance

2.1 Wider impacts of energy on the economy

The substitution of renewable power generation for fossil fuels and the growing global market for renewable power equipment offer opportunities to improve the trade balance. Europe's strength is in the production of wind components rather than solar (where China is dominant).

A number of studies have sought to estimate the trade in energy equipment developing their own working definitions of what products comprise the sector. These studies have tended to focus on the trade in renewables equipment, and on particular technologies. Much less attention has been paid to trade in conventional power generation equipment.

Renewable power generation plants are more capital-intensive than those based on fossil fuels[25]. The substitution of capital for fossil fuel inputs offers the opportunity to reduce exposure to volatile global energy prices. If the capital equipment is produced within Europe, it also offers the possibility of reducing Europe's energy trade deficit (and, potentially through first-mover advantages, establish an industry that can serve global markets).

Table IV.2 outlines the definitions of solar and wind components used in the European Commission's *Energy Economic Developments in Europe* report (European Commission 2014). On this definition intra and extra-EU27 trade in solar and wind components increased considerably between 2000 and 2012.

Most EU Member States have a trade deficit with the rest of the world in solar components, largely driven by the emergence (since 2006) of exports from China. China is the world's largest producer of solar panels, accounting for about 65% of global production. China exports more than 90% of its production, the majority of which (80%) serves the EU market.

Some 60% of extra-EU exports of solar equipment are accounted for by five countries, including Japan (25%) and the US (14%). The EU trade deficit in solar components fell from €21bn in 2010 to €9bn in 2012, but this largely reflected a fall in EU imports. Germany had the largest intra and extra-EU trade deficit in 2012, amounting to €1.9bn, followed closely by Italy (€1.86bn). Positive trade balances in the Czech Republic and Cyprus mostly reflect a surplus in *intra-EU* trade.

[25] DECC (2013) and USIEA (2015) provide levelised cost estimates for a number of alternative technologies.

Table IV.2: Components in wind and solar industry

Solar components	Wind components
Photosensitive semiconductor devices, including photovoltaic cells (HS code: 85414090)	Wind-powered generating sets (HS code: 85023100)
Inverters with power handling capacity > 7.5 kva, excluding a kind used with telecommunication apparatus, automatic data-processing machines and units thereof (HS code: 85044088)	Parts of electrical lightening or signalling equipment, windscreen wipers, defrosters and demisters of a kind used for motor vehicles, n.e.s, excluding burglar alarms for motor vehicles (HS code: 85129090)
	AC generators "alternators", of an output > 750 kva (HS code: 85016400)
	Gear boxes for machinery, excluding those for civil aircraft (HS code: 84834094)
	Towers and lattice masts of iron or steel (HS code: 73082000)
	Parts of engines and motors, n.e.s (HS code: 84129090)

Source: European Commission (2014) Energy Economic Developments in Europe - Part III Renewables: Energy and Equipment Trade Developments in the EU.

Unlike trade in solar components, most Member States have had a sustained trade surplus with the rest of the world in components for wind power, amounting to €2.45bn in 2012. The EU is a leader in the manufacture of wind turbines and their components, with seven of the top ten turbine manufacturing companies based in Europe, producing 43% of all wind turbines in the world.

Some 55% of EU exports went to five countries in 2012, with a third of exports going to the US and Canada. Some 59% of extra-EU imports come from five countries, with China a dominant presence accounting for 40% of the total (up from 4% in 2006) (European Commission 2014).

Within the EU the largest trade surpluses in wind components in 2012 were seen in Germany (€1.9bn), Denmark (€1.5bn) and Spain (€1.2bn). The largest trade deficits were recorded in the UK (€873m) and Sweden (€302m), mainly driven by a large intra-EU trade deficit.

2.2 The impact on employment of investment in low carbon generation and energy efficiency

The drive for energy efficiency and investment in low carbon power generation brings with it a range of potential job opportunities. Overall, the EU is seen to have the highest rate of employment in renewable energy sector per head of population except for Brazil[26]. Most immediate are the direct opportunities among the manufacturers of the investment goods and services (and associated supply chains) needed to deliver the low carbon outcomes. The State of Renewable Energies in Europe (2014) reports total (direct and indirect) employment in the wind power sector in the EU in 2013 as 302,450, with Germany accounting for the largest proportion of employment (137,800), followed by the UK (36,000), Italy (30,000), Denmark (27,500), France (20,000) and Spain (20,000). According to the EurObserv'ER report *The State of Renewable Energies in Europe* (2014), total (direct and indirect) employment in the

[26] Renewable energy in Europe 2016, European Environment Agency.

photovoltaic industry in the EU in 2013 was 158,900, with Germany accounting for the largest proportion of employment (56,000), followed by the UK (26,400) and France (15,600).

However, jobs will also be lost as increased demand for 'new' products (e.g. wind turbine blades) will be accompanied by less demand for other goods (e.g. turbines for conventional power stations), and so it is important to identify the net as well as gross employment impacts. It may well be that particular sectors, or indeed organisations, will experience both positive and negative effects. Whether a shift to low-carbon technology produces a net increase in investment-related employment depends on the scale of investment and on labour mobility between sectors (including skills reorientation and training): in the case of investment in power generation, the jobs supported by each 1MW capacity is greater for low carbon renewable technologies than for fossil-fuel generation (reflecting substitution during the plant's operation towards capital services and away from current inputs of fossil-fuel energy).

Energy efficiency and low carbon investment further supports employment in two ways: by directly lowering energy costs it improves the competitive position of sectors and (where energy-efficiency options are cost-effective) it releases household spending on energy and makes it available to purchase other goods and services. These additional purchases are likely to support greater domestic employment than would the equivalent value spent on energy (because conventional energy has a high import content and a lower labour content).

There have been numerous studies over the past decade that have identified an effect on employment of energy efficiency and low carbon technological improvement and investment. In the majority of studies, the net employment effects of energy efficiency are positive, irrespective of the modelling approach used.

Employment in investment-related goods and services

A recent study for DG Energy at the European Commission (European Commission, 2015) estimated EU28 employment in energy efficiency (EE) goods and services at 0.9m as of 2010, a figure that increased to 2.4m if peripheral EE activities were also included. The study estimated that between 100,000 and 300,000 extra jobs could be created if available estimates of energy saving potential were realised. This report also reviewed much of the previous literature, a summary of which is included, with some more recent publications, below.

Most studies find that investment in energy efficiency has a small net positive effect on employment. This reflects the tendency for those sectors providing energy efficient goods and services (especially the buildings and construction sector) to be more labour-intensive than energy-producing sectors, particularly in energy importing countries (Quirion, 2013). However, the scale of reported employment impacts varies considerably, according to the intensity of the measures, (for example. the speed and depth of building renovation, see e.g. BPIE, 2011, and Cuchi and Sweatman, 2011).

These findings are supported by an analysis of the employment impacts of deep building renovations in Poland by Uerge-Vorstatz et al. (2012). Based on data collected and scaled-up from a number of case studies, the report estimates that a programme costing between €2.2bn and €7bn in 2010 prices, and saving between €0.6bn and €1.3bn of energy in 2010 prices a year would have a direct labour impact in the construction sector of between 15,000 and 87,000 full-time equivalent (FTE) jobs in 2020 compared to baseline. Most of the new jobs were expected to require skilled labour.

The Polish report also looks at the net effects, using input-output analysis. It distinguishes three types of induced effects: those generated by the additional jobs created by the investment in construction, job losses in the energy sector from reduced demand, and the induced impacts fuelled by the spending of energy cost savings. On aggregate, the study estimates that between 86,000 and 254,000 additional jobs (FTE) per year could be generated in 2020, depending on the intensity and depth of the buildings renovation scenarios. Manufacturing (through the supply of materials for the renovations) and construction are more labour-intensive than energy supply (Uerge-Vorstatz et al. 2012).

Pikas et al., (2015) estimated the employment impacts related to renovating apartment buildings in Estonia. The study found that 17 direct and indirect jobs were created for every €1m of investment. Directly, ten jobs were created in on-site construction activities, and between one and six were related to consultancy and manufacturing industries, respectively.

In a study for the American Council for an Energy Efficient Economy (ACEEE) study, Bell (2012) reported the same finding that investments in energy efficiency create jobs in labour-intensive industries, such as construction, especially in the refurbishment and installation of EE measures in buildings. For example, a $1m investment supports, on average, 20 construction jobs compared to just 14 in the less labour-intensive manufacturing sector. However, Neubauer et al. (2013) reported a much lower employment yield for investment in conventional energy generation, with only 10 jobs for every $1m spent.

Evidence from other national sources also highlights the importance of considering the export potential of services developed domestically. In Denmark, the Danish Energy Agency (2013) estimated that the growth potential of energy efficiency equipment and advice was around 27bn Danish krone (€3.6bn) by 2020, supporting 9,000 new jobs. Two-thirds of these new jobs would be due to the export of energy efficient equipment and advisory services to other European and international markets.

A recent report by VHK (2014), which considers the direct employment impacts of eco-design and energy labelling services in the EU28, suggested that an extra 0.8m direct jobs would be created in the industry, wholesale and retail sector in 2020. The direct employment relates strictly to identifiable jobs in the added-value chain of the product. Employment displacement effects are not considered.

Indirect effects

Indirect effects of energy efficiency measures are more difficult to estimate since they depend not just on the relative labour content of the investment and the displaced energy products, but on subsequent behavioural responses.

Roland-Holst (2008) examined the impact of a historical decrease in energy intensity in Californian households between 1972 and 2006. Here, the resulting switch of expenditure to other goods and services is found to have created 1.5m FTE jobs with an average annual salary of $30,000. The shift from largely imported energy to spending on goods with stronger supply chains at state-level created a further multiplier effect in terms of job generation. Taking into account the slower growth in the energy supply chains, for every new job foregone in these sectors, the authors estimated that more than 50 new jobs were created across the state.

A study of the UK (Barker and Foxon, 2008).) found energy efficiency policy raised the annual rate of economic growth by around 0.1 percentage points between 2000 and 2007. The cumulative impact of the boost to growth together with those policies announced for the period 2007 to 2010 – was estimated to have increased employment by 0.8% (or 271,000 jobs) in the UK in 2010

Cambridge Econometrics and Ricardo AEA (2013) looked in detail at just one dimension of energy efficiency and low carbon investment, that of low carbon vehicles. It found that total effects, including the jobs generated in the manufacture of the new automotive components as well as indirect effects coming from lower spending on fuel by households and firms (and the associated competitiveness effects) could produce a *net* increase of 350,000-445,000 jobs in Europe by 2030. Of these, broadly two-thirds were the result of indirect effects of redirected expenditure.

3 Energy and household consumption

3.1 Underlying drivers and trends

Rising household energy use in the EU reflects trends towards smaller households and higher uptake of household appliances (offsetting the greater energy efficiency of, particularly, larger appliances).

There is a substantial literature on the trends in energy efficiency, both within the EU and other parts of the world. This literature[27] highlights a number of key drivers of energy usage in households. The relative price of energy (determined by a combination of absolute energy prices and household income levels) is understood to play a role, but within the EU the influence of income on consumption is less clear (Enerdata 2015). There are also a number of other drivers, which can be broadly split into technological, policy and others. Technological influences are changes in technology which influence household energy use; this can either be efficiency gains (e.g. new technology which reduces energy use in large appliances) or cause an increase in demand for energy (e.g. the shift towards larger and more energy-intensive televisions). Policy influences are reflected in the role that legislation plays in shifting energy demand; for example, EU directives have hastened the shift towards more efficient large appliances. Other factors include consumer attitudes (for example the shift towards less environmentally-damaging consumption) and cultural effects (whereby different nationalities, ethnic groups and age groups have different expectations and demands on the energy system), which can all be assessed as distinct from the income effect.

At a global level, household energy use has been increasing since the 1990s (IEA 2008). In 2005, over half of total household energy demand was for air heating, where trends towards larger living spaces and decreasing household size have more than offset the gains in energy efficiency. At the same time, the energy demand for use by appliances (including air conditioning units) increased rapidly, overtaking water heating as the second-largest source of energy demand from households in the late 1990s. This has been driven by increasing uptake of appliances; the energy usage of individual devices declined in almost all cases over 1990-2005 (with the exception of televisions).

In the EU, overall energy usage by households increased over 2000-2012, reflecting increasing numbers of dwellings (as population has increased and average household size decreased) and an increase in living standards leading to an increased uptake of household appliances and increased household space. These trends persisted even following the economic crisis: increasing use of appliances, including IT devices and air conditioning, while increasing numbers of households also put upwards pressure on overall household energy use (ADEME 2015).

On a country-by-country basis, however, it is apparent that individual Member States have observed different trends. For example, household energy consumption per dwelling decreased rapidly in a number of Member States after the economic crisis, particularly those most severely affected by the crisis (such as Greece, Cyprus and Ireland), linked to falling household incomes.

[27] See, for example, Mikalauskienė, Štreimikienė and Alebaite, The Main Drivers of Energy Consumption in Households, 2012.

Space heating remains the largest end-use of energy in households, although its share of total household use is decreasing (from 71% in 2000 to 67% in 2012), suggesting that energy efficiency gains in this area have been more rapid than across other uses; and indeed every Member State (with the exception of Finland) used less energy for air heating per square metre in 2012 than in 2000. It is notable that new buildings played only a minor role in this efficiency gain in most Member States (even over a period as long as a decade, new dwellings make up a modest proportion of the total housing stock). In the EU the increasing energy use of appliances has been driven by small appliances: while large appliances have increased in number, this has been offset by increasing energy efficiency.

3.2 Energy poverty

In 2014, around 10% of households in the EU were not able to keep their home adequately warm, a figure that rises above 25% in Bulgaria, Greece, Portugal, Cyprus and Lithuania. In most countries poorer households spend a higher proportion of their income on energy services.

There is no clear consensus definition of energy poverty, which is a multidimensional concept. It is often interchangeably used with the notion of fuel poverty, the latter sometimes defined as occurring when households do not have sufficient resources to heat their home to a comfortable temperature. The social groups most susceptible to energy poverty are low-income households living in poor quality, energy-inefficient housing. Innovations involving the development of affordable energy efficiency measures for buildings therefore have a role in reducing the prevalence of energy poverty in the EU. Clearly, differences across Member States in fuel prices and energy bills affect the extent of energy poverty, as does the distribution of incomes.

There are three broad methods to measure energy poverty.

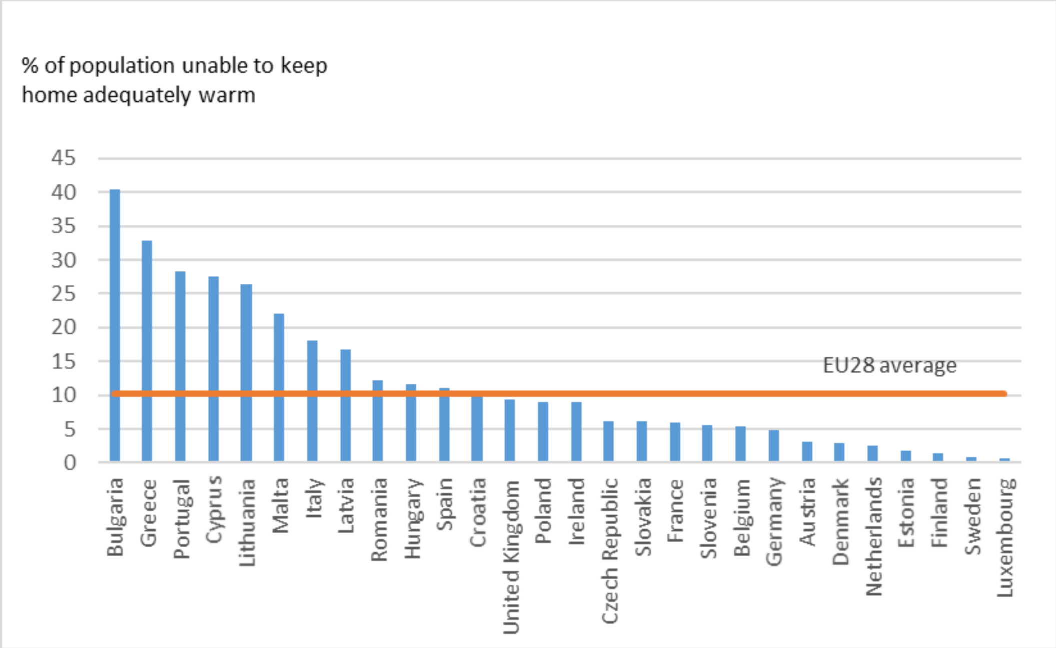
The *temperature approach* measures the internal temperature of rooms to ascertain whether thresholds for adequate warmth are reached.

The *expenditure approach*, the most common approach, is based on the ratio of expenditure on fuel to household income; it is open to debate what threshold to adopt as the boundary above which a household is deemed to be in energy poverty, and in particularly whether that threshold should somehow be estimated using the scale of spending required to achieve an adequate level of comfort rather than how much was actually spent.

The *consensual approach* typically involves surveying households and asking them whether they can afford to heat their homes adequately and pay their energy bills. The household survey EU SILC includes questions to provide consensual-approach indicators of fuel poverty. It reports that, in 2014, around 10% of households in the EU were not able to keep to keep their home adequately warm. As shown in Figure IV.5, there is considerable variation in prevalence across Member States with households in Bulgaria, Greece, Portugal, Cyprus and Lithuania most at risk.

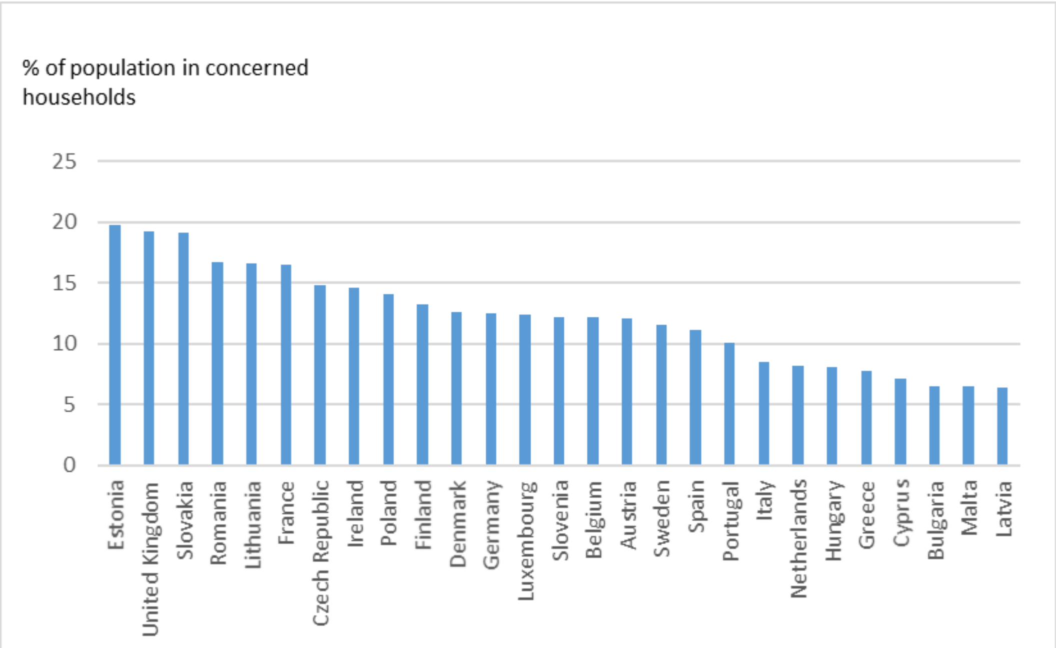
As Figure IV.6 shows, a measure based on the expenditure approach gives a very different ranking of Member States in terms of fuel hardship. Of course, poor households may be so constrained as to be unable to raise spending on fuel, while a country with a more equal income distribution is likely to see smaller differences in per household energy spending regardless of whether the average spend achieves a basic level of comfort.

Figure IV.5: Incidence of one measure of energy poverty in the EU in 2014



Source: *Eurostat EU SILC database, 2014 data*

Figure IV.6: Proportion of population in households spending twice the national average on fuel, across EU member states

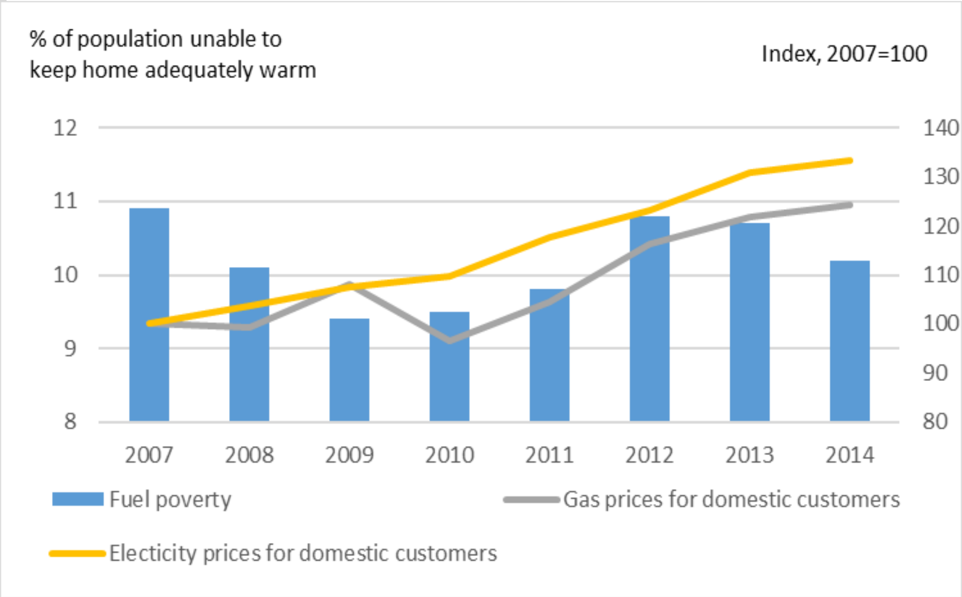


Source: *Commission Staff Working Paper - An Energy Policy for Consumers SEC (2010) 1407 final and Eurostat (demo_pop database).*

Figure IV.7 shows that the incidence of energy poverty in the EU as a whole has broadly followed the economic cycle, with rates falling as the pre-recession peak was reached and rising in periods of recession or weak growth (e.g. 2009-12). Most but not all Member States have followed this broad profile (though the precise timing of peaks/troughs may differ slightly). Among those countries experiencing markedly different trends since 2007 are: Bulgaria, Romania and Poland, where rates of fuel poverty have fallen sharply throughout the period; Germany where rates fell over the period of recession and recovery but have since risen slightly; and the UK where rates since 2007 have been on an upward trend (though fell back marginally in 2014).

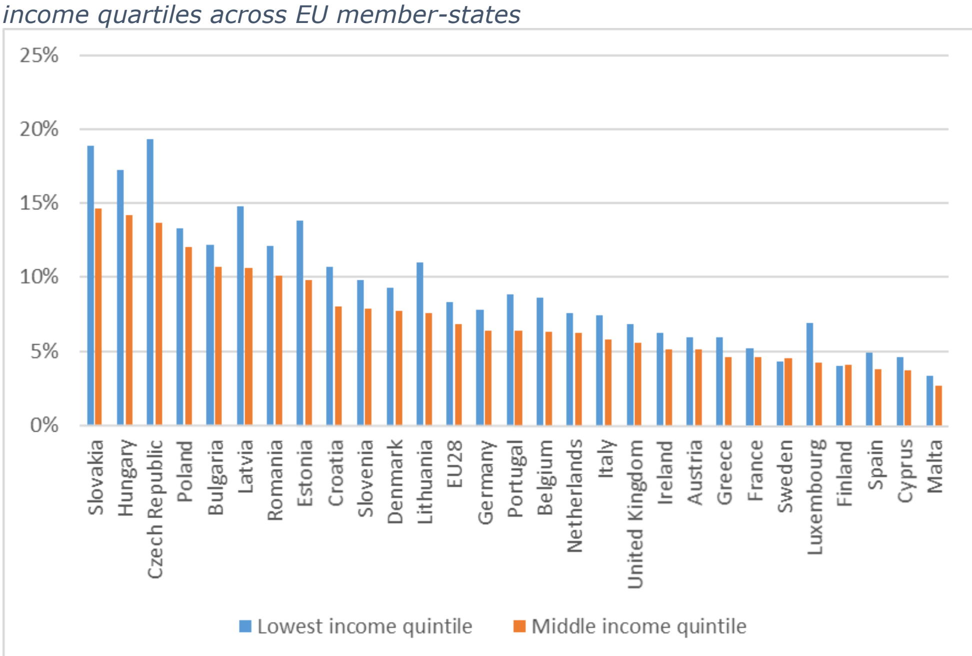
Figure IV.8 shows the share of household expenditure on energy services for the lowest and median income quintiles. The proportion of spending on energy services for the median income group rages from 3-4%, in Spain, Cyprus and Malta, to 14-15%, in Slovakia, Hungary and the Czech Republic. The warm climate explains the low shares in many of the Mediterranean regions. It is perhaps more suprising that the shares of houshold expenditure on energy services are so low in Finland and Sweden, where energy prices are relatively high and the climate is much cooler. In lower income countries, such as Slovakia, Hungary and the Czech Republic, the cost of essential goods and services (such as energy) form a larger share of total houshold incomes. In almost all countries (with the exception of Finland and Sweden), spending on energy as a proportion of total houshold expenditure is higher for the lowest income quintile compared than for the median quintile. This is paticularly the case for the Czech Republic and Slovakia, where energy expenditures account for almost 20% of total houshold spending for the lowest income quintile.

Figure IV.7 Trends in EU fuel poverty and household energy prices



Note(s): Fuel prices shown are prices faced by medium-sized households. Source: *Eurostat EU SILC and nrg_pc databases.*

Figure IV.8 Share of household expenditure on fuel for the lowest and the middle income quartiles across EU member-states



Source: *Eurostat (2015), Structure of consumption expenditure by income quintile (COICOP level 2), 2005 data for Italy and Luxembourg; 2010 data for all other countries and the EU28.*

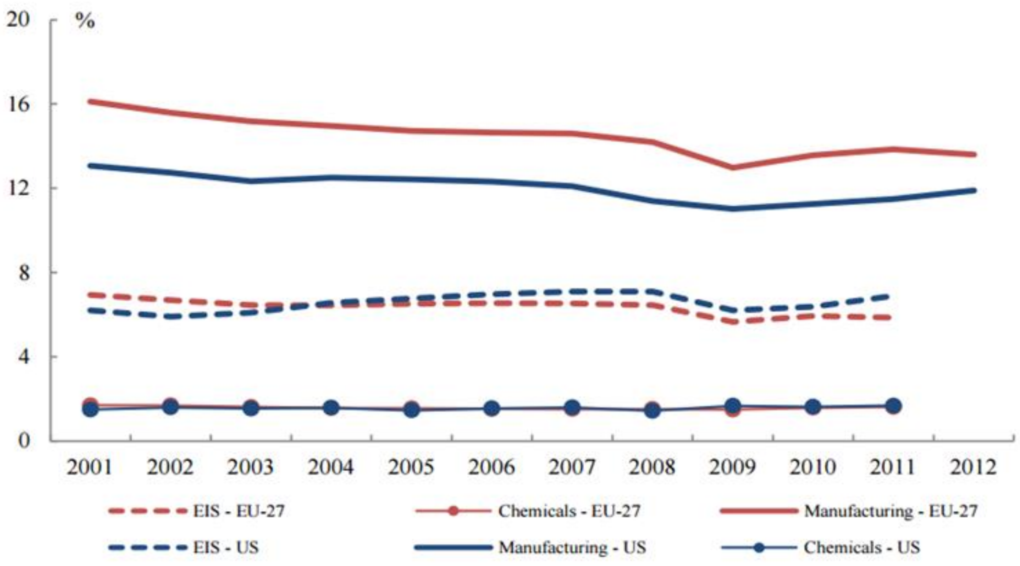
4 The competitiveness of energy-intensive industry and its value chain

The EU has seen a reduction in the share of energy-intensive industries in its GDP in the past decade, whereas in the US the share has increased a little, perhaps reflecting the impact of the shale gas revolution on energy costs in the US.

Industry competitiveness is a complex and multi-faceted notion, used with different meanings. In some cases, the notion refers to the capacity of a company or industry to maintain its market share relative to other companies or industries. In other cases, competitiveness refers to the attractiveness of a company, industry or country for investment, in particular with regard to foreign direct investment. There is a growing literature examining the competitiveness of energy-intensive industries, identifying many factors influencing competitiveness, including energy efficiency, costs of production, and environmental regulation.

Figure IV.9 shows the share of a selection of energy-intensive sectors and manufacturing in GDP in the EU and the US, from 2001 to 2012. The two regions display a similar trend in terms of manufacturing share of GDP, but for the energy intensive sectors there is a slight restructuring in the EU away from energy-intensive industry evident from 2005. The gap between energy-intensive sector GDP shares in the EU and the US widened in 2011. European Commission (2014a) suggested that this was due to lower energy prices in the US as a result of the shale gas revolution.

Figure IV.9: Share of selected energy intensive sectors and share of manufacturing in GDP – 2001 to 2012



Note: For the EU-27 energy intensive sectors include Fabricated metal products, Basic metal, Other non-metallic mineral products, Chemicals and chemical products, Coke and refined petroleum products, Paper and paper products, Mining and quarrying. For the USA, energy-intensive sectors include Mining, Non-metallic mineral products, Paper products, Petroleum and coal products, Chemical products, Primary metals, Fabricated metal products

Source: European Commission (2014a), Energy Economic Developments in Europe.

While the EU's higher energy costs may be associated with weaker export performance, it is difficult to identify the impact of energy costs on the output and investment decisions of energy-intensive industries.

There is a particular challenge in assessing the influence of energy costs on the competitiveness of energy-intensive industries arising from the fact that production is highly capital-intensive and prices for commoditised products are often set in global markets. Changes in energy prices may not trigger decisions to change the level of output so long as marginal revenues exceed marginal costs. A true assessment of the competitiveness of a location for production may only be revealed on those rare occasions when a decision has to be made on whether to invest to renew or replace aging plant. Even then it may not be easy to distinguish the important of the cost of energy in the decision compared with other factors such as the availability of long-term contracts for energy supply (to give certainty about future energy costs) and the dynamism of local demand for the product (which tends to favour investment in the countries undergoing rapid industrialisation and development).

The European Competitiveness Report 2014 examined the link between energy intensity, the contribution of energy costs to the total cost base and competitiveness for manufacturing sectors, considering also the role of other drivers of export performance. Over the period examined (1995-2007), energy prices rose particularly strongly in the EU, which pushed up the share of energy costs in overall costs even though energy intensity decreased as firms invested in more energy-efficient technology. A negative relationship was found between energy intensity and exports, as well as between energy cost shares and exports. The study concluded that in the EU, higher energy prices had a negative effect on export competitiveness, which had not been fully offset by improvements in energy efficiency. There is a considerable heterogeneity in the energy characteristics between the energy-intensive sectors and indeed between firms within a sector, which means that the impact of changes in energy costs (either through price or through improved efficiency) on the overall cost base will vary. For example, within the basic metals sector, energy costs comprise around 30% of total costs for aluminium but only between 4.8% and 13% for steel manufacture (depending on technology). The European Competitiveness Report 2014 concludes that "the fact that the electricity and gas cost share, even at a high level of aggregation, has a proven (statistically significant) negative effect on export competitiveness suggests that potentially some subsectors may be experiencing much stronger export losses".

Another factor influencing the competitiveness of energy-intensive firms is environmental regulation. This has much been discussed in the literature, and no clear consensus has emerged. Jaffe et al (1998) discuss the linkages between environmental regulation and competitiveness in the manufacturing sector. They consider three indicators of competitiveness: export growth; shifts in the locus of production of 'pollution-intensive' goods to countries with less stringent regulations; and changes in investment in highly regulated industries. They concluded that there was 'relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness'.

A possible indicator of reduced competitiveness of energy-intensive industries as a result of environmental regulation is carbon leakage – a rise in emissions in one country as a result of an emissions reduction in another country (due to the effective relocation of production between countries). A recent investigation of carbon leakage in EU energy-intensive sectors in the context of the EU Emissions Trading Scheme (ETS) did not find evidence of significant carbon leakage, with changes in imports and exports instead attributed to global demand developments and input price changes

(European Commission, 2013). The analysis also considered whether investment had been adversely affected by the ETS. It concluded that although there was evidence of investment relocation from the EU to the rest of the world in certain sectors, this was not necessarily due to increased carbon costs. Instead, it was posited that the reason for the relocation of investment outside the EU was due to the growth in demand in emerging economies, though it recommended a more in-depth study analysing investment leakage to provide stronger evidence.

Part V. Drawing lessons for the future

1 How might the drivers of energy demand and greenhouse gas emissions be different in the future than in the past?

A greater focus on buildings as a key source of future reductions in energy intensity

For the EU, what is most markedly different now compared with the past is the lesser importance of the most energy-intensive activities, partly reflecting somewhat slower growth in demand for their products compared with downstream and tertiary sectors, and partly reflecting the growth in imports of commoditised industrial products especially from China. Consequently, while there remains some scope for achieving reductions in overall energy intensity by improving energy efficiency in these sectors, the size of this contribution will be less in future simply because of their smaller share in the overall economy.

Instead, future reductions in energy intensity are likely to be more focused on buildings, both residential (household use of energy for heating and cooling and in appliances) and non-residential (notably the commercial sector).

Cuts in carbon emissions will depend on transport electrification and decarbonisation of power generation, with a particular emphasis on renewable sources

The pervasive role played by electricity in energy use throughout the economy and the role electricity is expected to play in decarbonising transport (unless fuel cells become the dominant technology) mean that achieving deep cuts in carbon emissions will require decarbonisation of power generation. In the past, a shift towards gas in the mix of fossil fuels used in power generation was an important driver of cuts in carbon emissions, while nuclear remained a key low-carbon source in some countries. Future cuts will require greater take-up of renewable sources in power generation, a trend that has already been evident in the most recent years.

Meeting long-term (2050) carbon emissions targets will eventually require emissions sources to be addressed for which decarbonisation appears to be more costly

In the longer term, emissions sources that are not the first priorities for the next decade will need to be addressed, including process emissions and aviation.

2 How can the macro models be adapted to better address key issues in the future?

A more detailed treatment (including behavioural features) of household energy use and uptake of innovations that promote energy efficiency and low-carbon use

The greater importance of the residential sector as a focus for reducing energy intensity suggests that there would be substantial benefit in more detailed modelling of household energy use, distinguishing different technologies within the household, allowing an explicit treatment of potential improvements in energy efficiency of particular technologies as a result of regulation, and making the macroeconomic link to the impacts on household spending of (1) the financing of expenditure on the technologies, and (2) the spending of the income released by lower spending on energy. This analysis could also contribute to a better understanding of the relationship between uptake of more energy-efficient technologies by households and impacts on energy poverty.

An explicit treatment of the take-up of different technologies in power generation, of the innovation and its spillovers triggered by the transition to 'advanced' energy technologies, of the financing constraints on take-up of renewables in power generation, and in understanding the extent of crowding-out[28] effects

The importance of electricity for meeting the goals of energy security and cutting carbon emissions and the distinct differences between the implications for these goals of different technologies in power generation make it essential to model the take-up of those technologies explicitly.

The scale of investment required to decarbonise Europe's power generation sector is very large. It will require mobilisation of private finance, and the factors that may hinder or promote this are not yet well represented in the models. Furthermore, the macroeconomic impact depends critically on whether such mobilisation would divert investment away not only from the fossil-fuel power plants that would otherwise be built but also from other sectors in the economy, and this should be explicitly represented in the modelling.

An integrated approach to wider economic and social impacts

Because the use of energy is pervasive throughout the economy, policies that seek to influence energy demand and the mix of fuels have widespread impacts. These impacts are not limited to headline figures for GDP, but include effects on the labour market, wider social indicators, health, the environment (including local pollutants), competitiveness and public budgets. Models that integrate all these effects can provide insight into the trade-offs or complementarities that exist between policy objectives in different domains.

3 Key policy messages

A greater role for policies that tackle non-price barriers and support the incentives given by energy prices

Because future reductions in energy intensity are likely to be more focused on buildings, this suggests an important role for policies that work alongside energy prices to promote those reductions. This is partly because of the policy dilemma with respect to energy poverty when considering higher energy prices for households, partly because of the institutional separation between owners and occupiers for rented dwellings which can dilute the effectiveness of energy prices as an incentive for investment in energy efficiency, and partly because energy accounts for a low share of overall costs for firms in the commercial sector and so price elasticities are typically low. In contrast, regulation (building standards, appliance standards) and mechanisms to raise awareness of energy use (for example, smart metering) are likely to play a greater role. Poor households have very limited opportunities to avoid high energy prices or to improve the energy efficiency of their dwelling, so tackling the quality of the housing stock in which poor households live targets both energy intensity and energy poverty policy objectives.

[28] The term 'crowding out' is used here in the broad sense of a private sector behavioural response that in some way offsets or lessens the impact of a public policy initiative. We use the general meaning of the term, which consists in the debated process by which when an agent or group of agents (government, firms, individuals) borrow(s) significant amounts of funds in order to invest into productive capital, this demand diverts funds that would otherwise have been used elsewhere in the economy, by bidding upwards the price of finance (the interest rate). In this context, the concern is that policies that promote investment in renewable power generation might raise the cost / reduce the availability of project finance to the rest of the economy, so that (in the extreme) the scale of overall investment in the economy would be unaltered: more investment in renewable power generation is wholly offset by less investment elsewhere.

While there remains some debate over the extent to which higher EU energy prices have driven the reduction in the importance of energy-intensive industries in the EU economy, it seems likely that an emphasis on some form of international policy collaboration will be needed to mitigate the risk of carbon leakage.

In the long term, technological development to bring down the cost of energy-saving and carbon-saving technologies remains essential if decarbonisation is to be achieved alongside continued growth in living standards. This report has noted the recovery in the scale of public RD&D budgets in energy technologies in recent years, and the growing share of spending on renewables and energy efficiency, an effort that needs to be sustained and accelerated to maintain the ‘upstream’ flow of new technologies.

A greater role for policies that address obstacles to private finance for investment in renewables in power generation

The risks associated with large-scale investment in power generation projects based on renewables are different from those associated with conventional fossil-fuel plants. If private finance is to be mobilised, policy analysis will need to explore the extent to which those risks are a significant obstacle of investment and, if they are, the extent to which policy can address that obstacle.

The energy transition to a low carbon economy can also yield benefits in terms of lower energy dependence and more jobs, but the net losers are geographically concentrated

The substitution of extra-EU fossil-fuel imports by domestic production of renewable energy capital equipment in power generation and by refurbishment of buildings to improve their energy efficiency offers the prospect of raising GDP and increasing jobs. But production of fossil fuels within Europe will also suffer, and the location of this activity is geographically concentrated (in particular Member States, and in particular regions within Member States). Because the rationale for their location is based on geology rather than the presence of broader drivers of economic competitiveness, and because the industry is associated with skills that are not readily transferred to other sectors, there are risks that losses will not quickly be replaced by alternative jobs. EU-wide and national-level policy support schemes will be needed to facilitate the transition (including skill reorientation and training) and to try to avoid the deterioration of human and social capital associated with the loss of a major local employer.

Policies promoting the energy transition need to take account of wider (and perhaps unintended) environmental impacts

The earlier modelling discussion in this section referred taking account of the wider economic and social impacts of policies. There can, of course, also be wider environmental consequences, either complementary (as in the case of fossil-fuel local air pollutants) or competing (as in the case of some aspects of the energy-water-food nexus), and assessments of potential policy impact need to keep these in view. In particular, the water and land-use constraints potentially influencing low-carbon developments and energy generation in general are often not convincingly captured in modelling assessments.

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