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State of the Low-Carbon Energy Union: Assessing the EU's progress towards its 2030 and 2050 climate objectives

Lead authors: Thomas Spencer, Roberta Pierfederici, Oliver Sartor, Nicolas Berghmans (IDDRI)
Contributing authors: Sascha Samadi, Manfred Fischedick, Katharina Knoop (Wuppertal Institute), Steve Pye (UCL), Patrick Criqui, Sandrine Mathy (Grenoble Applied Economics Lab), Pantelis Capros, Panagiotis Fragkos (E3MLab/ICCS), Maciej Bukowski, Aleksander Śniegocki (WiseEuropa), Maria Rosa Virdis, Maria Gaeta (ENEA), Karine Pollier and Cyril Cassisa (Enerdata)

A SECTORAL APPROACH TO DEEP DECARBONISATION IN THE EU

In order to assess the adequacy of the EU and its Member States policies with the 2030 and 2050 decarbonisation objectives, this study goes beyond the aggregate GHG emissions or energy use figures and analyse the underlying drivers of emission changes, following a sectoral approach (power generation, buildings, industry, and transport). Historical trends of emission drivers are compared with the required long-term deep decarbonisation pathways, which provide sectoral 'benchmarks' or 'corridors' against which to analyse the rate and direction of historical change for each Member State and the EU in aggregate. This approach allows the identification of the necessary structural changes in the energy system and policy interventions to reach deep decarbonisation, and therefore the comparison with the current policy programs at European and Member State level.

PROGRESS NEEDS STRONG REINFORCEMENT AND SCALING UP

The EU has made significant progress in the structural decarbonisation of its energy system. However, despite of this progress, the EU is currently "off-track" to achieve its objectives by 2030 and 2050. First, the rate of change is insufficient across a large number of the indicators assessed. Second, too much of the change in aggregate emissions has been driven by cyclical effects rather than structural decarbonisation, notably the impact of the financial crisis and subsequent slow recovery. Third, long-term decarbonisation options, for example to decarbonise industrial processes and materials, are not being adequately prepared. While some policies under the EU's 2030 Climate and Energy Framework will have an impact, our study suggests that the ambition of EU and Member State policies is either a continuation of business as usual in terms of rates of progress, or is being dialled down in some cases.

The EU and Member State policy should significantly revise their approach to decarbonisation by refocusing on the key drivers of emissions in each sector. The EU's new Energy Union Governance Mechanism should be designed based on this principle and current proposals to implement the 2030 package should be adopted in the strongest possible form to put the EU back on track. The EU, in coordination with the Member States, should develop a suite of sectoral policies to complement the overarching emissions caps of the EU ETS and non-ETS sectors.

www.iddri.org

Institut du développement durable
et des relations internationales
27, rue Saint-Guillaume
75337 Paris cedex 07 France

SciencesPo

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Enerdata

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LIST OF FIGURES AND TABLES

EXECUTIVE SUMMARY

Is the EU on track for deep decarbonisation?

The EU has adopted an ambitious target for reducing its emissions by at least 40% by 2030, compared to 1990 levels. This is envisaged as a crucial milestone on the pathway towards a reduction of 80%-95% by 2050. In order to assess current trends and their adequacy with these objectives, it is necessary to go beyond aggregate GHG emissions in order to analyse the drivers of emissions changes, sector by sector, and Member State by Member State. In-depth analysis of the drivers of change can provide an understanding of whether the EU is on track with its objectives, provide a benchmark against which to assess current policy proposals, and identify areas where policy must be strengthened further. **This project analysed data from all 28 Member States and every sector of their energy systems in order to build an assessment of current progress towards 2030 and 2050 objectives.**

High level results

Three high level results can be concluded from the assessment:

The EU has made significant progress in the structural decarbonisation of its energy system. This is particularly evident in the power sector, where the carbon intensity of power production has dropped by 20.9% between 2000 and 2014, or a rate of 1.7% per year. EU houses also consume 21.2% less energy per m^2 in 2013 than in 2000; EU passenger transport consumes 8.7% less fuel per passenger kilometre in 2013 than in 2000. This represents real and significant progress in changing the underlying fundamentals of the EU energy system.

Despite this progress, based on this analysis we have concluded that the EU is currently "off-track" to achieve its objectives by 2030 and 2050. Three concerns can be highlighted here. First, the rate of change is insufficient across a large number of the indicators assessed. For example, the rate of energy intensity improvement of passenger transport has been just 0.7%/year in the years 2000-2013, whereas in scenarios reaching deep decarbonisation by 2050 it needs to improve at more than 2% per year this decade and the next. Second and relatedly, too much of the change in aggregate emissions has been driven by cyclical effects rather than structural decarbonisation, notably the impact of the financial crisis and subsequent slow recovery. For example, in 2015 EU industrial output remains 12% below its pre-crisis peak in 2007; while, in the transport sector, freight kilometres were down 9.3% across the same period. Third, long-term decarbonisation options, for example to decarbonise industrial processes and materials, are not being adequately prepared. This is a concern as their roll-out will take time.

In short, the nature of the transformations taking place calls into question Europe's capacity to reach deep emissions reductions in the longer term. Performances between different Member States are divergent even in the sector most advanced towards decarbonisation, i.e. electricity. But even here leading Member States are struggling against serious challenges, such as the phase out of coal. In other sectors, such as transport and industry, the transition towards deep decarbonisation has barely started in any Member State whatsoever. So far the transition in Eastern Europe has been driven largely by the windfall effects of the shift towards more efficient, market-oriented economies, but this will not suffice indefinitely. More worryingly, recent policy debates such as on

ETS reform reveal how difficult it has been to build a European political will to act forcefully. In sum, too much of recent achievements have been based on cyclical effects of the crisis, and we are not currently seeing the foundations being laid for deep decarbonisation in Europe.

Policy implications

From the project analysis, a number of implications for policy can be drawn:

EU and Member State policy should significantly revise their approach to decarbonisation by refocusing on the key drivers of emissions in each sector. By themselves, cross-sectoral emissions targets do not give sufficient impetus to the structural decarbonisation of the EU energy system. More attention to targeted policies and governance tools that address each of the key drivers of emissions in each of the major emitting sectors is needed, including those sectors covered by the EU ETS. The EU's new Energy Union Governance Mechanism should be designed based on this principle. For instance, Member States new National Climate and Energy Plans need to give ample focus to strategies for sectoral transformation towards 2050 goals, not just marginal actions to meet 2030 targets. Key Indicators used to track national and EU progress should also reflect key structural changes that are needed in major emitting sectors.

Current proposals to implement the 2030 package should be adopted in the strongest possible form to put the EU back on track. Proposals to reform the EU ETS and adopt non-ETS targets go some way to strengthening the decarbonisation of the EU energy system. However, by themselves they are not sufficient to put the EU on track to achieve its 2030 or 2050 commitments. This is especially true of the EU's energy efficiency objectives. If adopted in its current form—i.e. 27 to 30% energy savings by 2030—the target would represent a slowdown in the pace of energy productivity improvements for the EU. The EU ETS desperately needs be strengthened to avoid the risk of low and ineffective carbon prices persisting well in the late 2020s.

The EU should develop a suite of sectoral policies to complement the overarching emissions caps of the EU ETS and non-ETS sectors. In particular, in 2017 the EU should adopt very ambitious regulations to drive the decarbonisation of transport, and in particular the roll-out of alternative fuel vehicles, in which it is currently lagging behind. Likewise, targets, financing and monitoring of energy efficiency retrofitting and fuel switching in buildings should be strengthened.

The EU needs a shake-up of current policies for decarbonising energy intensive and trade-exposed industries. A renewed focus on industrial decarbonisation is necessary, given the inadequacy of the EU ETS signal and the fact that progress towards key decarbonisation technologies in these industries has stalled. The specific combination of technological challenges, financial risks, low profitability in the current context, and competitiveness concerns calls for a suite of policies that must go beyond carbon pricing and R&D funding. A new policy strategy is needed. It should involve a suite of policies and be linked to concrete sectoral decarbonisation strategies. It should include a renewed focus on technology "push" measures, for instance, by providing stable long-term funding for demonstration and early-phase commercialisation of promising "breakthrough" processes. It must also include a renewed focus on market "pull" measures to create a market for low-carbon materials and processes in industry.

The EU should consider policies to phase down coal in electricity, given the lack of an effective signal for coal retirement from the EU ETS. By 2030, unabated coal needs to drop by more than 50% to make way for low-carbon electricity sources. A failure to develop a smart retirement plan for unabated coal will continue to place pressure on EU electricity markets. This risks, in turn, undermining progress towards efficient and better integrated power markets that are needed for the transition to high shares of low-carbon generation to occur. Even assuming ambition reforms to the EU ETS, the EU will probably need to develop ways of facilitating national coal phase out strategies in individual Member States.

The consortium and methodological approach

To analyse the EU's progress, IDDRI developed an innovative approach and research consortium. The consortium consisted of 8 research institutes from 6 EU Member States. It analysed deep decarbonisation scenarios at EU and Member State level. From these scenarios the consortium derived "sectoral performance benchmarks" for each decade from now to 2050. These benchmarks were then compared with a large database of historical performance for every sector in every Member State. This approach enabled the detailed comparison of current trends and trends likely to be induced by current EU policy developments in the transformation of the EU energy system with what is required in order to reach very low emissions by 2050. The energy system is highly inert, and examining current trends in the light of the future requirements for deep decarbonisation allows the assessment of the policies currently in place. It allows the identification of the necessary structural changes in the energy system and hence policy interventions to reach deep decarbonisation, and therefore to compare this with the current policy programs at European and Member State level. It is from this analysis that the above conclusions are drawn.

The project analysed tens of thousands of data points and attempted to conduct one of the most comprehensive, robust and revealing assessment of the EU's "climate performance" in the energy sector to date.

1. INTRODUCTION

In 2009, the EU Council adopted the EU objective of reducing emissions by "80-95% by 2050 compared to 1990 levels" (European Council, 2009). This 2050 objective has formed the central long-term benchmark for subsequent policy analysis and decisions, such as the development of a first long-term low-carbon development roadmap and the proposal for a 2030 EU GHG target (European Commission, 2011). In March 2015, the EU submitted its 'Intended Nationally Determined Contribution' (INDC) ahead of the international climate negotiations in Paris, which committed the EU to reducing its emissions by at least 40% by 2030 (Latvian Presidency of the European Council, 2015). The EU INDC repeated the above-mentioned long-term 2050 objective of reductions of 80-95% by 2050.

In 2014, EU GHG emissions were already 22.9% below 1990 levels, meaning that the EU is well on the way to overachieving its objective of reducing emissions by 20% by 2020 (European Environment Agency, 2016).

However, a deeper question remains:

- **To what extent are the EU and its Member States actually on track with the deep transformation of their energy systems, in line with achieving the at least -40% target in 2030 and the -80-95% target in 2050?**

Addressing this question is the objective of this study. Rather than examining aggregate emissions trends, this study delves deep into the dynamics affecting each sector of the energy system. It examines the structural changes taking place in power production, transport, buildings and industry, and benchmarks these with the changes required to reach the 2030 and 2050 targets. As noted in other studies (IDDRI and SDSN, 2015; Spencer, Pierfederici *et al.*, 2015), deep decarbonisation of the energy system requires profound structural changes across all energy production and consumption sectors. The objective of this study is to assess the adequacy of the changes taking place. In so doing it aims to influence both the ambition and direction of future policy decisions, both at Member State and EU level.

This paper is structured as follows: Section 2 presents the methodology. Sections 3, 4, 5, and 6 address the power, buildings, industry, and transport sectors respectively. Section 7 provides conclusions and policy recommendations. Annex 1 provides detailed data tables containing the key results of the analysis.

2. METHODOLOGY

In order to track the progress that the EU and its Member States are making in transforming their energy systems towards the 2030 and 2050 objectives, this study follows a sectoral approach. We focus the analysis on power generation, buildings, industry, and transport.

The study combines both quantitative and qualitative analysis. The quantitative analysis is based notably on the principle of the Kaya decomposition, which breaks down changes in GHG emissions into the product of: population, activity level per capita, energy intensity of the activity, and carbon intensity of energy supply. In the sectoral context, 'activity level' refers to the economic activity in question: m^2 of household or commercial floor-space, passenger kilometres travelled, freight kilometres travelled, industrial production in physical terms for major sectors (steel, cement) and in monetary terms for the industry sector in aggregate. These indicators can reflect behavioural changes, such as people travelling more or living in bigger houses. They can also reflect changes occurring in the socio-economic system, such as population increase, variation in the industrial output due to the macroeconomic context, shift from an industry-based economy towards an economy more reliant on the service sector, size and spatial organisation of cities, etc. In order to track the progress made by the EU Member States, the study follows a common framework for every sector. This combines a set of common indicators: activity indicators, energy intensity, carbon intensity of energy, and penetration of low-carbon energy technologies. These common indicators are complemented by *ad hoc* sector-specific indicators as needed.

The Kaya breakdown is applied to historical data for each sector. This data comes primarily from the *Odyssee* database and *Global Energy & CO_2 Data* database, curated by Enerdata (ODYSSEE database, 2016). **This allows the analysis of the drivers of historical changes in emissions.**

The historical data is then compared with the transformations required to 2020, 2030, 2040 and 2050, as defined by long-term deep decarbonisation pathways. These pathways are broadly speaking consistent with the EU's aggregate emissions objective for 2030 and 2050. They give an internally coherent, feasible, sector-specific, and structured understanding of what must be achieved in order to reach a low-emissions energy system by 2050, taking into account relevant constraints such as the inertia of the capital stock. The pathways also take into account the diversity of Member States. Deep decarbonisation pathways for the UK, Germany, France, Italy and Poland have been used (see Appendix for models and scenarios description), a geographical grouping which was responsible in 2014 for about 62% of total EU28 GHG emissions.

The set of countries represents the EU in aggregate, as well as its broad blocks of Member States with similar characteristics: Northern Europe (UK, Germany, France); Southern Europe (Italy), and Central and Eastern Europe (Poland). A decarbonisation scenario for the EU28 as a whole is also analysed. The chosen scenarios are among the most up to date scenarios for those countries, incorporating the latest policy developments. They also ensure a very high level of granularity and transparency, which allow a detailed analysis of the required transformation. It could also be argued that the EU's Effort Sharing Decision, currently under discussion, allows differentiated pathways between Member States. However, deep decarbonisation in a physically inert system like energy means that mid-term pathways (2030) are significantly constrained by what must be achieved by 2050. The stringency of deep decarbonisation means that all Member States need to converge to energy systems with broadly the same level of GHG performance by 2050, and be well on the way to this convergence by 2030 in order to reach the 2050 target.

The pathways therefore provide relevant, detailed sectoral 'benchmarks' or 'corridors', against which to analyse the rate and direction of historical change for each Member State and the EU in aggregate. Historical data is presented for all 28 EU Member States.

Let us address one objection to this approach immediately: namely that extrapolating from historical trends is insufficient to decide whether they are consistent with long-term transformations required. There is some truth in this argument. The energy system is highly inert, and examining current trends in the light of the future requirements for deep decarbonisation allows the assessment of the policies currently in place. It allows the identification of the necessary structural changes in the energy system and hence policy interventions to reach deep decarbonisation, and therefore to compare this with the current policy programs at European and Member State level. It is from this analysis that the above conclusions are drawn.

The quantitative analysis is complemented by a more qualitative approach which investigates the adequacy of the underlying EU policy settings for each sector studied, in order to meet the EU's GHG targets in 2030 and 2050.

3. POWER SECTOR

3.1. Historical trends in the light of required transformation

Power production is central to the achievement of the long-term objective of a transition to a low-carbon economy. It is responsible for a quarter of total EU GHG emissions and has the most ambitious long-term target: the European roadmap for a low-carbon economy by 2050 requires a 93% to 99% emission reduction from power production by 2050 (European Commission, 2011). Power generation holds significant emission reduction potential due to the advanced level of maturity of non-emitting production technologies. For example, onshore wind and large photovoltaic power stations have production costs between

70 and 90 €/MWh, which is already competitive compared to conventional thermal power plants (Bloomberg New Energy Finance, 2015; IRENA, 2015). Finally, the decarbonisation of electricity is also regarded as an enabler for the low-carbon transition of other sectors through electrification of end-use sectors (see the chapters on buildings, industry and transport).

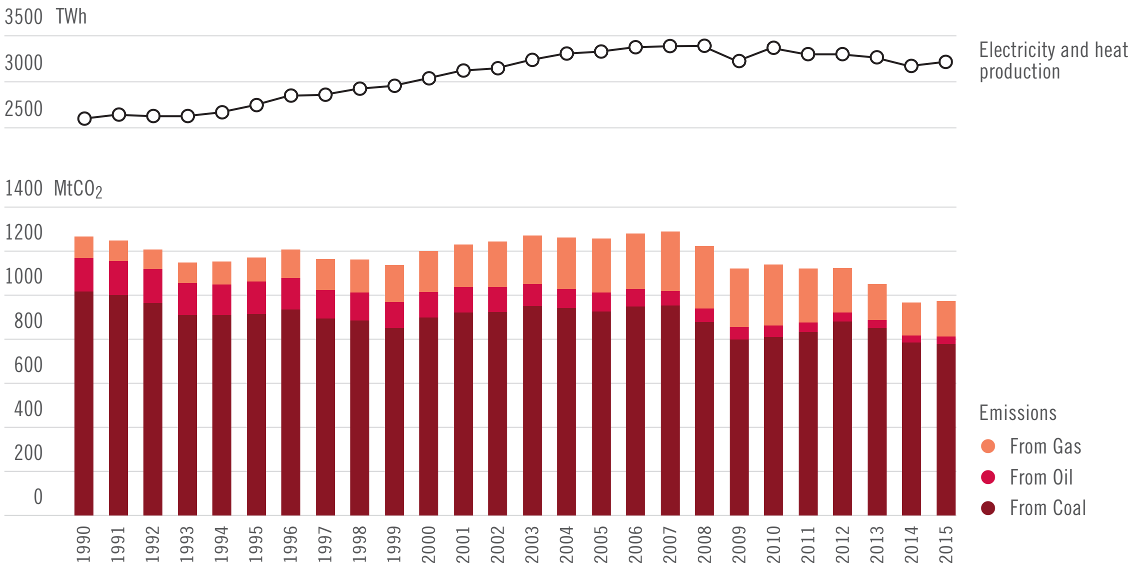
Historical data show a significant drop of 25% in CO_2 emissions from public production of power and heat in the EU between the peak in 2007 and 2014 (see Figure 1). During the same time period, the share of gross electricity consumption from renewable sources increased from 14.9% in 2005 to 27.5% in 2014 (Eurostat, 2016). **This shows that significant progress has been made on a key lever of decarbonisation, namely the carbon intensity of electricity production. However, the question remains whether this improvement is sufficient in light of the required trajectories detailed below.**

EU Member States have a wide variety of power mixes, due to their past policy choices and resource endowments. Figure 2 (bottom graph on the left side) represents the current spread of carbon intensity in electricity generation in EU Member States and the trajectories of the scenarios considered in the study. Power mixes have to converge towards low-carbon technologies from very different starting points, as illustrated by the range of carbon intensity of electricity production in different Member States: from below 100 gCO_2/kWh in France or Sweden that mainly rely on nuclear and hydro energy, to more than 700 gCO_2/kWh for heavily fossil-fuel based power in Estonia or Malta. By 2030, this needs to narrow to a corridor of about 440 gCO_2/kWh for the most emitting Member State's power sector, to about 40 gCO_2/kWh for the least emitting. By 2050, the convergence must essentially be complete: all deep decarbonisation scenarios considered for EU Member States reach less than 100 gCO_2/kWh by 2050. **This illustrates well the principle argued above: regardless of the nominal allocations of emissions targets in the short term, what matters is that Member States converge towards very low levels of emissions in each sector by 2050. The inertia of the energy system means that there is a "corridor" through which each Member State must pass to reach low-emitting energy systems by 2050.**

Figure 2 (top graphs) shows also the rate of change for all EU Member States in the carbon intensity of electricity. Between 2000 and 2010 the carbon intensity of EU28 electricity generation in aggregate declined by 1.5%/yr and the median between all Member States was a decline of 1.2%. This aggregate view hides a spread of outcomes between different Member States (vertical line in Figure 2), with a few countries experiencing a growing carbon intensity of electricity (MT, BG, FI, LT, SE, LU). Between 2010 and 2014, the rate of decline in EU28 carbon intensity of electricity accelerated to 2.04%/yr, while the median of all Member States was a decline of 3.52%/yr.

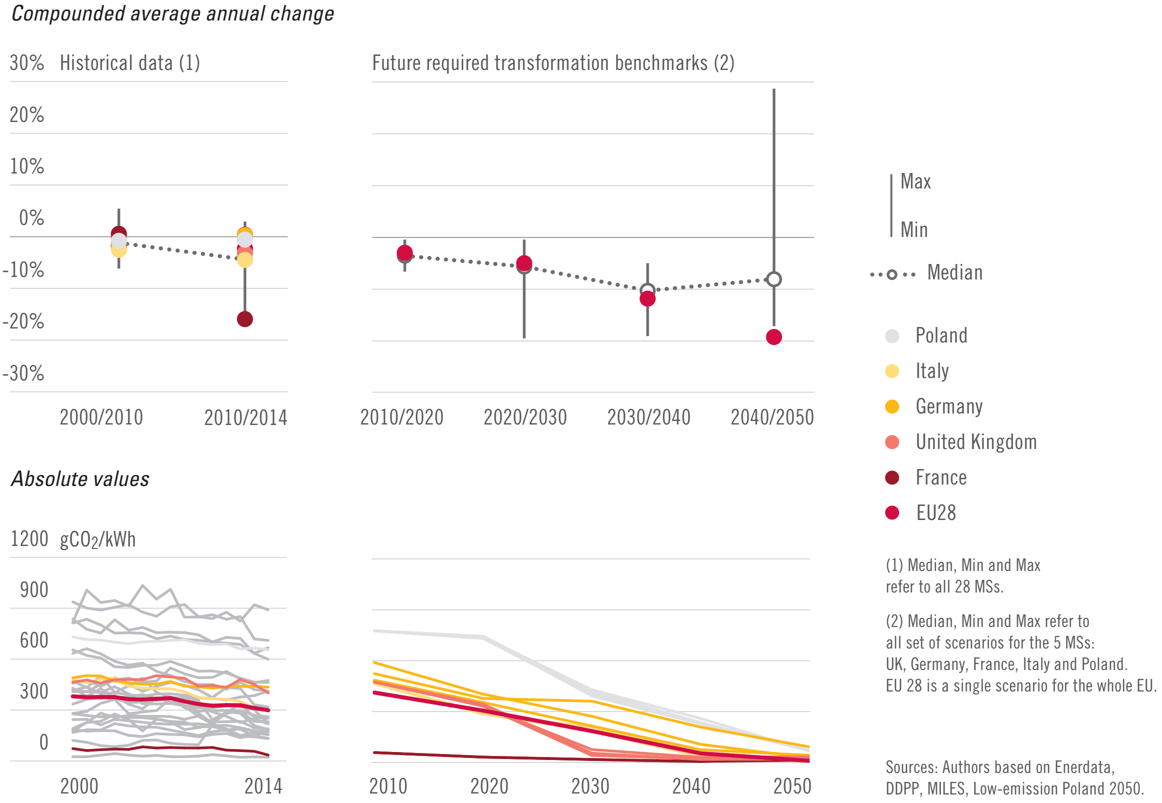
On the right hand side, Figure 2 shows the future required transformation benchmarks for the

Figure 1. EU-28 CO_2 emissions from public electricity and heat production



Source: Authors based on data from (Enerdata, Global Energy and CO_2 Database)

Figure 2. Carbon intensity of electricity



(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for the 5 MSs: UK, Germany, France, Italy and Poland. EU 28 is a single scenario for the whole EU.

Sources: Authors based on Enerdata, DDPP, MILES, Low-emission Poland 2050.

Note: While reading this graph, it should also be noted that the range of values presented by the future transformation benchmarks reflects a range of possible pathways that a specific sector could follow to decarbonisation. The spread of the future benchmarks is not only due to differences between the 5 MSs analysed, but it is also due to differences between a given country's set of scenarios.

carbon intensity of power production per decade to 2050. It can be seen that in the decades 2010-2020 and 2020-2030, the carbon intensity of power production at the EU-28 level must fall by 2.98%/yr and 4.97%/yr respectively. Likewise, in the scenarios covering the five Member States represented in the dataset underpinning this paper (UK, DE, FR, IT, PL), the median rate of reduction is 3.58% and 5.63% in these two decades respectively. Subsequent to 2030, the decarbonisation of power production continues to accelerate (expressed in compound annual change—the absolute change is lower in later periods than in earlier periods). This is because extremely low emissions from power production are required in 2050, in order to leave some emissions space for sectors that are more difficult to decarbonize. It should also be noted that in the case of one scenario set (for France), emissions intensity of power production increases in the decade 2040-2050. This is because, given the age of the nuclear fleet, in this scenario there are significant retirements of nuclear in the decades 2020-2040, which is replaced by renewables and gas for balancing. In the decade 2040-2050 this means that carbon intensity increases slightly, although because it is represented as a percentage change it looks quite high. The carbon intensity of the mix in this scenario set remains very low in absolute terms (ca. 20 gCO_2/kWh).

In short: in order to decarbonize the EU power sector, the EU and its Member States need to further accelerate the decarbonisation rate of power production and maintain a rapid rate of improvement for decades to come.

In the long term, all scenarios confirm that low-carbon technologies (renewables, nuclear, CCS) have to be dominant in power generation in order to achieve 2030 and 2050 emissions objectives. Figure 3 shows first of all the historical spread of the share of low-carbon technologies in all EU28 Member States. The spread in 2014 is significant, with some such as France having 95% penetration of low-carbon technologies (mainly nuclear power), while others such as Poland and Estonia having very low share. The scenarios analysis shows that this spread is expected to progressively lower down in the next few decades. The national scenarios included in the study converge towards an 80 to 98 % share of low-carbon energy in electricity generation in 2050, while the EU28 scenario from the MILES project foresees a 93% share for low-carbon energy in power production in 2050. **Significant efforts must still be made to scale up the penetration of low-carbon technologies notably in the decades 2020-2030 and 2030-2040,** so electricity can help decarbonise other end-use sectors. **A convergence to very high shares of low-carbon technologies is required across all Member States, with the spread of penetration rates across Member States reducing already by 2030 and even further to 2050.**

Finally, this penetration of low-carbon technologies in power production necessitates the progressive phase down of unabated fossil fuels in power production, notably coal, across all Member States. Figure 4 shows first of all the spread of penetration rates for coal electricity across all EU28 Member States. Secondly, it shows the rates required by decarbonisation scenarios during each decade towards 2050. **The share of unabated coal[1] falls already by 2020, and by more than half between 2010 and 2030 in ambitious decarbonisation**

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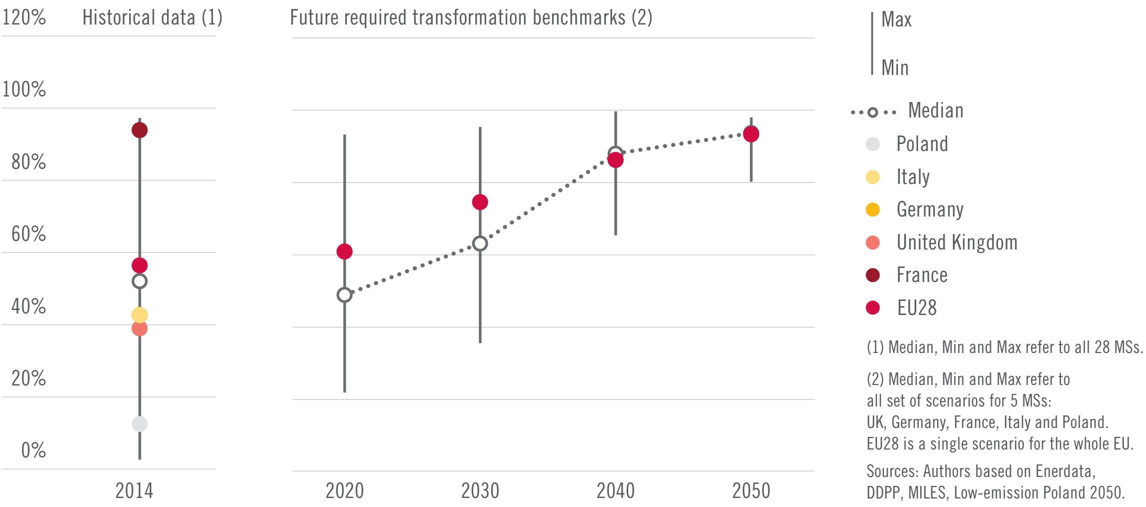
[1] Unabated coal refers to power production from coal in power plants not equipped with Carbon Capture and Storage technology.

Figure 3. Share of low carbon energy sources in electricity generation



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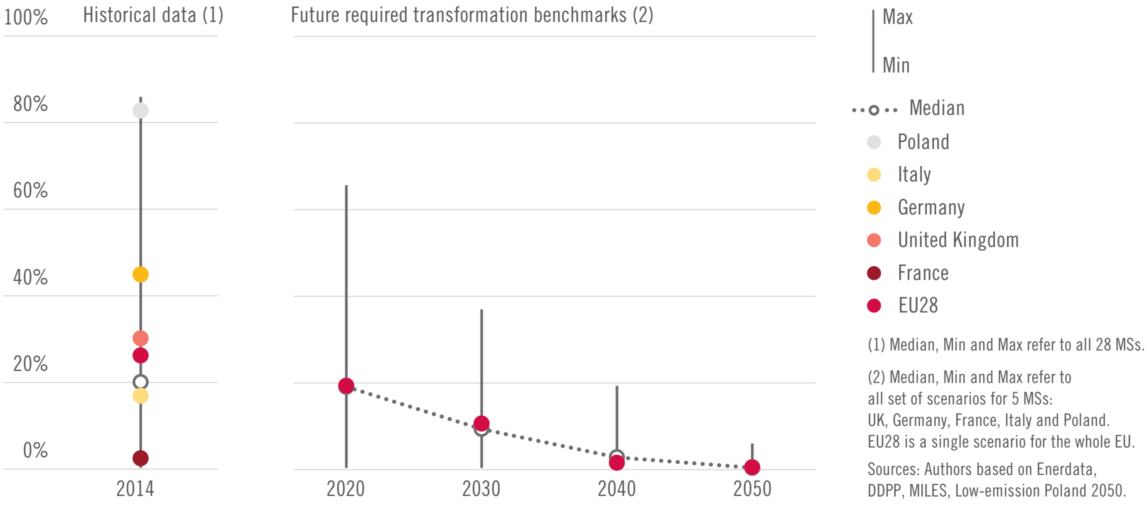
Sources: Authors based on Enerdata, DDPP, MILES, Low-emission Poland 2050.

Figure 4. Share of unabated coal in electricity production



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Sources: Authors based on Enerdata, DDPP, MILES, Low-emission Poland 2050.

scenarios consistent with the EU's low-carbon 2030 and 2050 objective, the reduction being relatively stronger in coal-dependent countries.

3.2. Policy discussion

The above discussion in section 3.1 highlighted three main messages:

- The EU has made significant progress in decarbonising power production over the past decade.
- A further acceleration in decarbonisation is required already in the decade 2010-2020, and very high rates must be maintained in the decades 2020-2030 and 2030-2040.
- This is based on the rapid upscaling of low-carbon technologies (mainly RES), and the phase down of unabated fossil fuels, especially coal.

At the same time, EU investments in new renewable production capacity have gone down in recent years and slow progress is being made so far on reducing the share of coal. Figure 5 shows that annual new RES-E capacities have increased fast in the EU until 2011, followed by a worrying scale back. This mainly comes from a reduction in PV installations in Germany and in other Member States, after support policies and especially feed-in tariffs have been revised or abandoned (Keepontrackproject, 2015). As a consequence, a number of countries have seen the growth rate of installed capacity of RES fall significantly in recent years, or are still following relatively slow rates of growth. The average annual growth rate of installed RES-E capacity in the EU decreased from 3.7 % to 2.3 % between 2011-2012 and 2013-2014. Meanwhile, the share of coal in EU electricity generation declined by 8 percentage points between 2000 and 2014 and was often displaced by gas-fired generation before 2010 (see Figure 6) for reasons not related to climate policy.

The push for gas-fired generation was mostly favoured by the gas-field developments in the North Sea, financial and political priorities and the impact of power market liberalisation. It was later reinforced by regulations on air quality that were adopted at the EU level (Large Combustion Plant Directive and Industrial Emission Directive)[2] and applied to all coal power plants. Nevertheless, this progress has stalled since 2010, because of adverse trends in the energy markets.

This discussion implies that policy frameworks still need to be strengthened along two lines, namely incentivizing investment in low-carbon technologies and frameworks to phase down unabated fossil fuels. It is further complicated by the context of a stalling electricity demand in most Western EU countries, a direct consequence of both the economic crisis and major energy efficiency improvements in several electricity uses and apparels. Combined with the large number of new conventional power plants (mainly Combined-Cycle Gas power plants) built on top of RES-E capacities during the first decade of the century, the European power market finds itself in a situation of oversupply, illustrated by historically low wholesale market prices.

Investing in an already oversupplied market could seem paradoxical. It is required, however, to achieve the long-term objective of the EU transition towards a low-carbon economy. It is also necessary because large shares of the European power plant fleet are expected to reach the end of their economic lifetime before 2030. That is the case for 130 to 170 GW of coal-fired power plants and most of the European nuclear fleet (Rüdinger, A. *et al.*, 2014).

Low-carbon generation technologies such as renewables, nuclear or CCS have high upfront capital costs. For operators, this raises the need for periods when electricity is sold at a higher price than the marginal cost of production to recover the cost of the high initial investments. Nevertheless, as low-carbon generation technologies increase their share in the mix and fossil fuel power plants with higher operational costs lose market share, investors will have to rely on fewer, lower and less predictable periods of high prices under current market design. This is called the "cannibalization" effect. This increases risks for the profitability of low-carbon investments and raises questions whether current incentives are appropriately set to foster the needed investments for the transition.

The challenge raised here concerns especially the future of renewable energy remuneration schemes. The guidelines on State aid for environmental protection and energy published by the European Commission (EC, 2014) paved the way for an EU harmonization of renewable support schemes, moving from feed-in tariffs to feed-in premiums determined through call for tender procedures that could also in the future put different renewable technologies in competition with each other. These State Aid Guidelines also envisage phasing out support to renewable energy after 2020. Such an approach has to be questioned. Given that at current price levels, no new investments in capacity of any technology would be profitable, a more pragmatic approach would be to define essential conditions that should be fulfilled before

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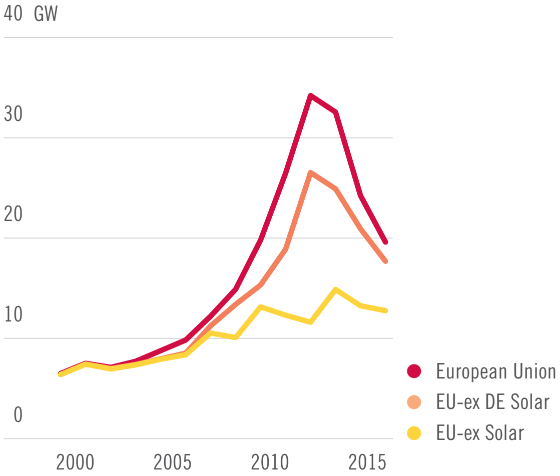
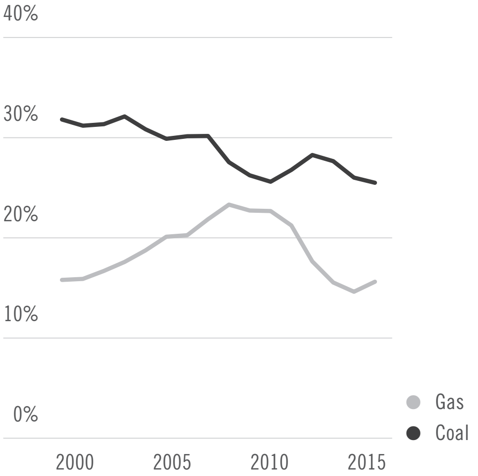
[2] Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants and Directive 2010/75/EU on industrial emissions

Figure 5. Annual renewable capacity additions in the EU 28



Sources: authors based on data from (Enerdata, Global Energy and CO_2 Database)

Figure 6. Share of coal and gas in gross electricity generation in the EU 28



Sources: authors based on data from (Enerdata, Global Energy and CO_2 Database)

the removal of support to renewables and other low-carbon technologies can be foreseen (Sartor, 2016). Smoothing the transition to the market will help prevent major variations in investments that could be detrimental and increase the cost of the overall transition.

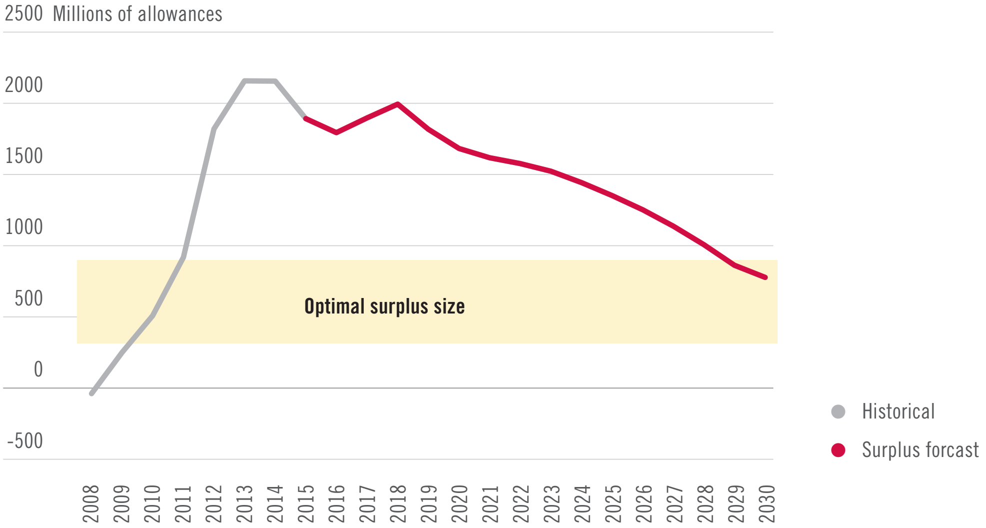
Currently, the oversupplied market situation makes public support for investments in renewables and other low-carbon technologies still necessary for the time being. Other additional de-risking policies could also be considered to further decrease the cost of investing in renewables, for example by preferential financing conditions or long-term power purchase agreements. It also raises the issue of how the power market design can be adapted to facilitate the inclusion of large shares of variable renewable generation and whether it needs to be complemented with other incentives in order to secure the transition to a low-carbon power system.

The oversupply on the power market is also due to the persistence of an important share of old and polluting production capacities in the market. This is the direct consequence of their relatively low marginal cost of production, which ensures their profitability during most of the time. Most of these assets have a limited flexibility and hence slow down the transition to a more flexible power market on the supply and demand sides, which will be needed to respond to renewables variability. It also delays the shift to investments in low-carbon technologies on a market-only basis. Figure 5 shows that in the long-term deep decarbonisation scenarios, the share of unabated coal has to converge in all EU Member States towards close to zero by 2050 and should be reduced to about 10% EU-wide in 2030. However, some national power mixes in Europe are still dominated by coal that represents more than 82% of electricity produced in Poland and 44% in Germany in 2014 (source: Enerdata). This implies that some EU countries have to bear higher efforts for decarbonising their power mixes and hence bear higher costs and upfront investments.

The EU and EU Member States have still not developed a comprehensive strategy to retire old and polluting coal plants. The EU ETS was believed to be the right instrument to incentivise high-carbon assets retirement, but it has been oversupplied with CO_2 permits and prices have dropped to 4 to 8 €/t since 2013. This is far below the level needed to make gas-fired power plants more profitable than lignite power plants, which is estimated at 35 €/tCO_2 in current market conditions (Buck, 2015). While an ETS reform process is underway and will be finalised during 2017, the current proposal does not appear to be sufficient to significantly tackle the oversupply of CO_2 permits before 2028 at the soonest, far after the needed retirement of most high carbon power plants. Figure 7 shows a projection of the surplus of allowances according to IDDRI's median scenario estimation for emissions and current ETS reform proposals. We find results that are in line with projections made by the European Environmental Agency (EEA, 2015).

The emergence of a meaningful reform of the ETS is still a possibility and should be encouraged. A first best option would be to align the ETS cap in line with long-term decarbonisation objective. A second measure would be to cancel the existing oversupply of CO_2 permits in the system. Lastly, a pragmatic approach could consist in finding

Figure 7. EU ETS surplus of allowances anticipated after current reform proposals of the EU ETS



Notes : Cap declines at 1.74% per year to 2020 and then 2.2% from 2020 on. MSR amendment to Directive passed in 2015 and backloading regulation are included. BAU emissions decline at 1% p.a. from 2013 level due to other policies.

Sources: EUTL database, Sandbag 2014 "Slaying the Dragon", IDDRI.

a framework allowing Member States to cancel EUAs corresponding to a more ambitious national policy in ETS sectors, possibly in cooperation with other ambitious Member States. One of the major backdrops in the current ETS design is that emission reductions due to national measures in ETS sectors free EU allowances that can be used by other actors in the scheme, loosening the carbon constraint for actors not covered by the measure. Currently, a number of Member States have also developed *ad-hoc* policies to get coal power plants out of the system: the UK adopted a carbon floor price on power production in 2013 (HM Revenue & Customs, 2014) and pledged to phase-out unabated coal power plants by 2025; France is planning one that will apply only to coal power plants starting in 2017; and Germany established a plan last year to put older lignite power plants into a cold reserve against a payment for power plant operators.

Finally, the development of flexibility in the power system will be necessary to cope with the variability of wind and solar production. At the European and regional level, it means encouraging the development of interconnectors when needed, alongside demand-side response, storage and back-up. It also shows the need to improve the compatibility between national power market rules in order to improve the efficiency of power exchanges between countries. These policies to change the "software" of the power system are expected to be highly challenging as they imply a redefinition roles, responsibilities and business models for participants.

4. BUILDINGS

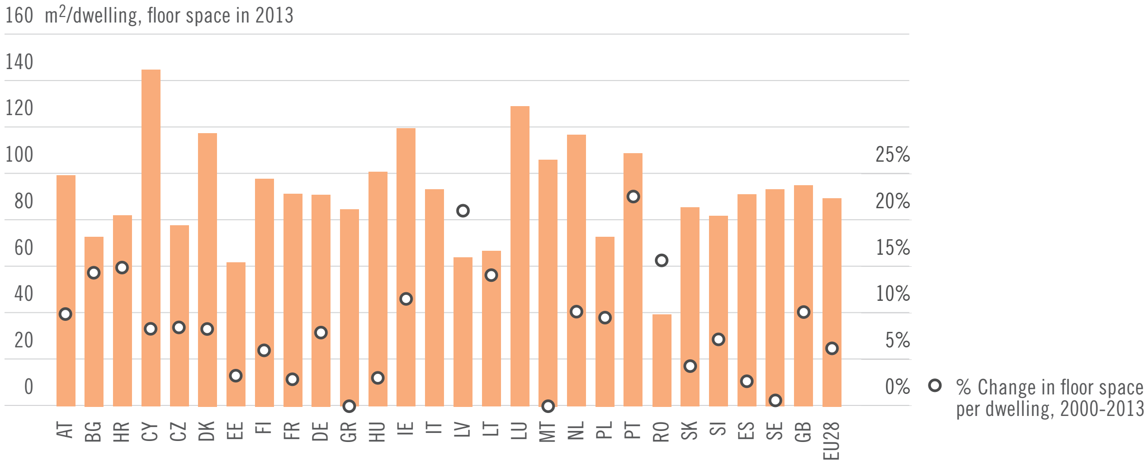
4.1. Historical trends in the light of required transformation

Direct emissions from the buildings sector (residential and services) accounted for 16% of total EU CO_2 emissions from fuel combustion in 2015. If we ascribe emissions from electricity production to the sector of final consumption (so-called indirect emissions), this rose to 33.6% of total energy related CO_2 emissions in the EU (Enerdata, Global Energy and CO_2 Database). 60% of total building sector emissions come from the residential sector, the rest from the services sector.

In the following section, the main drivers of emissions in buildings sector are analysed. These are:

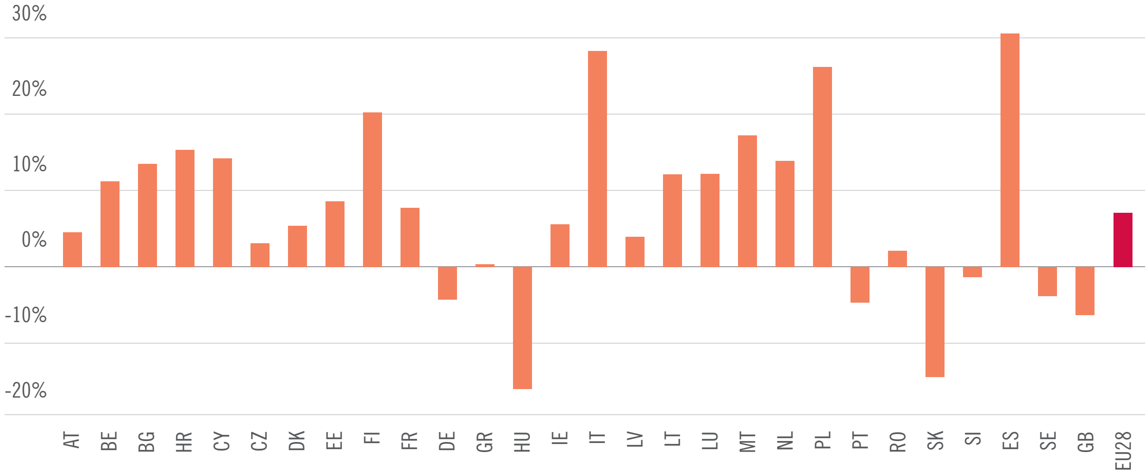
- Changes in energy consumption due to changes in activity levels, i.e. floor-space per capita which implies greater needs for heating/cooling/lighting services; the stock of appliances per capita; the number of employees per m^2 of service sector building space, etc.
- Increase in energy consumption due to behavioural changes of final consumers (for example, preferences for higher indoor temperatures increasing heating demand).
- Changes in energy efficiency of energy consuming equipment in the buildings sector, as well as the efficiency of the building envelop.
- Changes in the carbon intensity of final energy consumption in the buildings sector, due to changes in the fuel mix.

Figure 8. Floor space per dwelling, EU Member States and EU28



Source : authors based on (Enerdata, Odyssee, 2016)

Figure 9. Final energy consumption of buildings (% change 2000-2013)



Source : authors based on (Enerdata, Odyssee, 2016)

Figure 8 shows first of all that there has been a slight growth in the building sector activity level between 2000 and 2013 in almost all Member States, measured in terms of m²/dwelling. It also shows that there is a wide divergence between Member States in terms of floor space per dwelling, and that this difference was reasonably well correlated in terms of income per capita. Lower-income Member States typically have smaller dwellings, and have also generally had higher percentage growth in the floor space per dwelling relative to higher income Member States.

Driven in part by the growth in floor space, final energy consumption in buildings has increased in most EU Member States. Final energy consumption in buildings increased by 6% in the EU28 between 2000 and 2013. The majority of the increase occurred in the commercial sector (+20% between 2000 and 2013), while energy consumption in the residential sector remained almost stable. In some EU Member States, however, there were significant increases also in energy consumption in residential sector (namely in Ireland, Italy, Spain and Finland). Figure 9 shows the percentage change in buildings final energy consumption between 2000 and 2013.[3] For the EU28 in aggregate, final energy

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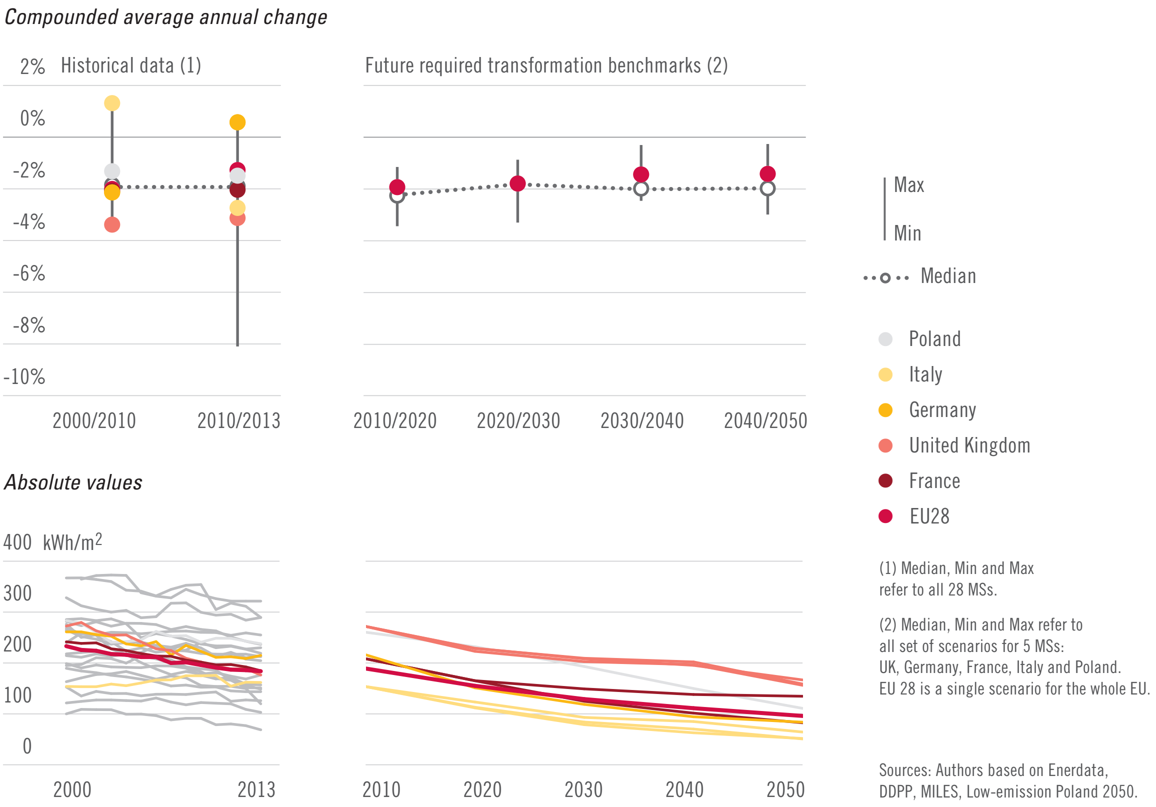
[3] It should be noted that care should be taken in interpreting these figures. Due to the sensitivity of residential energy consumption to climate conditions, annual energy consumption can vary significantly. For example, for Italy, the change for the 2000-2014 period was about 13% against the 28% shown in figure 2 for 2000-2013. In addition, in Italy the trend includes the progressive inclusion of previously unreported use of biomass for heating.

Figure 10. Energy Intensity of residential sector



Compounded average annual change

Absolute values

(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for 5 MSs: UK, Germany, France, Italy and Poland. EU 28 is a single scenario for the whole EU.

Sources: Authors based on Enerdata, DDPP, MILES, Low-emission Poland 2050.

consumption has increased in the building sector since 2000, while the fuel mix has remained rather constant. Between 2000 and 2013, there was a reduction of oil share in the fuel mix (-7pp) and small increase in the shares of wood (+3pp) and electricity (+4pp).

The following paragraphs now look at the adequacy of the above described changes in the light of the required trajectories for the EU's 2030 and 2050 low-carbon economy objectives. We start firstly with energy intensity in the residential sector. Figure 10 shows that energy intensity has improved at a rate of slightly less than 2% per year over the past decade in the EU28, and that the energy intensity improvement rate appears to have slowed down in recent years. Part of this may be due to climatic reasons (harsh winters in 2010, 2011, and 2012). Part of it may be due to macroeconomic factors, i.e. the long economic crisis starting in 2009 leading to a slowdown in the turnover of the building stock. **What is clear, however, is that to achieve the EU's 2030 and 2050 objectives, continued very strong improvements in energy intensity, above current levels, are needed over the coming decades. This cannot be based on 'low-hanging fruits' alone, as the rates of intensity improvement require ultimately getting to very low energy intensity levels.**

We turn finally to the decarbonisation of final energy consumption in the buildings sector. Decarbonisation of final energy can be achieved through switching to low-carbon electricity or bio-energy (bio-gas for example). The historical rate of improvement in the carbon intensity of final energy in buildings has reached around 1% per year in the EU28 (Figure 11). However, Figure 11 shows that to achieve the EU's 2030 and 2050 objectives, the rate of improvement in the carbon intensity of buildings final energy consumption will have to increase significantly already by 2030. It should be noted that the dramatic acceleration in carbon intensity improvements in the decade 2040-2050, showed in the lower bound of the range line, is due to a deep decarbonisation process taking place in the Italian scenarios.[4]

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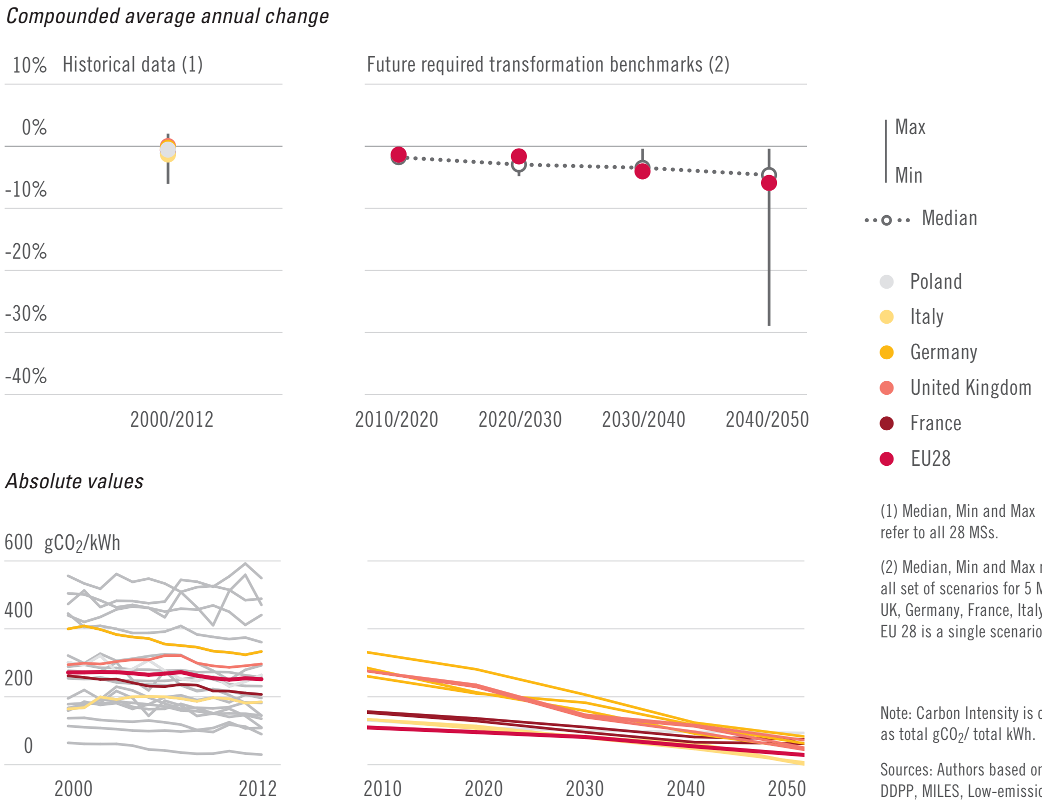
[4] In the Italian scenarios, compared to the other sectors, the building sector shows the lower marginal costs for decarbonisation measures. Given the absence of other constraints and a fixed service demand, the model pushes towards a very deep decarbonisation of the buildings sector between 2040 and 2050. In this decade, strong retrofit measures combined with a high penetration of low-carbon technologies in space and water heating (heat pumps, solar and biomass) leads to a dramatic reduction in CO_2 emissions in the buildings sector.

Figure 11. Carbon intensity of building sector



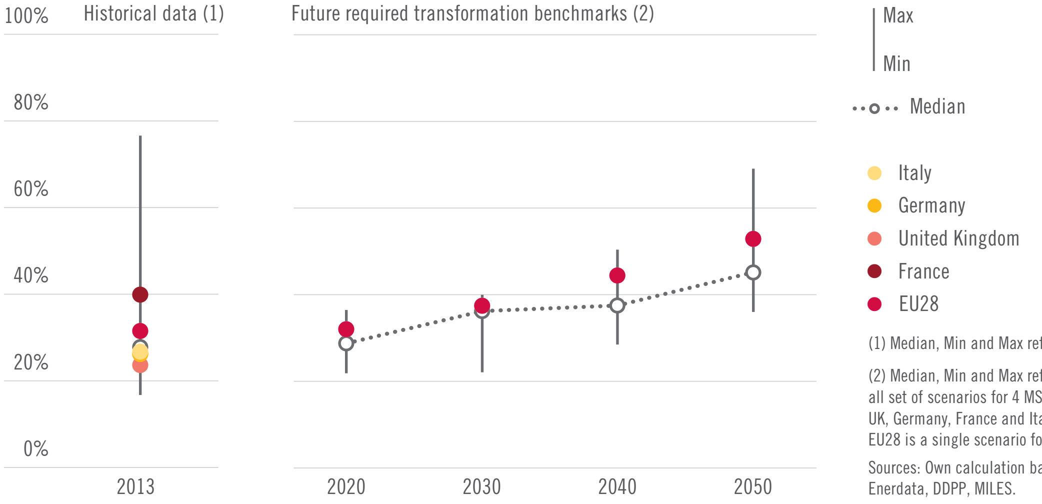
(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for 5 MSs: UK, Germany, France, Italy and Poland. EU 28 is a single scenario for the whole EU.

Note: Carbon Intensity is calculated as total gCO_2/ total kWh.

Sources: Authors based on Enerdata, DDPP, MILES, Low-emission Poland 2050.

Figure 12. Electrification of final energy use in buildings, historical and required

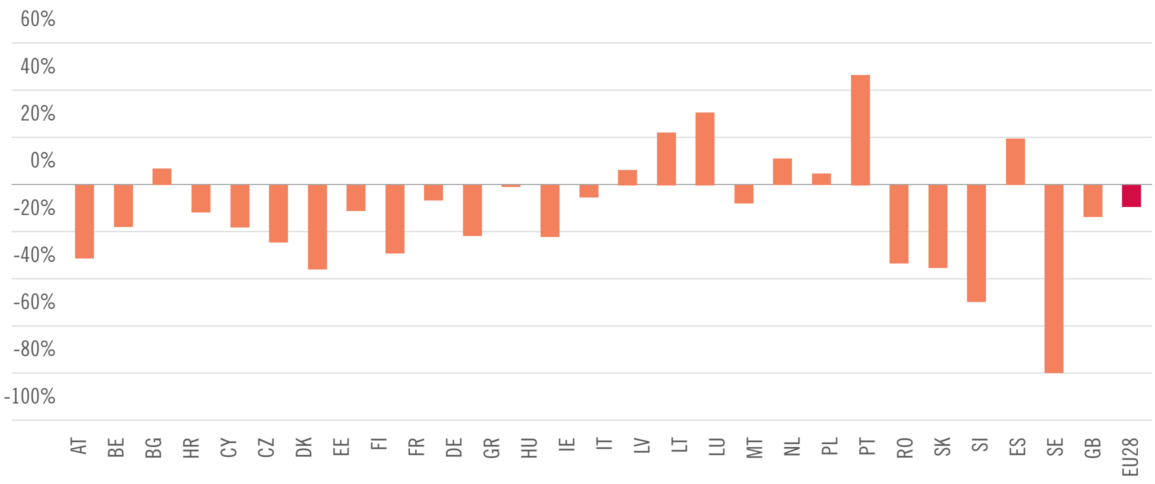


(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. EU28 is a single scenario for the whole EU.

Sources: Own calculation based on Enerdata, DDPP, MILES.

Figure 13. Change in direct CO_2 emissions of the buildings sector. 2000-2012, percent.



Source : authors based on (Enerdata, Odyssee, 2016)

One of the crucial levers to reduce the carbon intensity of energy consumption in the buildings sector is the shift away from fossil fuels to low-carbon energy carriers, in particular to electricity (provided that power generation has already been decarbonised to a great extent). In deep decarbonisation scenarios, the rate of penetration of electricity in final energy consumption needs to reach levels close to currently seen in France, one of the most 'electrified' Member States, by 2030 already (Figure 12). **This represents an important policy challenge, and needs to be a greater focus for future policy efforts.**

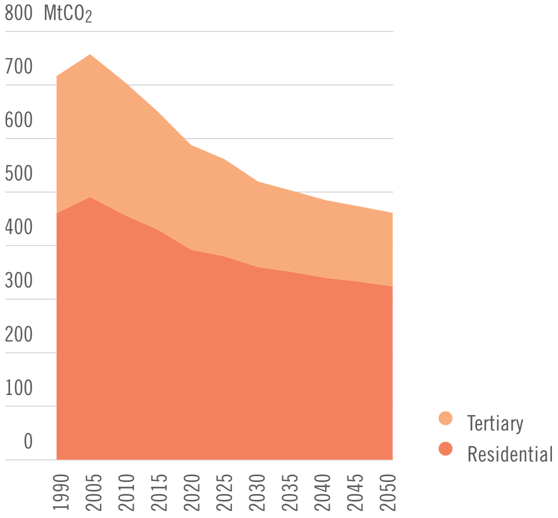
As a result of the above-described trends, direct CO_2 emissions from the building sector have fallen by 9.1% in the EU28 between 2000 and 2012.[5] More recent, less aggregated data for the EU28 suggest even deeper declines, of 17% between 2000-2015. However, buildings emissions are highly sensitive to annual weather conditions, and therefore an examination of the underlying drivers of change is necessary (as given above for energy intensity and carbon intensity of the fuel mix). Figure 13 shows that changes in emissions have been different in different Member States. Generally speaking, poorer Member States have grown their emissions, albeit from lower levels. Two exceptions to this were Italy and Spain, which also grew their emissions.

4.2. Policy discussion

The above analysis has suggested that by and large the EU has made progress in reducing energy intensity and emissions in buildings during the past decade. In its 2014 projections of future emissions by sector, the European Environment Agency has projected that, despite recent progress, the rate of declines in emissions from the buildings sector will start to slow down in future years (Figure 14). These projections are based on the estimated impact of existing policies in Member States. Overall, they point to a reduction in energy emissions of buildings of 36% between 1990 and 2050. They therefore show that existing policies and measures are expected to be dramatically insufficient to achieve reductions consistent with the EU's 80-95% reduction goal by 2050. But what is driving these results?

Figure 14. Past and projected future evolution of direct energy-related emissions from the buildings sector

(with existing policies and measures)



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[5] N.B. the aggregate figures given here exclude Romania, for which 2012 data was not available.

Emission reduction in buildings can be achieved through four main actions:

- Reduction of energy intensity of household appliances.
- Improvements in the energy performance of the building envelope (especially through retrofitting of existing buildings).
- Fuel switching (from fossil fuels to electricity and renewable energy).
- Reduction of energy consumption due to behavioural changes (although historically, policies have rarely explicitly targeted induced behavioural change).

By and large, current EU policy settings have proven quite effective at driving improvements in energy efficiency of household appliances. Due in large part to the combination of the EU's eco-labelling and eco-design regulations, the number of appliances that meet the criteria to be categorised as A-level performance has evolved so quickly that a revision of the labelling criteria is now required.[6] While not all appliances still meet the top criteria, and there is evidence of a need to improve enforcement of labelling, it is nevertheless now not uncommon for the average performance of many household appliances to have improved by a factor of between 2 and 4 since the early 2000s.[7]

However, while these improvements are expected to lead to significant savings over the coming decade as old and inefficient equipment is replaced, energy savings potentials relating only to the design of individual devices are expected to approach technical limits. In buildings, this means that smarter building design (for new buildings) and, more importantly, deep retrofitting of existing buildings is required to achieve deep energy savings and reductions in emissions over the longer term. **In this respect, policy progress remains largely inadequate to date.**

Unfortunately, no reliable database on the depth and number of retrofits per year exists (a fact which itself suggests a lack of sufficient attention to this crucial aspect of the energy transition). Nevertheless, expert estimates of the rate of retrofits puts the average annual rate across the EU at around 1 to 1,2% of the building stock per year—obviously too slow to achieve a retrofit of all currently buildings by 2050 (EEFIG, 2015). Moreover, the depth of the retrofits of existing buildings is also believed to be generally quite shallow. One study has estimated that if one categorised retrofits into "deep" (+60% savings in annual energy use), "medium" (30-60% savings) and "shallow" (0 to 30% savings), then roughly 5% of retrofits would be deep, 10% would be medium and the remainder would be shallow in the EU (EEFIG, 2015).

These findings also appear to be consistent with a recent Energy Efficiency Watch survey of roughly 1,100 building sector experts in all 28 Member States on progress in implementing the second National Energy Efficiency Action Plans. This study found that only 15% of national experts across the EU thought that their national government's energy efficiency retrofit programs were "very effective", 63% found them to be "partly effective", while 22% reported their national retrofit policies to be either "not effective" or "not implemented". These results strongly suggest that there is a need for a step-change in the level of ambition and effort put into making national retrofitting policies effective if they are to be made consistent with the EU's 80-95% decarbonisation goals by 2050.

Another major vector for decarbonisation of energy use in the buildings sector is fuel switching to decarbonised energy carriers. This includes switching to (decarbonised) electricity or directly to renewable energy sources, like solar, geothermal, heat pumps, biomass, biogas, and waste. As highlighted above, in recent years EU Member States have made some progress in this area thanks to renewable energy targets; technology support policies in the Member States; modular heating solutions which have declined in cost in recent years, such as heat pumps; and (until recently) rising costs of alternative fuels, such as oil and natural gas.

However, policies in EU Member States to support increased use of renewable heating and electrification are of uneven quality and could be further improved. Several Member States have either rolled back or made insufficient effort to re-inforce support schemes for heating from renewable energy following an initial take off in the 2007-10 period. This has occurred just as prices of heating from fossil fuel-based alternatives have begun to fall significantly—making them more competitive—and as a decline in new builds of homes has reduced installation rates (EPHA, 2013; ETSIF, 2014). This has led to a decline in the rate of deployment of key technologies such as solar thermal (which declined -7% in 2014 and is yet to return to its pre-crisis peak). Indeed, the European Commission's Renewables Progress Report suggests that the 2020 indicative targets for solar thermal, contained in the NREAPs, are likely to be missed by 41%-45% on average.

Other alternative heating technologies, such as (decarbonised) electricity, biomass, heat pumps, and district heating using biogas, have seen better

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[6] https://ec.europa.euenergy/en/topics/energy-efficiency/ energy-efficient-products

[7] Presentation by RTE at IDDRI, April 25th, 2016.

progress than solar thermal (cf. ETSIF, 2014; Europarl, 2015). However, these technologies also face headwinds from falling costs of alternative fossil fuels, cutbacks in government budgets, unfriendly thermal or building regulations, insufficient government incentives for inclusion in building renovations.

In conclusion, therefore, current policy settings within EU Member States for decarbonising the building sector place the EU on track for in the order of a 36% reduction in emissions from the building sector by 2050, far from the much deeper cuts required to achieve the EU's objectives. While current policies have been successful at improving the energy performances of appliances and building design for new buildings, significant shortcomings remain in the area of existing building retrofits, both for energy efficiency and fossil fuel substitution.

5. INDUSTRY

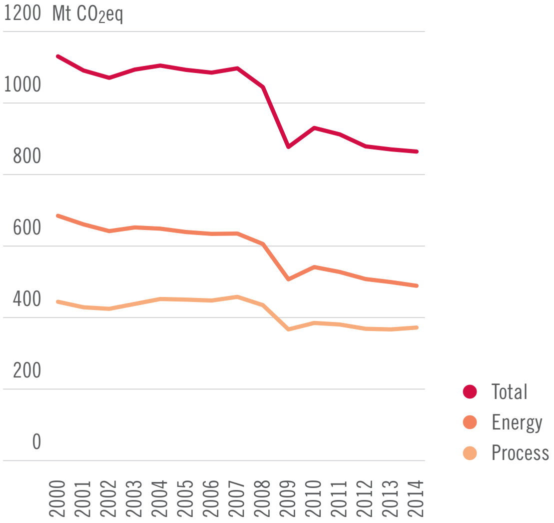
5.1. Historical trends in the light of required transformation

In 2014, the industrial sector in the EU28 accounted for approximately 19% of total direct GHG emissions (EEA, 2016). Roughly 57% of these direct emissions were linked to energy consumption while the remaining 43% were emissions from industrial processes. In 2014, the industrial sector was responsible for about 24% of EU total final energy consumption in Europe. As shown in Figure 15, total emissions from industry have decreased by 23% between 2000 and 2014, a significant decline. Much of this has come from declining energy combustion emissions, although a notable decline in process emissions is also observable. The timing of the decline in emissions is highly correlated with the economic crisis of 2008/09 and the subsequently very weak recovery in manufacturing activity in energy-intensive industrial sectors in Europe since then (Figure 16).

The impact of economic factors also seems to be confirmed by a decomposition of the decline in emissions from fossil fuel combustion. Energy consumption has decreased in the industry sector by 17% in the 2000-2013 period; while the fuel mix has remained rather stable (Figure 17). In terms of fuels, demand is currently dominated by natural gas and electricity, which each account for a third of final consumption. The biggest changes between 2000 and 2013 were a reduction of oil's share in the fuel mix (-6 pp) and small increase of renewables (+3 pp) and electricity (+4 pp) shares. Thus the majority of the decline in emissions stems from lower energy demand by industry.

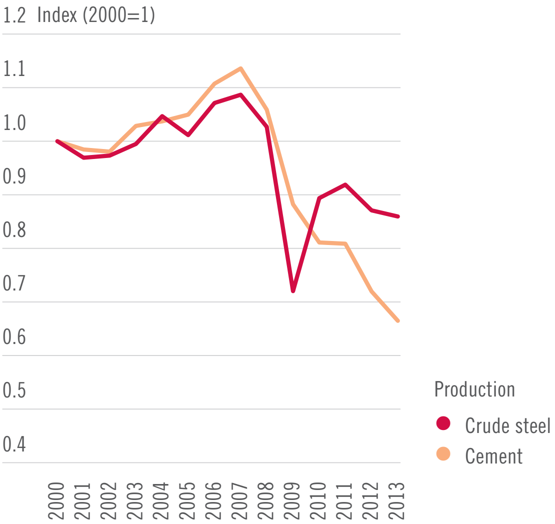
As shown in Figure 15 and Figure 16, the reduction in energy consumption has mainly reflected the very strong impact of the economic crisis and ensuing recession on industrial output. As Figure 18 shows, some energy efficiency improvements in energy-intensive industries did occur prior to 2008. However, for some of the major industries, like cement or steel, and even for industry as a whole, these have tended to stagnate or be reversed since the crisis, as the existing capital stock is run below full capacity, resulting

Figure 15. EU GHG emissions from Industry (2000-2014)



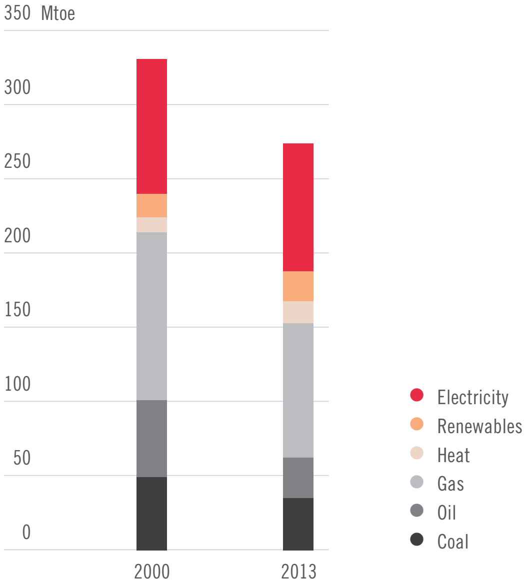
Source: IDDRI based on EEA data

Figure 16. Production index for steel and cement



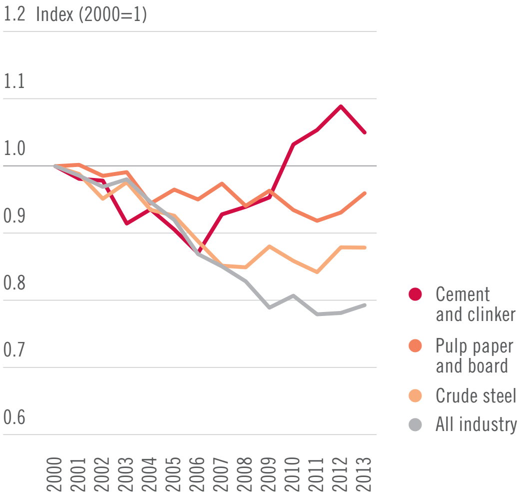
Source: authors based on (Enerdata, Odyssee, 2016)

Figure 17. Industrial final energy consumption by fuel, EU28



Source: Authors based on Enerdata, Odyssee, 2016.

Figure 18. Energy intensity (toe/t)* of energy intensive industries, EU 28



** Note: All Industry index is based on a measure of toe of energy consumption per € of value added in 2005€ euros. The other three series are measured in toe/tonne of production.*

Source: authors based on Enerdata, Odyssee, 2016.

in production inefficiencies, and as investment in new equipment has slowed.

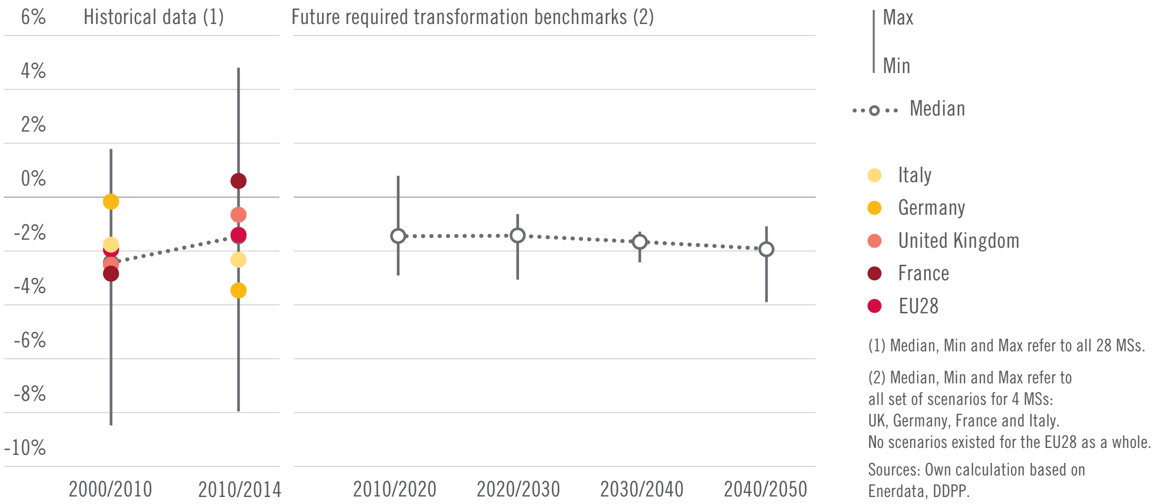
This section now compares these trends with required transformation rates in deep decarbonisation scenarios. We start with energy intensity (EI) before turning to carbon intensity (CI) of energy. Before doing so, it should be remembered that relative effort across EI and CI are interdependent, as poor performance on efficiency means more needed on carbon intensity and vice versa.

Figure 19 compares the rates of change seen over the last decade in terms of energy intensity improvement with the required transformations seen in deep decarbonisation scenarios to 2050. It can be seen that broadly speaking the recent historical rate of around 2% to 1.5%/yr improvement is in line with what needs to be achieved in deep decarbonisation scenarios. It should be remembered, however, that during the historical period studied, the net effect of structural change (induced in part by the economic crisis) appears to have been a significant contribution to improvements in energy intensity. Maintaining continued rates of energy intensity improvement at about 1.5% per decade, as is required in deep decarbonisation scenarios, will require a much stronger contribution from technological innovation and diffusion, particularly in a context where continued slow growth in industrial production and structural change within industry is not necessarily seen as desirable from a policy perspective.

Figure 20 studies the evolution of carbon intensity of industrial final energy consumption. It shows that for the EU28, the carbon intensity of industrial final energy consumption has decreased by 0.3% per year in the decade 2000-2010 and that this accelerated to 1.62%/yr in the years 2010 to 2013. Some of this was due to the introduction of renewable energy policies driving a 37% increase in the use of biomass during this period (Enerdata, 2016). Some of this relates to growing electrification. Some is also due to the structural change in the industry sector, as energy-intensive sectors heavily reliant on coal (cement, steel) declined in terms of their share in industrial energy consumption, leaving the residual energy mix relatively cleaner. For instance, total EU industrial production fell by about 12% from 2007 to 2013 due to the crisis, but steel and cement production fell proportionately much more (22% and 45% respectively) during the same period.

However, what's more important is the extent to which Figure 20 shows that deep decarbonisation requires profound changes in industrial carbon intensity in the decades notably after 2030. This requires the deployment of non-mature technologies such as CCS and/or increased electrification of industrial processes (either directly or indirectly e.g. with power to fuel technologies). This step change in the rate of decline in carbon intensity reflects assumptions in the underlying scenarios that high penetration of such breakthrough technologies would be difficult to achieve in a shorter timeframe. However, as noted below, the challenges

Figure 19. Industrial energy intensity



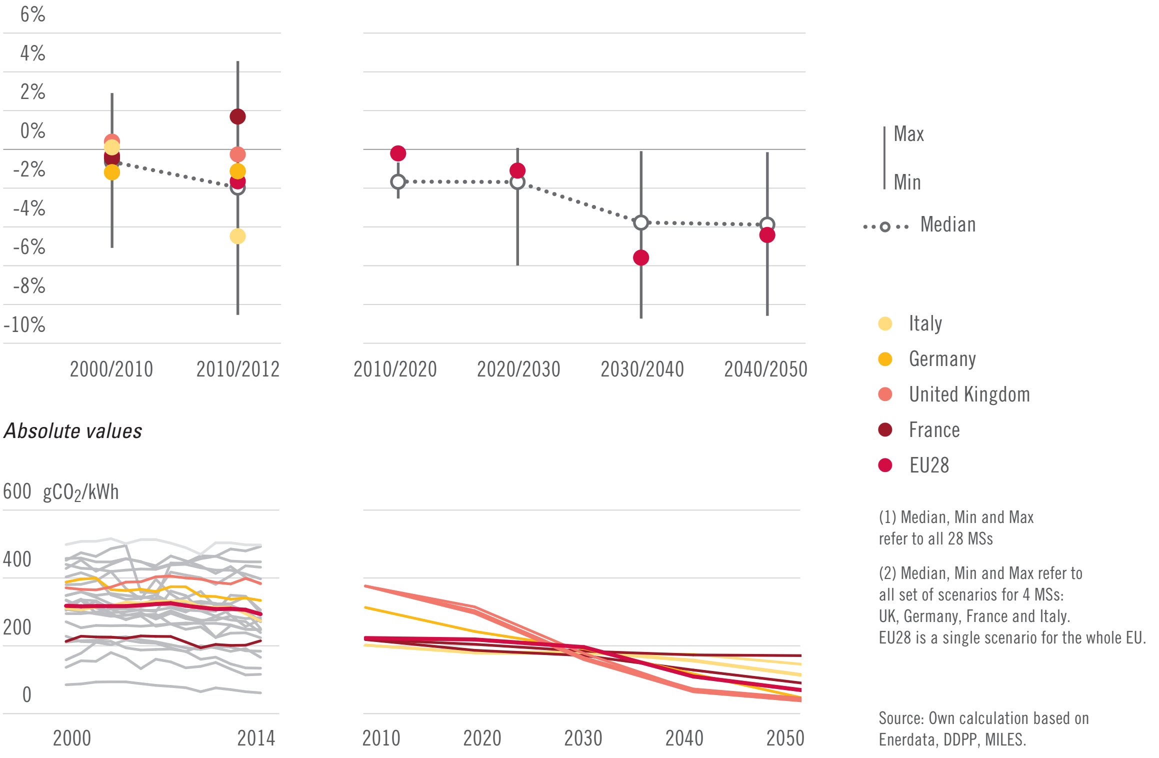
(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. No scenarios existed for the EU28 as a whole.

Sources: Own calculation based on Enerdata, DDPP.

Figure 20. Carbon intensity of industrial final energy consumption

Compounded average annual change



(1) Median, Min and Max refer to all 28 MSs

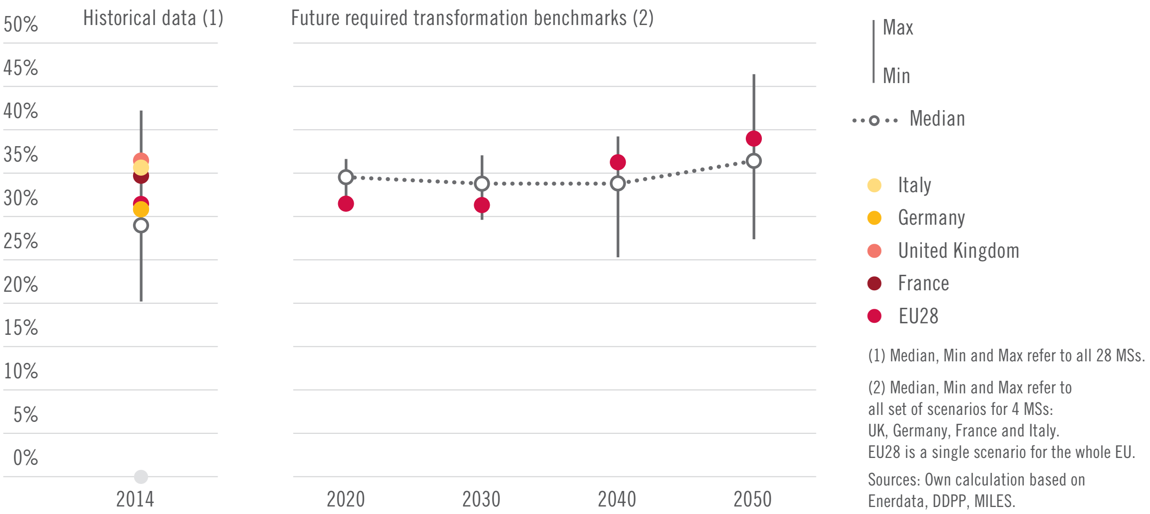
(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. EU28 is a single scenario for the whole EU.

Source: Own calculation based on Enerdata, DDPP, MILES.

associated with bringing these technologies to market would require significant preparatory work in the intervening time.

Pursuing this point, Figure 21 and Figure 22 show different levels of deployment of electrification and CCS in different scenarios that have been considered necessary to decarbonize industrial final energy consumption. They show that in addition to continuing a steady pace of deployment during the current and next decade, the rate of deployment of these alternatives are assumed to be scaled up very rapidly from 2030 onwards. These results reflect the assumptions of the underlying scenarios, namely that significant scale up

Figure 21. Electrification of industrial final energy consumption (% share)

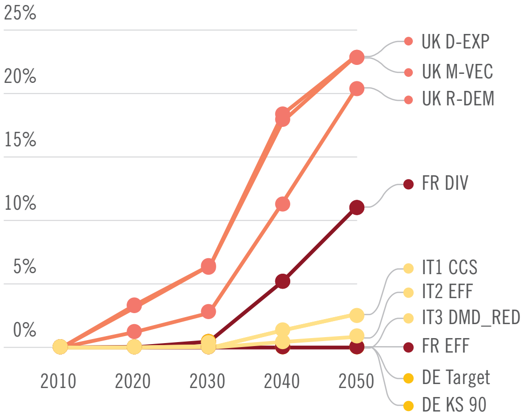


(1) Median, Min and Max refer to all 28 MSs.

(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. EU28 is a single scenario for the whole EU.

Sources: Own calculation based on Enerdata, DDPP, MILES.

Figure 22. Share of CCS in final energy consumption, Industry sector



Source: Own calculation based on Enerdata, DDPP.

of low-carbon alternatives—such as CCS and/or larger-scale electrification—would not be technically and economically feasible before 2030.

It is interesting to consider the implications of this time lag that is depicted in the Figure for tracking progress. In particular, it suggests that annual rates of improvement are not necessarily the only or the best indicator of the adequacy of progress towards decarbonisation of industry. We must also look at how well current policy frameworks are preparing the terrain for these changes, in view of the inertia of the industrial capital stock. The question of whether the EU is adequately preparing this terrain is therefore discussed in the next section.

5.2. Policy discussion

Looking forward, is the EU on track to achieving the outcomes described in the decarbonisation scenarios described above if one considers the current incentives provided by policy? To answer this question, it is first useful to distinguish between very carbon intensive sectors (here defined as: cement, steel, aluminium, chemicals production, pulp and paper, ceramics and glass products, oil refining) and a residual set of very diverse but individually less energy-intensive manufacturing processes (such as auto manufacturing, production of information and communications technology products and in general manufacturing of higher value added goods). Roughly speaking, each of these two sets of sectors represents about one half of total energy use in the industrial sector.

Furthermore, one can identify 5 basic vectors of decarbonisation for industrial sectors:

- Fuel-switching (emissions efficiency of energy).
- Energy efficiency.
- Production process improvements (material efficiency).
- Product improvements and more intensive use of products, e.g. of durable products (product service efficiency), re-use and recycling.
- Sustainable consumption.

These vectors of decarbonisation are relevant for identifying what kinds of policies are needed to decarbonise industrial sectors. The relevance of each of these vectors tends to differ significantly between emissions and energy-intensive sectors, on the one hand, and other manufacturing sectors, on the other. Each of these two broad categories of industries is now discussed in turn.

Energy-intensive industries

In carbon-intensive industries, opportunities for substantial further improvements in energy efficiency, fuel switching and even recycling tend to be limited (Neuhoff *et al.*, 2015). To be sure, these can still lead to further improvements in CO_2 intensity and need to be exploited; but overall, these improvements are generally not consistent with achieving deep decarbonisation of the EU energy system in line with what is required under a <2°C emissions scenario. Deep decarbonisation of these industries will tend to need to rely to a significant degree on important technological process improvements (such as carbon capture and storage to capture unavoidable process emissions, electrolysis-based steel production, direct reduction of iron using hydrogen), product innovations (such as low-carbon cement alternatives, high strength light weight metal alloys, etc), and incentivising more efficient use and better tailored products for end users to improve material efficiency (such as for materials used in construction or auto manufacturing).

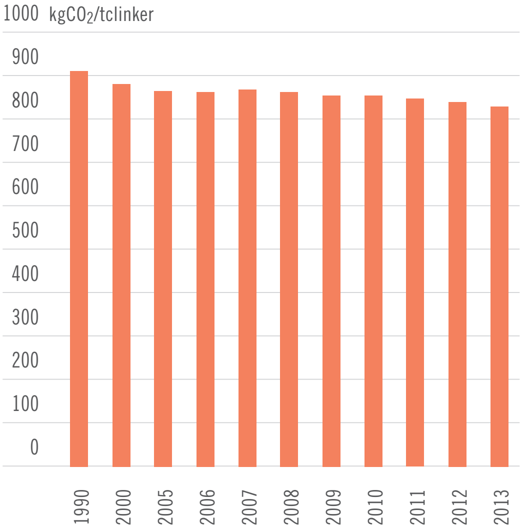
Unfortunately, current policies in the EU and its Member States are inadequate to drive these outcomes. For instance, as of July 2016, the EU had no industrial scale CCS projects that directly linked to industrial processes in operation. This was despite the fact that as of 2007, the European Council set a goal for Europe to have 12 large scale CCS demonstration projects by 2015 and European companies expressed interest in developing 13 different CCS under the EU's NER300 call for tender (EC, 2013). The failure to deliver on any of these projects was due a constellation of factors, including:

- A collapse of commercial willingness to undertake CCS projects following the collapse of the EU ETS carbon price.
- A collapse in the financial situation of large energy-intensive industrial companies in Europe since the crisis and in the wake of global overcapacity and a resulting change of business priorities.
- An insufficiently ambitious commitment of public funds (such as under the EU's NER300) to re-incentivize the private sector to participate under these circumstances (EC, 2013).
- A lack of public acceptance of large-scale projects in at least some of the EU member countries (e.g. Germany).

For similar reasons, innovative steel process projects funded under the ULCOS scheme also appear to have stalled (Neuhoff *et al.*, 2015).

In relation to product innovation, there also appears to be insufficient policy incentives for sectoral transformation.

Figure 23. Carbon intensity of clinker production in the EU



Source: authors, based on data from GNR.

For instance, all of the EU's large cement companies have developed innovative cement alternatives that significantly reduce CO_2-intensity of production.[8] However, no market for them currently exists given their higher incremental cost of production (MPA Cement, 2013). For instance, one company executive spoken to by the authors of this paper suggested that CO_2 prices in the order of 35 to 50 €/t cement would be needed to make his company's product viable.[9] Thus, in the absence of a meaningful CO_2 price on ordinary Portland cement, or alternative policies such as public procurement and regulations to promote these technologies, there is no incentive for businesses to shift into these products at large scale. As a consequence, many promising innovations appear to struggle to attract the necessary investment from incumbents or new businesses to make headway in the market. Thus, Europe remained faced with the result that has occurred in recent years, where the focus of companies is on very marginal improvements to things like the CO_2 intensity of clinker production (cf. Figure 23), rather than significant structural breaks in technology.

Similarly, the incentives for improved end-use efficiency and better product tailoring also face the challenge that there are too few policy incentives to make them happen. Given the challenge of regulating individual decisions at the product-use

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[8] http://cement.mineralproducts.org/documents/FS_12_Novel_cements_low_energy_low_carbon_cements.pdf

[9] Pers comm. to Oliver Sartor – company name kept anonymous.

level, policies to place stronger economic incentives for end-use efficiency are essential. These remain impossible as long as carbon prices are extremely low and no alternative policy or market pressure exists to give firms a structural incentive to improve efficiency in these ways. Overall, therefore, the current policy framework for incentivising a step-change in emissions from highly energy-intensive industries is currently missing.

It is sometimes claimed that energy-intensive sectors in Europe cannot engage in meaningful efforts at decarbonisation because they compete in global markets. The argument being that their costs would rise to undertake these activities and this would in turn undermine their competitiveness and economic viability, thus leading to "carbon leakage". It is obviously true that some (relatively extreme) approaches to incentivising emission reductions in industry could indeed lead to this outcome. On the other hand, public support of new technologies and process innovations as well as smart composition of aggregated policies (e.g. specific rules and exemptions for energy-intensive industries under the EU ETS) can set significant incentives without harming the competitiveness of companies.

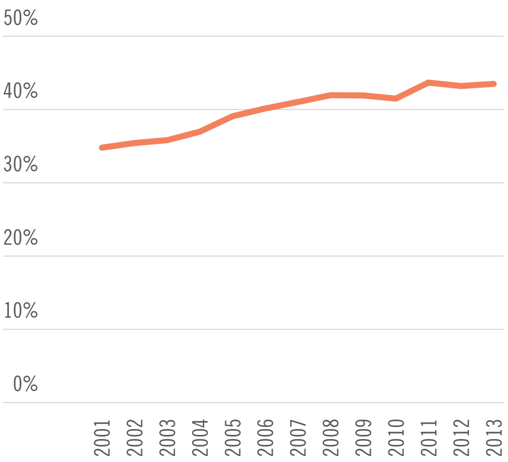
Indeed, there are also examples of approaches that have been applied to other sectors that did not necessarily lead to such outcomes. The example of renewable energy deployment and development is one such case. Another is that of the more nascent industry of electric vehicles, which, it is increasingly believed, can be supported through an initial period of non-competitiveness in the market until technology costs fall and they are gradually integrated into markets. A similar approach does not seem unreasonable for energy-intensive industry.

To be sure, in the long run, more coordinated approaches between major industrial economies on carbon regulation are likely to be necessary for instruments like carbon pricing to have their full effect. However, this does not necessarily preclude shorter-term measures that can be taken independently, such as sponsoring demonstration activities in breakthrough technologies, public procurement of innovative products, or indeed higher carbon prices combined with free allocation at the level of the best available technology benchmark.

Non-energy-intensive industries

Alternatively, if one looks at less energy-intensive industrial sectors, then key vectors for decarbonisation—broadly speaking—tend to relate to making significant improvements in fuel-switching (particularly to decarbonised electricity), energy efficiency and phasing out certain kinds of chemical compounds, such as F-gases, although other vectors could also play a role depending on the nature of the industrial process.

Figure 24. Electricity share of energy consumption in non-highly energy intensive industry* (EU28)



Defined as: all industry excluding steel, non-ferrous metals, non-metallic minerals, oil refining, and chemicals.

While meaningful EU policies exist to incentivise improving energy efficiency and the reduction of F-gas use, most Member States do not provide sufficient incentives for the electrification and decarbonisation of industrial energy use. To be sure, the rate of electrification of industry as a whole has increased from 28% to 32% from 2001 and 2015 (Enerdata, n.d.) and that of industry excluding highly energy-intensive industries[10] has increased from 35 to 44% (cf. Figure 24 and Figure 25). However, this result largely reflects non-policy factors, including:

- A declining use of oil and gas prior to 2009, as oil and gas prices rose faster than electricity prices (cf. Figure 26).
- Underlying technological changes in industry, with an increased mechanisation of tasks leading to a rise in the use of electricity uses.[11]

Moreover, since 2009, the trend in relative energy prices for industry has largely reversed and, while there remains a trend toward increasing mechanisation of industry, this has not been sufficient to sustain previous substitution from fossil fuels to electricity (or indeed other decarbonised fuels, such as waste heat and biomass).[12] If left

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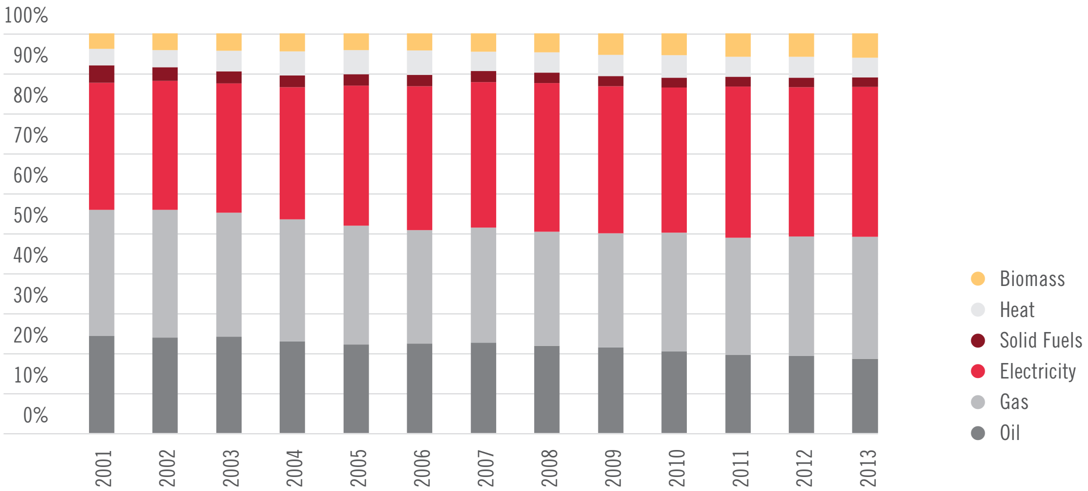
[10] Such as steel, non-ferous metals, non-metallic minerals, chemicals, oil refining, and pulp and paper

[11] http://www.enerdata.net/enerdatauk/press-and-publication/energy-features/electrification-industrial-consumption-europe.php

[12] Note also that the data for the series presented in Figure 28 do not extend beyond 2014, thus they do not

Figure 25. Composition of final energy consumption of non-highly energy intensive industry (EU28)



Source: IDDRI, Enerdata

unchanged, this can be expected to slow down incentives towards electrification of industry going forward.

To make up for this, dedicated policies are needed, but are lacking. Appropriate economic incentives to switch fuels are a key part of this equation. Just as rising prices of oil and gas relative to electricity have contributed to higher electrification, so too would rising taxation of oil and gas relative to electricity. However, as Figure 26 indicates, electricity still remains a significantly more expensive energy carrier for industry than alternative fuels on a cost/tonne of oil equivalent basis. To be sure, the choice of fuels of many industrial consumers is affected by several factors—including the ease of application of the fuel to specific industrial processes, existing plant design and the fixed costs of managing energy generation technologies on site. Thus there is no one price at which industry would shift *en masse* from alternative to electricity as a dominant fuel. Nonetheless, as the Figure indicates, the gap between the cost of electricity and other dominant industrial fuels remain significant and has not closed noticeably in recent times. This would appear to call for a stronger focus on economic incentives for industry to increase electrification.

Unfortunately, progress at EU level to change the relative economic attractiveness of alternative fuels to electrification has been slow in this regard. For instance, necessary revisions to the EU's Fuel Taxation Directive attempted in 2011 were met with strong resistance from several Member States. The Directive, which has not been successfully revised since 2003, contains a number of weaknesses. Minimum tax levels have not been adjusted since 2003, which means that inflation has reduced their real value. These levels are also based on the volume of fuel rather than energy or CO_2 content, which means that the most CO_2 intensive fuels are often taxed less than renewables (for instance, in the EU diesel is generally taxed less than biodiesel, and coal is the least taxed fuel among all fuels).[13] These policy settings are fundamentally inconsistent with a goal of driving fuel switching to decarbonised energy sources in industry.

Another missing piece of decarbonisation policy for industry in the EU is a lack of a clear guiding strategy (or set of sectoral strategies) for decarbonisation of European industry. Some individual sectors—particularly energy-intensive industries such as pulp and paper, cement, steel and chemicals—have developed at least a rough outline of a potential transition for their sector (CEPI, 2015; 2015c; Eurofer, 2015; Cembureau, 2013; Cefic, 2014) and several roadmaps have also been developed by independent researchers working in collaboration with these industries (e.g. Neuhoff *et al.*, 2015b; Neuhoff *et al.*, 2015b; IEA, 2009). To be clear, some of these strategies require updating and further development. However, they all represent genuine attempts to lay out at least possible pathways towards decarbonisation of some of the EU's key industrial sectors.

However, unfortunately, even these strategies that exist have not been a basis for close engagement with EU policy-making. Instead, EU

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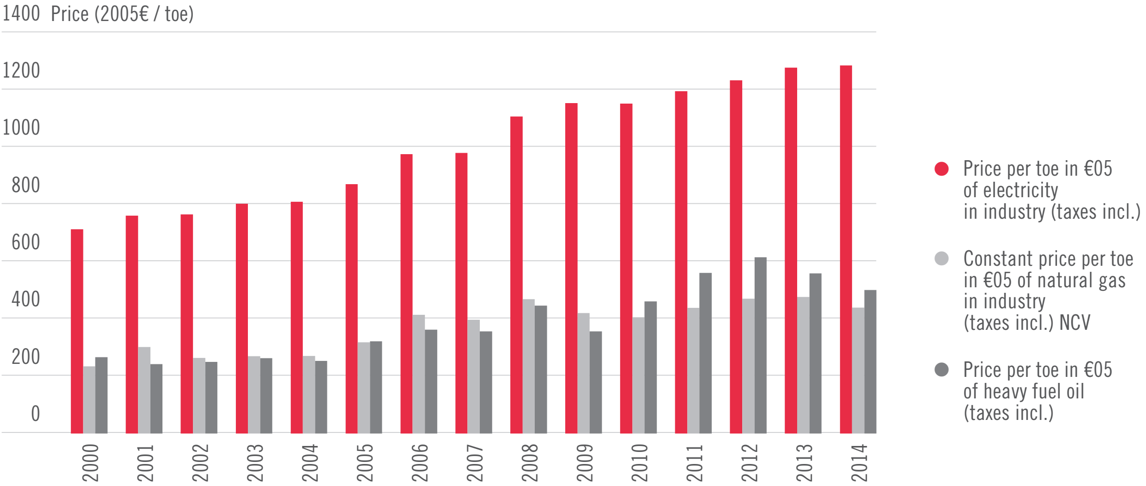
capture major further declines in oil and gas prices in 2015 and 2016.

[13] http://europa.eu/rapid/press-release_MEMO-11-238_en.htm?locale=en

Figure 26. Average industrial end user prices per tonne of oil equivalent (toe) of main industrial fuels in EU28

(incl. taxes, figures in constant euros 2005)



Source: IDDRI, based on data from Enerdata

policy has tended to continue along certain lines, such as the carbon market with its long debates between industry and policymakers about the levels of free allocation and benchmarking. These policy elements are of course necessary, for the reasons illustrated above. However, the how these policies concretely fit with possible industrial strategies towards decarbonisation, or indeed the long-term climate objectives, is largely ignored by these actors. A closer and more meaningful connection between concrete industrial strategies for decarbonisation and policy development is therefore needed.

Overall, therefore, there appears to be a strong case that the EU's current policy settings for decarbonising industry—both in high energy-intensive and less energy-intensive industries—are not yet consistent with the required transformation. In the former, more is needed to drive major technological production process changes, product innovation and smarter use of materials; while in the latter, stronger incentives for fuel-switching and continued progress on energy efficiency are necessary. More generally, a better alignment of industrial decarbonisation strategies at EU level and how they fit with EU policies is necessary.

A key issue for industrial decarbonisation is that as we are often dealing with long-lived capital stock and inertia in the tastes and demands of consumers, there will be a significant time-lag between policy signal to innovation and mass deployment of new low-carbon alternatives ; this is true for production processes, innovative products, or even for fuel-switching. It is therefore necessary to start immediately with strong incentives to induce this innovation and deployment if Europe is to have a chance of having these transformational changes mature in the post-2030 period. However, as this section has argued, the policy signal currently faced by the industrial sector is completely inadequate to this task. Continued marginal improvements in energy efficiency and carbon intensity, driven too much by crisis-induced structural change and not enough by innovation, will not be enough to achieve Europe's objectives for decarbonisation, growth and jobs.

6. TRANSPORT

6.1. Historical trends in the light of required transformation

The transport[14] sector currently accounts for around 27%[15] of total CO_2 emissions in the EU28. Reducing emissions from the transport sector represents a crucial challenge to meeting not only EU climate targets, but globally. The European Commission's 2011 Transport White Paper and "Roadmap for moving to a competitive low-carbon economy in 2050" set out the goal of reducing GHGs emissions from transport by around 60% below 1990 levels by 2050. Despite this target, overall CO_2 emissions

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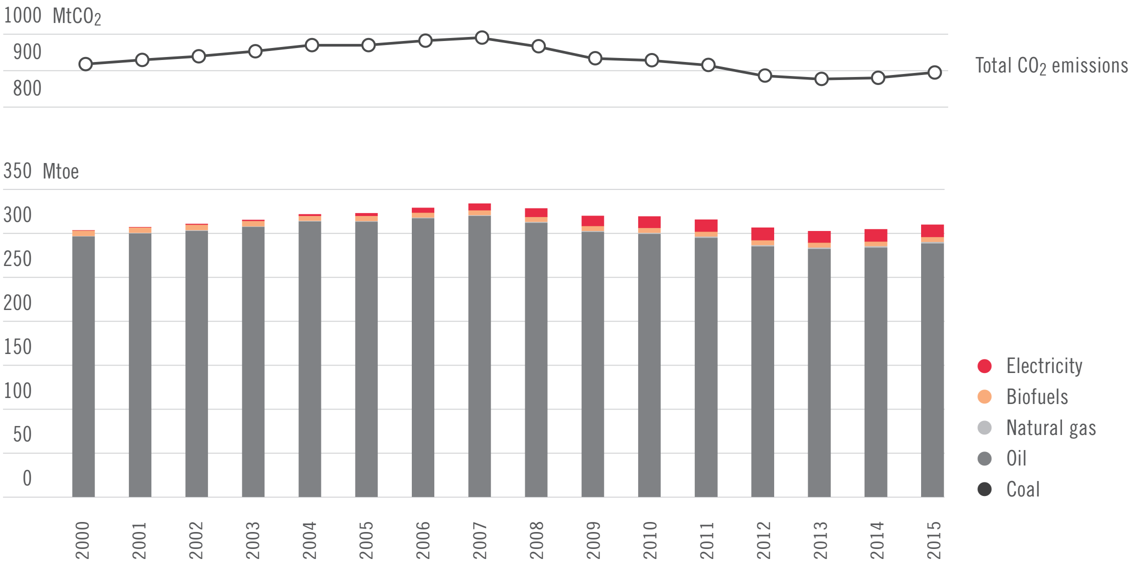
[14] The analysis of this section includes road, marine and aviation, unless otherwise stated. International aviation and marine transportation are excluded from the analysis.

[15] Value for year 2015, source: Enerdata.

Figure 27. Transport final energy consumption by fuel and total CO_2 emissions, EU 28



Source: Authors based on data from (Enerdata, Global Energy and CO_2 Database)

in the transport sector increased 16% in the period 1990 to 2015 and by 28%[16] in the period prior to the economic crisis (1990-2007).

Differently from the other sectors, where emissions started to reduce since 1990, transport sector emissions began to decline only from 2007. As shown in Figure 27, CO_2 emissions in the transport sector increased 7.9 % between 2000 and 2007, before reducing 11.4% from 2007 to 2013. In recent years, CO_2 emissions have started to increase again (+2% between 2013 and 2015). The temporary decline in CO_2 emissions between 2007 and 2013 can be mainly attributed to the effect of the economic recession, as described in greater detail below.

Different strategies can be adopted to reduce CO_2 emissions from the transport sector. Emissions can be reduced by decreasing the energy demand or through a process of decarbonisation of the fuel mix. The first option relates to reductions in the energy use due to improvements in the fuel efficiency or reducing the mobility (that is fewer kilometres travelled by passengers or fewer tonnes of goods transported per kilometre). The second option implies an increasing penetration of low-carbon (or zero-carbon) energy in final energy use. This can be achieved by expanding the use of biofuels[17] or, through a process of electrification of the transport modes (combined with a process of decarbonisation in the energy supply, assuring that the electricity is generated from low-carbon energy sources). Other low-carbon technologies necessary to the decarbonisation of the fuel mix (e.g. hydrogen-fuelled vehicles), although not yet available commercially, could represent a valuable option in the medium to long term.

As described below, the CO_2 emission reduction between 2007 and 2013 cannot be explained alone by improved fuel efficiency or reduced mobility, and cannot be explained without accounting for the effects of the economic recession. And neither can it be explained by a gradual decarbonisation of the energy consumption.

The fuel mix of the European transport sector is indeed dominated by oil products, which still represent 93% of the transport energy demand in 2015. Low-carbon energy only accounts for a very small amount of the energy consumption (Figure 28). While biofuel use increased significantly in the period—from 0.7 Mtoe in 2000 to 14.4 Mtoe in 2015—its overall share is still low, accounting for only 4.6% of total energy consumption. Furthermore, most biofuel use is concentrated in cars for passenger transport (75% of the total in 2013), while road freight transport is still almost fully depended on oil products. Electricity share in total transport energy consumption is very low and decreased from 2% in 2000 to 1.7% in 2013. Almost all electricity consumed in the transport sector is used in rail transport (99% in 2015), while only 1% is employed in road transport. The decarbonisation of the transport final energy use is thus still far from making any significant progress, especially in road and air transport.

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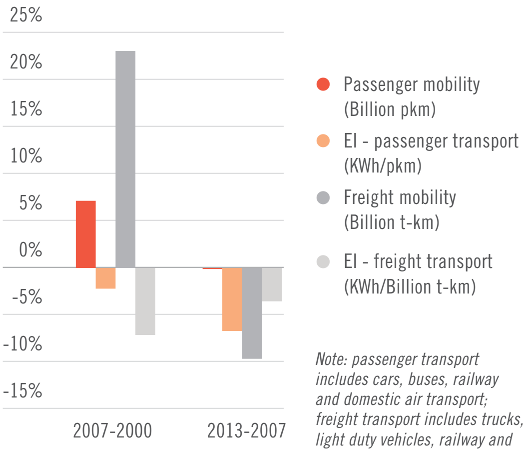
[16] Source: Enerdata.

[17] We refer here to lower life cycle CO_2 emissions than comparable fossil fuels.

Figure 28. Changes in energy intensity and mobility passenger and freight transport, EU 28



Sources: Own calculation based on Enerdata.

Note: passenger transport includes cars, buses, railway and domestic air transport; freight transport includes trucks, light duty vehicles, railway and water transport.

In terms of energy use, it can be seen from Figure 28 that the total energy consumption of transport follows a similar path to CO_2 emissions, growing by 10% between 2000 and 2007, declining by 9.4% in the period corresponding to the economic recession and then rising again 2.4% between 2013 and 2015.

The decline in the energy consumption between 2007 and 2013 is mainly due to a reduction in transport activity rather than to improvements in the fuel efficiency. As shown in Figure 28, the amount of transported goods (expressed in billion t-km) experienced a significant expansion (+23%) in the period 2000-2007, while passenger mobility increased by a smaller amount (+8%). At the same time, the rise of freight transport is accompanied by a relative decoupling from energy use, as shown by the decrease of -7.1% in the energy intensity.[18] In the second period, the dramatic decline in freight mobility (-9.6% between 2007 and 2013), together with some improvements achieved in the energy intensity of freight and passenger transport (-3.5% and -6.7% respectively), contribute to the overall decline in the transport energy demand.

Thus the trend in energy consumption is mainly correlated to the changes in transport mobility, particularly for freight transport, while the reduction experienced in energy intensity of passenger and freight transport can be related to improved fuel efficiency.

Looking into the mobility trends by country, passenger mobility per capita increased significantly between 2000 and 2007, mainly in Eastern European countries (e.g. in BG, HR, LV, LT), while the decline of passenger mobility in the following period affected especially Italy, Greece, Slovakia and Spain (Figure 29).

The effect of the economic trend on mobility is even more evident when looking at freight transport (Figure 30). Between 2000 and 2007, freight transport mobility increased sharply especially in Eastern European countries, where countries such as Bulgaria, Croatia, Hungary, Latvia, Lithuania, Poland, Romania and Slovenia experienced an increase in freight mobility of more than 50%. In the following period, the effect of the economic crisis likely combined with high oil prices reduced freight mobility in most of the EU28 countries, with the biggest decline occurring in the countries most affected by the economic downturn (GR, IT, ES, IE, PT).

Despite the decline in recent years in passenger and freight mobility, analysed scenarios expect a steady growth in transport mobility, with the only exception of passenger transport in Germany[19] (Figure 31 and Figure 32). In the EU28 as a whole, passenger kilometres are assumed to increase by 37% between 2010 and 2050, while freight mobility is expected to rise 56% in the same period.

The increasing mobility needs of people and goods, coupled with a fuel mix still (almost) entirely dependent on oil products, gives rise to serious concerns on how to meet the emission reduction targets without compromising economic growth. To ensure growth is sustainable, there is a need for an appropriate policy framework able to drastically reduce the energy intensity of transport and at the same time capable of pushing the process of decarbonisation forward.

In the following sections, the recent trends in energy and carbon intensity of transport are compared with the future required transformation benchmarks.

Figure 33 shows the annual change in energy intensity of passenger transport, which alone represents 65%[20] of total transport energy consumption. In the period 2000-2007, the energy intensity of the EU28 declined by -0.3%/yr, with some Member States experiencing a larger decline (up to -2.4%/yr in Greece) and others experiencing an increase in the energy intensity (up to +3.9%/yr in the Czech Republic).[21] In the following period, the rate of decline of the EU28

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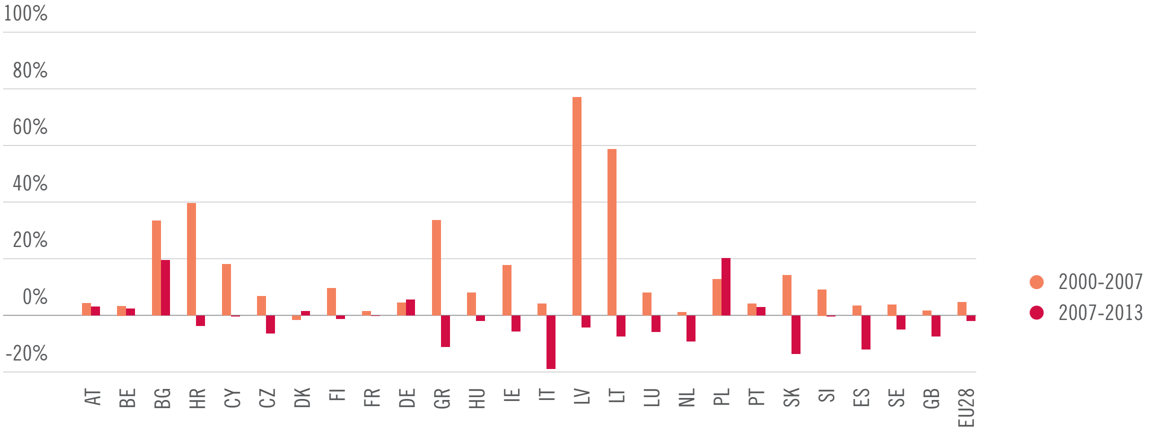
[18] Energy intensity is expressed in KWh/Billion t-km.

[19] When looking at per capita passenger mobility, due to the decreasing population trend expected in Germany, passenger mobility increases in two Germany scenarios between 2010 and 2050.

[20] Data for 2013 by Enerdata.

[21] The black bar represents the full range of annual rates of energy intensity for all EU Member States.

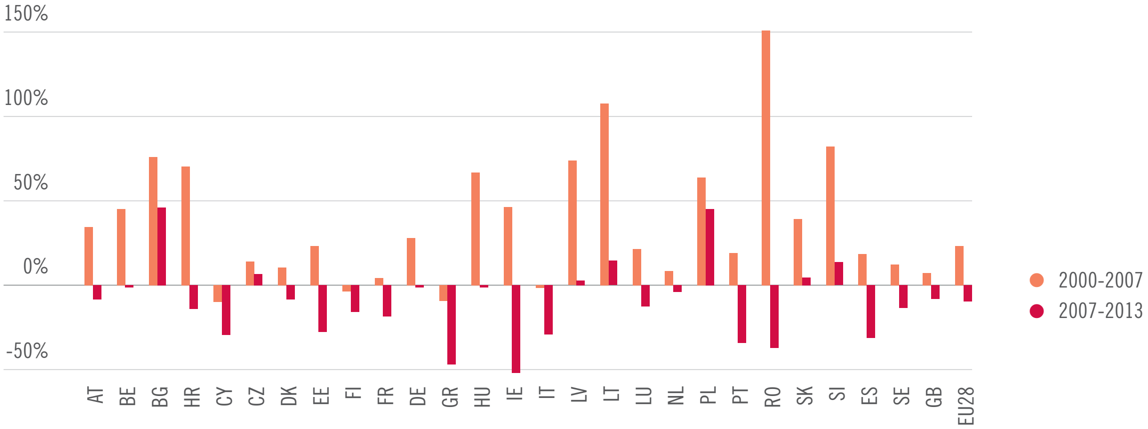
Figure 29. Passenger kilometres per capita (% changes in periods 2000-2007 and 2007-2013)



Sources: Own calculation based on Enerdata.

Note: Missing data for Estonia, Malta, Romania.

Figure 30. Tonne kilometres (% change 2000-2007; 2007-2013)



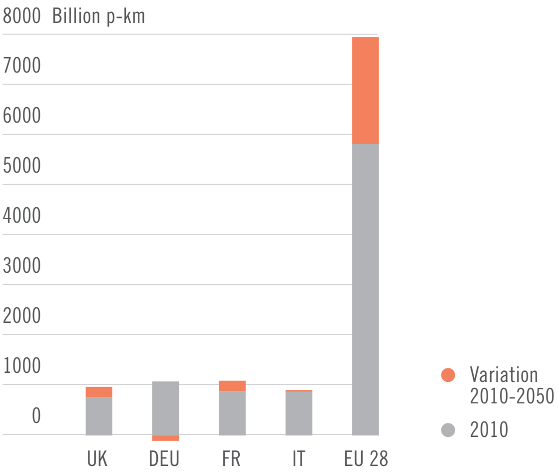
Sources: Own calculation based on Enerdata.

Note: missing data for Malta.

energy intensity accelerated, reaching -0.85%/yr. At the same time, all EU Member States experienced deeper reductions or a slowing down in the increase of the energy intensity compared to the previous period, as can be seen from the reductions across the full range of the Member States' energy intensity annual rates (black bar in the graph). Again, Greece experienced the highest reductions (-5.1%/yr between 2007 and 2012), while the biggest increase occured in Italy, where the energy intensity, after a period of decline between 2000 and 2007, started to increase again (+2.14%/yr).

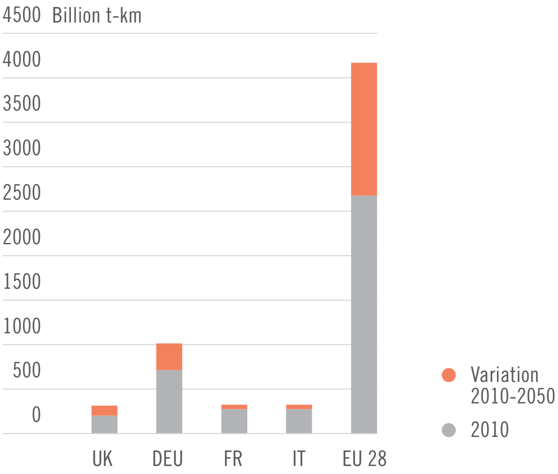
Despite this widespread acceleration in the energy intensity improvements in the period 2007-2012, the energy intensity must decline even more sharply already before 2020, according to the considered transformation benchmarks. In the decades 2010-2020 and 2020-2030, the EU28 energy intensity must fall by -1.63%/yr and -1.86%/yr respectively in order to be consistent with the long-term EU decarbonisation pathway. The transformation benchmarks for the 4 countries represented in the analysis (UK, DE, FR, IT) are even more ambitious, requiring a median annual reduction in the energy intensity of -2.40%/yr and -2.44%/yr for the decades 2010-2020 and 2020-2030 respectively. It can be noted that in both decades the biggest reduction occurs in France where the increase in passenger mobility, up to 2030, is accompanied by a continuous reduction in the energy use along the entire period 2010-2050. Between 2030 and 2040, the energy intensity decline keeps accelerating, with a reduction for the EU28 accounting for -2.19%/yr—a similar value is seen for the median of the 4 country scenarios (-2.29%/yr). In the last decade 2040-2050, the energy intensity continues to decline but at lower pace (-1.56% for

Figure 31. Passenger kilometers



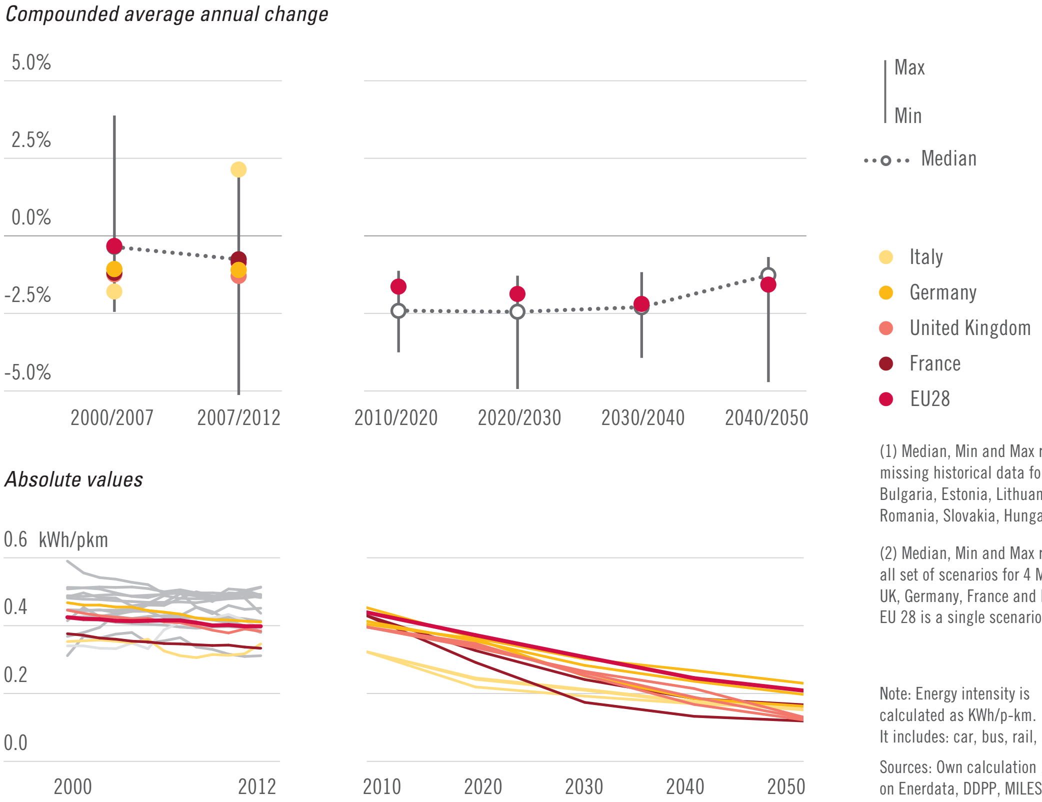
Note: The variation between 2010 and 2050 is based on an average of the country scenarios.

Figure 32. Tonne kilometers



Sources : Own calculation based on Enerdata, DDPP and MILES.

Figure 33. Energy Intensity - passenger transport, compounded average annual change



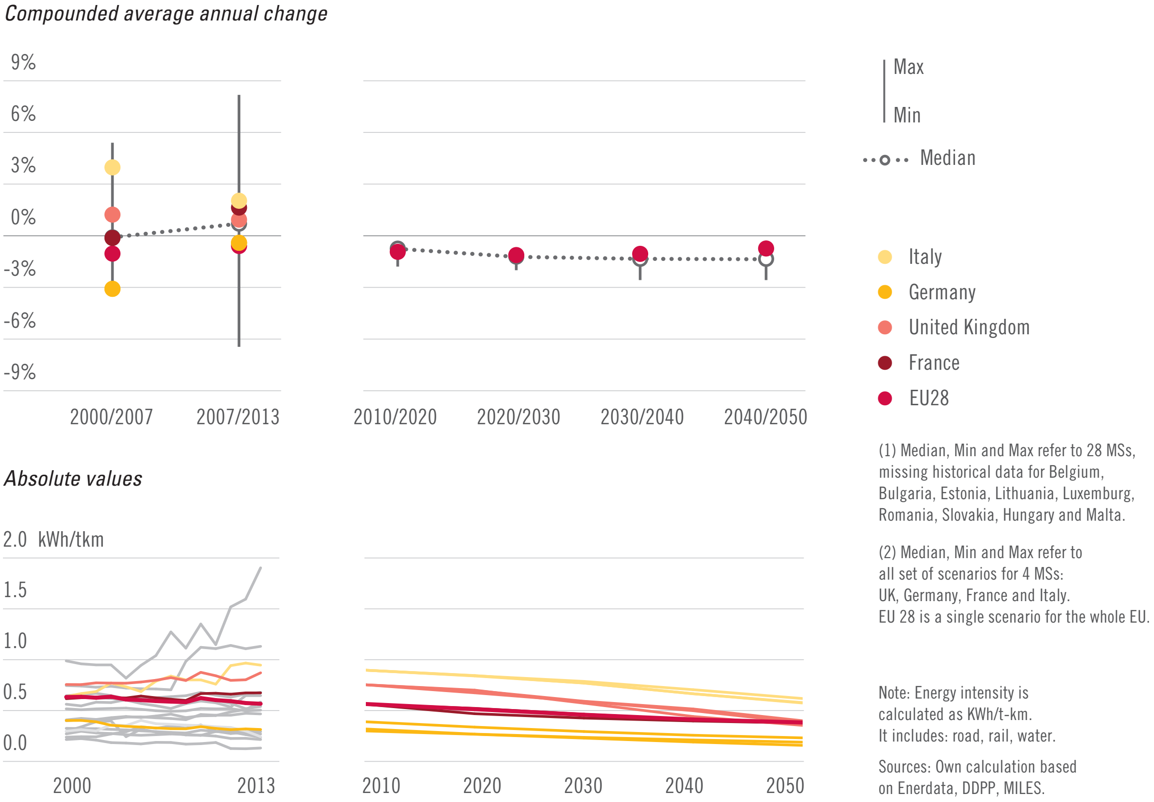
(1) Median, Min and Max refer to 28 MSs, missing historical data for Belgium, Bulgaria, Estonia, Lithuania, Luxemburg, Romania, Slovakia, Hungary and Malta.

(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. EU 28 is a single scenario for the whole EU.

Note: Energy intensity is calculated as KWh/p-km. It includes: car, bus, rail, air.

Sources: Own calculation based on Enerdata, DDPP, MILES.

Figure 34. Energy Intensity - freight transport, compounded average annual change



(1) Median, Min and Max refer to 28 MSs, missing historical data for Belgium, Bulgaria, Estonia, Lithuania, Luxemburg, Romania, Slovakia, Hungary and Malta.

(2) Median, Min and Max refer to all set of scenarios for 4 MSs: UK, Germany, France and Italy. EU 28 is a single scenario for the whole EU.

Note: Energy intensity is calculated as KWh/t-km. It includes: road, rail, water.

Sources: Own calculation based on Enerdata, DDPP, MILES.

the EU28 and -1.25% for the median of the country scenarios). This is because energy intensity improvements have already achieved large reductions (the overall decline in energy intensity in the EU28 accounts for more than 50% between 2010 and 2050)—while in the last two decades the decarbonisation of the fuel mix in the transport sector (mainly due to large-scale deployment of electric vehicles) experience its uptake (as shown in Figure 35). Nevertheless, note that the rate of decline in this last decade is still more ambitious than what was experienced historically until 2012.

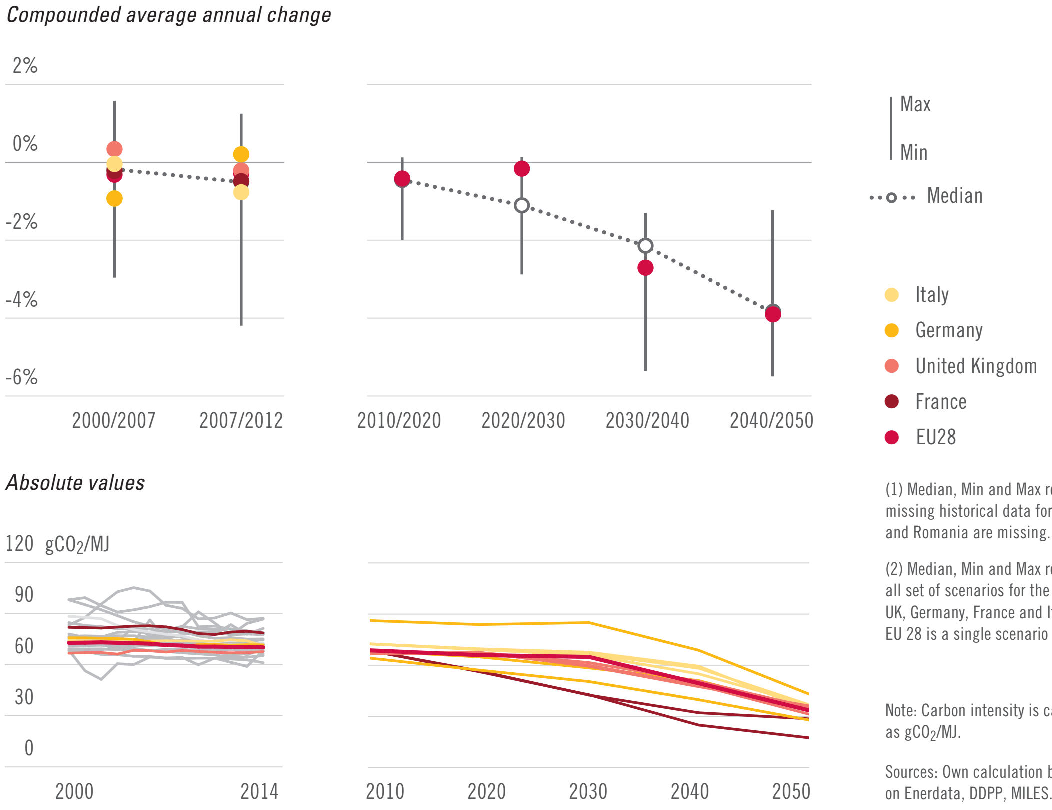
Compared to passenger transport, the energy intensity of freight transport experienced larger improvements in the first period 2000-2007, when the EU28 energy intensity declined by -1%/yr (Figure 34). Even in this case, the variability across Member States was quite high, as shown by the wide range of results, from a decrease in the energy intensity of Germany (by -3.1%/yr) to an increase by +5.4%/yr in Czech Republic. After 2007, the effect of the economic downturn appears clear: the rate of decline of energy intensity slowed in the EU28 (-0.6%/yr) while the median value of the EU Member States increased from -0.1%/yr to +0.7%/yr. In this period it can be noted also an increase in the spread of the full Member States' range, from -6.5%/yr in Poland to +8.2%/yr in Ireland.

Looking at the transition scenarios, it seems that freight transport has less potential of reducing energy intensity compared to passenger transport. The EU28 energy intensity reduction indeed accounts for -1.1%/yr in both decades 2020-2030 and 2030-2040, and it slows down to -0.7%/yr between 2040 and 2050.

As described above, the improvements in energy intensity of passenger transport decelerate in the decade 2040-2050. At the same time, no significant acceleration in energy intensity reduction of freight transport is envisaged in the future decades. A possible explanation of this result, together with the technical constraints peculiar to the transport sector, is the acceleration of fuel switching, which becomes an important driver of emission reduction in the transport sector, especially after 2020.

Figure 35 illustrates the effect of the transition to low-carbon technologies in total transport. It can be noticed that the annual change of carbon intensity remained constant for the EU28 as a whole in the periods 2000-2007 and 2007-2010, with an annual decline of -0.3%. Looking at the median of the Members States, there appears to be a slight acceleration in the carbon intensity reduction in the period 2007-2012 with respect to the previous period, from -0.2%/yr to -0.5%/yr. This result reflects also

Figure 35. Carbon Intensity – Total Transport, compounded average annual change



Compounded average annual change

Absolute values

(1) Median, Min and Max refer to 28 MSs, missing historical data for Estonia and Romania are missing.

(2) Median, Min and Max refer to all set of scenarios for the 4 MSs: UK, Germany, France and Italy. EU 28 is a single scenario for the whole EU.

Note: Carbon intensity is calculated as gCO_2/MJ.

Sources: Own calculation based on Enerdata, DDPP, MILES.

the wide range across countries, which increases in the second period (from -3%/yr in Luxemburg to +1.6%/yr in Austria between 2000 and 2007; and from -4.2%/yr to +1.3%/yr between 2007 and 2012 in Ireland and Slovakia respectively). This outcome reflects the gradual penetration of low-carbon technologies/energy sources, mainly occuring in passenger transport. During the period 2000-2012, the share of low-carbon energy in passenger transport increases by 5.2pp in the EU28. The decarbonisation of freight transport appears to be more difficult. Indeed, in the same period, the share of low-carbon energy rises only by 2.1pp across the EU28.

Looking at future benchmarks, it can be seen that in the EU28, the carbon intensity reduction in the period 2010-2020 is slightly higher than observed historically (-0.4%/yr), suggesting that an acceleration in the process of decarbonisation is required already before 2020. Interestingly, while the rate of decline in carbon intensity continues to accelerate decade after decade in all country scenarios, in the EU28 there is instead a deceleration during the decade 2020-2030. This is mainly due to a slowdown in the penetration of biofuels between 2020 and 2030, while other low-carbon fuels/technologies are not expected to be available at a large scale before 2030. After 2030, the decarbonisation process of the EU28 accelerates again, with carbon intensity declining by -2.7%/yr and -3.9%/yr in the periods 2030-2040 and 2040-2050 respectively, largely based on the extensive electrification of the passenger vehicle stock.

It should be noticed that while the EU28 scenario assumes very limited penetration of hydrogen-fuelled vehicles, all country scenarios (with the only exception of France) envisage the take up of hydrogen-fuelled vehicles from 2040—or even earlier in the case of the UK—as a way to decarbonise the transport sector.

In the EU28 scenario, the decarbonisation of the transport sector occurs mainly through an increasing penetration of biofuels (especially 2nd generation) and electricity in total final energy consumption, which in 2050 reach a share of 38% and 16% respectively. Nevertheless, it should be noted that the decarbonisation strategies for the transport sector are very different across the country scenarios analysed: a high penetration of hydrogen-fuelled vehicles (between 24% and 30% of total transport energy consumption in 2050) is assumed in the UK scenarios;[22] biofuels play a sig-

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22. The UK scenarios assume that constraints on biofuel imports (due to sustainability concerns and increase in global demand) as well as on domestic resources might limit the access to biofuel resources. Given these

nificant role in the Germany scenarios; an almost complete phase out of oil and its replacement with gas and electricity is the strategy adopted in the France scenarios ; while Italy's scenarios opt for a more balanced transport fuel mix. In all transition scenarios however, electricity plays a significant role, taking up a share of transport final energy consumption from 12% to 27% in 2050. Different is the case of biofuel, for which the penetration in the energy use varies widely across scenarios (from 5% to 42% in 2050), showing how biofuels are not always seen as an effective way to decarbonise the countries' transport sector.[23] With a current share of electricity equal to 1.7% of total energy use and a share of biofuel of less than 5% in the EU28, there is a long way to go to reach these benchmarks.

In July 2016, the Commission adopted the Low-Emission Mobility Strategy which, among other elements, pushes for the deployment of low-emission energy—including advanced biofuels, electricity, hydrogen and renewable synthetic fuels—with the aim of increasing the share of low-emission energy up to about 15-17% of transport energy demand in 2030.

Looking at the carbon intensity analysis above, overall it seems that only small improvements have been achieved up to 2012, while a deeper decarbonisation is required in the near future, especially from 2020 onwards. This requires a significant mobilization of financial resources to invest in the technologies and infrastructures necessary to the transition and a robust policy framework able to support the shift to low-emission mobility. Given the narrow time span left before 2020, those actions must be put in place at the earliest opportunity.

6.2. Policy discussion

The above analyses illustrates that the decarbonisation of transport is still at an early stage. It allows drawing three main insights:

- Overall, passengers and freight transportation has been increasing in the EU since 2000, mainly in fast-growing eastern European states but also to a certain extent in Western developed countries. In this respect, behavioural changes away from private transport and cars towards more environmentally-friendly transport modes (rails, bicycles, walking) should be encouraged to stay under a 2°C scenario according to the long-term scenarios considered in our study.
- Transport energy intensity has been declining but at an insufficient rate compared to long-term objectives. The rate of change will need to accelerate strongly in the coming decades. This transition will need to start sooner and go deeper in passenger transportation where more potential to reduce energy intensity exists and technological solutions to decarbonize are closer to market-competitiveness compared to freight transportation.
- Electric and plug-in hybrid vehicles currently still represent a low share of the vehicles market. However, the use of electricity for mobility is widely seen as a central technology development to reach a low-carbon transportation system. Even if the market share of electric vehicle and hydrogen/synthetic market shares is still highly uncertain according to the scenario analysis, the development of these technologies will be a game-changer for the industry and will require significant policy intervention combined with extensive deployment of infrastructure (e.g. battery recharging infrastructure to facilitate massive penetration of plug-in hybrid and electric vehicles).

Compared to other sectors, emission reduction envisaged in the transport sector is smaller (EC, 2011): 54 % to 67 % by 2050 compared to 1990, according to the 2050 Roadmap. However, these intended reductions will be particularly challenging given that they involve a set of complex interactions between areas of decision: urban and public transport planning and infrastructure (especially battery recharging infrastructure as a prerequisite for penetration of electric vehicles), technological progress and their accessibility to market, standards regulation, fuel prices and their taxation, trade rules for products and services, and consumer preferences.

For individual road transportation, the main European policy has been so far the setting of energy efficiency and CO_2 standards that became mandatory since 2009 for car manufacturers. The aim is to reach progressively an average CO_2 emission factor of less than 130 gCO_2/km in 2015 and 95 gCO_2/km from 2020 for new cars sold. The assessed progress towards the targets set has been positive and manufacturers reached the 130 gCO_2/km threshold in 2013, two years in advance. Nevertheless, recent studies revealed a significant and growing gap between test and real world emissions (ICCT, *From laboratory to road: A 2015 Update of official and «real-world» fuel consumption and CO_2 values for passengers car in Europe*, 2015). This divergence has

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constraints in the model, hydrogen becomes a feasible option.

[23] This depends largely on specific model assumptions with regard to biomass resources and economic potential as well as on model constrains on biofuel imports.

been shown to increase from 8% to 40% between 2001 and 2015. In this regard, the EU should first make sure that emissions control procedures are revised according to identified discrepancies and make sure that the measured standard are translated into real world emission reductions. Then, emission standards for vehicles should be continuously tightened in coherence to long-term decarbonisation objectives during the next revision for new post-2020 targets and could be extended to lorries (HDVs-heavy duty vehicles) in order to give a clear vision of what technologies are needed in the long term for manufacturers. Considering alternative fuels, European policies focused heavily in the past on the promotion of biofuels that started as a security of supply measure and then turned into a climate change mitigation motivated policy (ECN, 2006). A first EU directive was adopted in 2003 and contained indicative targets for 2005 and 2010 for biofuels and was followed by the adoption, as part of the 2020 Energy and Climate package in 2008, of a 10 % target for renewable energy in the transport sector energy consumption. Nevertheless, resource limitations and doubts on the environmental performance of first generation biofuels (related on the indirect land use effect of biofuels cropland)[24] induced a revision of Member States' policies to develop biofuels. Combined with a slowdown in demand for transportation fuel, it capped the consumption of biofuels in Europe at around 14 Mtoe since 2010 (see Figure 36) after a strong increase in the previous decade. In addition, a 7% cap on the contribution of crop-based biofuels to the transport renewable energy target for the EU has been approved last year, and sustainability criteria will be strengthened from 2017[25] in order to favor second generation biofuels. The European Commission recognised significant potentials for second generation biofuels, but current technical and resource limitations complicates the setting of clear targets and thus policy signals. Electric vehicles have become with time a more credible solution for short-distance travels in light-duty vehicles. Nevertheless, there is still few alternatives to liquid fuels in marine, aviation and heavy-duty transport, where biofuels could contribute their share to switch to low-carbon transportation.

Electro-mobility is now widely seen as the solution to decarbonize short to medium-distance personal road transportation and several European countries have already set ambitious targets for the development of electric and plug-in electric hybrid vehicles and the related battery recharging infrastructure. For example, France has set in last year's Energy Transition Law a target of 7 million charging points for electric vehicles in France in 2030, while Germany has an ambitious target of having 1 million electric cars in 2020 that will probably be missed at current path. The challenge here lies in setting robust policies to incentivize consumers to opt for electric vehicles instead of conventional vehicles, and developing the needed infrastructure to make electric vehicles a viable option for consumers.

Public policies have generally concentrated in setting up financial incentives to buy an electric car. In France for example, individuals receive a subsidy of 6,700 € to 10,000 € when they buy a new electric-car. It can be complemented by policies aiming to raise taxes on polluting cars or directly on fossil fuels that make the use of the electric car more economical for the consumer, by implementing or raising a CO_2 tax on fuels for example. For public authorities, raising taxes on fuels have the important advantage of increasing revenues that can be used to finance other incentive policies and increase investments in other public sectors. However, it also has strong redistributive effects and tends to disproportionally impact poorer population first because of their higher share of transport expenses in their overall household expenses and their limited capacity to switch to a more efficient car technology due to a limited access to finance. Redistributive measures to accompany the transition have to be considered in the policy mix to avoid increasing fuel poverty, especially in rural or suburban areas where inhabitants face a limited offer of public transportation for their daily commute.

Another important issue regarding the development of electric vehicles is the development of charging station infrastructure and its coordination with electric grid development and planning. The development of electro-mobility can be disruptive for the electric grid. Although energy transport consumption volumes appear to be manageable, the challenge lies in the moment when electric cars are being charged: it can be feared that the natural behavior of consumers will end up in important consumption levels happening at the same moment, i.e. returning home after work (US Department of Energy, 2010). Smart charging and grids can play an important role in smoothing the charging of electric vehicles, incentivizing charging at times when electricity is abundant and thus can be offered at lower prices, diminishing

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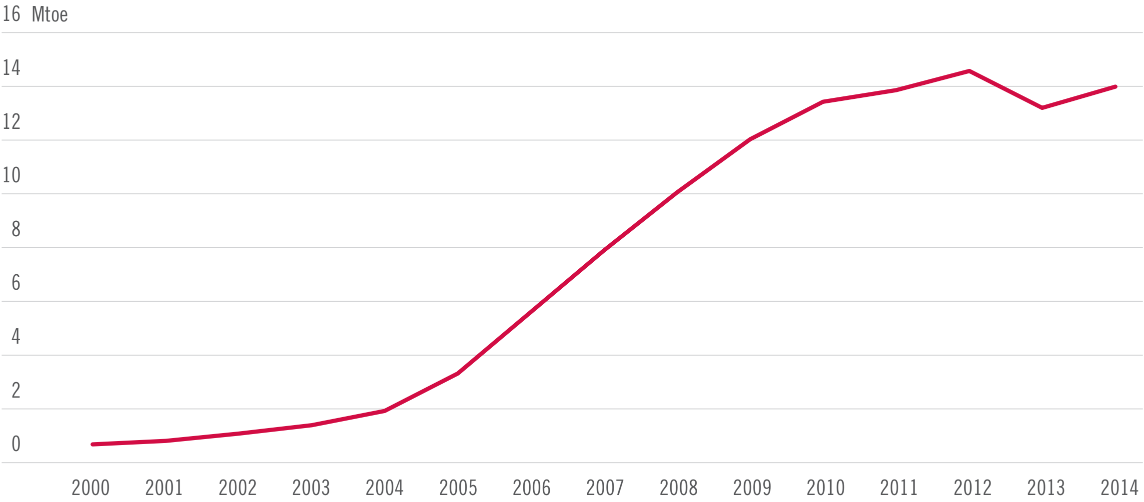
[24] Indirect land-use effects refer to the increase in carbon emissions due to overall land-use changes induced by the increased demand for land to grow biofuel crops.

[25] Biofuels must achieve GHG emissions savings of at least 35 % in comparison to fossil fuels and taking into account life-cycle emissions. This criterion will rise to 50% in 2017 and 60 % in 2018 for new production plants.

Figure 36. EU28 biofuels consumption in road transport



Source: Enerdata.

the risk of congestion of the distribution grid, and reducing the need of investment in grid infrastructures and production capacities. At the consumer level, the proceedings and costs of having a charging point at home or at the office can be a significant enabler or disincentive to switch to an electric car. A standardized approach following reasonable pricing of the installation and operation of the charging point from the users viewpoint will help foster consumers' confidence. The EU should also play an important role in setting common rules on charging standards to guarantee the ability to travel throughout Europe, and manage the impact of charging on grid management.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

General conclusions

The EU has adopted an ambitious target for reducing its emissions by at least 40% by 2030 and 80-95% by 2050, compared to 1990 levels. The EU has also established an annual process—the State of the Energy Union—whose role, in part, is to monitor and evaluate progress towards these goals. In this context, there is a need for further thought about what represents adequate progress and what methodologies to apply to evaluate it. This paper is a contribution to this discussion.

A key conclusion of this paper is that, to assess current trends and their adequacy with these objectives, it is necessary to go beyond aggregate GHG emissions or energy use figures, and to analyse the underlying drivers of emissions changes, sector by sector, and Member State by Member State. Based on this kind of analysis, we conclude that the EU has made some significant progress in the structural decarbonisation of its energy system.

However, despite this progress, the EU is currently "off-track" to achieve its objectives by 2030 and 2050. First, the rate of change is insufficient across a large number of the indicators assessed. Second and relatedly, too much of the change in aggregate emissions has been driven by cyclical effects rather than structural decarbonisation, notably the impact of the financial crisis and subsequent slow recovery. Third, long-term decarbonisation options, for example to decarbonise industrial processes and materials, are not being adequately prepared.

Perhaps of even greater concern, however, is the fact that there appears to be a gap between, on the one hand, policy proposals being discussed in the development of the EU's 2030 Climate and Energy Framework and, on the other hand, the rate of progress that 2050 pathways to the EU's goals say is needed during the coming decade. While some policies will have an impact, our study suggests that the ambition of EU and Member State policies is either a continuation of business as usual in terms of rates of progress, or is being dialled down in some cases.

Policy recommendations

The above analysis suggests the following policy recommendations.

First, the EU and Member State policy should significantly revise their approach to decarbonisation by refocusing on the key drivers of emissions in each sector. By themselves, cross-sectoral emissions targets do not give sufficient impetus to the structural decarbonisation of the EU energy system. More attention to targeted policies and governance tools that address each of the key drivers of emissions in each of the major emitting sectors is needed, including those sectors covered by the EU ETS.

The EU's new Energy Union Governance Mechanism should be designed based on this principle. For instance, Member States' new National Climate and Energy Plans need to give ample focus to strategies for sectoral transformation towards 2050 goals, not just marginal actions to meet 2030 targets. To do so, Member States will need to have developed their own processes for identifying possible pathways to their 2050 goals, taking account of their national circumstances. The EU should promote the development of these tools, where they do not yet exist. Moreover, the EU is developing a set of "Key Indicators" to track national and EU progress towards decarbonisation. These indicators should reflect key structural changes that are needed in major emitting sectors, not just progress towards intermediate 2030 targets.

Second, current proposals to implement the 2030 package should be adopted in the strongest possible form to put the EU back on track. Proposals to reform the EU ETS and adopt non-ETS targets go some way to strengthening the decarbonisation of the EU energy system. However, by themselves they are not sufficient to put the EU on track to achieve its 2030 or 2050 commitments. This is especially true of the EU's energy efficiency objectives. If adopted in their current form—i.e. 27 to 30% energy savings by 2030—they would represent a slowdown in the pace of energy productivity improvements for the EU (EU ASE, 2016). While the 27-30% number sound "big", they are distorted by the fact that they are calculated relative to an energy use baseline dating back to before the economic crisis of 2008/09 (EEA, 2015).

The EU ETS also needs be strengthened to avoid the risk of low and ineffective carbon prices persisting well in the late 2020s. Barring this, the EU should explore ways to allow individual Member States to go further with domestic policies in ETS sectors, without undermining the EU carbon price.

Third, the EU, in coordination with the Member States, should develop a suite of sectoral policies to complement the overarching emissions caps of the EU ETS and non-ETS sectors. In particular, in 2017 the EU should adopt very ambitious regulations to drive the decarbonisation of transport, and in particular the roll-out of alternative fuel vehicles, in which it is currently lagging behind what is needed to be on track towards its 2050 goals. Likewise, targets, financing and monitoring of energy efficiency retrofitting and fuel switching in buildings should all be strengthened.

Fourth, the EU needs a shake-up of current policies for decarbonising energy-intensive and trade-exposed industries. A renewed focus on industrial decarbonisation is necessary, given the inadequacy of the EU ETS signal and the fact that progress towards key decarbonisation technologies in these industries has stalled. The specific combination of technological challenges, financial risks, low profitability in the current context, and competitiveness concerns calls for a suite of policies that must go beyond carbon pricing and R&D funding. A new policy framework is needed.

This framework will need involve a suite of policies and be linked to concrete sectoral decarbonisation strategies. Key elements should include a renewed focus on technology "push" measures, for instance, by providing stable long-term funding for demonstration and early-phase commercialisation of promising "breakthrough" processes. It must also include a renewed focus on market "pull" measures to create a market for low-carbon materials and processes in industry, such as product labelling, public procurement, and revisions of building and product standards where appropriate, etc. In the wake of the Paris Agreement, international cooperation on policies and approaches for decarbonising industry in a world of unequal carbon prices should also be prioritised.

Finally, the EU should consider policies to phase down coal in electricity, given the lack of an effective signal for coal retirement from the EU ETS. By 2030, unabated coal needs to drop by more than 50% to make way for low-carbon electricity sources. A failure to develop a smart retirement plan for unabated coal will continue to place pressure on EU electricity markets. This risks, in turn, undermining progress towards efficient and better integrated power markets that are needed for the transition to high shares of low-carbon generation to occur. Even assuming ambitious reforms to the EU ETS, the EU will probably need to develop ways of facilitating national coal phase out strategies in individual Member States.

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APPENDIX: DESCRIPTION OF MODELS AND SCENARIOS

Country: UK

Team: UCL; Reference: Pye, S. *et al.* (2015)

Model: UK TIMES

UK TIMES is an energy system model that explicitly represents the technology and fuel choices across different sectors under decarbonisation objectives. These choices are made based on what is economically optimal, subject to a range of constraints that ensure greater realism. Such constraints include balancing of supply-demand, limits on technology build rates, and representation of available resources, e.g. wind, bioenergy etc. Energy service demand drivers are exogenous to the model, while the supply choices (including electricity generation) are endogenous.

Scenarios

Scenario D-EXP (decarbonise & expand) puts a strong focus on near-term power sector decarbonisation based on a mix of low-carbon technologies including wind and nuclear, enabled by effective policy incentives. A stronger role for CCS emerges towards the end of the 2020s, with increasing build out across all of these generation technologies post-2030. This system expansion allows for increasing levels of end-use sector electrification, which becomes the core pillar for decarbonisation of end-use demand.

Scenario M-VEC (multi-vector transition) foresees a system that is less reliant on electrification for decarbonisation, due to more limited deployment of key low-carbon generation technologies, namely nuclear and CCS. Wind generation capacity is greater than in D-EXP, resulting in more significant challenges for system operation. While electrification is lower, a generation system emerges that is actually larger in capacity terms. Other energy vectors, including hydrogen and bioenergy, play a much stronger role in decarbonisation of the energy supply in the longer term (post-2030).

Scenario R-DEM (reduced demand) illustrates how supply-side decarbonisation can be moderated by action to reduce demand. Stronger efforts are focused on building retrofit, motivated by government pushing to address affordability concerns and fuel poverty. Additional policy efforts also focus on reducing demand for passenger transport. Efforts to develop and deploy low-carbon technologies occur in parallel, although the ambition is scaled back due to the success of demand-side measures.

Country: Germany

Team: Wuppertal; Reference: Hillebrandt, K *et al.* (2015)

Scenarios

For the detailed analysis of potential decarbonisation pathways for Germany, the authors of the German DDP chose the following three illustrative scenarios from the literature:

Scenario Target (Government Target Scenario) from the study "Development of Energy Markets – Energy Reference Forecast" (Schlesinger *et al.,* 2014). This scenario foresees final energy demand reductions through high energy efficiency improvements. This is accompanied by increased use of domestic renewable energy sources.

Scenario 100-II (Renewable Electrification Scenario) from the study "GROKO II – German Energy Supply Scenarios Based on the EEG Draft Bill" (Nitsch, 2014). This scenario focuses on an expanded use of renewable energy sources/carriers and high electrification. It achieves GHG emission reductions by 2050 that are somewhat higher than the government's minimum target but lower than those of the most ambitious scenarios available.

Scenario KS 90 (90% GHG Reduction Scenario) from the study "Climate Protection Scenario 2050" (Repenning *et al.,* 2014). This scenario investigates the measures and strategies that would be needed to achieve greenhouse gas emission reductions of 90% by 2050. It focuses on final energy demand reductions through energy efficiency, substitution of fossil fuels through electricity and net imports of bioenergy. This is the only scenario for Germany which foresees the use of CCS in industry.

CCS for use in the power sector is also not envisioned by any of the energy scenarios for Germany released within the past few years as it has become clear that there is very little acceptance for this technology within German society, especially given the low-carbon alternatives available in electricity generation.

Country: France

Team: EDDEN, CIRED; Reference: Mathy, S., Criqui, P., Hourcade, J.C. (2015)

Model: Imaclim-R France

Imaclim-R France is a computable general equilibrium model that quantitatively represents the interrelated technical and economic impacts of different energy scenarios. The model allows for the consistent analysis of how changes in technological systems and economic constraints impact various measures' effectiveness. It uses physical variables (number of motor vehicles, collective dwellings or individual houses, annual energy efficiency of technologies, etc.) allowing for the integration of sector-specific data related to how economic incentives impact final demand and technology systems.

Scenarios

Scenario EFF (Efficiency) assumes a 2% annual reduction in per-capita final energy consumption in France until 2050. This result is achieved mainly through strong effort towards thermal retrofit of buildings and behavioural changes in transport. The development of renewable energy sources, in particular solar and wind, is also relevant and mirrors the diminishing share of nuclear power in the electricity mix. In the transport sector the uptake of electric, hybrid-electric or natural-gas vehicles is also envisaged.

Scenario DIV (Diversity) implies a less drastic reduction in demand and focuses more on compensation by a larger decarbonized energy supply, primarily from three very different sources: third-generation nuclear power plants, biomass energy, and urban heat networks.

Country: Italy

Team: ENEA, FEEM; Reference: Virdis, M.R. *et al.* (2015).

Models: TIMES-Italy

TIMES-Italy is a partial equilibrium model of the Italian energy system. It is a bottom-up model of intertemporal optimization, which minimizes total cost for the energy system to meeting a given demand, subject to environmental and technological or policy constraints.

Scenarios

Scenario CCS (CCS + Renewables) envisions powering the energy system with a large share of electricity from renewables and with fossil fuel technologies, coupled with CCS. These allow for the deep decarbonisation of the electricity system, and lead to a high level of electrification of heating and transport services.

Scenario EFF (Energy Efficiency) assumes fewer options are available to decarbonize the electricity system, resulting in relatively higher costs and a reduction of the electricity consumed by end-use sectors. This scenario focuses instead on an increased reliance on advanced energy-efficiency technologies, and greater use of renewable energy for heat and transportation.

Scenario DMD_ RED (Demand Reduction scenario) models the response of the energy system to a limited availability/commercialization of CCS (especially in the industrial sector) and a high cost of decarbonisation. This scenario foresees demand reductions through efficiency improvements in end-uses sectors, transport modal shift and reduction of industrial output. Fuel switch in final sectors is also envisaged.

Country: Poland

Team: WISE, ISD; Reference: Bukowski, M. (ed.) (2013)

Models: MEEP

MEEP (Microfoundations-based Energy and Emissions Projection model) is a national-scale model of energy use and GHG emissions in Poland. It provides sectoral-level projections based on both macroeconomic trends and bottom-up technological shifts (e.g. introduction of RES, electrification of passenger vehicles, increasing share of passive buildings).

Scenarios

Scenario European Coal envisions a process of diversification of energy sources until 2030, while renewable sources gain relevance and are complemented by gas-fired power plants. However, the main investment stream goes to low-emission coal fired power plants and in 2030-50 conventional coal and gas-fired capacity is replaced by power plants with CCS.

Scenario French Model focuses on the extensive deployment of nuclear power, which in 2050 results in half of the total electricity produced. This replaces most of the coal-fired capacity, with the rest of the mix composed by a combination of natural gas and renewables.

Scenario Distributed Autarky envisages the expansion of renewables and shale gas to ensure energy self-sufficiency. The coal-fired capacity is replaces by gas-fired plants.

Scenario Distributed Integration foresees the development of renewables sources. However, in this scenario the domestic gas-based energy generation does not develop and Poland integrates the Europe-wide system based on renewables and distributed generation. Given its poor RES sources, Poland imports about one third of its energy from abroad.

Scenario Full Diversification envisions a diversified energy mix (fossil fuels with CCS, nuclear, renewables and distributed generation) where no source gains a dominant position.

Region: EU28

Team: ICCS; Reference: Fragkos *et al.*, 2016; Paroussos *et al.*, 2016; E3M Lab, 2013.

Models: PRIMES

The PRIMES energy model simulates the European energy system and markets on a country-by-country basis and provides detailed projections of energy demand by sector, energy supply (including power sector, gas supply, hydrocarbon, etc.), market prices of energy commodities, CO_2 emissions, investment in all energy sectors, energy technology penetration, and energy system costs over the period from 2015 to 2050 in 5-year intervals. The PRIMES model covers all EU28 Member States and all non-EU European countries.

Scenarios

Scenario EU INDC assumes full implementation of the Climate and Energy package for 2030. The scenario assumes the achievement of the 40% GHG emission reduction target for 2030 as set out in the EU INDC to COP21 and the long-term objective of 80-95% reduction in GHG emissions by 2050. The scenario allows for the development of all major low-carbon technologies based on cost-efficiency while taking into account specific policy measures and specificities at the national level: energy efficiency and renewable energy sources (RES) in all sectors, carbon capture and storage (CCS) in power generation and in industrial applications, and electrification of the road transport sector.

Carbon prices are the main driving mechanism enforcing the GHGs reduction target. In line with economic efficiency considerations and cost-optimal allocation of abatement efforts across sectors and EU Member States, carbon prices are the same in all sectors from 2025 onwards. The scenario further assumes full anticipation by all energy system actors of the implementation of the EU INDC and the long-term transition to a decarbonised economy, i.e. enabling conditions that are needed in order to set in place the cost-efficient transition to a competitive low-carbon economy by 2050. The enabling conditions include factors such as technology development (e.g. of electric vehicles, CCS or photovoltaics) and the behaviour of energy system actors (e.g. infrastructure providers, technology manufacturers, energy consumers, lawmakers) compatible with the strong emission reduction target, inducing early adoption of low and zero carbon technologies by consumers and timely development of clean energy infrastructure (e.g. smart grids, battery recharging infrastructure). Market failures and non-market barriers to efficient energy consumption and accelerated RES deployment are assumed to be gradually removed in the EU INDC scenario.

IDDRI

State of the Low-Carbon Energy Union: Assessing the EU's progress towards its 2030 and 2050 climate objectives

Lead authors: Thomas Spencer, Roberta Pierfederici, Oliver Sartor, Nicolas Berghmans (IDDRI)
Contributing authors: Sascha Samadi, Manfred Fischedick, Katharina Knoop (Wuppertal Institute), Steve Pye (UCL), Patrick Criqui, Sandrine Mathy (Grenoble Applied Economics Lab), Pantelis Capros, Panagiotis Fragkos (E3MLab/ICCS), Maciej Bukowski, Aleksander Sniegocki (WiseEuropa), Maria Rosa Virdis, Maria Gaeta (ENEA), Karine Pollier and Cyril Cassisa (Enerdata)

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