

Cost-effective decarbonisation in the EU – An overview of policy suitability

1. Introduction

The EU has a stated commitment to reduce its GHG (and consequently, CO₂) emissions by 80-95% from 1990 levels by 2050. Various modelling studies have sought to determine cost-effective pathways for achieving this aim. This paper first identifies the contemporary CO₂ emission and energy consumption profiles, and recent trends, for key sectors of the energy system (power generation, heavy industry, residential buildings and road (passenger car) transport¹), and the profiles they must exhibit by 2030 and 2050 to achieve a cost-effective low-carbon transition, based on a comparison of results of four key modelling studies. For each sector key elements of the policy landscape at EU level are presented, along with a discussion of their likely contribution to the contemporary profile. For each sector, this concludes with an overview discussion of the apparent suitability of the current policy landscape for driving the changes needed to achieve required profile outlined for 2030 and 2050. This paper therefore provides, first, a comparison of recent sector-level CO₂ emission and energy consumption trends with what is required in the future in order to achieve a cost-effective decarbonisation of key sectors of the EU energy system, and second, a recent, cross-sectoral overview of the suitability of the existing suite of key EU policy instruments (including recently announced changes) for achieving these requirements.

Section 2 first presents the four modelling scenarios from which 2030 and 2050 requirements are distilled. Section 3 then describes the approach taken by the analysis. Sections 4-7 follows this to present the analysis for each sector identified above, in turn. Section 8 concludes.

2. Decarbonisation studies and scenarios

¹ The agriculture, upstream and waste sectors are excluded, due to their relatively minor contribution to CO₂ emissions in the EU (~2%).

This section presents four studies that seek to project cost-effective pathways for the decarbonisation of the EU's energy system by 2050. It is from these studies the key elements of the sector profiles required by 2030 and 2050 are derived.

The first two studies were completed as part of the CECILIA2050 project, to which this Special Issue is dedicated. The first employs the European TIMES Model (ETM-UCL), a dynamic partial-equilibrium energy system model with an inter-temporal objective function to minimise total discounted system costs. The second study employs the economic-environmental model GINFORS, an environmentally extended global multi-regional input-output model. The decarbonisation scenarios applied to these models, which were aligned in order to produce complementary insights (including GDP, population and household number projections), sought to achieve an 80% reduction in CO₂ emissions in the EU by 2050 from 1990 levels. The EU's '20-20-20' targets for CO₂ emissions, renewable energy and energy efficiency are achieved in these studies by design. Further detail on these models, scenario design and their results, may be found in Solano *et al* (*this issue*) and Meyer *et al* (2014). The third study examined is the Energy Roadmap 2050 (ER2050), produced in 2012 at the request of the European Council to 'explore the challenges posed by delivering the EU's decarbonisation objective [of an 80% reduction in CO₂ emissions by 2050] while at the same time ensuring security of energy supply and competitiveness' (European Commission, 2012, p.3). In this paper we examine the results of the 'Diversified Supply Technologies' scenario, under which a cost-minimising, technology-neutral approach determines the evolution of a decarbonised energy system. The 20-20-20 targets are also achieved in this study, by design. Results for the ER2050 were produced by the partial-equilibrium energy system model PRIMES. More information on the model, scenarios and results of this study may be found in European Commission (2011b). The fourth and final study considered is the 2012 edition of the International Energy Agency's (IEA) '*Energy Technology Perspectives*'. In this paper we consider results for the EU in the '2 Degrees' scenario (2DS), under which the global energy system reduces CO₂ emissions by 2050 consistent with an 80% chance of limiting average global temperature increase to 2°C (approximately a

50% reduction in global CO₂ emissions from 2009 levels). This analysis also employs a TIMES modelling platform – the ETP-TIMES. For more information, see IEA (2012).

Each of these studies seek to project cost-effective decarbonisation pathways, but not necessarily least-cost. Each imposes a range of constraints to take into account issues such as lead times, political preferences and public acceptance, which may produce additional cost against what the models employed may otherwise produce in order to achieve the level of decarbonisation required. However, this improves the practical feasibility of the pathways produced.

3. Approach to sectoral analysis

Sections 4-7 first outline contemporary sector profiles, and then examine how such profiles should evolve to 2030 and 2050 in order to achieve a cost-effective low-carbon transition, based on a comparison of results of the four key modelling studies identified in Section 2. Such characteristics are commonly presented as minimum or maximum threshold values (as appropriate), to reflect the requirement that CO₂ emissions are to be reduced by *at least* 80% by 2050 from 1990 levels, and that underachievement in one sector would require others to compensate. Projections for CO₂ emissions and energy consumption are provided against 1990 and 2014 (the most recent year for which comprehensive data is available), and are rounded to the nearest 5%. Energy distribution and related infrastructure, such as electricity transmission and distribution, smart meters and electric vehicle charging points, are not considered. Although alluded to (e.g. ‘acceleration of efforts to develop the transmission system is needed’ (IEA, 2012, p.568)), such infrastructure are not considered or presented in detail in the four studies examined.

For each sector, key elements of the policy landscape at EU level are then presented, along with a discussion of their likely contribution to contemporary profiles. This concludes with a discussion of the apparent suitability of the current policy landscape for driving the evolution of the sector towards the profile outlined for 2030 and 2050. The analysis is necessarily not exhaustive in each sector, but

addresses the principal instruments and elements at the EU level. Measures introduced purely at the national level, not as a direct result of specific EU-level requirements, are excluded from the analysis, as are those that seek to encourage innovation as their primary motive.

4. Power sector

4.1 Contemporary sector profile

Power generation accounted for the largest proportion of CO₂ emissions in the EU28 in 2014, at 31%.² In the same year, conventional thermal (coal and gas) accounted for 48% of total generation, nuclear for 27%, hydropower for 13%, and other renewables (principally wind) accounting for the remaining 12%. Between 2004 and 2014, CO₂ emissions decreased at an average annual rate of 2.5%, with total electricity generation remaining largely stable. As such, CO₂ intensity of generation reduced by an annual average of 10 gCO₂/kWh (to 351 gCO₂/kWh in 2014).³

4.2 Required sector profile – 2030 and 2050

Each study examined projects a reduction in CO₂ emissions from the power sector of at least 60% by 2030 and 90% by 2050 below 1990 (20% and 90% below 2014) levels, respectively, despite a significant increase in power generation (at an average of around 35% by 2050, from present levels) in order to satisfy increasing electrification of end-use sectors (discussed in subsequent sections). As such, the CO₂ intensity of power generation should reduce to a maximum of around 150 gCO₂/kWh by 2030, and 10 gCO₂/kWh by 2050.

Although projections of the specific composition of the generation profile vary relatively substantially between the four studies (e.g. projected deployment of

² Data from European Environment Agency's GHG Data Viewer. Excluding land use, land use change and forestry.

³ EUROSTAT Statistics.

renewable generation varies from around 55% (IEA) to 90% (GINFORS) by 2050), there are two points of clear consensus. The first is that unabated fossil fuel generation must reduce substantially, to a maximum of around 40% of total generation by 2030, and 10% by 2050 (with what remains sourced from natural gas, with generation from unabated coal entirely removed by 2050). The second is that generation from renewables⁴ should increase rapidly to 2030, and be the largest single power source by 2050 (accounting for at least 40% and 60% of generation by 2030 and 2050). Nuclear generation maintains or decreases in proportional contribution in all cases from current levels. Fossil fuel with carbon capture and storage (CCS) is introduced in two of the four scenarios examined by 2030, and in three by 2050⁵ - achieving around 25% of generation in the ETM-UCL study.

4.3 Policy landscape – key elements

The EU Emission Trading System (EU ETS), cornerstone of the EU climate policy landscape, has capped CO₂ emissions from the power and heavy industry sectors since 2005.⁶ However, empirical evidence suggests that whilst the EU ETS induced short-term ‘fuel switching’ from coal to gas generation (particularly in the UK and Germany, in 2005 and 2006) utilising existing capacity, it contributed little to the development of new generation capacity and CO₂ abatement in this sector. Instead, CO₂ abatement was likely driven by the 2008 financial crisis, which Bel and Joseph (2015) calculate is responsible for the vast majority of abatement exhibited by EU ETS sectors since its inception (with the instrument itself responsible for just 12%), resulting in a persistently low (but relatively volatile) carbon price. The practice of free permit allocation between 2005 and 2011 was also a contributor (Agnolucci & Drummond, 2014). Although full permit auctioning was applied to the power sector from 2013⁷, the prevailing carbon price has remained well below €10 /tCO₂ since 2011; a result of the build up of surplus permits in the system (around 2.1 billion) in

⁴ Including hydroelectricity and Biomass with CCS (present in the ETM-UCL results).

⁵ Not included in the GINFORS study (in power or industry) as an exogenous constraint.

⁶ Along with commercial (domestic) aviation, N₂O from the production of nitric, adipic, glyoxal and glyoxalic acids, and PFCs from aluminum production. Non-Member States Iceland, Lichtenstein and Norway are also covered.

⁷ Except some derogations in certain Member States.

the wake of the financial crisis (European Commission, 2016). To address the surplus, a Market Stability Reserve (MSR) will enter into force in January 2019. The MSR will function by triggering adjustments to annual auction volumes. When 833 million or more permits are in circulation, a volume of permits equal to 12% of the circulation volume may be deduced from auction volumes and placed in the MSR. Similarly, 100 million permits will be released (if available) and made available for auction when permit circulation is fewer than 400 million. In parallel, the Linear Reduction Factor (LRF), the annual rate at which the EU ETS cap reduces, will increase from 1.74% to 2.2% from 2021.⁸ This means the cap will reduce to 43% below 2005 levels by 2030, and achieve the EU ETS' contribution to the EU-wide target of 40% reduction in GHG emissions by 2030.

The second key instrument is the Renewable Energy Directive (RED) (2009/28/EC), which places legally binding targets on Member States for gross final energy consumption sourced from renewables by 2020 (operationalising the 20% EU-wide target for 2020). Whilst there is no explicit sub-target for renewable electricity, the rapid increase in its deployment in recent years (from 14% of generation in 2004 to over 25% in 2014), accounts for a significant proportion of overall renewable energy deployment (European Commission, 2015). This deployment was driven by dedicated support mechanisms in Member States, the most common of which are feed-in tariffs (FiTs). Although specific designs vary substantially, producing varied levels of deployment success, FiTs are commonly cited by the literature as being highly effective in encouraging deployment, as they provide long-term financial certainty upon which investment decisions may be taken (Agnolucci & Drummond, 2014; Butler & Neuhoff, 2009). However, Guidelines for State Aid for Environmental Protection and Energy (2014-2020) require that support for all 'large' installations (with an installed capacity of 1MW and over, or 6MW for wind) are subject to a competitive bidding process from January 2017, to ensure on-going support is cost effective. Smaller installations are exempt from this requirement (European Commission, 2014a).

⁸ Against the average total quantity of allowances issued annually in Phase 2 (2008-2012).

4.4 Policy suitability

To reach 2030 requirements, CO₂ emissions must reduce by an annual average of around 1.4% from 2014 levels. Although this is below the rate experienced between 2004 and 2014, the reduction in the rate of CO₂ intensity of generation must accelerate from an annual average of 10 gCO₂/kWh to around 12.5 gCO₂/kWh. Between 2030 and 2050, CO₂ emissions must reduce at an average annual rate of 8.5%, with CO₂ intensity reducing by an average of 7 gCO₂/kWh annually.

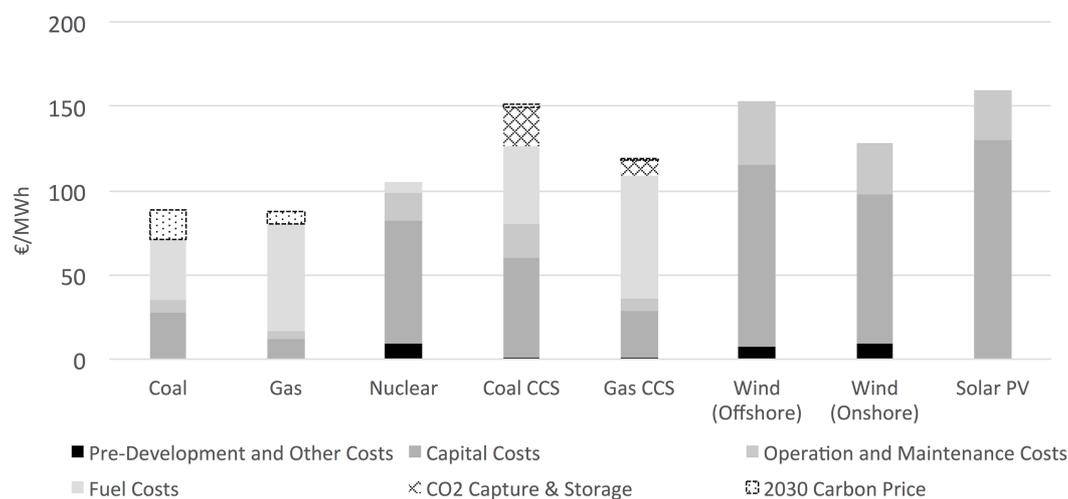
The LRF adjustment from 2021 under the EU ETS initially appears capable of satisfying the 2030 emission requirement for the power and industry sectors, with a cap set at 20% below the combined minimum CO₂ abatement requirements for these sectors as presented in this paper (see Section 5 for industry sector requirements). Whilst the literature broadly concludes that the MSR will have a positive impact on the surplus and permit prices (e.g. Neuhoff *et al*, 2015), the European Commission (2014b) projects that under such thresholds the surplus would only reduce below 800 million in the late 2020s⁹, meaning that in practice emissions from these sectors may be higher than the nominal cap for these years (with permits 'banked' from previous years used for compliance). Indeed, the EEA (2015a) project emissions under the EU ETS reducing to just 31% below 2005 levels, rather than 43%. However, this remains approximately in line with the minimum requirements for these sectors presented in this paper.

Regardless of the extent to which abatement is achieved in practice by 2030, the division of effort between the power and industry sectors, and whether such abatement would be achieved through short-term measures (such as fuel switching), or through structural changes (such as the development of renewables), is not clear *ex-ante*. Point Carbon (2015) project that such structural reform of the EU ETS will

⁹ This assessment was based on Option 2d in European Commission (2014b), which although slightly different in form to the MSR design adopted (e.g. the upper threshold modeled was 1 billion permits, rather than 833 million), the same conclusion may be reasonably applied.

produce a carbon price of around €30 by 2030. Figure 1 illustrates recent projections of the levelised cost of generation (LCOE) for various key generation technologies in the UK, with a project initiation date of 2019 (2018 for coal)¹⁰, with a €30 /tCO₂ carbon price added.

Figure 1 – Levelised Cost of Electricity (Source: DECC 2013; DECC 2012)



Based on the projections presented in Figure 1, it is clear that a €30 /tCO₂ carbon price in 2030 alone, *ceteris paribus*, would be insufficient to incentivise the development of renewables, nuclear or CCS installations over unabated coal and gas installations. Any abatement induced by the EU ETS in the power sector by 2030, therefore, is likely to continue to be a result of fuel switching from existing coal to gas capacity, or through investment in new gas rather than (unabated) coal plant. However, elements of LCOE for different options may vary substantially over time and geographies (e.g. coal and gas prices, capital costs of renewable technologies), injecting uncertainty to this conclusion for the medium to long-term.¹¹ This includes possible CO₂ constraints and resulting prices beyond the 2030 horizon – an important consideration for such long-lived infrastructure. At present the LRF of 2.5% is set to continue to 2050, producing a 2050 cap 90% below 2005 levels, or 92% below 1990 levels (exceeding the cumulative minimum requirements for 2050 for both the power and industry sectors as presented in this paper).

¹⁰ GBP is converted to EUR at a rate of 1.3. All values have a 10% discount rate applied by the source.

¹¹ For CCS options technological availability is a further issue, although policy instruments to address this concern are beyond the scope of this paper.

Member States, on average, are on track with their indicative trajectories for the deployment of renewable electricity and other renewable energy in order to meet the 2020 RED target. If the growth rate of renewable electricity as a proportion of total generation were to continue at the average annual rate experienced between 2004 and 2014, its value would reach over 48% by 2030 and 75% by 2050 – exceeding the requirements presented in this paper. However, the European Commission (2015) projects a reduction in the rate of growth, producing a shortfall of renewable electricity of 8.5-13% by 2020, as part of a 8.5-12% shortfall for renewable energy more broadly (reaching 17.5-18.3% of gross final energy consumption). A principal reason for this is the presence of non-economic barriers to the deployment of renewables. Zane *et al* (2012) identify the presence of complex or inefficient administrative procedures and long lead times and delays as key barriers to the wider deployment of renewable electricity.¹² The RED requires Member States to introduce ‘enabling initiatives’ to remove such barriers, including simplification and increased transparency for spatial planning and other administrative and authorisation procedures, however in 2013 the European Commission (2013) reported limited and slow progress in implementing these obligations, with many Member States failing to address this aspect entirely. Although the European Commission (2015) reports that some recent progress has been achieved in this area, it recognises that further improvements are required.

Another potential barrier to deployment is the shift to competitive bidding processes for support mechanisms. Whereas FiTs provide certainty to investors on their return, competitive support allocation approaches (such as auctions) may be less effective, as they entail a higher investment risk (although the extent to which this is true depends on the specific instrument chosen, and its particular design) (Butler and Neuhoff, 2008; Alishahi *et al*, 2012). In addition, competitive processes are likely to favour the deployment of large, centralised installations by commercial organisations (e.g. utilities), which due to the increased complexity, administrative

¹² Along with issues such as grid capacity, and cost of connection.

burden, and level of and uncertainty on return are more likely to engage in such a process than smaller, community-level organisations. A more crucial issue may present itself in the medium term. Kampman *et al* (2015) find that although renewable energy would likely have increased in some Member States in the absence of EU requirements, mandatory targets have been crucial in driving deployment in others. In contrast to the '20-20-20' targets for 2020 instituted by the 2020 Climate and Energy Package, the 2030 Climate and Energy Framework imposes a target for renewable energy at the EU, rather than Member State, level.¹³ As such, it is possible that support mechanisms for renewable energy of all descriptions may weaken (or potentially, cease) in some Member States after 2020 (or once their mandatory targets have been achieved).

However, a more fundamental issue is the design and operation of the electricity market. With generators entering the market according to their merit order, increasing penetration of (near) zero marginal cost renewable generators increasingly displaces fossil fuel and nuclear capacity, reducing wholesale electricity prices and revenue for all market participants, creating a 'missing money' problem (Joskow, 2013) and rendering all generators (fossil fuel, nuclear and renewables) uneconomic without parallel (and increasingly expensive) support instruments (e.g. renewable energy support and capacity mechanisms), preventing investment in new capacity of all kinds. If the current design persists, therefore, support for instruments that encourage the deployment of renewable electricity or that make unabated fossil fuel generation more expensive, would likely decrease in order to preserve energy security, reliability and affordability. The European Commission recognises this, and recently consulted on potential new market designs. However, the final proposed design, and date and mode of introduction, is not yet clear.

5. Industry sector

5.1 Contemporary sector profile

¹³ 27% of gross final energy consumption by 2030.

CO₂ emissions from the industrial sector (both energy-related and from industrial processes) accounted for 21% of total CO₂ emissions in the EU28 in 2014, with the manufacture of chemicals and iron and steel responsible for around half of this. Between 2004 and 2014, CO₂ emissions and total energy consumption by the sector reduced by an annual average of 2.5% and 1.8%, respectively, with the energy carrier mix remaining largely static (electricity and gas around 30% each, with the remainder divided between coal, petroleum products, derived heat and renewables).^{2,Error! Bookmark not defined.}

5.2 Required sector profile – 2030 and 2050

Three of the four studies examined project relatively consistent reductions in CO₂ emissions from the industrial sector, at around 50% below 1990 (20% below 2014) levels by 2030, and 70% below 1990 (50% below 2014) levels by 2050. Such reductions occur despite increasing industrial output.¹⁴ This is achieved principally through a combination of energy efficiency and the use of CCS on industrial processes. The GINFORS study projects a reduction of just 26% below 1990 (20% above 2014) levels by 2050, however this is due in large part to emissions accountancy¹⁵ (and the absence of CCS technologies, discussed below) in the model.

Both the ETM-UCL and ER2050 studies project final energy consumption to remain largely stable to 2030, but to reduce by 5% and 10%, respectively, below present levels by 2050. The IEA, however, projects a 20% increase by 2050.¹⁶ Energy consumption should therefore, at a minimum, not increase from current levels. Each of these projections is significantly below the energy consumption projections in their 'reference' scenario counterparts for 2050 (between 15% and 30%), indicating a relatively significant increase in energy efficiency (and reduction in energy

¹⁴ Growth in demand for industrial products is driven primarily in all studies discussed by GDP growth, but with different results on the structure, scope and assumptions applied to each model.

¹⁵ 'Industrial' emissions in GINFORS also considers emissions from industry-related buildings and transport, rather than direct energy consumption and emissions associated with industrial processes alone.

¹⁶ 2030 data are not readily available for this study.

intensity) over time. The composition of the energy consumption profile in the two studies for which such data is available (ETM-UCL and IEA) remains largely static over the assessment horizon, and thus little CO₂ abatement is delivered through fuel switching. The major driver for abatement in the industrial sector is the application of CCS on industrial processes – responsible for over half of the projected abatement in the sector between the present day and 2050 in the ETM-UCL results (and approximately 15% by 2030), and nearly two-thirds in the IEA projections.¹⁶

5.3 Policy landscape – key elements

As with the power sector, the principal instrument addressing CO₂ emissions from industry is the EU ETS. As discussed in Section 4, the key driver for reductions in CO₂ abatement since 2005 in the power and industry sectors was the 2008 financial crisis, which also produced the permit surplus which the MSR, to be introduced in 2019, is intended to address. Although free permit allocation to the power sector ceased in 2013, it continues in the industry sector based on product-specific ‘benchmarks’; the average CO₂ emissions of the top performing 10% of installations in the EU producing a given product. Installations that meet these benchmarks receive 100% free permit allocation, with others receiving less in proportion to their emissions. Free allocation will reduce from 80% in 2013 to 30% in 2020. Industries or sub-sectors considered at risk of carbon leakage receive 100% free allocation, continuing into Phase 4 (2021-2030). For Phase 3 (2013-2020), over 150 industries are considered at risk of carbon leakage, accounting for 97% of industrial emissions (DECC, 2015). A revised definition of carbon leakage will be applied for Phase 4 (discussed below). Member States are also permitted to compensate electricity-intensive industries for ‘indirect costs’ of the EU ETS carbon price on electricity consumption¹⁷.

¹⁷ Member States that provide such compensation are the Netherlands, Germany, Greece, the UK, Spain, Belgium (Flanders) (plus Norway) (Carbon Market Watch, 2015).

The second key instrument is Article 8 of the Energy Efficiency Directive (EED) (2012/27/EU), which requires all large companies¹⁸ to receive a mandatory energy audit every four years (beginning in December 2015 at the latest), unless the company has implemented a certified Energy Management System (EMS). Given the recent nature of this instrument, it is likely to have had negligible or no effect on energy consumption in such firms thus far. The industry sector is also notionally subject to other instruments influencing CO₂ emissions and energy consumption at EU and Member State level, although in practice exemptions or derogations for EU ETS sectors are in place (Branger & Quirion, 2013). A key example is the exemption for energy-intensive industries from the common minimum taxation requirements for energy products laid down by the Energy Taxation Directive (ETD) (2003/96/EC).

5.4 Policy suitability

To reach 2030 requirements, CO₂ emissions must reduce by an annual average of around 1.3% from 2014 levels. To meet 2050 requirements, the rate must increase to 2.5% from 2030. This is below the average rate experienced between 2004 and 2014, however as discussed above, a significant proportion of abatement may be ascribed to the financial crisis. Although energy consumption need only be maintained at approximately current levels, rather than a continuation of the 1.8% average annual reduction experienced between 2004 and 2014, it is reasonable to conclude that this was driven to a substantial degree by the financial crisis (producing the reductions in CO₂ emissions experienced).

Conclusions regarding the future of the EU ETS discussed in Section 4 are also applicable here. Although the projected cap in both 2030 and 2050 is more stringent than the combined minimum requirements of the power and industry sectors presented, the continued surplus of permits (despite the introduction of the MSR and uprated LRF) renders achievement of the 2030 cap (in particular) uncertain in

¹⁸ Enterprises which employ more than 250 people, or more than €50 million annual turnover and an annual balance sheet of over €43 million.

practice, and the division between and form of abatement taken by the two sectors is unclear.

In principle, a carbon price of €30 /tCO₂ in 2030 may induce relatively substantial reductions to energy consumption and CO₂ emissions in key industrial sectors. Neuhoff *et al* (2014a; 2014b) estimate potential for a 0.5 MtCO₂/year reduction in the cement sector, and a 15-35% reduction in current CO₂ emissions from the EU's steel sector, resulting from the use of the most energy efficient technologies currently available. A key barrier for the installation of such measures, which are often cost-effective at current energy and carbon prices, is long payback periods, which do not justify significant periods of plant shutdown. They state that increasing CO₂ prices through a reformed EU ETS may be reduced or overcome this issue (but only above a €20 /tCO₂ price for the cement sector). Additionally, Neuhoff *et al* (2014a) suggest that substitution of clinker in cement for less CO₂-intensive materials is cost-effective at carbon prices of €10/tCO₂, but have not been widely adopted due to the free allocation of permits, the pass-through and discounting of the value of the opportunity cost of such permits.

The continuation of 100% free permit allocation to sectors on the carbon leakage list in Phase 4 may therefore continue to dissuade such investments, which would otherwise be cost-effective. Although the revised criteria for identifying sectors at risk of carbon leakage reduced the number of qualifying sectors by around two-thirds, the proportion of industrial emissions considered at risk of leakage reduces only marginally, from 97% to 94% (DECC, 2015). As such, the industry sector will continue to be subject to a carbon price under the EU ETS only notionally rather than in practice, providing little incentive to reduce CO₂ emissions until at least 2030.

Estimates of carbon prices required to allow the cost effective uptake of CCS in the industrial sector vary significantly. The IEA (2012) estimates values of €55-140/tCO₂ for CCS in iron and steel, and between around €50-185/tCO₂ for the cement sector, reflecting the deep uncertainty that remains around this technology (not least its availability in the first instance). As such, even if the industry sector were subject to a

real carbon price and CCS were available and within the price ranges indicated above, a €30 /tCO₂ price in 2030 would not incentivise its deployment (unless a clear, rapidly rising and relatively predictable price were in place soon thereafter).

It is too early to postulate how effective Article 8 of the Energy Efficiency Directive may be in increasing energy efficiency in the industrial sector. However, given its informative rather than incentivising nature (firms are not required to act on the information they receive from audits), it is unlikely to significantly alter the picture painted above. In addition, as energy demand is not a criterion, smaller companies with large energy consumption profiles are not covered by the Directive (Eichhammer & Rohde, 2016).

6. Residential buildings sector

6.1 Contemporary sector profile

CO₂ emissions from the buildings sector (residential and commercial) accounted for 21% of total CO₂ emissions in the EU28 in 2014. As the residential sector accounts for over 70% of this², it is this sector on which this paper will focus. Between 2004 and 2014, CO₂ emissions and total energy consumption by the residential sector reduced by an annual average of 2.7% and 1.8%, respectively, with the energy carrier mix remaining relatively static (with natural gas holding a 35-40% share, electricity around 25%, petroleum products and renewables around 15% each, and district heat and coal accounting for the remainder).^{2,3} The energy intensity of the EU residential stock in 2009 was 200 kWh/m² (Lapillonne, Pollier & Sebi, n.d), and reduced to around 185 kWh/m² by 2012 (Gynther, Lapillonne & Pollier, 2015) – an average annual reduction of 2.6%.¹⁹

6.2 Required sector profile – 2030 and 2050

¹⁹ Data for 10-year average value is not readily available.

The four studies are highly varied in their projections for CO₂ emissions from the residential buildings sector. The ETM-UCL and ER2050 studies project emissions reducing by 15% and 40% by 2030 from 1990 levels (an increase of 20% and 15% from current levels), and reducing by 15% and 85% by 2050 (an increase of 15% and a reduction of 80% from current levels), respectively. The IEA projects a value central to this range by 2050, with a reduction of 50% from 1990 (30% from 2014) levels.¹⁶ GINFORS projects a reduction of 40% from 1990 (5% from 2014) levels by 2050 for all buildings, although given its relative dominance, this may be taken as indicative of abatement in the residential sector.

These values driven to a significant extent by differences in projected final energy consumption, which range between an increase of 15% and reduction of 5% from 1990 (an increase of 20% and no change from 2014) levels by 2030, and between no change and a reduction of 30% on 1990 (an increase of 5% and a reduction of 30% on 2014) levels by 2050. These values are projected by ETM-UCL and ER2050, respectively. The IEA projects final energy consumption to increase by 5% by 2030 on 1990 (and 2014), and to reduce by 5% by 2050 on 1990 (and 2014) levels.²⁰ These projections must be seen in context of increasing energy service demands over time. Using residential floor space projections employed by the IEA²¹, energy intensity must reduce to 136 – 183 kWh/M² by 2030, and 89 – 132 kWh/m² by 2050. Again, the upper and lower values are projected by the ETM-UCL and ER2050 studies, respectively (with the IEA projecting values of 145 kWh/m² in 2030 and 121 kWh/m² in 2050).

The difference in final energy consumption (and by extension energy intensity) in these projections is due to differences in the deployment and development of energy efficient products and technologies for both building envelopes (e.g. insulation) and energy-using products (e.g. heating systems, white goods) in the

²⁰ 1990 and 2014 comparisons for GINFORS are not presented, as energy consumption in residential buildings cannot be readily disaggregated.

²¹ IEA (2012) projects an increase in residential floor space from 19.5 billion m² in 2010 to 24.7 billion m² to 2050, driven primarily by increasing household income. Assumed to be a linear increase between 2010 and 2050 for the calculations in this paper.

models. The ETM-UCL, for example, does not contain building envelope efficiency options. This is the key driver behind the lack of more substantial energy and CO₂ reductions over time compared to other studies (Solano-Rodriguez *et al*, *this issue*). However, as cost-optimisation models, energy-using products that deliver cost savings are immediately deployed, achieving energy and CO₂ savings at a negative cost (slimming the 'energy efficiency gap'). Changes to consumer preferences and behaviours (e.g. reduced thermostat levels) are not considered in any study reviewed.

Although energy efficiency is projected to drive the majority of CO₂ abatement in the residential sector, a reduction in the CO₂ intensity of the energy satisfying the remaining demand, particularly for space heating, is also projected. In the IEA study, a shift 'mainly towards biomass-fuelled boilers...[and] high-efficiency, bi-modal heat pumps powered by low-carbon electricity' is projected (IEA, 2012, pg.576). The ER2050 study also projects a 'trend towards electrification (i.e. heat pumps)' (European Commission, 2011b, pg.16), whilst the GINFORS results suggest that 'the division of energy carriers in [both residential and commercial] energy use remains mostly constant...[there is] a slight increase in electrification' (Drummond, 2014). However, specific data are not readily available for these studies. Data from the ETM-UCL also suggest a relatively modest shift towards electrification (18% of final energy demand in space heating in 2030 and 2050), with biomass and natural gas accounting for the majority of the remainder by 2050.

In conclusion, CO₂ emissions from the residential sector should be at least 30% below 1990 levels by 2030 (3% below 2014 levels), and 50% by 2050 (31% below 2014 levels). Average energy intensity should reduce to a maximum of 150 kWh/m² by 2030 and 100 kWh/m² by 2050, whilst residential space heating demand should be satisfied by at least 50% zero-emission energy at the point of use, with natural gas accounting for the vast majority of the remainder.

6.3 Policy landscape – key elements

The Energy Performance of Buildings Directive (EPBD) (2010/31/EC) contains three key provisions. The first is the requirement for minimum energy performance standards (MEPS) for new buildings, set by each Member State. However, evidence suggests that MEPS are often poorly enforced, with compliance often found to be relatively low across Member States (Pan & Garmston, 2012). The second key provision is the requirement for all new buildings from 2020 to be classified as 'nearly-zero energy buildings' (NZEB), with remaining energy consumption to be substantially satisfied by renewables. The third provision is the requirement for an Energy Performance Certificate (EPC), illustrating energy performance data, to be issued for any building sold or rented to a new owner or tenant. Whilst all Member States have a functioning EPC scheme, their design and structure differ somewhat (often resulting from a slow and partial implementation of the EPBD), producing different levels of clarity and effectiveness (Economidou *et al*, 2011).

Article 7 of the EED requires Member States to introduce Energy Efficiency Obligation Schemes (EEOS), for energy distributors and suppliers to achieve annual savings of 1.5% total average energy sales by volume over 2009-2012, each year over the period 2014-2020. Eligible savings may be produced in any end-use sector, although transport and EU ETS sector may be excluded from the initial sales volume calculation. Member States may use alternative instruments to achieve the target. Of the 479 instruments Member States have reported will contribute to compliance, 21 (4%) are EEOS (targeting 34% of required savings). The largest category is fiscal incentives (including grants), at 184 (38%, targeting 19% of savings) (Forster *et al*, 2016). Member States project 42% of savings will be achieved in the (residential and commercial) buildings sector (Rosenow *et al*, 2016).

The Ecodesign Directive (2009/125/EC) subjects an expanding range of energy-using and energy-related products to minimum environmental performance standards (usually related to in-use energy consumption). The Energy Labelling Directive (ELD) (2010/30/EU) requires energy-using and energy-related products, usually those also obligated under the Ecodesign Directive, to display energy efficiency labels at the point of sale. Products covered include heating, ventilation and air conditioning

systems, various consumer appliances and lighting products across a range of sectors. Kemna (2014) find that the combination of these instruments is relatively effective in delivering energy savings, projecting savings in 2020 of 19 against the counterfactual% for the products covered, however it is unlikely that the ELD is a substantial contributor to this, for three reasons. First, the introduction of A 'plus' labels produces confusion and a feeling of diminishing returns, reducing its efficacy compared to the simpler 'A-G' scale used pre-2010 (LE and Ipsos, 2014; Heinzle and Wüstenhagen, 2012). Secondly, around 90% of appliances covered fall into the 'A' category (Heinzle & Wüstenhagen, 2012), reducing the ability for consumers to differentiate between products. Thirdly, even if consumers are aware of and presented with the label, the information communicated is only effective in impacting product choice if the consumer considers it important. Waide and Watson (2013) found that almost half of their multi-country respondents considered energy efficiency a key aspect in purchase decisions for products with energy labels, with aspects such as capital cost likely to hold higher importance.

As with the industrial sector, household energy consumption may be exempt from the minimum taxation requirements of the ETD. It may also be subject to a reduced-rate VAT, under the VAT Directive (2006/112/EC). In the UK alone, the application of a 5% VAT rather than the standard 20% rate produces an implicit annual energy subsidy of £5 billion (Advani *et al*, 2013) (although the EU ETS places a upstream carbon price on electricity consumption, and many Member States fund their renewable electricity support mechanisms through a levy on household electricity bills).

6.4 Policy suitability

To reach the minimum requirements by 2030, CO₂ emissions should reduce by an annual average of around 0.2% from 2014 levels. Energy intensity must reduce at an annual average of 1.3%. To meet 2050 requirements, these rates must increase to an annual average of 1.7% and 2% from 2030, respectively. These rates are below the average experienced in recent years, which were driven by a combination of more

efficient new buildings, renovation of existing buildings, and more efficient space heating and electric appliances (Gynther *et al*, 2015), likely induced to a significant degree by the instruments described above (and their predecessors). However, the extent to which such instruments may allow for such rates to continue is uncertain.

The EPBD allows Member States to set the definition of 'nearly-zero' for NZEBs, with many setting such definitions well above zero, most commonly at 45-50 kWh/m²/year for residential properties (BPIE, 2015). Two issues may prevent even these levels from being achieved in practice. The first is the potential for a continued lack of enforcement of MEPS. The second is the 'performance gap' phenomenon - the difference between expected and actual energy (or CO₂) savings from the introduction of a given technology or measure. The evaluation of the performance of a technology or measure is usually based on engineering and modelled estimates of how it will perform, rather than actual measured energy or CO₂ savings – an approach that routinely overestimates actual outcomes (Rosenow & Galvin, 2013). Additionally, few Member States require any proportion of the remaining energy consumption to be satisfied by renewables (Ecofys, 2014).

Although at least two-thirds of existing buildings are likely to be present in 2050 (Šajn, 2016), there are a number of potential issues with the key instruments designed to increase their energy efficiency. Although the Ecodesign Directive (in particular) has been (and is projected) to significantly increase the efficiency of energy-using products, this does not influence the efficiency of building envelopes, which as discussed above, is key in reducing energy consumption (and associated CO₂ emissions) in the sector. Article 7 of the EED is notionally designed to induce such efficiency measures. However, under half of the annual 1.5% annual reduction target is ascribed to efficiency in buildings, and still less the residential sector. In addition, Rosenow *et al* (2016) estimate that around 86% of expected energy savings as notified by Member States are at least partially at risk of not being realised due to ineligibility of notified measures, a lack of additionality of savings, risk of non-delivery, and risk of double counting. Issues surrounding the performance gap are in addition to this. Even if such items were to be corrected, the obligation by Member

States to increase energy efficiency of the end-use sectors ceases in 2020 under this Directive and within the broader climate and energy framework targets.²²

The lack of requirements by Member States for new buildings from 2020 to cover remaining energy consumption from renewables (despite EPBD requirements), coupled with taxation exemptions, effective subsidisation of domestic energy consumption in some Member States and the application of carbon pricing to electricity only, means there is little requirement or incentive to shift towards zero-emission energy at the point of use in this sector.

7. Road transport sector

7.1 Contemporary sector profile

CO₂ emissions from the (domestic) transport sector accounted for 25% of total CO₂ emissions in the EU28 in 2014. The road transport sector accounts for around 95% of this.² Between 2004 and 2014, CO₂ emissions and total energy consumption by the road transport sector reduced by an annual average of 0.8% and 0.4%, respectively. The energy carrier mix in road transport remained relatively static over this time, with petroleum products accounting for around 95% of total energy consumption (with a shift towards diesel from petrol, with the latter reducing from 41% to 29% of total petroleum products consumed). The remaining 5% comprised largely of electricity and renewables (i.e. biofuels).^{2,3}

As passenger cars account for over 60% of both CO₂ emissions² and energy consumption in road transport²³, and 83% of all inland passenger transport³, and as it is the sub-sector which, as discussed below, is projected to require and drive the largest abatement efforts in road transport in the future, it is on this mode that this paper will focus. CO₂ emissions from cars reduced at an average annual rate of 0.7%

²² In contrast with the 2020 targets, as with renewables, the 2030 Climate and Energy Framework target for energy efficiency is to be binding at the EU level only.

²³ As reported by the ETM-UCL.

between 2004 and 2014 (although emissions increased between 2004 and 2007, following a long-term trend, this has been offset by relatively rapid reductions since 2008).² The average CO₂ intensity of new cars purchased has reduced from 163.4 gCO₂/km in 2004, to 123.4 gCO₂/km in 2014 (EEA, 2015b) - an average annual reduction of 4 gCO₂/km.

7.2 Required sector profile – 2030 and 2050

The studies project CO₂ emissions from road transport to develop between a 7% increase and a 21% reduction from 1990 levels by 2030 (ETM-UCL and GINFORS²⁴, respectively), and to reduce between 15% and 65% by 2050 (ETM-UCL and ER2050, respectively). These translate to reductions of between 10% and 35% by 2030, and 30% and 70% by 2050, below current levels. GINFORS and ER2050 project final energy consumption to reduce by around 15% from current levels by 2030, but diverge to a reduction of between 10% and 45% on current levels by 2050, respectively. The ETM-UCL projects energy consumption in road transport to remain largely stable over the assessment horizon, whilst the IEA projects 2050 consumption to reduce by 35% from current levels.¹⁶

These values are in large part a result of changes (or not) to the profile of final energy consumption in passenger cars. The ETM-UCL projects energy consumption to remain stable over time, with relatively minor shifts in fuel profile (petrol and diesel continue to satisfy over 75% of energy demand, although with a shift to the latter, which exhibits a lower CO₂ intensity), producing relatively modest abatement in road transport by 2050. By contrast, the ER2050 study projects energy consumption reducing by 60% from current levels by 2050, coupled with substantial electrification; almost 80% of private passenger transport demand satisfied either by plug-in hybrid or pure electric vehicles (European Commission, 2012, p.20), producing much more extensive CO₂ abatement than other studies. As such, CO₂

²⁴ However, in GINFORS, the 'transport' sector is defined as a service sector delivering transport services to commercial activities and private households. Private individual car use is considered separately, under 'household' emissions.

emissions from passenger cars should reduce by at least 20% from current levels by 2030, and 50% by 2050.

These developments must take place despite a likely increase in passenger travel demand. The ER2050 study projects passenger-kilometre demand for private cars to increase by 28%, whilst the ETM-UCL projects a 72% increase in passenger car vehicle-kilometre demand. Neither ETM-UCL or GINFORS consider modal shift, such as from private cars to public transport, as a function of scenario and model design. Both IEA and ER2050 assume some small modal shift (largely from aviation and private cars to public transport and rail), although the effect is relatively minor. The CO₂ intensity of all passenger cars should therefore decrease from approximately 290 gCO₂/km at present, to a maximum of 180 gCO₂/km by 2030, and 90 gCO₂/km by 2050.²⁵

7.3 Policy landscape – key elements

Regulation 443/2009 sets fleet-average CO₂ emission performance standards for new cars registered in the EU, for each manufacturer, set at 130 gCO₂/km from 2015, and 95gCO₂/km by 2021. In 2015 the average value for new cars registered was 119.6gCO₂/km (8% below the target) (EEA, 2016a). However, there is a significant (and increasing) gap between the results of laboratory tests upon which compliance is based, and real-world performance of vehicles. ICCT (2015) estimate on-the-road CO₂ emissions to be 36% higher than lab-based tests for private cars and 45% for company cars, meaning that the CO₂ intensity of new vehicles is likely not decreasing at the rate at the rate officially reported. To reduce this differential, it was agreed in March 2014 that the Worldwide harmonised Light vehicles Test Procedure (WLTP) will be adopted in the coming years. Despite this, the regulation is likely to have induced some reduction in CO₂ intensity of the average new passenger car against the counterfactual. However, the EEA (2012) suggest that the financial crisis was a

²⁵ Current value calculated using 2014 CO₂ emissions from passenger cars, and assuming static transport demand of 1,816 bvk as reported by the ETM-UCL for 2010. 2030 value assumes 25% increase in vehicle-kilometres, and 50% by 2050.

key contributor to the shift towards the purchase of smaller, less powerful (and therefore less CO₂-intensive) cars since 2007, reducing overall CO₂ emissions overall, *ceteris paribus*, against the counterfactual. In addition, the EEA (2015c) indicates the financial crisis is also likely to have been a primary driver for the levelling and subsequent reduction in passenger car transport demand since 2009 (as part of a wider reduction in passenger transport demand), further reducing total CO₂ emissions from the sector.

Three other instruments are applied at the EU level. The first is the ETD, which applies EU-wide minimum tax rates on transport fuel. These rates are levied on the basis of fuel volume, producing different minimum rates on an energy (€10 /GJ and €8 /GJ for petrol and diesel, respectively) and carbon content basis (€145 /tCO₂ and €100 /tCO₂) (European Commission, 2011a). However, most Member States apply rates (often significantly) above the minima, with only two applying the minimum rate for petrol, and seven for diesel (Maca *et al*, 2013). In January 2015, taxes and levies comprised an average of 65% of petrol prices across the EU, and 35% of diesel prices (a tax component of €0.76/l and €0.36/l, respectively) (Drummond, 2015).

The second instrument is the RED, which requires 10% of final energy consumption in transport to be sourced from renewables by 2020. In 2014, this rate was 5.9%³, which the EEA (2016b) estimate reduced emissions from the sector by 39 MtCO₂ (equivalent to a reduction of around 4.5% of road transport emissions in that year). However, the European Commission (2015) find that slow progress toward the 2020 target is being made, largely a result of uncertainty surrounding and increasing awareness of indirect land-use change effects of first generation biofuel, along with lack of commercially available advanced (second and third generation) biofuels. To tackle these issues, amendments in 2015 to the RED and Fuel Quality Directive (2009/30/EC), *inter alia*, limit the share of biofuels derived from crops grown on agricultural land limited to 7% of the 10% target, establish an indicative target of 0.5% for advanced biofuels, and introduce stronger incentives for the use of renewable electricity by increasing its weighting in calculations for compliance with the 2020 target.

The third instrument is Directive 1999/94/EC, on the CO₂ labelling of passenger cars, which requires Member States to ensure information regarding CO₂ intensity is provided to the consumer at the point of sale of a new passenger car. Various studies conclude that these labels have had no noticeable effect on consumer purchasing decisions, due to a combination of a lack of awareness of these labels, poor understanding of what the labels mean when consumers are aware, and a more fundamental issue of the low importance consumers place on environmental concerns relative to other factors (such as price, safety and performance) (Gartner, 2005; AEA, 2011; Codagnone *et al*, 2013).

Although excluded from the scope of this paper, other instruments initiated independently at Member State level hold influence over CO₂ emissions from the passenger car fleet. Key examples include registration and circulation (ownership) taxes (in which 14 Member States consider CO₂ emissions as a parameter for the former, and 12 for the latter (van Essen *et al*, 2012)), and subsidies for the purchase of low-emission vehicles. In addition, company car tax arrangements in most Member States constitute a substantial market distortion. In all Member States, a company car is bought by the employer for use by the employee, who declares the vehicle as an in-kind benefit as part of taxable income (with the particular proportion determined differently between Member States). Fuel costs are also commonly covered by the employer, which is often, alongside the costs of maintenance, insurance and other taxes, plus the purchase price of the vehicle itself, VAT deductible. Additionally, as the employee receives the vehicle as an in-kind benefit substituting for a proportion of forgone salary, social security and other related taxes levied on income, which are paid by both the employer and employee, are not due. This incentivises the purchase of larger, often more CO₂-intensive vehicles, with the driver of the vehicle not liable for fuel costs, and thus incentives to adjust mileage (Maca *et al* 2013).

7.4 Policy suitability

To reach the minimum requirements by 2030, CO₂ emissions must reduce by an annual average of around 1.4% from 2014 levels. To meet 2050 requirements, these rates must increase to an annual average of 2.3% from 2030. This exceeds the average rate of 0.8% experienced between 2004 and 2014.²

For the CO₂ intensity of the passenger car fleet to reduce to a maximum of 180 gCO₂/km by 2030, and 90 gCO₂/km by 2050, assuming a full replacement of the passenger car fleet in Europe every 13 years, (McKinsey&Co, 2009, p.21), the average CO₂ intensity of new cars purchased must reach these levels by 2017 and 2037, respectively. Although the reported average CO₂ intensity of new vehicles is already well below the 2030 target, as discussed, this value is not being achieved in practice. Assuming on-the-road emissions are on average 40% above that reported for new vehicles (both private and company cars), cars sold in 2015 exhibit a fleet-average of around 200 gCO₂/km. This value should therefore reduce by at least 10 gCO₂/km in both 2016 and 2017 for the 2030 target to be achieved – over twice the average rate of reduction for reported values. This value may then reduce to an average annual reduction of 4.5 gCO₂/km to 2037, in order to achieve the 2050 target. However, if the target of 95 gCO₂/km in 2021 is achieved both in reported and on-the-road emissions through the use of the WLTP, then it is likely that both the 2030 and 2050 targets for CO₂ intensity would be comfortably achieved. Although, at the time of writing, neither the date for introduction of the new test procedure, or its specific design (and thus the extent to which the report and on-the-road differential will be reduced), had been agreed. Instruments introduced at the Member State level (registration and circulation taxes, and subsidies) are likely to continue to influence the evolution of the average CO₂ intensity of new cars purchased, regardless of the extent to and rate at which the above Regulation increases stringency in practice. In combination, such measures are likely to determine achievement, or otherwise, of the transport-related RED target (along with the increased weighting afforded to electricity).

Whilst these instruments act to influence the composition of the passenger car fleet, they do not influence the extent to which such vehicles are driven. Fuel prices are a

key determinant of travel demand (Nijland *et al*, 2012). Although taxes and levies (notionally governed by the ETD, but which is only binding in practice for a small number of Member States) were a substantial proportion of petrol and diesel prices in the EU in January 2015, underlying (and relatively unpredictable) fuel costs (driven by international oil markets) are more significant over time in determining final prices. For example, between 2005 and 2015, average EU petrol prices fluctuated by approximately the same value as the taxes and levies proportion of the price in January 2015. For diesel, it was almost double.²⁶ However, company car tax arrangements in many Member States act to dampen or even remove the price signal provided by fuel prices, regardless of level and composition. Given the proportion of company cars in the EU fleet (around half of all new car purchases in the EU are company cars (Copenhagen Economics, 2010), such an effect is significant.

8. Conclusions

This paper provides an overview of whether the policy landscape at the EU level for key sectors of the energy system (power generation, heavy industry, residential buildings and road (passenger car) transport) is suitable for driving the changes required for a cost-effective decarbonisation pathway in the EU.

For the power and industry sectors (and the wider economy), the EU ETS has been the cornerstone instrument for CO₂ abatement since 2005. However, it has been largely ineffective in driving CO₂ abatement in these sectors, with abatement largely driven by the 2007/8 financial crisis. Although future amendments to the EU ETS (designed to correct current failures) are likely to underachieve against their stated objectives, the abatement achieved by 2030 is likely to be in line with collective requirements for these sectors. If the cap continues to reduce beyond 2030 at the post-2021 rate, 2050 abatement targets will also likely be achieved. In the power sector, renewable electricity support mechanisms have been successful in

²⁶ Data sourced from the European Commission's Weekly Oil Bulletin.

stimulating deployment, however non-economic factors (such as planning and authorisation procedures) and the lack of Member State-level renewables targets post-2030 may substantially retard the rate of deployment in the future. A more substantial issue is the design of the electricity market, which is currently not designed to cater for a high penetration of renewables alongside conventional generation. In the Industry sector, the continuation of free permit allocation under the EU ETS for the vast majority of installations is likely to provide little incentive abatement in the short- to medium-term.

The ability of the policy landscape in the residential building sector to drive the changes required to 2030, and particularly 2050, is questionable. Requirements for 'nearly-zero energy buildings' by 2020 are likely to be significantly underachieved in practice due to the low ambition of specific regulations imposed by Member States, and the lack of enforcement of existing requirements. Almost all energy savings targeted by instruments designed to encourage energy efficiency improvements to the fabric of existing buildings, where the majority of energy efficiency and CO₂ abatement opportunities lay, are at least partially at risk of not being realised. Even if this were not the case, the targeted savings are insufficient, and Member States are not obligated to extend them after 2020. In addition, the uptake of low-carbon energy in this sector is not commonly required or incentivised, and due to misaligned fiscal signals, actively discriminated against.

Regulation 443/2009, which seeks to progressively reduce the CO₂ intensity of new cars in the EU, is the principal instrument for reducing CO₂ emissions from the passenger car sector (the sector commonly projected to drive abatement in the wider (road) transport sector). However, differences between reported and on-the-road emissions are substantial, significantly reducing the purported success of this instrument. A new compliance procedure is to be introduced to reduce this differential, and coupled with the existing targets, may allow this instrument alone to satisfy 2030 and perhaps 2050 requirements. However, the procedure design has not been finalised, or date of introduction agreed, injecting uncertainty into this conclusion. Regardless, it is likely that Member State-level instruments, such as

registration, circulation and fuel taxes, and arrangements for company car taxation, will have a significant effect on the evolution of the car fleet and associated CO₂ emissions.

In summary, the suite of EU policies designed to encourage the decarbonisation of key sectors of the energy system exhibits a range of issues, including a lack of appropriate stringency in design or practice, a lack of practical implementation or enforcement of stated requirements, and short-termism, with a number of instruments, targets or requirements expiring or subject to substantial uncertainty after the early 2020s. Such issues must be corrected if the EU is to maintain a cost-effective decarbonisation pathway over the coming decades.

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