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Glossary

BER	Building Efficiency Rating
CAP	Common Agricultural Policy
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CEFIC	European Chemical Industry Council
CH4	methane
CO_2	carbon dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
COVID-19	Coronavirus disease 2019
EAFRD	European Agricultural Fund for Rural Development
EC	European Commission
EEA	European Environment Agency
EED	Energy Efficiency Directive
EEG	Renewable Energy Sources Act
EEM	Energy Efficient Mortgage
EEMI	Energy Efficient Mortgage Initiative

EEO	Energy Efficiency Obligation
EFA	Ecological Focus Areas
EMF	European Mortgage Federation
ECBC	European Covered Bond Council
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ESD	Effort Sharing Decision
ESIF	European Structural and Investment Funds
ESR	Effort Sharing Regulation
ETS	Emissions Trading System
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GHG	greenhouse gas
HDVs	High Duty Vehicles
HFC	hydrofluorocarbons
ICAO	International Civil Aviation Organization
ICCT	International Climate Change Taskforce
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KfW	Kreditanstalt für Wiederaufbau
LULUCF	Land Use, Land Use Change and Forestry
MAC	Marginal Abatement Cost
MEPS	Minimum Energy Performance Standards

MIT	Massachusetts Institute of Technology
$MtCO_2e$	Metric Tons of Carbon Dioxide Equivalent
Mtoe	Millions of Tons of Oil Equivalent
N_2O	nitrous oxide
NDCs	Nationally Determined Contribution
NEDC	New European Driving Cycle
NF_3	nitrogen trifluoride
NOx	nitrogen oxide
NZEB	Nearly Zero-Energy Buildings
PPAs	Power Purchase Agreements
R&D	Research and Development
RDE	Real Driving Emissions
SF_6	sulfur hexafluoride
SILC	Sustainable Industry Low Carbon
UNC	University of North Carolina at Chapel Hill
UNFCCC	United Nations Framework Convention on Climate Change
VAT	value-added tax
WLTP	Worldwide Harmonized Light Vehicle Test Procedure

Executive Summary

This paper analyses climate mitigation policy in the European Union (EU) for five sectors which account for 95 percent of greenhouse gas emissions: power, transport, residential housing, manufacturing, and agriculture. It discusses sectoral policies needed to achieve the emission reduction goals presented in the EU Green Deal, serving as a complement to the companion paper "EU Climate Mitigation Policy," which focuses on broader EU-level policies.

The EU has made important progress in reducing emissions, with total emissions currently nearly a quarter below their 1990 level. But achieving a climate-neutral economy by 2050 will require much stronger policy action. Moreover, progress has varied across sectors. Emissions from power and industry have fallen by about a third, buildings by a quarter, and agriculture by a fifth—while transport emissions have increased. This paper argues that this divergence reflects cost differences among the available abatement channels, but also variation in the effective carbon prices, market imperfections, and policy gaps. It proposes specific sectoral policies to address these issues.

Comprehensive and predictable carbon pricing would be key to ensuring that activities and investments shift to exploit the lowest cost abatement options. However, even with the right carbon prices, complementary policies are essential to address sector-specific factors which hinder emission reductions, including financing constraints, incomplete markets, and political sensitivities. Examples of such policies include facilitating investment in power grids and vehicle charging infrastructure; support for nascent green technologies and technology diffusion; removal of subsidies and tax breaks for emissions-intensive activities; use of regulations and "feebates" to induce behavioral changes; policies to address incentive mismatches between home owners and renters; financing options for liquidity-constrained individuals, farmers, and firms; strengthening of emissions measurement and disclosure requirements; and a shift in farm subsidies away from livestock and toward land stewardship.

The large stimulus packages put together by European governments to facilitate recovery from the COVID-19 crisis provide an opportunity to intensify the adoption of climate-friendly policies. In the near term, prioritizing green investments—especially in public network infrastructure, which tends to react less to carbon prices—would support both job-rich growth and emissions reduction. As the recovery takes hold, a gradual increase in carbon prices would provide much needed revenues and create a virtuous circle of cost-efficient investments and adjustments in behavior. Part of the revenues can be used for targeted compensation of vulnerable groups adversely affected by the transition.

Power and Manufacturing

Emissions from power generation have fallen on the back of an improved energy mix, but still account for a third of total emissions. Meeting future emissions goals will require a decisive expansion of renewable power, which is no longer costlier than fossil fuels. In addition, grid infrastructure will need to be strengthened to cope with supply intermittencies from renewable power and to satisfy greater demand from the electrification of downstream sectors.

The past decline in manufacturing emissions reflects substantial efficiency gains in energy use and process-related emissions. Yet the sector still has untapped emission-reduction potential. Technologies currently available for cutting remaining industrial emissions often have high costs and are not yet produced at a large scale at the current low carbon prices; further investment is needed to increase their adoption.

Carbon pricing should remain the main tool to cut further power and manufacturing sector emissions. Introducing a carbon price floor to the Emissions Trading System (ETS) would steer investors and consumers toward green power sources, discourage carbon-intensive processes, and incentivize investment in green technology. More ambitious member states can adopt additional carbon pricing of industrial emissions at a national level. Free allowances granted to certain industries in the ETS should be gradually phased out, and a carefully designed carbon border adjustment mechanism can be considered to prevent reductions in EU emissions being reflected in higher emissions abroad. Higher carbon prices would also make support schemes, including subsidies, for renewable power unnecessary. And where the carbon prices needed to incentivize investments would be unfeasibly high, revenue-neutral instruments such as feebates can be considered.

Further public support is needed in areas where market failures constrain private sector investment even if the carbon price is right. Such support should prioritize infrastructure, renewables R&D, and displaced workers. Specific examples include:

- Network infrastructure such as power grids (especially across borders) and district heating
- R&D or early-stage technologies with large knowledge spillovers (for example, new renewable sources, power storage technologies, and carbon capture and storage)
- Financing for renewable plants with large fixed costs, or operated by small firms or households
- Removing existing regulatory hurdles to help unlock green investment
- Regional development and active labor market policies for displaced workers.

Transport

Transport has grown to become one of the EU's largest emitting sectors, as efficiency gains have been more than offset by increases in travel demand. The near-term scope for reducing reliance on oil products is limited, so emissions reductions need to rely on demand management, shifting to cleaner transport modes, and improving fuel efficiency. Ambitious decarbonization goals will require an accelerated uptake of cleaner technologies such as electric cars. Policies to reduce transport emissions include:

- **Fuel taxes.** Despite high taxes on road transport fuel, prices may be still below their efficient levels, considering all external costs such as congestion, air pollution, and climate. Including transport in the ETS would be one way to apply more comprehensive carbon pricing in the sector. Governments should also complement fuel duties with road pricing schemes.
- **Standards.** New car efficiency standards have been broadly effective, notwithstanding problems in emissions testing. The recent adoption of standards for certain heavy-duty vehicles will bring the EU in line with other major countries.
- **Incentives for cleaner cars.** Most countries use fiscal instruments to steer vehicle purchasing decisions, but low- and zero-emission vehicles remain a small fraction of sales. Feebates can be used to more aggressively shift purchases toward cleaner vehicles. Complementary policies such as the development of charging infrastructure are also needed.

- **Modal shifts.** Policies to promote cleaner transportation modes, such as walking, cycling, and mass transportation, would have co-benefits in terms of heath and reduced congestion.

Unlike road transport, technologies to fully decarbonize aviation do not yet exist. Investment in R&D will be needed to speed up the pace of innovation. Air transport has benefitted from a generous tax framework, with most emissions untaxed. Should EU authorities assess the new international offsetting scheme CORSIA—Carbon Offsetting and Reduction Scheme for International Aviation—as ineffective, they could consider extending ETS coverage, from intra-European Economic Area flights only at present, to all flights to and from the EU.

Residential Buildings

Residential building emissions have declined broadly in line with the total, driven by higher energy efficiency of new buildings and a cleaner energy mix, partly offset by population growth, larger dwellings, and smaller household sizes. Increasing the renovation rate of existing buildings and promoting greater electrification could more than halve the current emissions using existing technologies. A move to net zero emissions will require full electrification and a clean power mix.

Many abatement measures are already self-financing, but public interventions are needed to help overcome market failures and incentivize investment. Renovation rates are held back by inadequate price incentives due to limited environmental taxation, liquidity constraints, cost-benefit mismatches between owners and renters, and unawareness or uncertainty of potential energy savings from renovation. A comprehensive policy response, which could vary by country, would encompass:

- **Carbon pricing.** Residential housing has one of the highest "carbon pricing gaps." Increasing the coverage and price of CO2 emissions, including by reducing tax expenditures on emission-intensive fuels would improve incentives for investments in emission reduction.
- **Regulations.** Binding targets for energy efficiency improvements could help speed up the renovation rate. This should be accompanied by harmonizing and regulating energy efficiency ratings and increasing availability of building efficiency information.
- **Financing.** Enhanced financial support through "green mortgages" and means-tested, low-interest loans or grants for renovation would boost demand, especially for lower-income households. Designing energy-dependent property taxes and expanding options for "on-bill financing" of investments in energy efficiency could help overcome the owner-user barrier.

Agriculture

Given its exposure to changing weather patterns, agriculture stands to benefit most from effective climate change mitigation. Emissions from the sector account for about 10 percent of total EU emissions. After falling in the 1990s, they have remained nearly unchanged since 2005. The main abatement channels include improved soil management and reduced livestock emissions. Agriculture also offers significant potential for carbon sequestration. Croplands and permanent grassland, which occupy more than half the territory of the EU, can stock large reserves of carbon via enhanced farm management practices.

Large subsidies, measurement challenges and investment costs hold back emissions reduction. Some abatement measures can be self-financing due to savings from lower fertilizer use, greater crop efficiency, and less transportation of animal food. However, most farmers operate on low margins and depend on financial support from the EU, which does not reward reducing emissions from livestock. Also, the lack of precise emissions measurement, potentially high carbon leakage, and inelastic demand for food can undermine effective abatement through price-based supply-side policies. Demand measures aimed at shifting consumer choices away from beef and dairy have large potential for reducing emissions, as well co-benefits for health.

The new planning period (2021–27) for the EU's Common Agricultural Policy (CAP) offers an opportunity to improve incentives for emissions reduction via agroecology and conservation. For example, the scope of the current "green payment" mechanism to incentivize livestock emissions reduction can be broadened, the carbon storage capacity of farmland for which there is no general payment mechanism can be improved, and crop insurance support should be aligned with climate action to remove disincentives to more sustainable farming.

Fiscal policies and regulations at the national level could effectively complement amendments to the CAP. This could include removing tax expenditures favoring emission-intense products (for example, some countries have lower VAT rates for dairy/meat products) and introducing standards and measures to raise awareness, such as CO_2 footprint labels on food.

CHAPTER

1 Introduction

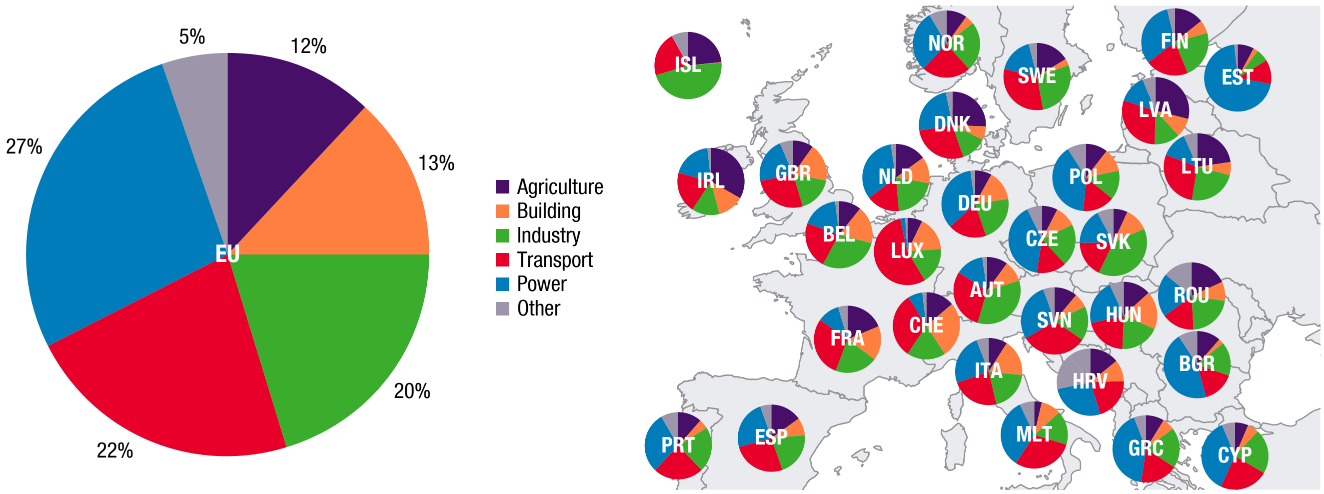
Motivation

Rising temperatures pose major global risks. Macroeconomic risks can stem from the impact of gradual warming (such as rising sea levels and reduced crop yields), extreme weather events (already more frequent), and risks related to the transition to a low carbon economy (Batten 2018). The scale of the risks will depend on the extent to which global temperatures rise, which in turn are crucially driven by man-made GHG emissions (IPCC 2018). The longer action to curb emissions is delayed, the greater the GHG accumulation in the atmosphere, and the more abrupt and costly will be the necessary action to stabilize global temperatures (IMF 2019 *Fiscal Monitor*). Even if Europe is not projected to be the hardest-hit region, climate change poses threats also to European countries as set out in more detail in the companion paper on EU-level emissions reduction policies (Chen and others 2020).

EU countries are taking a lead in reducing greenhouse gas emissions. As part of the Paris Agreement, EU countries have pledged to reduce overall GHG emissions by 40 percent relative to 1990 levels by 2030. Climate mitigation has been singled out as a as a policy priority for the EU legislature from 2019–25, and the EU Green Deal (EC 2019c) proposes more ambitious targets of at least 50 percent reduction by 2030, and net zero emissions by 2050. However, despite the progress observed in the last three decades (overall emissions are currently nearly a quarter below their 1990 level), countries' aggregated projections suggest that—like many other signatories of the Paris Agreement—the EU is not on track to meet the 2030 Paris target, and further effort will be required, all the more to meet the new more ambitious targets.[1]

[1]As of 2019, EU countries project a 30 percent reduction by 2030 under current policies and measures, while additional policies planned for the coming years would bring it to a 36 percent reduction (EEA 2019).

Figure 1. Greenhouse Gas Emissions by Sector, 2017



Source: United Nations Framework Convention on Climate Change.
Note: Excludes international aviation and shipping. Country list uses International Organization for Standardization (ISO) country codes.

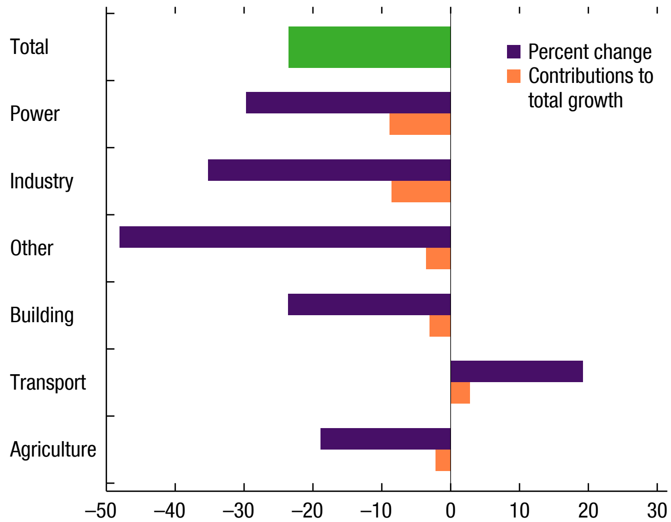
Delivering on the EU's climate ambitions will require significant progress across all sectors of the economy. Five sectors dominate EU emissions, with power, industry, transport, buildings and agriculture accounting for 95 percent of total emissions in 2017 (Figure 1).[2] However, the relative importance for each sector varies significantly across countries. Progress over the last three decades has been uneven, with the strongest emissions reductions coming from the power and industry sectors, while transport emissions have continued to expand (Figure 2).

Sectoral Approach

This paper analyzes climate mitigation policy design in the European context from a sectoral perspective. Within each sector, the analysis is organized following a similar structure. Each chapter first provides an overview of sectoral emissions and drivers to date, as well as prospects going forward. Second, it takes stock of available and potential abatement channels. Third, it reviews policy frameworks, including the roles of carbon pricing and supplementary policies. Assessing the desirable balance between price and non-price policies is difficult in practice and depends on political factors. The paper follows a pragmatic approach, by flagging current gaps in carbon pricing, facilitating the

[2]The remaining 5 percent are primarily accounted for by waste-related emissions. The decomposition here follows the United Nations Framework Convention on Climate Change classification. Hence, sectors' indirect emissions associated with electricity usage are associated with the power sector and international aviation is not included. In individual sector discussions, concepts can differ to adequately reflect the sector's abatement potential discussed. This is marked accordingly.

Figure 2. EU+UK: Greenhouse Gas Emissions by Sector
(Percentage points, 1990–2017)

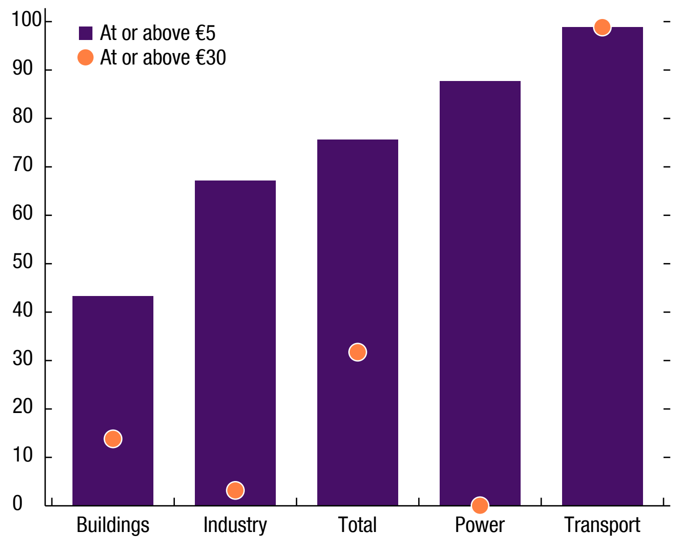


Source: United Nations Framework Convention on Climate Change.
Note: Excluding international aviation and shipping.

benchmarking of countries relative to one another, and discussing qualitatively the benefits and drawbacks of alternative policies. It also seeks to highlight positive examples and good practices. In aiming to cover the five largest-emitting sectors within a reasonable overall length, the paper does not attempt to be comprehensive within sectors. For example, the transport chapter focuses on passenger vehicles rather than commercial, and similarly the buildings chapter covers residential buildings but not public or commercial buildings, which can be subject to somewhat different policy considerations. Finally, the paper does not consider carbon-absorbing sectors such as forestry and other forms of non-agricultural land use. As in the companion paper, the principal country coverage is that of the EU, although Iceland, Norway, Switzerland, and the United Kingdom are often included in cross-country comparisons.

The sectoral approach mirrors the European framework design. The EU climate change mitigation policy framework follows a sectoral structure, involving both target-setting and the application of the policy toolkit (Table 1). The ETS provides a unified cross-country carbon pricing framework but is mainly limited to emissions from energy generation and large industries. The majority (55 percent) of emissions arise from sectors outside the scope of the ETS and are dominated by road transport and buildings, with agriculture playing a significant role in some countries. For non-ETS sectors, the "Effort Sharing Regulation" (ESR) defines emission reduction targets at the country level (with more ambitious targets for richer economies).

Figure 3. EU+UK: Emission Pricing Coverage, 2015
(Percent of sector total)



Sources: OECD 2018; and IMF staff calculations.
Note: Median for Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, and United Kingdom.

Table 1. Existing EU Main Climate-Related Targets and Goals

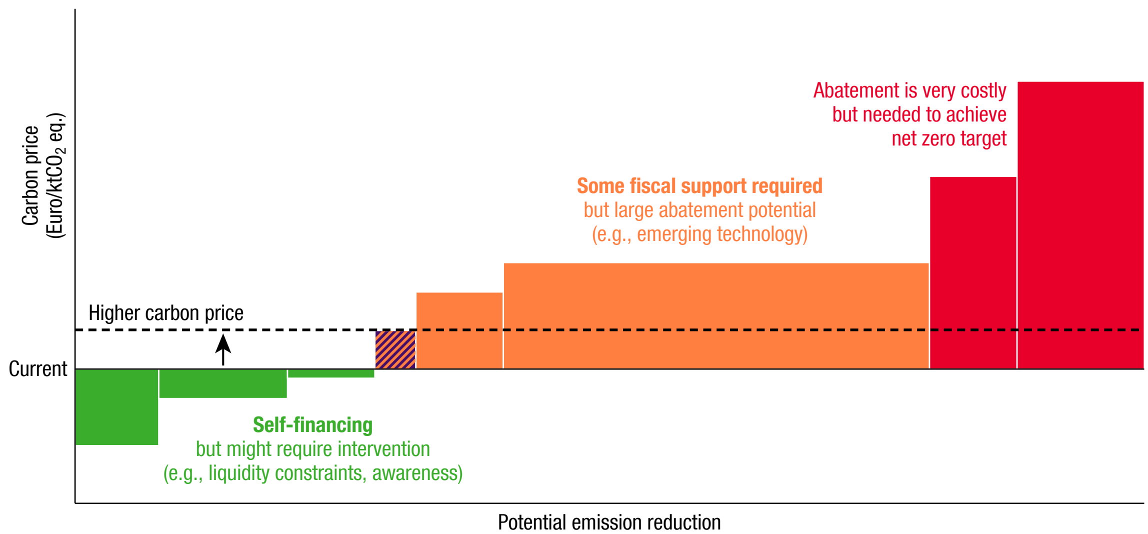
	Power	Industry	Transport	Residential	Agriculture
GHG Emissions	EU overall 40 percent reduction from 1990 level by 2030				
	EU–ETS cap: −43 percent by 2030 relative to 2005				
			EU: −30 percent by 2030 relative to 2005 Effort Sharing Regulation targets by country		
			EU-wide target*		
Renewable Energy	Increase in share of renewable sources in the EU to at least 32 percent of final energy consumption by 2030				
			Target by country**		
Energy Efficiency	Improvement in energy efficiency of at least 32.5 percent at EU level by 2030 (relative to EC's 2007 baseline)				
			EU-wide target*		

Source: IMF staff.
Note: Table shows targets prior to any revisions for EU Green Deal. Orange denotes a country-level target; grey denotes EU-level target.
*Indicative target of a 20 percent reduction from 2008 levels by 2030 and a 60 percent reduction in transport greenhouse gas emissions by 2050 compared to 1990. Also, EU binding targets related to new vehicle efficiency.
**Target of 14 percent minimum share of renewable energy in transport final energy consumption by 2030.

Within these country-level targets, multiple measures in the non-ETS sectors (including any explicit carbon pricing) are set at the national level to complement EU-wide measures such as efficiency standards and tax rate floors. Effective carbon pricing coverage and rates tend to vary considerably across sectors (Figure 3).

Conceptually, there are valid reasons for differing supplementary policies across sectors. Carbon pricing is a key tool in driving the transition to a low carbon

Figure 4. Marginal Abatement Cost Curve



Source: IMF staff based on Hood (2011).
Note: The figure shows a stylized marginal abatement cost curve, which plots out the marginal costs of achieving a cumulative level of emissions abatement in order from the lowest- to highest-cost technology or measure. Each block represents a particular abatement channel, with the bar's width representing volume of CO_2 reduction potential and its height showing the average cost of abatement per unit of CO_2 saved.

economy in a cost-effective manner, as discussed in detail in the companion paper.[3] However, political constraints and/or market barriers and frictions other than the climate externality may require supplementary policies (Stern-Stiglitz Review). These are likely to vary by sector, and may relate, for instance, to the dynamics of innovation (for example, learning by doing, economies of scale, R&D externalities, network externalities); to the slow adoption of new or existing technologies (for example, public good provision, asymmetric information, financial constraints, myopia); or other factors. For instance, supplementary policies may be needed to address non-price barriers to otherwise self-financing abatement measures (purple section of Figure 4). Conversely, some abatement opportunities (green section of Figure 4) may be too costly for an early-phase carbon price to unlock without rising to levels that raise concerns over distributional impacts. More targeted policies, such as dedicated technology funds, low-carbon technology mandates, or R&D support, may be needed to bring forward new mitigation options and reduce future abatement costs.

[3]Once emitters are confronted with the full cost of their actions, they will find ways to reduce their carbon output. How exactly they do this is left to them, rather than prescribed by a regulator. This flexibility is associated with economic efficiencies in the form of lower overall abatement costs. More generally, the appeal of carbon pricing is that it provides across the board incentives to reduce energy use and shift toward cleaner energy; it can induce investment and innovation in the absence of non-price barriers; it can mobilize a valuable source of new revenue; and it can be straightforward to administrate (for example, building off existing fuel tax collection).

As highlighted in the individual chapters, sectors differ along several dimensions relevant to policy design.

- **Abatement opportunities.** In some sectors, there is evidence of untapped cost-effective measures with significant abatement potential (such as insulation in residential housing), suggesting the presence of significant non-price barriers. On the other end, technologies for full decarbonization do not yet exist in some "hard to treat" sectors (such as aviation and shipping). Carbon pricing by itself is unlikely to be an effective mechanism in bringing forward low-carbon innovation and investment in multiple areas, such as carbon capture and storage technology (CCS), energy efficiency in buildings, low-carbon heat, and electric vehicle charging infrastructure.
- The **risk of "carbon leakage"** whereby emissions intensive production shifts from higher- to lower-taxed jurisdictions, is typically more significant in industry, agriculture, and international transport, compared to sectors that are harder to outsource, such as domestic transport and residential buildings.
- **Technological lock-in periods.** The life expectancy for cars is generally shorter than for planes, which in turn is generally shorter than for housing. As a result, in some sectors, policy measures on flows may be adequate, while others may require policies to replace, renovate or retrofit the existing stock directly. Carbon pricing (acting on fuel use) may not be sufficient on its own to incentivize these investments, so complementary measures such as investment subsidies, standards and feebates can play important roles.[4]
- Some activities may be associated with significant **co-benefits or other external costs**, strengthening the case for policy action. For instance, a dietary change away from beef and dairy would bring health improvements as well as reducing agricultural GHG emissions, and a shift toward mass transport would reduce congestion and local air pollution.
- The **distributional implications** of different policy alternatives in certain sectors may be more regressive or may affect certain segments of society disproportionately (absent mitigating policies). For instance, domestic energy spending as a share of total consumption tends to be more regressive than road transport spending. The closing of coal mines will have significant employment consequences in specific regions.

Interrelations across sectoral policies needs to be taken into account. Clearly, less progress in one sector will require higher ambitions in other sectors, but technologies themselves may also be interrelated, particularly for the energy sector. As discussed in this paper, electrification will need to play a crucial role in decarbonizing various sectors (such as road transport, residential

[4]Feebates combine features of environmental standards and carbon pricing, and stand between the two in terms of economic efficiency—see Chapter 3 for details.

heating, and industry). This implies that progress toward a clean energy mix is a pre-condition for progress in many sectors. It also implies that electricity demand will increase significantly over the next decades. Anticipatory investments to upgrade electricity networks will be required, so grid capacity constraints do not hold back the needed accelerated uptake of electric vehicles. Solutions that enhance system flexibility (for example, "smart" vehicle charging or building heating and cooling), will be important to ensure that power demand peaks are manageable and enable maximum use of renewable generation. At the same time, sectoral energy efficiency measures (for example, lighter and more aerodynamic vehicles, residential insulation, etc.) will help reduce the increase in electricity demand.

The COVID-19 crisis does not diminish the importance of tackling climate change, but adds to the importance of identifying comprehensive policy packages that can deliver both economic growth and emissions reductions. GHG emissions have temporarily fallen with the "great lockdown" COVID-19 recession, but concentrations of CO_2 in the air have continued to increase albeit temporarily at a slower pace. Meanwhile countries are facing much more challenging economic conditions, with high unemployment and poverty incidence, large fiscal deficits, and much increased public debt ratios. Behavioral changes in the aftermath of the pandemic can also be expected, which could affect climate change mitigation efforts in as yet unpredictable ways.[5] In these circumstances it is important for countries not to lose sight of climate objectives, but to consider how to prioritize and sequence green policies so as to best support economic recovery. Carbon pricing can provide a much-needed source of revenue, but the pace of fuel price increases needs to be gauged so as not to hinder nascent growth. Low oil prices provide an opportunity to cut fossil fuel subsidies without increasing overall fuel bills. And of particularly importance from a sectoral point of view, governments are likely to bring forward and augment public investment, as a boost to demand while businesses and consumers remain reluctant to consume and invest. "Green" investments, including priority areas laid out in the chapters that follow, are often relatively job-intensive—for example, building renovation, installation of solar and wind generation, and adoption of more sustainable farming methods—and should therefore be at the forefront of governments' recovery packages.

[5]For example, businesses may emerge from the lockdowns more comfortable with videoconferences in lieu of business travel. Conversely (in terms of emissions), people may seek to move from city centers to the suburbs, and/or rely less on public transport. It is too early to speculate on the net effect of such changes.

CHAPTER

2 Power Sector

Overview of Emissions and Drivers

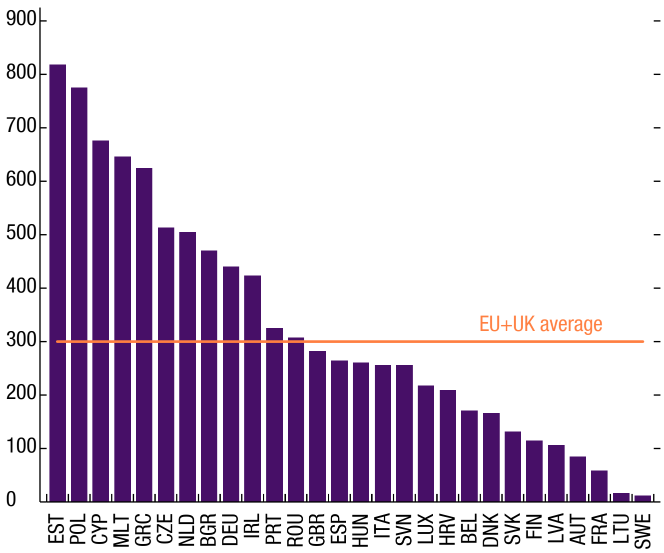
Domestic energy production accounts for about 30 percent of EU GHG emissions. Nearly half of the EU's energy consumption is produced domestically, mostly in the form of electrical power.[1] However, the emission share of domestic energy production is relatively lower as imports are dominated by fossil fuels (mainly oil and gas for transport and heating), which are more carbon intensive. Within power generation, GHG emission intensity is relatively higher in most Eastern European countries, which are more reliant on coal, while the least-emitting large producer is France, due to the importance of its (emission-free) nuclear sector (Figure 5).

Emission reductions in the power sector have been mainly driven by improvements in emission intensity (Figure 6). Over the past two decades, the ratio of emissions per electricity produced has declined in virtually all countries. In comparison, reductions in electricity produced per unit of GDP have been uneven and unable to compensate fully for the positive effect of GDP growth on total emissions, reflecting sustained demand for electricity from downstream sectors. In general, Scandinavian countries have been among the most successful in reducing emissions through improvements in emission intensity.

Notwithstanding progress in recent years, the penetration of renewables remains low. Renewable energy still accounts for less than 30 percent of EU primary energy production, and 20 percent of final energy consumption (Figure 7). The main energy sources are fossil fuels (mainly coal, gas, and

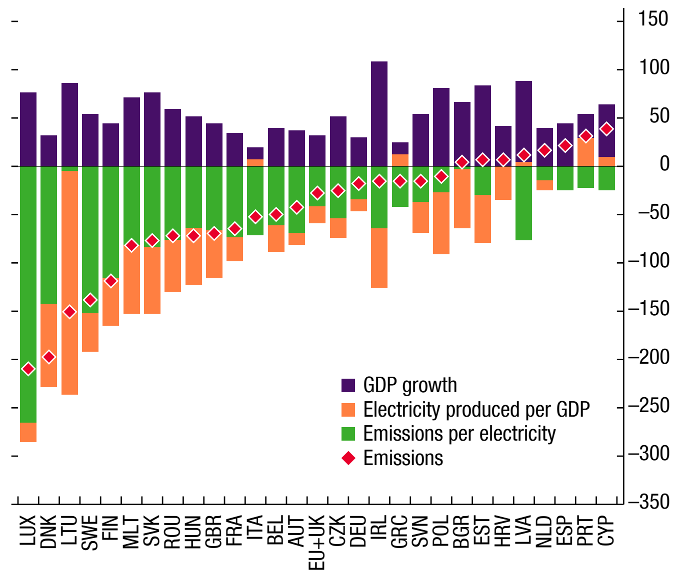
[1]Power represents 88 percent of the energy generated in the EU. Other activities included in the energy production sector are fossil fuel extraction, distribution and refining, and some forms of heat production (for example, district heating).

Figure 5. GHG Emission Intensity of Power Generation, 2016
(g CO_2 equivalent / kWh)



Source: European Environment Agency.
Note: Country list uses International Organization for Standardization (ISO) country codes. GHG = greenhouse gas.

Figure 6. GHG Emissions—Power Sector: Drivers, 1996–2017
(Growth in percent; contributions in percentage points)



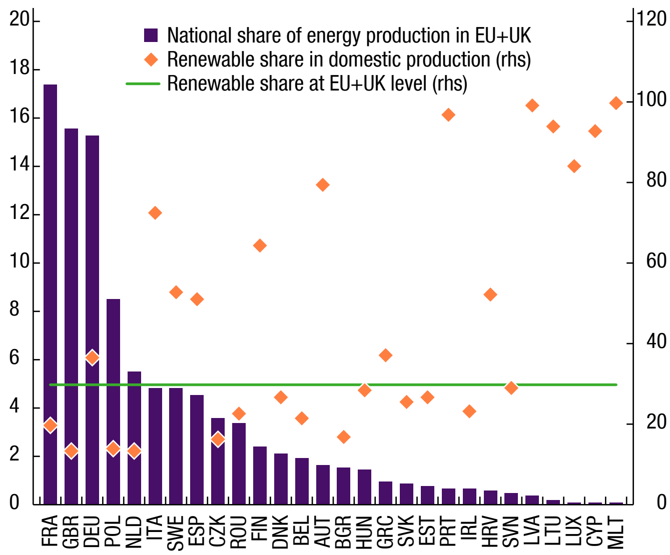
Sources: European Environment Agency; and IMF, *World Economic Outlook*.
Note: Growth rates are computed as change in logs. Country list uses International Organization for Standardization (ISO) country codes. GHG = greenhouse gas.

crude oil), followed by nuclear (Figure 8). Within renewables, 60 percent of production comes from bioenergy and waste, while the share of purely emission-free sources is still small. Across countries, the largest energy producers (France, United Kingdom) display some of the lowest renewable shares in the EU.[2] Germany is the only large producer with an above-average share, owing to more supportive policies (Box 1).

The EU has set progressively tighter emission reduction goals for the power and industry sectors. Both the energy production and industry sectors are covered by the ETS, so their emission reduction targets are set jointly. The EU's current target is to cut emissions from these two sectors by 21 percent in 2020 (relative to 2005), by at least 43 percent in 2030 (the target is likely to be increased in the context of the Green Deal), and by virtually 100 percent in 2050. While the energy sector is on track to "overperform" the 2020 goal, future goals will not be attained unless the current pace of emission reductions is accelerated (Figure 9).

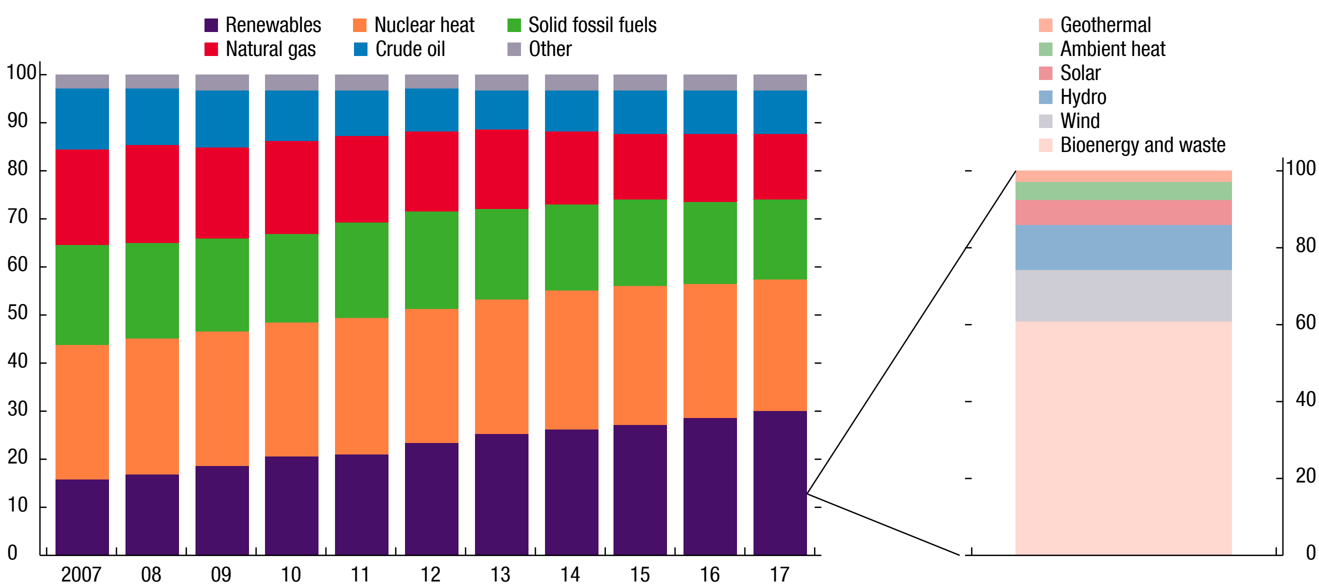
[2]In France, this is due to the weight of nuclear energy, which is emission free but not classified as renewable energy by the EU. In the United Kingdom, relatively low-emitting natural gas has a large share.

Figure 7. Renewables in Energy Production
(Percent)



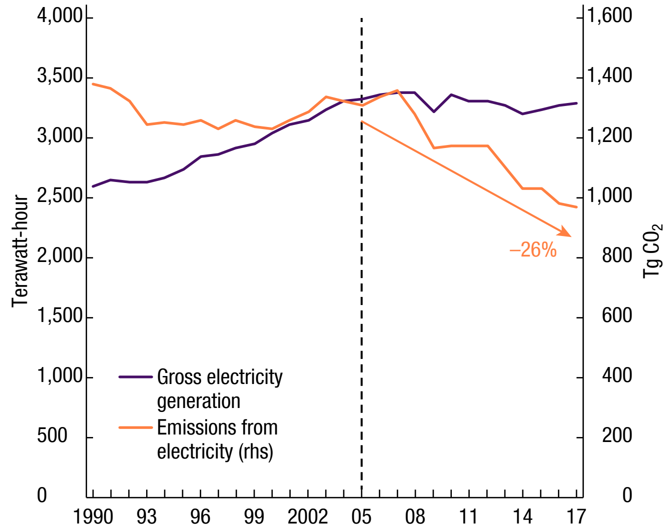
Source: European Environment Agency.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 8. EU+UK: Production of Primary Energy by Fuel Type
(Percent of total)



Source: European Environment Agency.

Figure 9. EU+UK: Electricity Generation and Emissions



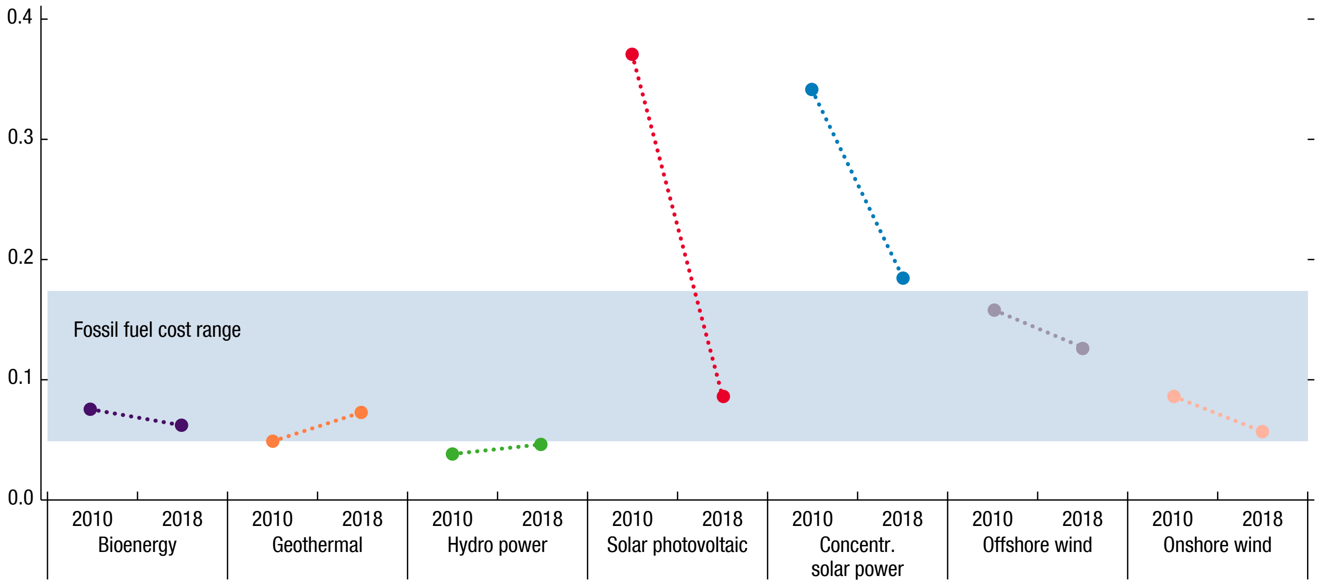
Source: European Environment Agency.

Abatement Channels

Further reducing emissions in power generation will require transitioning from fossil fuels to renewables. Barring an expansion of nuclear energy, which poses potential environmental issues other than GHG emissions, further increasing the share of renewables is the only way to achieve a meaningful reduction in emissions per energy consumed. A substitution of coal with gas may help in the short term, but it would not allow to attain the ultimate EU target of zero net emissions by 2050. As of 2018, the cost per unit of power of new renewable plants was already similar or lower than for new fossil fuel plants across different technologies (excepting offshore wind and concentrating solar power), so price competitiveness is no longer an issue (Figure 10).[3] However, given the extended lifetime of existing plants (20–40 years), an effective abatement strategy would call for a frontloaded effort to phase out quickly high-emitting plants. Spurring innovation is also a key channel, both in renewable energy generation and in CCS to absorb any remaining emissions from power plants (for example, from biofuels), although CCS is still far from being price competitive.

[3]Similar reported costs across technologies could also partially reflect profit maximization, which would predict that competitive firms invest in each technology up to the point where marginal costs equal electricity prices. To the extent this is the case, it would imply investors could run into increasing costs as they expand renewable capacity.

Figure 10. Cost of Utility-Scale Renewable Power Generation Technologies
(2018 USD/kWh)



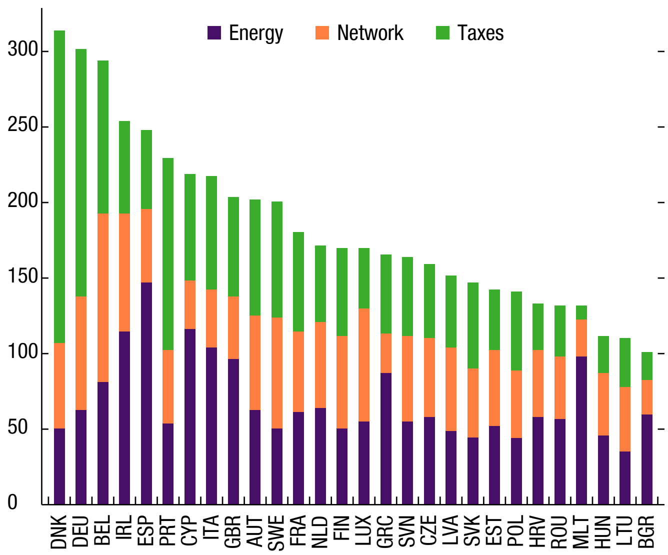
Source: International Renewable Energy Agency (IRENA 2019).
Note: Global weighted-average discounted lifetime cost per unit of electricity (LCOE) for plants commissioned in each year. The real weighted-average cost of capital is 7.5 percent for OECD countries and China and 10 percent for the rest of the world. The blue shade represents the fossil fuel-fired power generation cost range.

The transition to renewables and the electrification of downstream sectors will demand upgrading electrical infrastructure. The decentralized and intermittent nature of some renewable sources such as solar and offshore wind increases the need for coverage and interconnection of electrical grids, as well as for energy storage technologies. Further pressure comes from the expected increase in demand for electricity as other sectors such as transport and industry move from combustion to electrical engines and buildings from onsite heating to electrification (see respective sections). Both factors raise the needs for infrastructure investment.[4] Despite convergence in electricity prices across countries in recent years, the remaining dispersion in pretax prices (including within continental Europe) suggests further margin to integrate national electricity markets (Figures 11 and 12).[5] Innovations with potential in electrical infrastructure include storage systems such as "power-to-gas" technology, which convert electricity into emission-free gases such as hydrogen that can be later used for combustion or electricity generation; decentralized market platforms; and more efficient digitalized grids (ECOFYS 2019a).

[4]At the same time, electrification in other sectors can also help. For example, electric cars can provide storage capacity for renewable power.

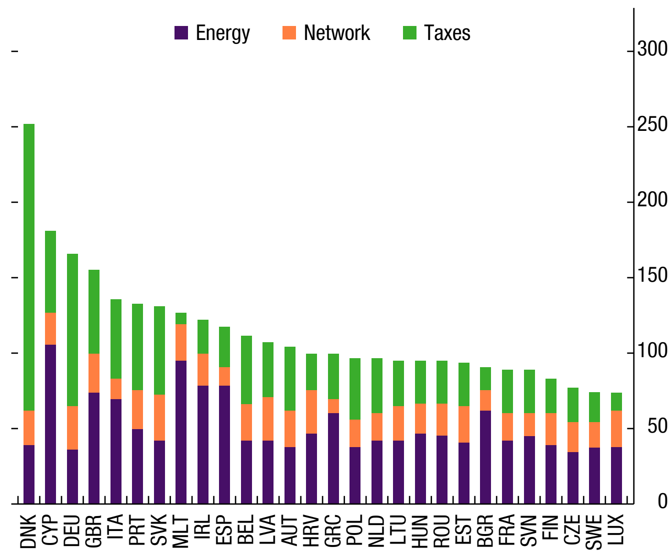
[5]Electricity prices tend to be substantially lower for industry than for households, as governments often set lower taxes or network charges for industry in order to boost its competitiveness.

Figure 11. Household Electricity Prices, 2018
(EUR/MWh; consumption band: 2,500–4,999 kWh)



Source: Eurostat.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 12. Industry Electricity Prices, 2018
(EUR/MWh; consumption band: 2,000–19,999 kWh)



Source: Eurostat.
Note: Country list uses International Organization for Standardization (ISO) country codes.

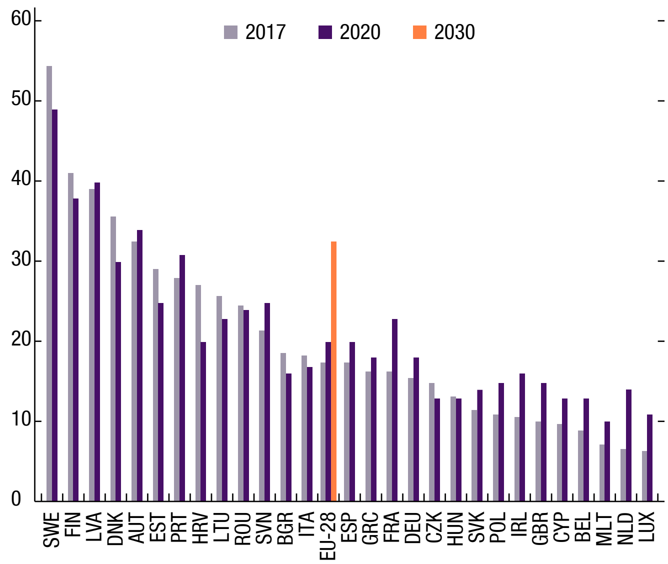
Going forward, CCS will require developing carbon transport networks to link emission source to storage sites.

Consistent with these abatement options, the EU Green Deal raises the targets for renewable penetration and grid interconnectedness. In addition to the emission-reduction goal, the EU aims to achieve the following targets by 2030 in the energy sector: (1) increase the aggregate renewable energy share of final energy consumption from 20 percent in 2020 to 32 percent (Figure 13) and (2) deepen energy interconnection from 10 to 15 percent of domestic production in each country. The latter means that each country's electrical grid should be able to transport at least 15 percent of the electricity produced by its power plants to neighboring countries. At the national level, countries have also committed to achieve specific renewable energy shares through National Renewable Energy Action Plans.

Policy Frameworks

The main EU policy tool to contain energy sector emissions is the Emissions Trading System (ETS). The ETS auctions emission permits for the energy and industry sectors. Effectively, this sets a common EU price for carbon

Figure 13. Share of Renewables in Final Energy Consumption
(Percent of total energy consumption)



Source: Eurostat.
Note: Country list uses International Organization for Standardization (ISO) country codes.

emissions (see companion paper for a detailed discussion).[6] Current prices are at €25 per ton of CO_2 and have been lower and volatile in the past decade.[7] Beyond carbon pricing, the EU is designing a renewables financing mechanism and the Green Deal pledged €1 trillion of public funds by 2030 to support green investment, but the fraction that will be allocated to energy production and distribution is still to be announced. On the private financing side, the EU is developing an Action Plan to encourage the flow of capital toward green technologies.

EU policies coexist with national measures to support renewable investment. In addition to the price incentives provided by the ETS and EU investment programs, countries have implemented various policies to support investment in renewable energy, in many cases using multiple instruments at a time (Figure 14). These include:

[6]Lower-income EU countries are allowed to allocate permits freely to the power sector if the funds are used for modernization investments, but the allocation of free permits deducts from their potential auction revenue (EC 2015a).

[7]While some EU countries impose national carbon taxes, energy production is usually exempt as it is already covered by the ETS (EEA 2016b).

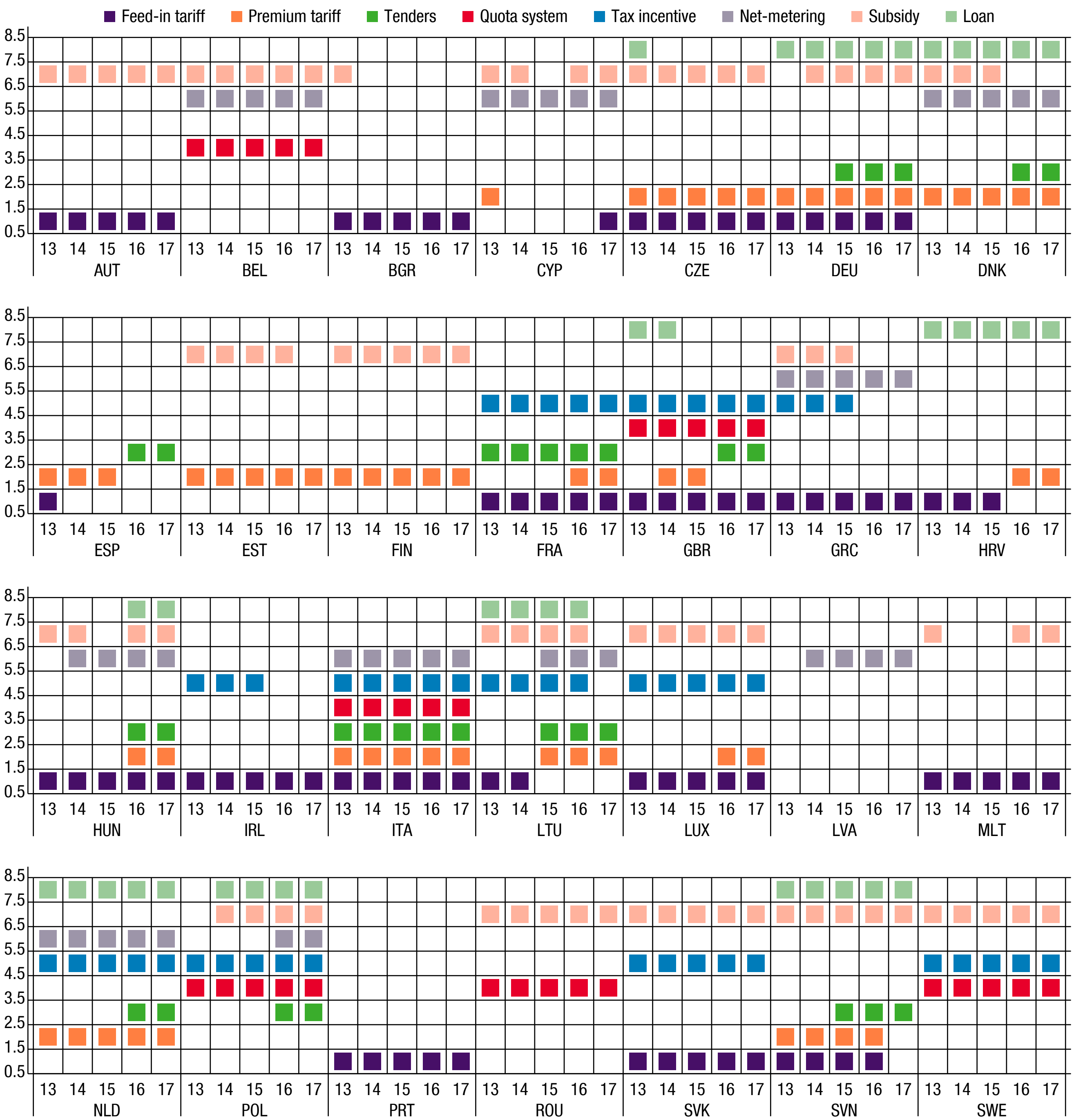
- **Auctions/tenders:** renewable energy producers submit bids to supply a given quantity of power, which is compensated at above-market rates. Tenders are usually technology-specific, but a few countries have opened them to any renewable technology.
- **Feed-in tariffs:** governments mandate that utility firms or transmission system operators pay an above-market price to renewable producers during a certain period.
- **Quotas:** either energy producers or wholesalers are required to supply a certain fraction of their energy from renewable sources. Typically quotas are tradeable between market participants.
- **Net metering:** electricity consumers who also generate electricity, for example, households with a solar installation, are allowed to "virtually" consume their self-generated electricity any time at a fixed price, to mitigate the cost of hourly fluctuations in production.
- **Tax incentives**. For example, feebates that tax power generators with higher emissions and rebate the revenue to those with lower emissions.[8]
- **Investment grants.**

Auctions have become the most widespread tool at the national level. Many countries have moved from fixed feed-in tariffs to feed-in premiums determined by competitive bidding, in line with EC state aid guidelines. The rationale was to maximize cost-efficiency and to control either the volume of new installations or the fiscal cost. In most of the countries that introduced auctions, implicit public support fell, reflecting increased competition and lower technology costs and interest rates. However, the uncertainty and delays caused by the transition toward auction systems has slowed down renewables deployment in some cases (ECOFYS 2019b). Going forward, corporate renewable power purchase agreements (PPAs), that is, private sector purchases of renewable power motivated by stakeholder pressure, are expected to play a larger role in increasing demand for renewables.

Countries have also committed resources to electricity infrastructure investments. EU capital expenditures in electricity transmission are projected at €152 billion over the next decade (ECOFYS 2019a). Gas transmission and electricity storage follow with €41 and €14 billion, respectively. Financing channels for these projects combine (1) revenue from regulated grid tariffs; (2) public funds from the EU Connecting Europe Facility and national budgets; (3) debt, including loans from the European Investment Bank and the European Bank for Reconstruction and Development; and (4) equity.

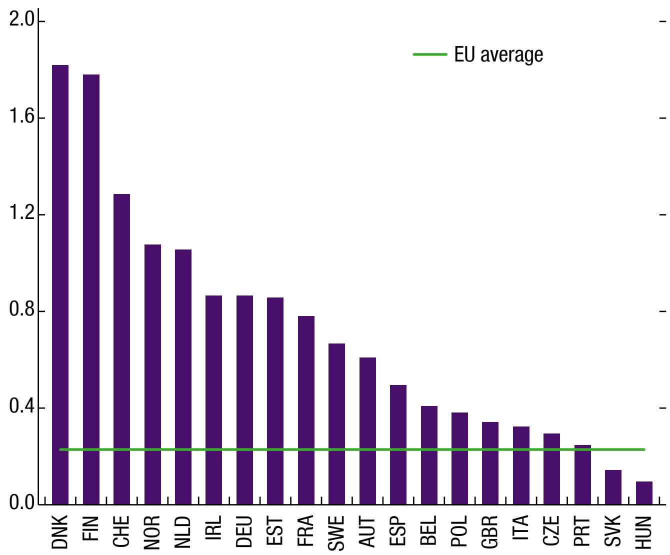
[8]The Swedish feebate for NOx emissions from power plants implemented in 1990 is a successful albeit restrictive case.

Figure 14. Support Schemes for Renewable Energy



Source: ECOFYS.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 15. Public Expenditure for R&D in Renewable Energy Sources, 2015
(Basis points of GDP)



Sources: IMF, *World Economic Outlook*; OECD; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

A common challenge for investors is the need for long-term investment planning against a backdrop of uncertain regulation and utilization rates. As of 2017, the EC estimates that electricity interconnection capacity in the following countries is below 30 percent of the projected renewable power capacity in 2030, suggesting critical investment needs: Cyprus, United Kingdom, Greece, Ireland, Spain, Italy, and Germany (by increasing order of interconnection—EC 2017).

Renewable R&D support has been limited in most countries. The EU starts with an early-mover advantage, currently registering 30 percent of the world's patents in renewable energy (EC 2017). However, momentum seems to be slowing (Acemoglu and others 2019) and public R&D in renewables is low in most countries, averaging less than 0.7 basis points of GDP (Figure 15).[9] For comparison, EU total public R&D is 0.23 percent of GDP (Eurostat). Aside from renewables, a number of EU countries support R&D in electrical grid innovation through favorable tariffs or specific allowances (EC 2019a).

[9]Data for most countries are available up to 2015. In 2015, EU countries promised to double public R&D in renewables by 2021 as part of the Mission Innovation within the Paris agreement.

Policy Recommendations

Carbon pricing at the EU level should be the main tool to incentivize the transition toward clean energy sources. Carbon pricing allows equating the marginal abatement cost to the social cost of emissions, both across countries and technologies. The EU ETS constitutes an appropriate framework to implement carbon pricing in the power sector. It should be strengthened by reducing the amount of outstanding permits, so prices reach sufficient levels to meet emission goals, and introducing a robust price floor to provide stability to investors (see companion paper). The companion paper shows that gradually increasing the uniform carbon price to €60–100 per ton by 2030 would permit the EU to meet its emission reduction and renewable share goals.[10] Instead, differentiated carbon prices across countries would lead to an inefficient allocation of mitigation efforts and could be subject to the "waterbed effect," where efforts in one country are partially undone by relaxation in others. However, absent sufficient progress at the EU level, national efforts are welcome. Phasing out low regulated electricity prices and any tax exemptions for fossil fuels are necessary steps to make energy prices more consistent with social costs.[11]

Support for renewable R&D and infrastructure investment is key to tackling additional market failures. Higher energy pricing would already provide incentives for the private sector to step up innovation in cleaner energy sources (Newell, Jaffe, and Stavins 1999; Popp 2002). However, other market failures beyond emission externalities impede an efficient response from the private sector. R&D in clean energy technologies is particularly subject to positive knowledge spillovers, as rewards to innovators tend to accrue further in the future than in other technologies, making public R&D and subsidies to private R&D essential in this sector (Dechezleprêtre, Nachtigall, and Venmans 2017). Public R&D should be targeted to basic or early stage research, and managed at the EU level given the largely borderless nature of knowledge flows. Electrical, gas, district heating, and carbon networks constitute natural monopolies, so public support for investment is needed to achieve an efficient level of provision. Grid planning should prioritize international connectivity and digitalization to maximize efficiency and capacity. High fixed costs, financing constraints, and investor short-termism may prevent the front-loaded investment needed to expand the renewables share and electricity grids fast enough to meet EU goals. This would justify publicly guaranteed loans, public-private partnerships, or grants to young innovative firms, as well as developing the green financing market.

[10] Prices are expressed in 2019 euros. The range is based on different revenue recycling options.

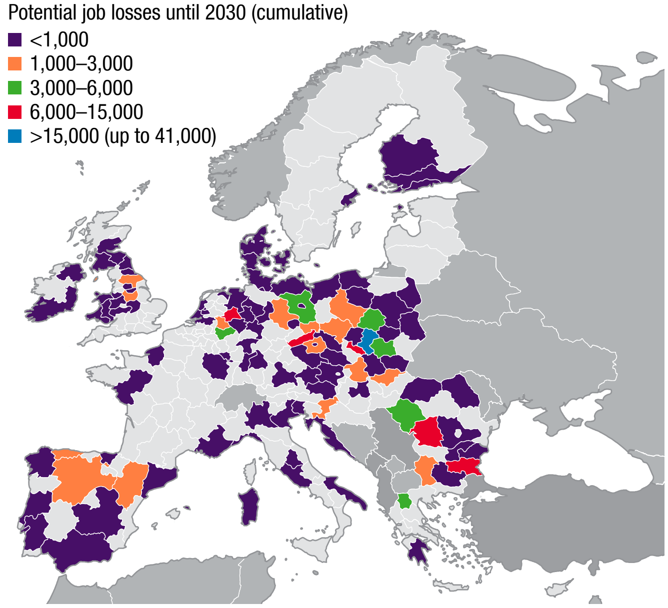
[11] Coady and others (2019) estimate EU foregone consumption tax revenue in fossil fuels at about $46 billion, while explicit subsidies are much less prevalent at $1 billion.

Subsidies to renewable investment would lower the carbon prices needed to achieve the targets, easing political concerns. With a sufficient carbon price, many of the renewable support policies in place would become redundant (Jones and Keen 2009). The carbon price consistent with a reduction of emissions by 50 percent by 2030 is estimated to incentivize €1.4 trillion of investment in renewables over the next decade, more than the amount needed to reach the EU renewables goal (see companion paper). Moreover, while investment in green energy plants may generate some positive learning by doing externalities, these tend to be limited and short-lived (see Bollinger and Gillingham 2014 for a study of solar generation, and Nemet 2012 for the case of wind turbines). Hence, generalized subsidies to technological deployment are less justified than at the R&D stage. Another motive for green investment subsidies is assuaging political resistance against energy price hikes, since subsidies lower the carbon price required to achieve a certain emission reduction. For example, a feebate scheme for power generators would achieve cuts in emissions without adding a net tax burden on the industry. However, other instruments such as income taxes or cash transfers would be better targeted than energy subsidies to compensate and protect vulnerable groups.

Policy tools such as subsidies, auctions, and regulations must be predictable, impartial, and easily accessible. They must strike a balance between building in robust anti-corruption safeguards and still delivering a streamlined process for private sector participants (for example, in public procurement). Market-based instruments such as auctions can be more cost-effective, flexible, and transparent than regulations, although in certain cases they diminish certainty for investors (Vollebergh and van der Werf 2014). The empirical evidence remains mixed on whether market-based or regulatory approaches encourage more renewable innovation (see Popp [2019] for an exhaustive review of the optimal policy literature). While in principle energy-neutral policies should avoid the risk of handpicking the wrong technologies, they can also create a bias for technologies closer to the competitive stage to the detriment of others with higher future social returns (Johnstone, Hascic, and Popp 2010). Box 1 provides a case study of how a combination of policies has fostered a rapid transition to renewables in Germany.

Compensation policies should address the impact of carbon pricing on vulnerable consumers and workers. Model simulations indicate that the carbon prices needed to meet emission goals would raise electricity prices by 20 percent on average by 2030 compared to 2020, and lower employment in coal mining by 70 percent. Low-income households would suffer the most from an increase in electricity prices as a share of their income, while coal-mining communities face the prospect of a surge in structural unemployment as coal power generation becomes unprofitable. The effects of abandoning coal

Figure 16. Projected Job Losses in the Coal Mining Sector by 2030



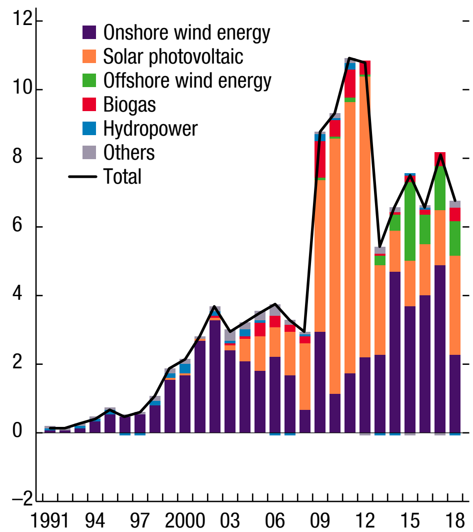
Source: Alves Dias and others 2018.
Note: EU+UK-wide job losses add to about half of those projected by the model, which incorporates the more ambitious emission goal in the Green Deal (–50 percent).

would be felt particularly deeply in a few European regions (Figure 16). Governments could use existing social safety nets, such as unemployment benefits, the income tax system or cash transfers, to mitigate the effects on low-income households, while local policy tools would be better suited to foster growth in coal-mining areas. The latter could include active labor market policies and well-targeted public investment.

Box 1. Renewable Energy Transition Policies in Germany

The Energiewende *(energy transition) is Germany's plan to transition to a low-carbon, nuclear-free economy. The transformation has primarily focused on expanding the share of renewable energy in power generation. The boom of wind and solar power, triggered by policy and financial supports, pushed renewable sources to overtake coal as the most important power source in Germany in 2018. Looking ahead, the slow progress of grid expansion and storage solutions pose new challenges to achieve the authorities' ambitious target of 65 percent of power consumption covered by renewable sources by 2030.*

Figure 1.1. Germany: Increases in Renewable Electricity Capacity
(Gigawatts, annual change)



Source: AGEE-Stat.

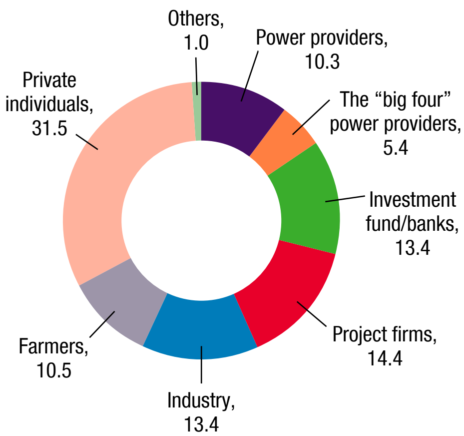
Financial incentives for renewable energy investment in Germany date back to 1990, when the government introduced feed-in-tariffs above wholesale market prices, fixing returns for investors in advance for 20 years. However, the initial feed-in rate was not high enough to make the production of renewable energy competitive with conventional energy. The Renewable Energy Sources Act (EEG) in 2000 stipulated significantly higher fixed feed-in tariffs for renewable energy production and priority access to the grid for renewables. The feed-in tariffs were later reduced (for new investors) in 2014 and further converted into auctions in 2017. (Figure 1.1).

The rapid growth of renewables in power generation since 2000 was led by German households' participation in renewable energy investment. The feed-in tariffs encouraged households to install photovoltaic (PV) panels on their roofs, either feeding the electricity into the grid or consuming it themselves. Households also banded together to invest in larger-scale installations. Various legal forms of ownership allowed them to own solar parks and wind turbines. In 2016, the total installed renewable energy capacity amounted to 100.3 gigawatts, of which 31.5 percent was owned by private individuals and another 10.5 percent by farmers (Figure 1.2).

Despite the boom in wind and solar power, the current share of power consumption covered by renewable sources is still far from the government's goal of 65 percent by 2030. More importantly, recent trends in renewable investment indicate new challenges. The auction scheme opened the sector to market competition but may have put

Box 1. Renewable Energy Transition Policies in Germany *(continued)*

Figure 1.2. Ownership of Renewable Power Capacity, Germany, 2016
(Percent of total)



Source: Renewable Energies Agency.

smaller competitors at a disadvantage. The lagging expansion of high-voltage transmission lines, which are needed to transmit power from productive wind farms in the north and northeast to industrial centers in the south, also poses a barrier to renewable expansion. Further, appropriate storage solutions are needed to cope with the volatility of renewable power supply.

Chapter

3 Transport Sector

Overview of Emissions and Drivers

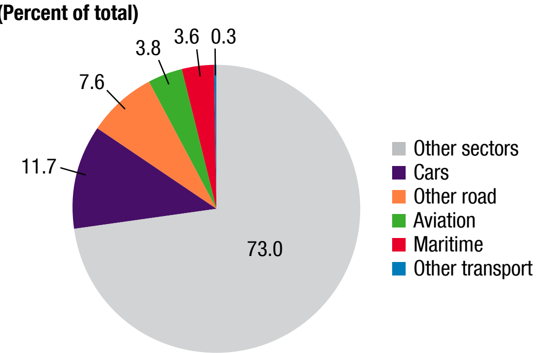
The transport sector (including international travel) has grown to become the highest-emitting sector at the European level. Total transport emissions account for nearly 30 percent of total EU emissions, ranging between 15 and 40 percent of the total at the individual country level.[1] Surface transport is the largest-emitting subsector, with about 70 percent of emissions (70 percent of which is accounted for by cars). In contrast to all other main sectors, transport emissions have increased significantly over time and are now nearly one-third larger than in 1990, driven by higher emissions in road transport and aviation (60 percent and 30 percent, respectively, of the increase). Passenger and freight traffic (and emissions) dropped in the aftermath of the global financial crisis, but have since recovered. Similarly, the very sharp fall in traffic associated with the COVID-19 crisis is expected to be temporary.

Gains in efficiency have been more than offset by material increases in demand for transport. Road transport emissions per distance travelled have decreased across most European countries (Figure 17). Distance travelled in relation to real GDP has also typically decreased, particularly in countries that have shifted away from manufacturing. However, this trend has been more than offset by growing population and real income. For instance, income growth in many Eastern European countries has led to significant increases in car ownership rates and traffic. The increase in travel demand has been particularly large for air transport, with air traffic growing in importance relative to all other transport modes.

[1]Excluding international aviation and navigation, transport accounts for about one-fifth of total EU28 emissions, and the sector is the highest-emitting sector in about one-third of EU28 countries.

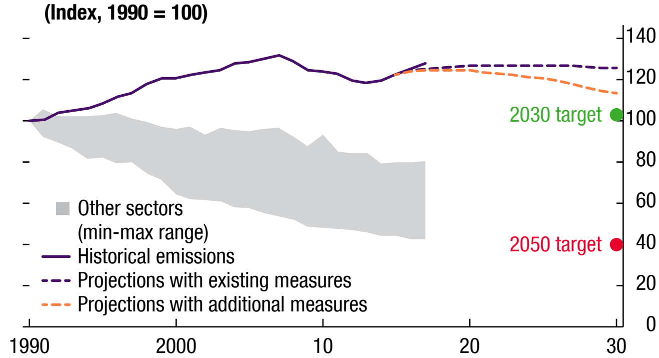
Figure 17. Transport Sector Emissions and Drivers

1. EU+UK: GHG Emissions Sectoral Composition, 2017
(Percent of total)



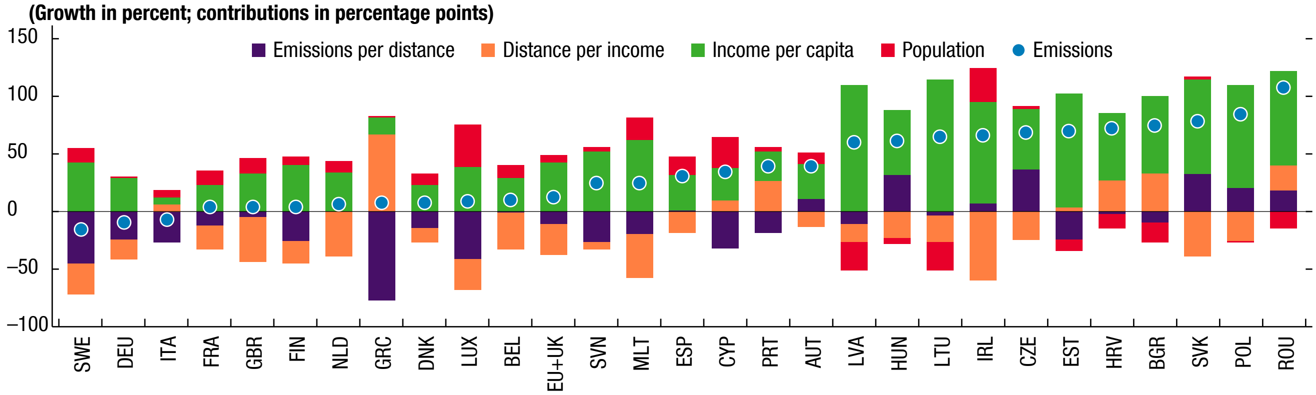
Sources: United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Includes international transport.

2. EU+UK: Transport GHG Emissions
(Index, 1990 = 100)



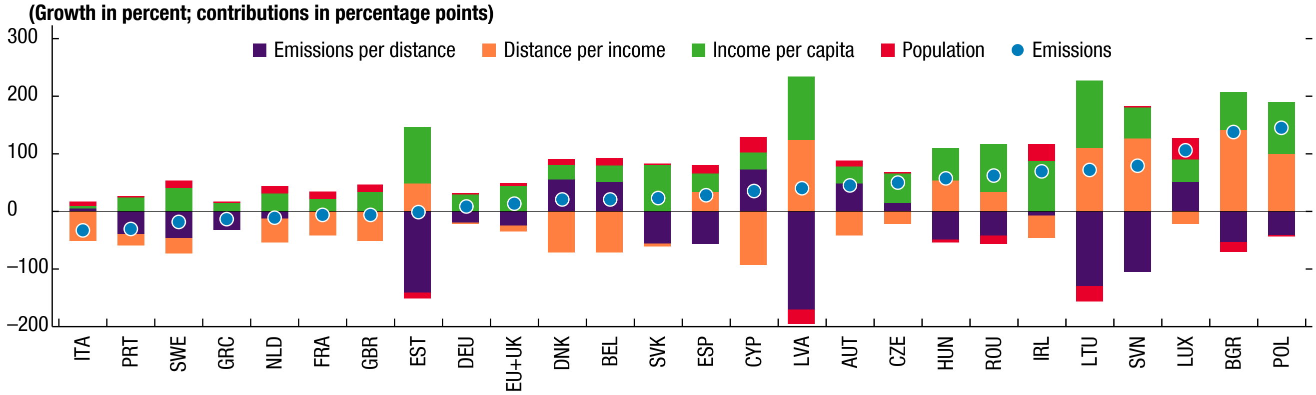
Sources: United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Includes international transport.

3. Drivers of Growth in Car Transport Emissions, 1995–2017
(Growth in percent; contributions in percentage points)



Sources: Directorate-General for Mobility and Transport; Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Car transport refers to road transport of cars and light-duty vehicles. Growth rates are computed as change in logs. Country list uses International Organizations for Standardization (ISO) country codes.

4. Drivers of Growth in Freight Transport Emissions, 1995–2017
(Growth in percent; contributions in percentage points)



Sources: Directorate-General for Mobility and Transport; Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Freight transport refers to road transport of heavy-duty vehicles. Growth rates are computed as change in logs. Country list uses International Organizations for Standardization (ISO) country codes

Attaining the EU transport sector climate goals would require a significant change in transport emissions trends. In 2011, the EC set out an indicative target of a 20 percent reduction in transport GHG emissions (excluding international maritime) from 2008 levels by 2030, and a 60 percent reduction by 2050 compared to 1990.[2] After decreasing from 2007 to 2013 (in the aftermath of the financial crisis), transport emissions have reverted to their precrisis trend, increasing each year through 2019. Official projections based on policy measures currently in place show emissions broadly constant over the next decade.[3] The implementation of planned policy measures, such as tighter standards, would reduce emissions by about 10 percent, but they would remain off-track relative to established goals absent additional policy action (according to member states' 2019 projections). Moreover, the sector's targets were set as part of an EU strategy to meet an overall goal of reducing GHG emissions by 80 to 95 percent by 2050. Attaining the new more ambitious goal of net zero emissions would therefore require even greater efforts.[4]

Abatement Channels

The scope and alternatives for reducing emissions in the transport sector vary significantly depending on the time horizon, specific subsector, and country characteristics. In broad terms, reducing the environmental impact of transport can be addressed by managing travel demand or shifting toward cleaner transportation (including changes in transportation modes, improvements in the efficiency of traditional vehicles, or the deployment of cleaner technologies—fuels and vehicles).

- **Time horizon.** The scope for significantly reducing the transport sector's reliance on oil and oil products appears limited over the short to medium term.[5] As a result, emission-reduction measures would rely heavily on demand management, shifting to cleaner transport modes and improving efficiency in existing technologies.[6] However, there is likely a limit to how

[2]The target was reiterated by the EC in 2016. Emissions from international maritime transport have a target of at least 40 percent reduction relative to 2005 by 2050. Additional targets include attaining a 14 percent share of renewable energy in the transport sectors' final energy consumption for each member state by 2030, and reducing transport sector oil consumption by 70 percent relative to 2008 by 2050. The average share of renewable energy used in transport across EU28 stood at 8 percent in 2018, with significant variation across countries (from 30 percent in Sweden to close to 0.4 percent in Estonia).

[3]Projections refer to 2019 country projections submitted under the Monitoring Mechanism Regulation (EC No. 525/2013).

[4]Indeed, the EC has already noted in the context of Green Deal communications that transport emissions would need to be reduced by 90 percent by 2050 to be in line a climate neutral economy by 2050.

[5]Despite improvements in efficiency, the transport sector is still highly dependent on oil and oil products, accounting for 92 percent of its energy needs (EEA 2019).

[6]The latter includes vehicle efficiency, as well as gains from changes in fuel mix.

low emissions of conventional vehicles can go (as ultimately, a fuel has to be burned to produce power). With travel demand closely linked to economic development, attaining ambitious decarbonization objectives will require an accelerated uptake of clean technologies over the coming decade. Greater reliance on less emission-intensive transport modes will also remain crucial over the long term, as some subsectors are hard to decarbonize. Moreover, a move to cleaner technologies will not necessarily mitigate other externalities such as congestion.

- **Subsectors.** Full decarbonization of cars and vans is already technologically feasible, and electric vehicles are falling in cost on the back of declining battery prices.[7] Electric vehicles are broadly expected to reach cost parity with conventional vehicles over the coming decade.[8] Decarbonization of heavy-duty vehicles would be more challenging given the higher energy needs (from longer distances and heavier loads), but could be achieved through a combination of electrification and use of (sustainably produced) hydrogen fuel. Aviation and shipping are harder to treat sectors as technologies for fully decarbonization do not yet exist. While some needs could be met by less emissions-intensive transport modes (for example, greater use of rail for freight), remaining emissions on those sectors would have to be offset in other sectors to attain a net zero target (Burke, Byrnes, and Fankhauser 2019).
- **Country characteristics.** Abatement strategies would also be affected by country characteristics such as economic growth rates, fleet age, and the energy production mix. Countries with relatively old car fleets (such as Estonia, Latvia, Lithuania, and Poland) could reduce emissions by more than a quarter if they upgraded their car fleet to the average emission intensity of new cars in Portugal (the best-performing country over the last three years) (Figure 18). Decarbonization of the road transport sector via electrification requires a clean energy mix as a precondition.[9] The expected co-benefits in terms of air quality improvements and reducing congestion and noise would also affect the choice of abatement options.

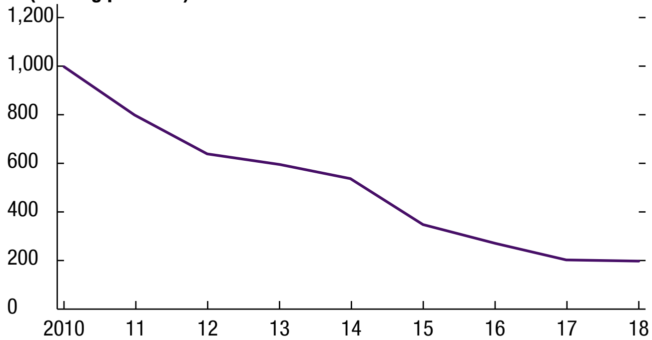
[7]Technology may imply other production-related pollution and or health hazards. This applies potentially to all sectors. This discussion is beyond the scope of the paper.

[8]There is less consensus as to when over the next decade parity would be reached: BloombergNEF 2019a argues it would be reached by 2022, CCC 2019a expects by mid-2020s, and MIT 2019 contends it would happen only toward the end of the decade (as the cost of raw materials is expected to rise following a sharp increase in demand).

[9]Estimates suggest there could be no gains from car fleet electrification in countries with a dirty electricity production mix such as currently in Estonia and Poland (assuming the country average mix is in line with the marginal mix used by electric car owners). Using wind power, lifecycle emissions of an electric vehicle could result in emissions almost 90 percent lower than an equivalent combustion engine vehicle (EEA 2018; IEA 2017).

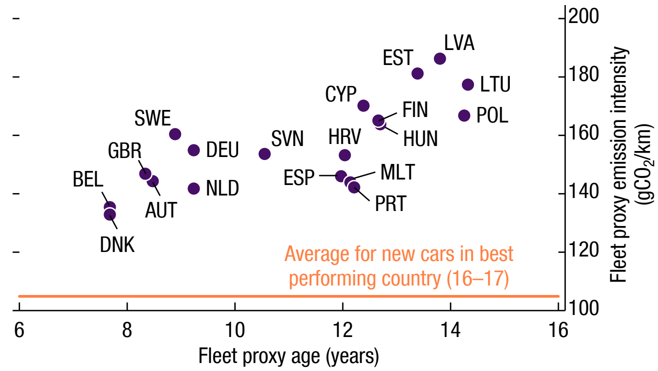
Figure 18. Car Efficiency and Electrification Potential

1. Average Cost of Electric Vehicle Battery Packs (Sterling per MWh)



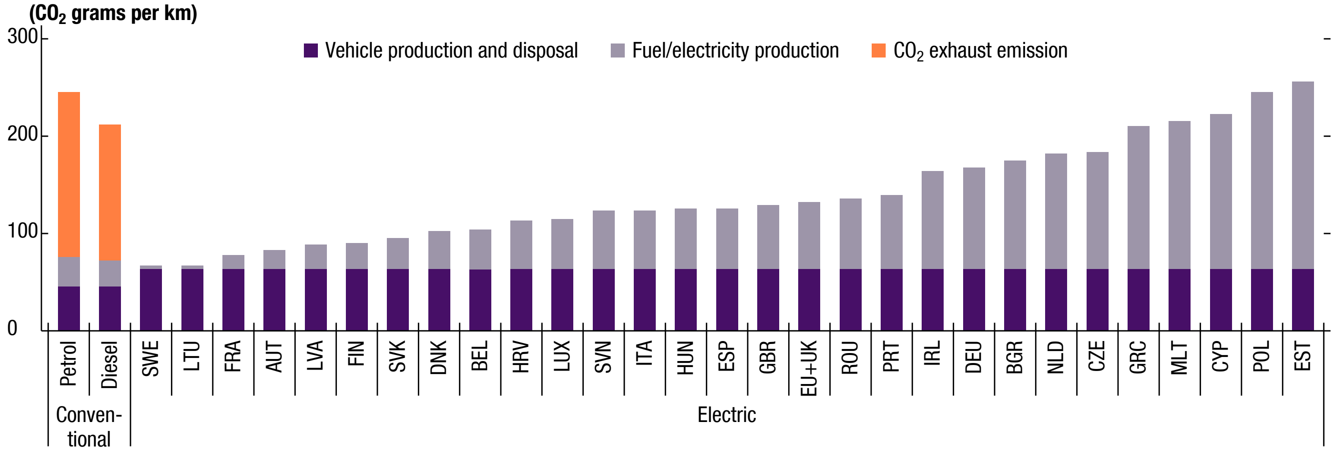
Sources: CCC 2019; and IMF staff calculations.

2. Passenger Car Emission Intensity and Age



Sources: Eurostat; and IMF staff calculations.
Note: Eurostat reports the share of the car fleet in the following categories: less than 2 years, 2 to 5, 5 to 10, 10 to 20, more than 20. The fleet proxy age is computed multiplying those shares by 1, 3.5, 7.5, 15, and 20, respectively. Proxy emission intensity is computed multiplying those shares by the average emission intensity for new cars in each country for 2017–16, 2015–13, 2012–08, 2007–00, 2000, respectively. If those are missing for any country, it is extrapolated using EU trends (obtained from the average of the max-min reporting countries).Country list uses International Organizations for Standardization (ISO) country codes.

3. Life-cycle CO_2 Emissions by Car Type (CO_2 grams per km)



Sources: European Environment Agency; and IMF staff calculations.
Note: Lifecycle emissions for passenger cars are obtained from TNO 2014. Electricity production emissions are obtained multiplying electricity emission intensity (gCO_2/kwh) for 2016 by a conversion factor for electric vehicles of 0.236 kwh/km (TNO 2014). Estimated for an average mid-class vehicle and a total distance of 220,000 km. Country list uses International Organizations for Standardization (ISO) country codes.

Road Transport Policy Framework

European countries rely on a multipronged approach to pursue their transport sector climate goals, including price-based and regulatory measures. This chapter discusses the pros and cons of fuel economy standards, fuel taxation, other fiscal incentives, and additional complementary policies.

Fuel Economy Standards

Standards may be less cost-efficient compared to price-based measures, but typically benefit from lower opposition. Standards typically mandate a specific amount of fuel economy/CO_2 reduction. They prompt people and firms to switch to greener technologies but do not discourage vehicle use, provide little incentive to outperform the given standards, and raise no revenue (which could be used to address distributional concerns). Standards tend to be politically acceptable, as they avoid an explicit tax burden on motorists, but the costs of implementing them are uncertain and are still passed on to consumers. If the costs are too high, the demand for the new vehicles could fall and drivers would continue to use inefficient vehicles. In some cases, standards may address specific market failures, which are difficult to address with price measures.[10] Feebate schemes (discussed in more detail below) have certain advantages compared to regulations: they provide continuous incentives to outperform given standards, automatically adjust to technology changes, and (if revenue-neutral) can be set aggressively to influence purchase decisions (as they avoid a tax burden on the new average motorist). On the downside, the amount of fuel consumption/CO_2 reduction with feebates is uncertain, so schedules may need to be adjusted over time.

Fuel economy standards for new vehicles lie at the center of the EU framework for transport.[11] Mandatory efficiency targets set at the EU level have been in place since 2009 for passenger cars and since 2011 for light duty vehicles (for example, vans). Individual manufacturers' requirements apply on the average of the new cars sold at the EU level and are adjusted based on the average weight of each manufacturer's fleet (with higher emissions allowed for heavier fleets). Manufacturers that do not meet their target face penalties in proportion to their deviation from target, and the number of cars sold. Upcoming targets

[10]For instance, standards may better help drive innovation and penetration, if customers heavily discount the value of future fuel savings. A broad literature documents that cost-effective energy saving technologies tend be adopted less or more slowly than is socially optimal (Greene, Evans, and Hiestand 2013; Gerarden, Newell, and Stavins 2017).

[11]In addition to vehicle efficiency, standards and other energy-efficiency policies may target the fuel mix. For instance, the Renewable Transport Fuels Obligation legislation in the United Kingdom targets at least 12.4 percent of total fuel sales to be accounted for by biofuels by 2030.

stand at 95 g CO_2/km for cars in 2021, and 147 g CO_2/km for vans in 2021. The EU has recently agreed targets for 2025 and 2030 prescribing a reduction in emissions of 15 percent by 2025 and 37.5 percent (31 percent for vans) by 2030, both relative to a 2021 baseline. The EU is the only market worldwide to have set mandatory targets up to the year 2030.

The existing system of fuel efficiency standards is broadly perceived as effective, but it has been partly flattered by measurement issues. EU average new-car emissions have dropped from 170 g/km in 2001 to 120 g/km in 2018, largely attributable to the mandatory limit imposed by regulation (ICCT 2018, 2019a, 2019b). However, emissions from passenger cars in everyday operation have not declined as much as these statistics would seem to indicate. The gap between the official (lab-based) and real-world emissions measurements has increased over the years.[12] For standards (or feebates) to be effective, it is vital that official measurements stay (or move) close to the real-world ones. Some progress is expected with the introduction of new measurement methodologies (WLTP—Worldwide Harmonized Light Vehicle Test Procedure and RDE—Real Driving Emissions). It has been argued that these methodologies could introduce new loopholes (ICCT 2015a; Stewart and others 2015), so continued attention would be required.

Meeting the 2021 EU efficiency target for new passenger cars will require significant effort. Despite the general improvements in vehicle efficiency over the last two decades, the last two years have seen a reversal in this trend (Figure 19).[13] A key factor contributing to the increase in emission intensity is the simultaneous shift away from diesel vehicles and toward larger petrol vehicles, specifically SUVs.[14] The shift away from diesel cars has been in great part policy-induced in many countries, given the recognition of diesel's negative consequences for local air pollution.[15] Significant year-over-year improvements in efficiency, exceeding those observed over the last two decades, would be necessary to meet the 2021 target. Unlike with US regu-

[12]In 2018, EU countries reported emission factors both under the old (NEDC—New European Driving Cycle) and new more realistic (WLTP) protocols for about 30 percent of new registrations. For those vehicles, the WLTP emission factor was on average 20 percent higher than the NEDC emission factor. This gap varies considerably among countries depending on fleet characteristics (such as vehicle category, vehicle mass, engine capacity segment, and manufacturer), as well as driver behavior and environmental conditions (EIONET 2019).

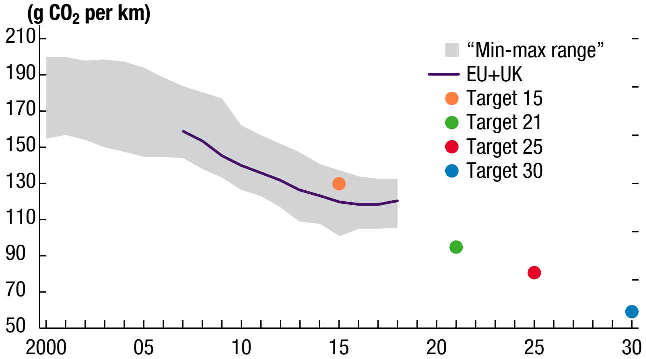
[13]In 2018, the van segment also recorded the first increase in CO_2 emissions per kilometer since the van regulation came into force in 2011, partly driven by a shift toward larger vehicles.

[14]On a like-for-like basis (that is, controlling for vehicle type), diesel cars emit about 15 to 20 percent less than petrol cars. However, diesel engines tend to be fitted to larger and heavier vehicles, which increases fuel consumption. As a result, sales-weighted average CO_2 emissions per km are similar for petrol and diesel cars.

[15]For instance, the 2017 United Kingdom Budget announced that, from April 2018, new diesel vehicles not meeting a standard for nitrogen oxide emissions would face higher taxes to generate revenues to pay for air quality improvements. France initiated in 2016 a gradual alignment of gasoline and diesel taxes.

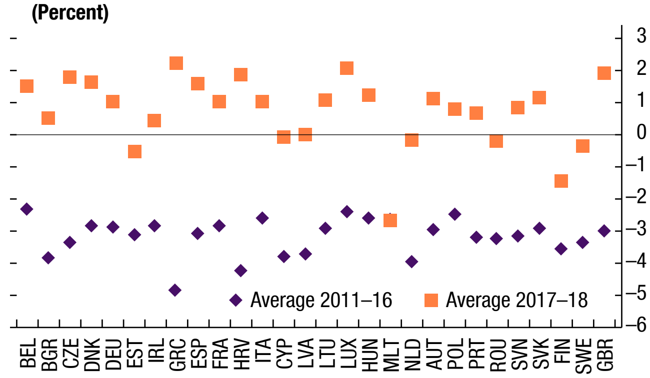
Figure 19. New Car Efficiency

1. Average Fuel Efficiency from New Passenger Cars (g CO_2 per km)



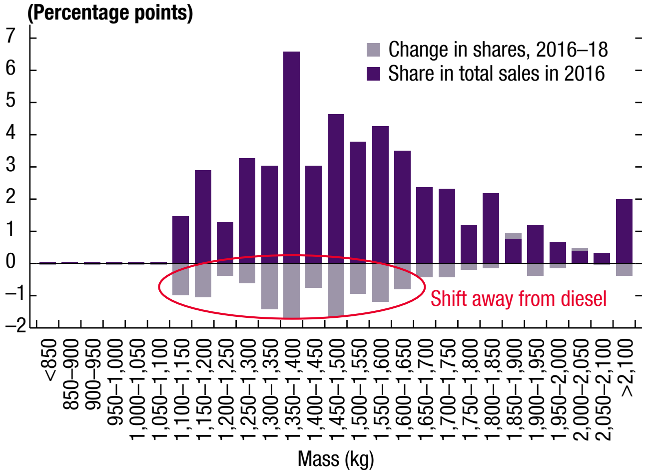
Sources: European Environment Agency microdata; Eurostat; and IMF staff calculations.

2. New Passenger Cars: Growth in CO_2 Emissions per KM (Percent)

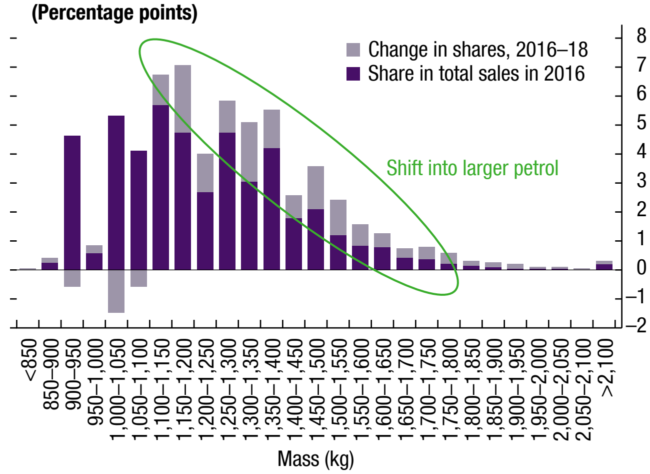


Sources: European Environment Agency microdata; Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

3. EU+UK: New Passenger Car Sales: Diesel (Percentage points)



4. EU+UK: New Passenger Car Sales: Petrol (Percentage points)



Sources: European Environment Agency microdata; Eurostat; and IMF staff calculations.
Note: The dark purple bars (stock) across both charts add up to 100 percent; the light purple bars (change) across both charts add up to zero.

lation, where manufacturers must comply with annual targets, EU standards are set only for certain target years, allowing for a delay in adjustment until those years. As a result, extrapolating data trends could be misleading. If targets are not met, authorities will need to assess the need for higher regulatory penalties, or additional policy measures, such as stronger fiscal incentives for cleaner and smaller cars.

The EU has recently adopted emission standards for certain new heavy-duty vehicles (HDVs). Lorries, buses, and coaches are responsible for about a quarter of total road transport emissions, with country level shares typically higher in manufacturing countries. While data are scarce, some analysis suggests that HDV fuel efficiency has been mostly stagnant over the last decade (ICCT 2018; BloombergNEF 2019b). Until recently, the EU had neither mandatory procedures for monitoring fuel efficiency in the sector, nor mandatory targets. The emissions standards for HDVs adopted in 2019 set targets for reducing the average emissions from the highest-emitting HDV segments (accounting for about 65 percent of HDV emissions) for 2025 and 2030 by 15 and 30 percent, respectively, relative to a 2019–20 baseline. The EU became the last major market to introduce emission standards for trucks, following the United States, Canada, China, Japan, and India.[16]

Fuel Taxes

Tax instruments proportional to fuel consumption are an efficient instrument to target emission reductions. The cost of fuel is a key contributor to most vehicles' running costs, and therefore a key determinant of travel demand. Such instruments include taxes explicitly aimed at carbon pricing (carbon taxes or the price of ETS permits if applicable), as well as other taxes in proportion to fuel consumption (such as VAT, excise taxes, etc.). There is empirical support for the effectiveness of carbon taxes in reducing transport emissions (Andersson [2019] shows that CO_2 emissions from transport declined by 11 percent after the introduction of a carbon tax and VAT on transport fuel in Sweden).

Road transport fuel is in general already heavily taxed in Europe relative to other goods. Most countries tax fuels above the minimum rates provided in the EU Energy Tax Directive. Taxes and duties typically account for 45 to 65 percent of the final price. Countries commonly apply VAT at standard rates, and most countries do not charge explicit carbon prices (OECD 2019).[17] Effective carbon rates in the road transport sector are significantly higher than in other sectors (OECD 2018b).[18] In most European countries, at least 90 percent of the road sector emissions were effectively priced at or above a benchmark carbon cost of €60 per ton of CO_2 (a midpoint estimate of the carbon costs in 2020 and a low end estimate for 2030, OECD 2018b).

[16]Targets and coverage will be reviewed in 2022.

[17]European exceptions include Finland (€62 per CO_2 ton), France (44.6), Sweden (120), Ireland (20), Slovenia (17), Portugal (7), Iceland (33), Norway (54). Road transport is not currently covered by an ETS anywhere in Europe, but plans are underway in Germany.

[18]Effective carbon rates are the total price that applies per CO_2 emissions from explicit carbon taxes (which set a tax rate on carbon content), other taxes such as excise taxes (usually set per unit of energy product, but can be translated into effective rates based on carbon content), and price of tradable emission permits (if applicable).

Despite generally high levels of taxation, fuel prices in Europe still appear below their economically efficient levels. Road use gives rise to multiple negative side effects in addition to climate change, including congestion, noise, accident, and local air pollution. Estimates provided by Coady and others (2019) suggest that retail petrol and diesel prices do not typically reflect the full range of associated external costs (Figure 20).[19] Across European countries, retail prices would have to increase by a median of about 20 percent to come to their efficient levels. Higher carbon pricing could be implemented with a dedicated carbon tax, or via an ETS framework (Box 2). Ultimately, all external costs should be appropriately reflected in prices (for instance, congestion and diesel local pollution typically have higher external costs than the climate externality).

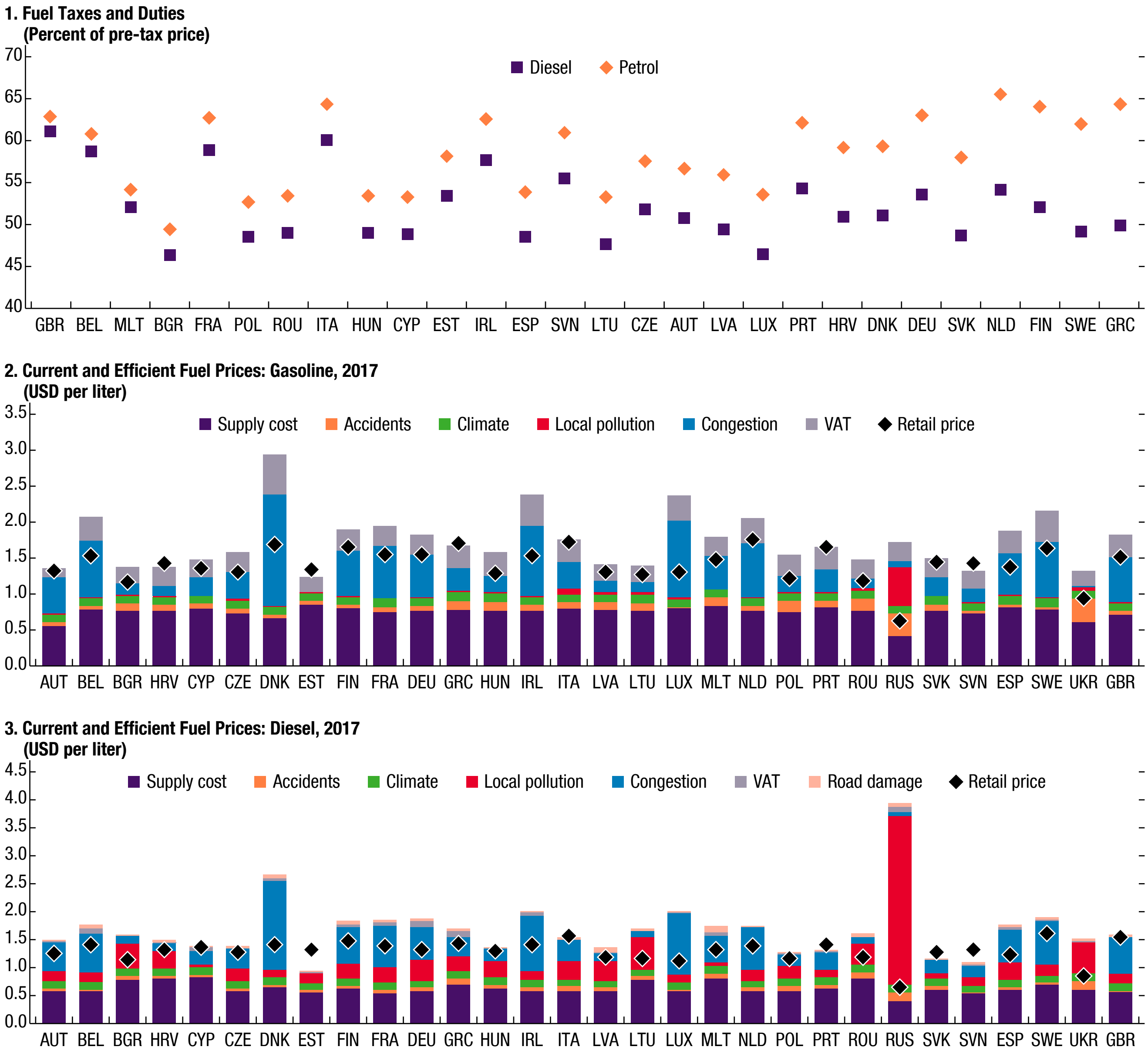
It is a good practice to routinely uprate fuel duties at least in line with inflation. Fuel duties are typically set in nominal terms and uprated only occasionally. Multiple countries have therefore seen a significant reduction in real terms in their fuel duty over the last years (for example, Belgium, Germany, Hungary, Lithuania, Poland, United Kingdom), leading to worsening congestion, pollution, and GHG emissions (Figure 21). For instance, the UK government has maintained a freeze on fuel duty since 2010/11, implying a cut in real terms of about 15 percent. Begg and Haigh (2018) estimate that traffic has increased by about 4 percent as a result of the freeze. Moreover, failure to uprate may come at a significant fiscal cost while, as a redistributive measure, it is poorly targeted. The current low price of oil could provide an opportune window for restoring the real value of duties, particularly in countries with significant fiscal needs.

Taxing diesel at higher rates than gasoline is sound environmental policy (OECD 2019). Diesel has a higher carbon content per liter and is associated with larger non-climate external costs: diesel cars (particularly old diesel models) perform far worse than petrol cars in terms of the local air pollution they generate. However, across most European countries, diesel taxes per liter are materially lower (for example, Greece, Sweden, Finland, Netherlands, Slovakia, and Germany).[20] This cost advantage increases demand for diesel cars. Currently only in the United Kingdom are diesel and gasoline being taxed at the same rate, but various countries (for example, Belgium and France) have begun closing the gap. The use of differential tax schedules on the purchase of new vehicles (see next section) allows the flexibility to encourage a transition away from diesel, without penalizing drivers who previously purchased diesel vehicles in response to earlier government incentives.

[19]We thank Coady and coauthors for sharing their calculations. See Figure 20 footnote for details.

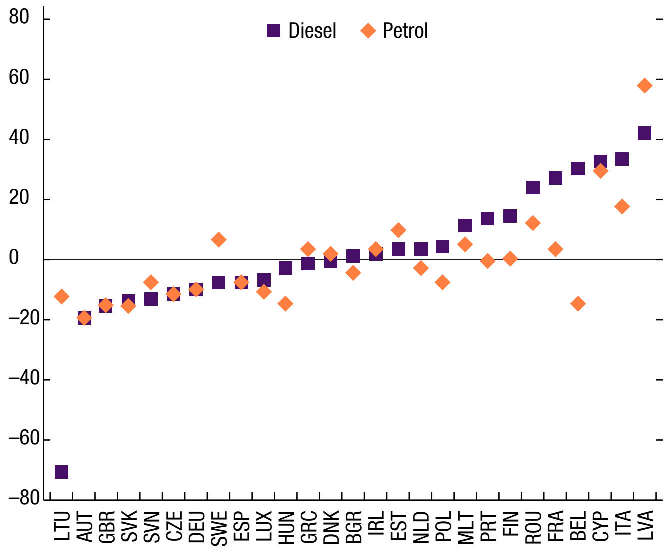
[20]This disparity is even larger when tax rates are considered relative to energy content or CO_2 emissions per liter, which are about 10 and 16 percent higher, respectively, for diesel than for petrol (Transport and Environment 2017).

Figure 20. Fuel Taxation and Efficient Prices



Sources: Coady and others 2019; Oil Bulletin; and IMF staff calculations.
Note: Efficient prices are computed as the sum of supply costs, a broad range of external costs (including and beyond climate), and corresponding consumption taxes (VAT). While most petrol is consumed by households and subject to VAT, much of diesel consumption is an intermediate input so VAT would be rebated (estimates weight VAT by the share of household consumption in total road diesel consumption). The baseline estimation assumes a carbon price of 45USDtCO$_2$. Monetizing external costs is not straightforward, and estimations are inevitably uncertain. Country list uses International Organization for Standardization (ISO) country codes.

Figure 21. Real Growth in Fuel Duties, December 2018 versus January 2011
(Percent change)



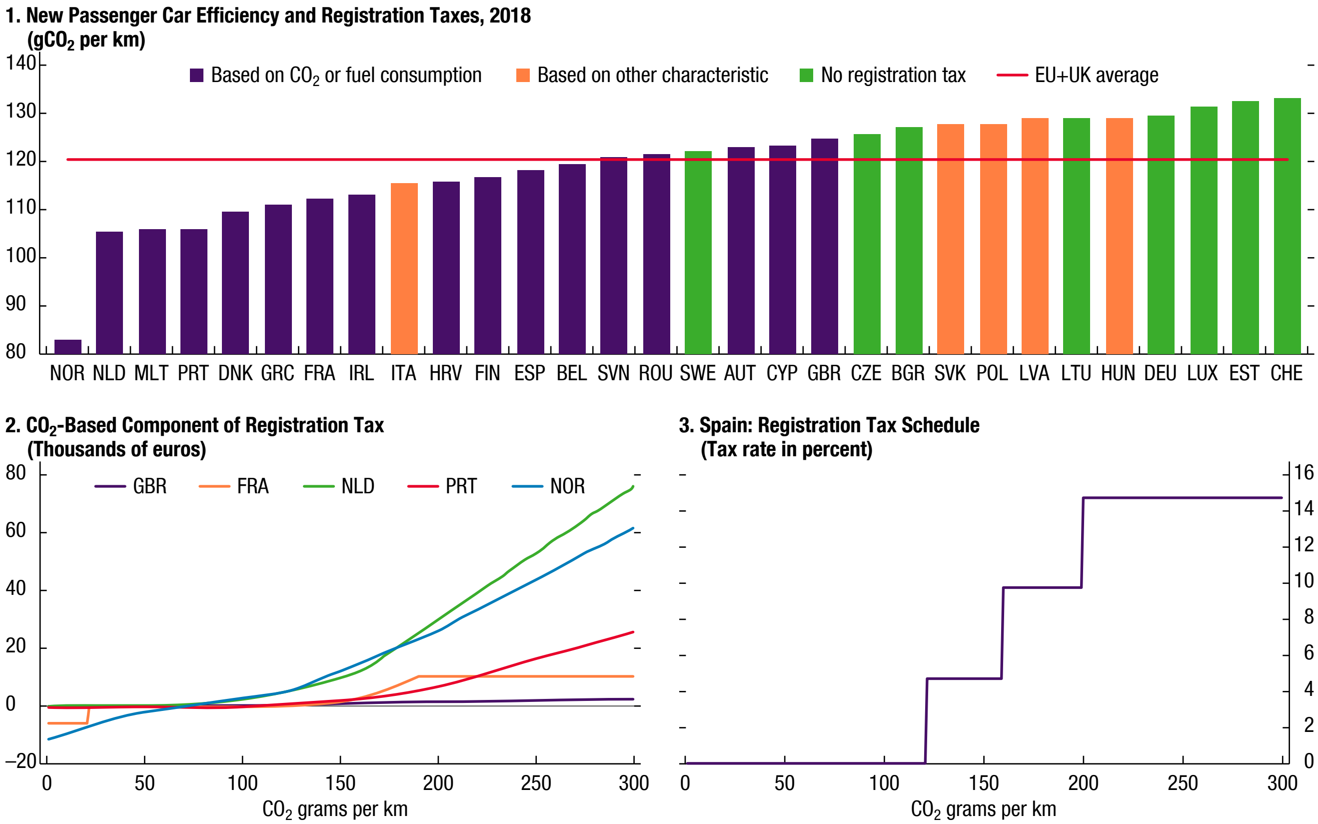
Sources: Haver Analytics; Oil Bulletin; and IMF staff calculations.
Note: Nominal duties deflated by Harmonized Index of Consumer Prices. Country list uses International Organization for Standardization (ISO) country codes.

Cleaner Vehicle Incentives

Most European countries employ incentives or taxes based on emissions to steer vehicle purchasing decisions. Acquisition taxes and recurring ownership taxes are not based on actual use and are therefore less well targeted at emissions than fuel duties. However, acquisition taxes may play a role if people react more strongly to higher upfront costs than to future lower running costs. They may also be more politically viable, as they apply on the flow of new cars as opposed to the entire fleet. The economic rationale for recurring ownership taxes is less clear: its environmental effectiveness appears dominated by a combination of fuel duties and acquisition taxes (Adam and Stroud 2019).[21] Evidence suggests that countries with CO_2-differentiated vehicle taxes have typically achieved a greater reduction in emission intensity (Dineen, Ryan, and Ó Gallachóir 2018), with acquisition taxation playing a more significant role than recurring ownership taxes (Gerlagh and others 2016).

[21]Company cars account for a significant share of new car sales in many European countries (for example, Germany), making the taxation of the private use of company cars relevant. Only some European countries (such as Netherlands, United Kingdom) have introduced CO_2-related elements in the taxation of this in-kind benefit (Runkel and Mahler 2018).

Figure 22. Acquisition Taxes



Sources: European Automobile Manufacturers Association 2018; and IMF staff calculations.
Note: In panels 1 and 2, country list uses International Organization for Standardization (ISO) country codes. In panel 2, France includes maximum EUR6k bonus scheme for low emissions cars. The United Kingdom does not reflect grants for low emissions. In panel 3, Spain tax rate is applicable on acquisition price of the car.

The effectiveness of a tax depends on its design. France, Netherlands, Norway, and Portugal provide good examples of registration tax schedules that are highly graduated according to CO_2, increasing steeply in each additional gram beyond certain limits (Figure 22). The United Kingdom provides less differentiation. Spain's stepwise system increases significantly payable taxes at certain thresholds, providing few incentives to reduce emissions below the thresholds (Mock 2015). Some countries have no CO_2-related registration tax at all, such as Bulgaria, Czech Republic, Estonia, Germany, Lithuania, Luxembourg, and Switzerland (Table 2).

Feebates can provide powerful incentives for low-emission investments with no first-order tax burden on the average motorist. Feebates are a special case of CO_2-based acquisition taxes that provide for a sliding scale of fees on vehicles with above average emission rates and a sliding scale of rebates

Table 2. Passenger Car CO_2 and Proxy-Based Taxation

Country	Registration/Purchase		Ownership		Subsidies for low/zero emissions?
Austria	✓	*	✓	*	yes
Belgium	✓	*	✓		yes
Bulgaria	n.a.		✓	*	
Croatia	✓		✓		
Cyprus	✓	*	✓		
Czech Republic	n.a.		✓		
Denmark	✓	*	✓		
Estonia	n.a.		n.a.		
Finland	✓	*	✓		
France	✓	*	✓		yes
Germany	n.a.		✓	*	yes
Greece	✓	*	✓	*	
Hungary	✓	*	✓	*	
Ireland	✓	*	✓	*	yes
Italy	✓		✓	*	
Latvia	✓		✓		
Lithuania	n.a.		n.a.		
Luxembourg	n.a.		✓	*	yes
Malta	✓	*	✓		
Netherlands	✓	*	✓	*	
Norway	✓	*	✓		yes
Poland	✓		n.a.		
Portugal	✓	*	✓		
Romania	✓		✓	*	yes
Slovakia	✓	*	✓		
Slovenia	✓		✓	*	yes
Spain	✓		✓	*	
Sweden	n.a.		✓	*	yes
Switzerland	n.a.		✓	*	
United Kingdom	✓	*	✓	*	yes

Source: IMF staff based on German and others 2018; Runkel and Mahler 2018; and Wappelhorst, Mock, and Yang 2018. Detailed data by country available at European Automobile Manufacturers Association Tax Guide 2018.

Note: ✓ denotes CO_2 or fuel consumption based, ✓ denotes based on other characteristic, n.a. denotes instrument is not used, * denotes benefits for low/zero emission vehicles. The table is based on information as of 2018, and therefore excludes recent initiatives such as Spain's RENOVE 2020 Plan.

to products or activities with below average emission rates.[22] Feebates are revenue neutral, and therefore there is no change in revenue with the progressive cleaning of the vehicle fleet (as would a fixed CO_2-based tax scheme). Feebates can be set to dramatically alter relative prices of low/high emission vehicles. While the subsidy for cleaner vehicles would decline over time as the average emission rate of the fleet declines, this would be appropriate as the costs of zero-emission vehicles declines over time.

Complementary policies to CO_2-based taxation may be necessary to guard against potential unintended consequences.

[22]Specifically, a feebate system imposes a charge on new vehicle sales equal to the product of (1) a price on CO_2 emissions; (2) the difference between the vehicles CO_2 emission rate per mile and the fleetwide average CO_2 per mile; and (3) the average lifetime mileage of vehicles. That is, CO_2 price × (CO_2/mile – fleet average CO_2/mile) × lifetime mileage.

- A high tax on the acquisition of new cars could discourage people from replacing their old cars with newer/cleaner ones. Potential solutions include the combination of an emissions-based registration tax with a scrappage subsidy that also depends on emissions, or the use of revenue-neutral feebates that do not affect the price of the average new vehicle.
- Vehicle purchase subsidies could result in higher ownership and additional vehicle mileage (and emissions). For instance, sales of new vehicles increased by 3.5 percent in France following the introduction of the bonus-malus system. In Netherlands, tax reductions for small, low-emissions cars are estimated to have caused an annual extra sale of some 25,000 to 30,000 cars (German and others 2018). The same could happen with the measures proposed under the current COVID-19 recovery plans in some countries. To offset the undesirable impact on emissions, fuel taxes could be raised at the same time. Now is an opportune time to do so as fuel prices are relatively low.

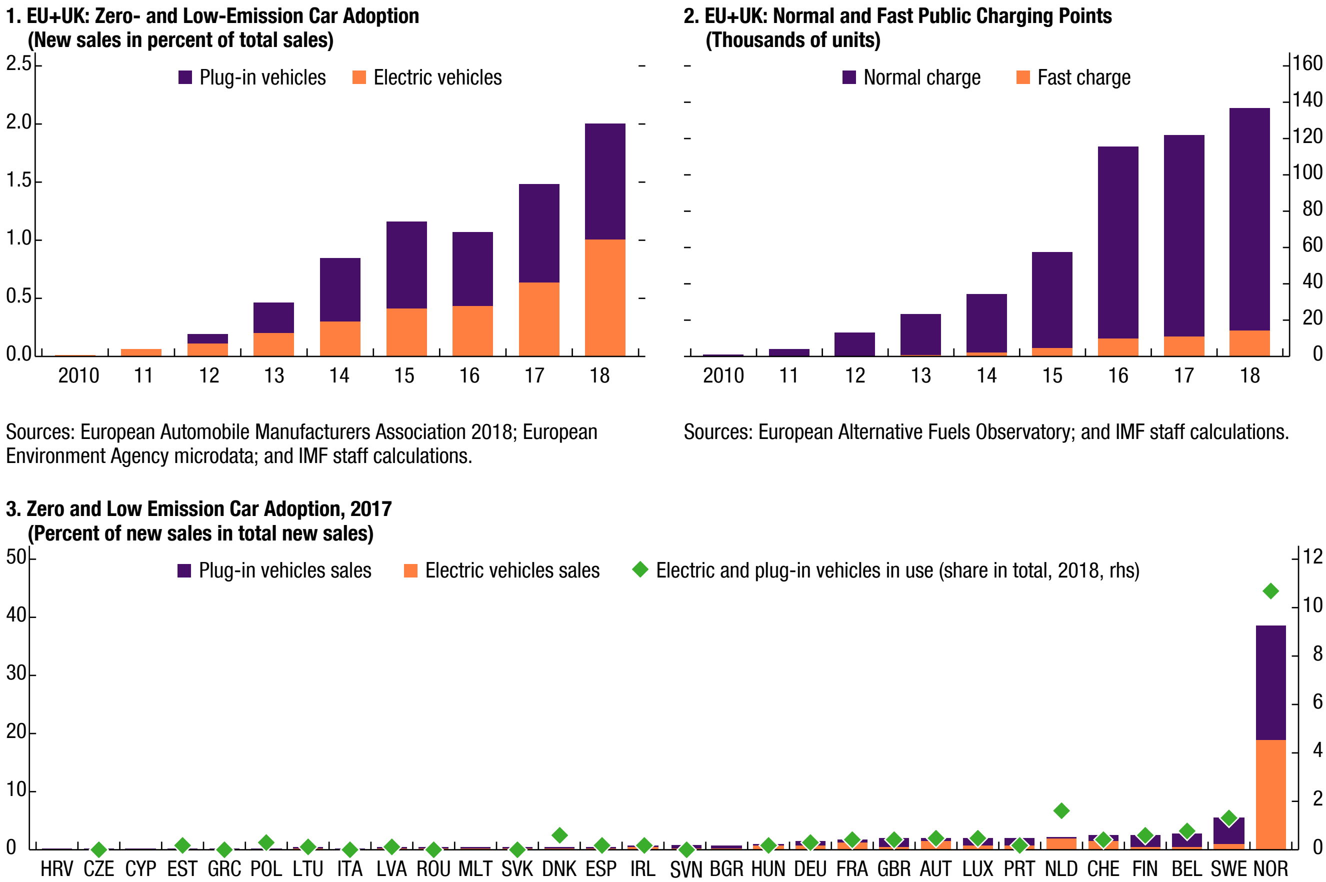
Over the last decade, the number of countries offering incentives for the adoption of low- and zero-emissions vehicles has increased significantly. Most EU countries provide at least one of these measures. Incentives come in different forms, such as exemptions or reductions to registration and ownership taxes, one-time purchase subsidies to consumers, subsidies for the installation of charging infrastructure, and other benefits (for example, free parking access, reduced toll rates, use of restricted lanes, etc.).

- These instruments are typically justified on the ground of induced innovation, learning by doing, and economies of scale that would otherwise not be achieved (Gillingham and Stock 2018).[23] Electric vehicles also exhibit network effects, whereby the purchase of an additional electric vehicles makes the installation of a charging station more profitable. The case for this type of incentives is weaker in countries in which electricity is produced on the margin by fossil fuels (for example, Poland), unless there are good prospects of the electric grid becoming cleaner.[24]
- While sales of low- and zero-emission vehicles have increased in recent years, these vehicles typically remain a small fraction of total fleet or even new sales (Figure 23). A few country examples suggest that an active, long-term, and broad-based approach can foster adoption. For instance, Norway has the highest proportion of electric vehicles in Europe (about 15 percent of the total fleet), favored by fiscal incentives that make the cost of these cars comparable to similar conventional cars. Conditional on the

[23]Numerous papers in the transportation literature provide evidence suggesting that these subsidies indeed increase demand for clean vehicles (Zhou, Levin, and Plotkin 2016).

[24]For instance, Estonia and Poland, which offer relatively few incentives for zero-emission vehicle adoption, have the largest carbon emission intensity for electricity production in the EU.

Figure 23. Zero- and Low-Emission Car Adoption



Sources (panel 1): European Automobile Manufacturers Association 2018; European Environment Agency microdata; and IMF staff calculations.

Sources (panel 2): European Alternative Fuels Observatory; and IMF staff calculations.

Sources (panel 3): ACEA 2018; European Environment Agency; European Environment Agency microdata; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

size of the incentive, transparent, easily accessible and frontloaded schemes tend to be more successful (Yang and others 2016).

- As electric vehicles continue approaching cost parity with conventional vehicles, a number of countries have or are in the process of scaling back incentives (for example, United Kingdom).

There is a strong case for public support for the expansion of charging infrastructure. The extent of charging infrastructure differs considerably among countries, and the lack of charging stations (range anxiety) is often identified as a barrier to the adoption of electric cars. Electric cars currently offer an average range of about 150 miles, which is more than sufficient for most car journeys (for example, average trip distances in the United Kingdom are 8 to 12 miles) but could be a limitation for longer trips. Network infrastructure requires a coordinated system and is the kind of public good that the market may underprovide in the absence of public support. Springel (2018) uses vehicle registration data from Norway to show that subsidies for charging stations are more effective for increasing electric vehicles uptake than are purchase subsidies for electric vehicles, though their effectiveness tapers off with increased subsidy.

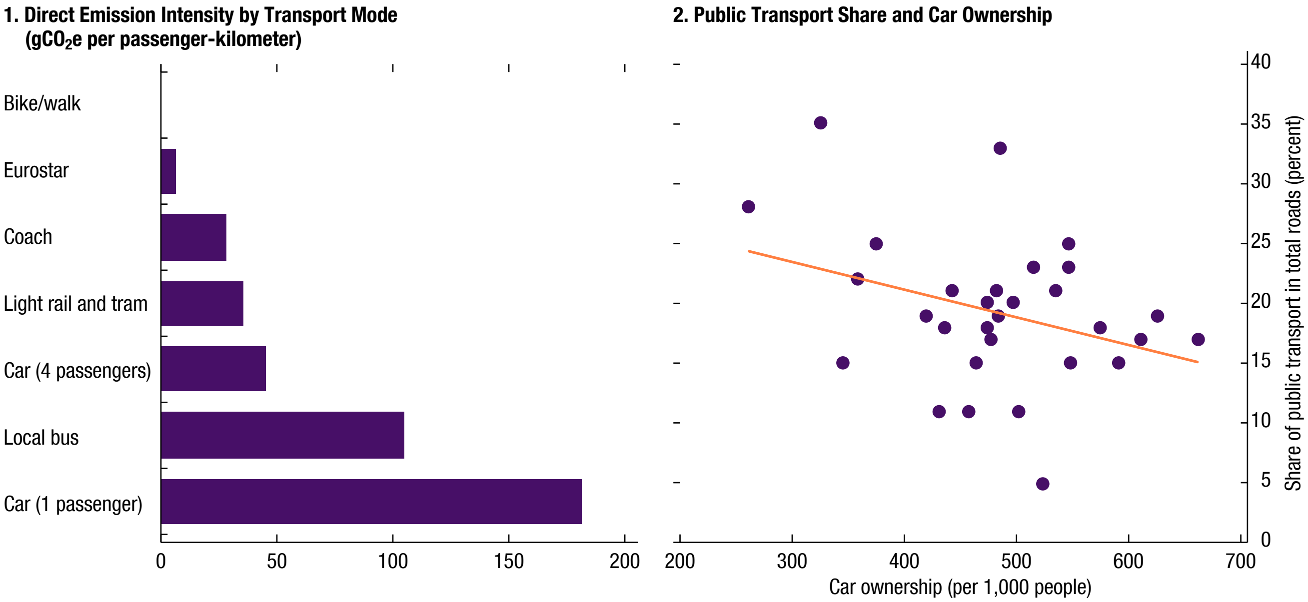
The announcement of credible deadlines for discontinuing conventional cars in the future can be used to signal governments' commitment to decarbonizing the sector and encourage long-term investments. A few countries have complemented their framework for zero-emission vehicle adoption with commitments to discontinue the sales of combustion engine vehicles. Getting all cars and vans to be electric by 2050 will require all sales to be electric significantly earlier than that to minimize transition costs. The average age of a car in the EU is about eight years, and in many countries more than 60 percent of the fleet is older than one decade. In the European context, the goal is to shift to all new zero-emission vehicles by 2025 in Norway, 2030 in Netherlands, and 2040 for France and the United Kingdom (2035 for Scotland).

Transport Modal Shift

Policies to reduce transport emissions should seek to foster the most efficient transport mode for each journey. Bus rapid transit, rail, and waterborne modes tend to be relatively carbon-efficient per passenger or ton kilometer compared with conventional heavy or light duty road vehicles, or aviation (although this varies with vehicle occupancy rates) (Figure 24). Shifting to more sustainable modes of transport could be a cost-effective alternative to private car ownership (CCC 2019a). In cities, lower requirements for vehicle range and higher population density facilitate the switch to cleaner transport. Policies to promote a shift to lower-emission intensive transport modes include pricing measures (for example, adequate pricing of externalities, the elimination of unjustified tax/subsidy distortions), as well as investment in infrastructure, and policies targeted at changing consumer behavior.

- **Walking and cycling.** Facilitating walking and cycling should become an integral part of urban mobility and infrastructure design, which would be associated with health co-benefits. Electric bikes offer many of the benefits of light duty vehicles, such as flexibility of routes and scheduling freedom, but with much lower emissions and other externalities. Active mobility can be promoted with investments in safe and attractive infrastructure, such as convenient pedestrian pathways, cycle highways, shared bicycle systems, and bike parking availability.

Figure 24. Transport Modes



Sources: UK BEIS/DEFRA GHG Conversion Factors 2019; and IMF staff calculations.

Sources: Eurostat; UK BEIS/DEFRA GHG Conversion Factors 2019; and IMF staff calculations.

- **Public transport.** European countries differ significantly in the share of public transport in total land transport. The prevalence of public transportation tends to be inversely correlated with car ownership (although a few countries such as Austria have both relatively large ownership and high public transportation rates). The share of passenger travel accounted for by railways has been broadly stable at the EU level, with significant decreases in some eastern European countries, but with increases in some EU15 countries such as France and the United Kingdom. In addition to infrastructure investments, fiscal incentives and physical restrictions (such as no-parking zones, and dedicated bus lanes) tend to be effective in incentivizing a shift toward public transport (IPCC 2014; EEA 2013). The integration of modal networks (airports, ports, railway, metro, and bus stations) can reduce travel time, making it more attractive for users.[25]
- **Freight.** In transporting goods, modal shifts need to play a significant role, given the difficulty in decarbonizing sectors such as aviation and heavy-duty road vehicles. Shifting freight from medium-haul aircraft and road trucks to rail and coastal shipping typically offers large emission mitigation potential.[26]

[25]Although the expansion of public transport faces a challenge in the near term—given the need for social distancing amid the COVID-19 pandemic—it will remain important in the medium to long term.

[26]In turn, this would require measures to manage better, and to increase the capacity of railways and inland waterways (EC 2020).

The EC established in 2011 a nonbinding target to move 30 percent of road freight over 300 km to other modes such as rail or waterborne transport by 2030, and more than half by 2050.[27] The scope for replacing road haulage over short distances is more limited, as it is hard for other modes to compete in terms of speed, flexibility, and reliability (EEA 2016a).

- **Setting targets.** National and/or EU-wide strategies could benefit from setting (additional) goals for modal shift. For instance, the EC may establish modal shift targets for short- and medium-distance passenger trips (in addition to long-distance). Most recent national strategies do not establish a specific ambition for certain transport modes, such as biking. However, France adopted in 2018 a national Plan Vèlo, committing to triple cycle use by 2024 to 9 percent of the transport modal split. Policies to promote modal shift require good quality passenger mobility statistics to inform the setting of targets and allow for the monitoring of progress.
- **Infrastructure investment.** Infrastructure investment appraisals should take an all-encompassing view. A shift to active mobility, increased use of public transport and shared mobility schemes (such as bike and carsharing) could have positive impacts on climate, health, air pollution, reduced congestion, safety, and accessibility. An expensive project may be assessed as viable once these factors are taken into account. On the other hand, when considering "dirty transport" projects, urban planning and infrastructure investment should be mindful of potential lock-in effects resulting, for example, form the slow turnover of vehicle stocks (particularly aircraft, trains, and large ships) and the long-life and sunk costs of infrastructure that is put in place.

Challenges

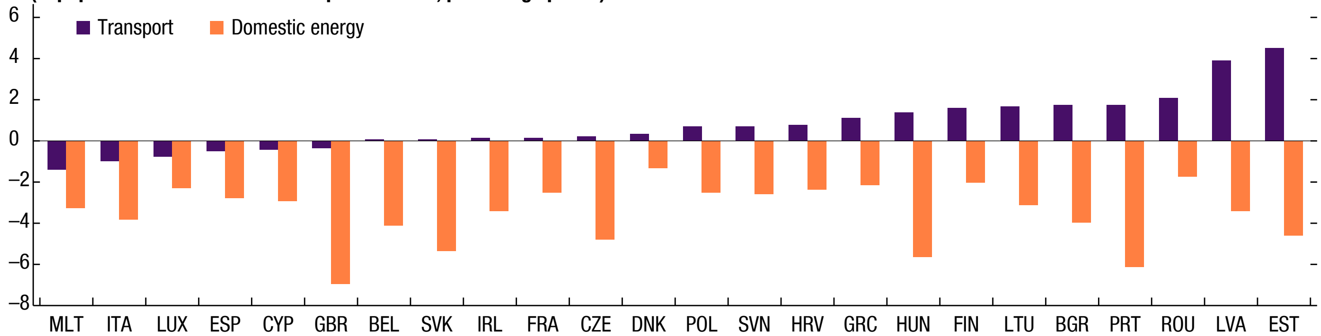
Distributional considerations. Unlike domestic energy consumption, transport fuel expenditure as a share of total expenditures is typically not higher for poorer households than for other segments of the income distribution (even after taking bus and coach fares into account) (Figure 25). As a result, the direct effect of higher fuel prices is not necessarily regressive. Nonetheless, governments have showed concern about "horizontal" implications of policies (that is, treating individuals of a same income level too differently, say, based on their house location relative to work). For instance, Germany has proposed an increased commuters' allowance to compensate for higher fuel costs as a result of CO_2 pricing, albeit only for long-distance commuters.[28] The essential tension here is that there is no way of directly compensating high-carbon consumers (such as long-distance travelers) without partly undoing the objective of the

[27]Three-quarters of total freight transport in the EU is associated with distances of more than 300 km (EEA 2014).

[28]In the German commuter allowance scheme, anyone travelling more than 20 kilometers to work gets a deduction per kilometer from their income tax in their annual tax return.

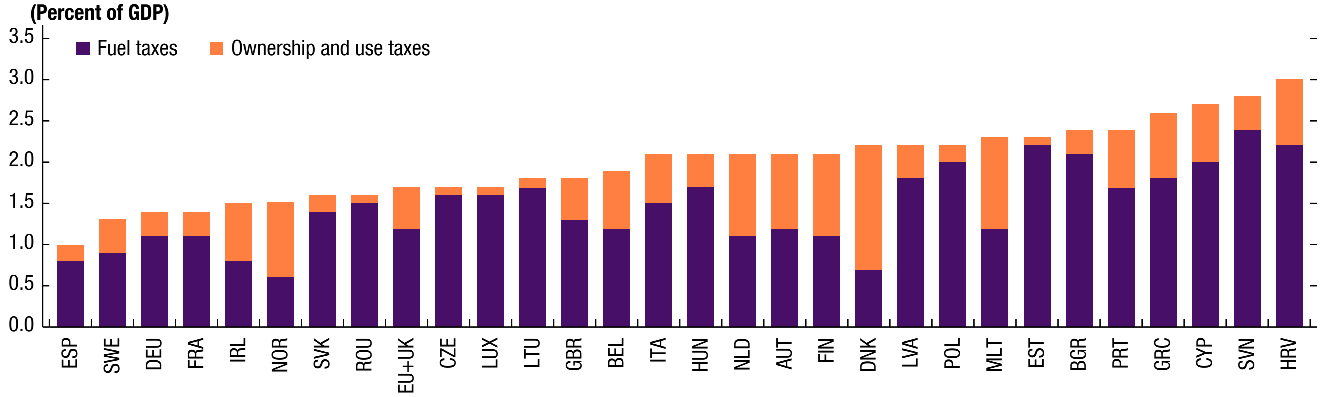
Figure 25. Distributional and Revenue Challenges

1. Cross-Quintile Difference in Share of Total Consumption
(Top quintile mean versus bottom quintile mean; percentage points)



Sources: Eurostat; and IMF staff calculations.
Note: Quintiles are based on total equivalized consumption using OECD scale. Country list uses International Organization for Standardization (ISO) country codes.

2. Fiscal Revenues from Road Transport, 2017
(Percent of GDP)



Sources: Directorate-General for Mobility and Transport 2019; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

carbon tax. Subsidies to certain public transport modes could be considered as an alternative with potentially better distributional implications.[29]

The future of transport taxation. Fuel duties typically constitute a significant source of revenue but will decline over time in line with improvements in vehicle efficiency and fleet electrification. In most countries, electricity is taxed at much lower rates than conventional fuels, in part because the tax is not intended to contribute to road financing. The potential for intelligent road pricing schemes should be considered, as they provide many attractive features: they can address vehicle attributes and actual vehicle use as well as congestion, air pollution and other externalities from road transport (Adam and Stroud 2019).

[29]For instance, the introduction of free public transportation in Luxembourg in March 2020 is expected to more than offset the impact on transport costs of recent fuel price increases for lower-income households (STATEC 2019).

Air Transport

Growth in air transport demand has driven significant growth in the sector's emissions over the last three decades. In the EU28, the number of passengers traveling by air has increased by about 40 percent only in the last decade. Distance travelled measured on a passenger-kilometer basis (only available for domestic and international intra-EU flights) has increased by about 125 percent since 1995 (Figure 26).[30] The rapid expansion in air transport was helped in part by the deregulation between 1987 and 1997 of the European aviation market (including air carrier licensing, market access, and fares) that led to the growth of low-cost airlines and an expansion of smaller regional airports. Nearly half of the air passengers correspond to intra-EU flights, while national and extra-EU account for 17 and 36 percent of total, respectively. Emissions from air transport have grown in tandem, with flights now accounting for more than 10 percent of total transport emissions.

The sector poses significant challenges for decarbonization, emphasizing the role of demand management and innovation investment. There are conceptually three ways to deliver net-zero aviation: to invent a new electric aircraft, to change the fuels of existing aircraft, or to develop negative emissions technologies. These technologies as of today remain in the very early stages of development. Despite some room for efficiency improvements in the short to medium term, the main levers for emissions reduction for the aviation sector are reducing demand for flights and long-term innovation (Burke, Byrnes, and Fankhauser 2019).[31] Investment in research, development, and deployment will be needed to speed up the pace of innovation. A robust price signal could complement policies to drive innovation investment and have a direct impact via direct demand reduction.

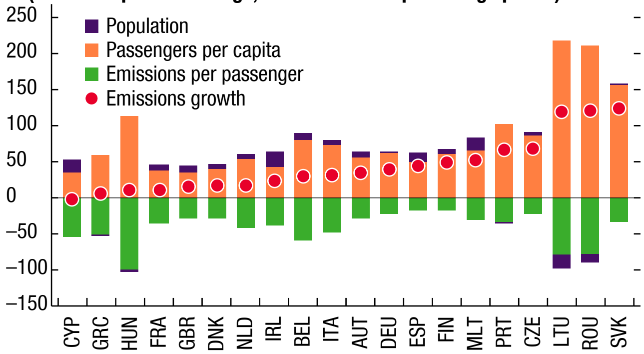
Several features of the international air transport sector call for multilateral (either global or at least EU-level) policy coordination. Tax frameworks are grounded on international agreements. Carbon leakage is a risk, as airlines using home airports as a stopover destination might choose to reroute elsewhere to exploit differences in prices. Alternatively, there is a risk of "tankering," that is, carriers filling their aircraft as much as possible whenever landing outside the EU to avoid paying higher taxes, and so increasing the level of emissions.

[30]Air plays a relatively minor role in freight transport, as it is generally an expensive transport mode in terms of tonne-kilometers and only competitive for longer distances and relatively light high-value or perishable goods.

[31]Sustainable fuels can contribute to aviation decarbonization but are currently not an economically attractive substitute for conventional jet fuel. Their future take-up across the sector will depend on progress toward commercial scale production, improvements in cost-competitiveness, and policy support. The EC has recently launched a policy initiative (ReFuelEU Aviation) to boost the demand and supply of sustainable fuels.

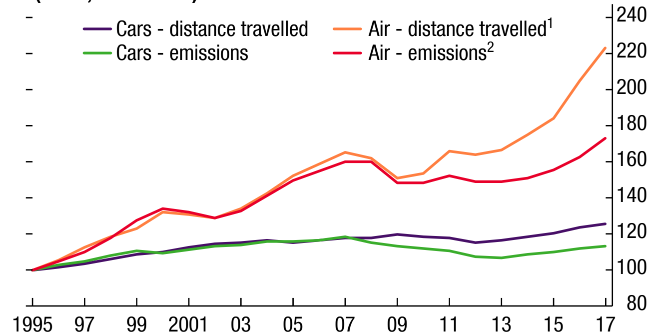
Figure 26. Aviation Emissions and Drivers

1. Aviation Emissions Growth, 2002–17
(Growth in percent change; contributions in percentage points)



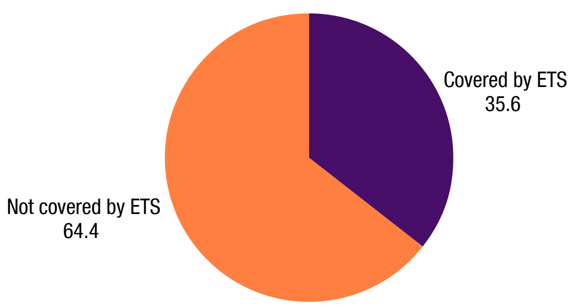
Sources: Directorate-General for Mobility and Transport 2019; European Commission; Eurostat; Haver Analytics; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Includes domestic and international. Growth rates are computed as change in logs. Country list uses International Organization for Standardization (ISO) country codes.

2. EU+UK: Passenger Transport Demand and Emissions
(Index, 1995 = 100)



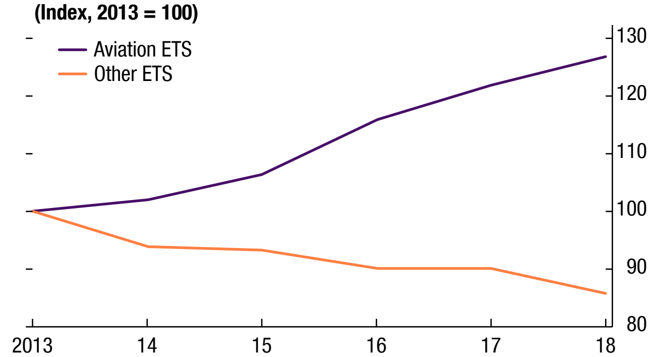
Sources: Directorate-General for Mobility and Transport 2019; European Commission; and IMF staff calculations.
[1]Excludes extra-EU travel
[2]Includes extra-EU travel.

3. EU+UK: Aviation Emissions, 2017
(Percent of total)



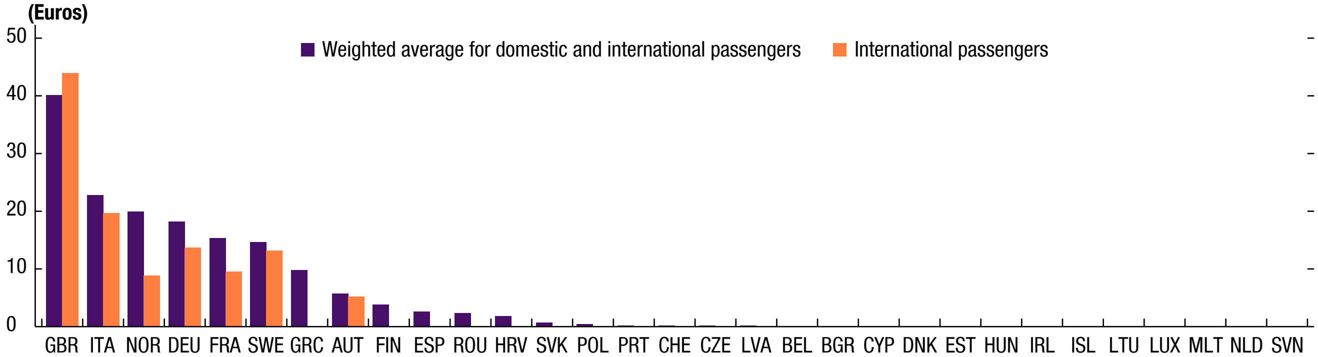
Sources: European Commission; and IMF staff calculations.

4. ETS Emission Growth by Subsector
(Index, 2013 = 100)



Sources: European Commission; and IMF staff calculations.

5. Average Aviation Taxes per Passenger
(Euros)



Sources: European Commission; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Air transport has generally benefited from a less stringent taxation framework relative to other transport sectors, particularly for international travel.

- *Aviation fuels in EU member states are not subject to excise taxes of the kind generally applied to other transport fuels.* Fuel tax exemption on international flights is rooted on international conventions and a large number of bilateral agreements.[32] European rules allow member states to tax aviation fuels for domestic aviation, but currently none do. Outside the EU, several countries levy such tax (for example, Australia, Canada, Japan, Norway, Switzerland, United States). Recent analysis by the European Commission (2019) suggests that a hypothetical introduction of jet fuel taxes on all flights at the EU's minimum rate for aviation kerosene (€330 per thousand liters) would increase the average ticket price by 10 percent, and reduce passenger demand and CO_2 emissions by about 11 percent with negligible impact on aggregate employment and GDP.
- *Moreover, international aviation is exempt from VAT, effectively subsidizing the sector relative to other sectors.*[33] European countries follow International Civil Aviation Organization (ICAO) guidelines by not charging VAT on international flights. EU countries should consider a coordinated reversal to this exemption, at least for international intra-EU flights. On the other hand, most European countries do charge VAT on domestic flights (exceptions include, for instance, the UK), although many countries apply reduced rates.
- While some countries apply ticket taxes, these are typically not well designed as an environmental tax (not targeted towards reducing emissions). Ticket taxes are usually charged on a per passenger, or at best, based on coarse distance categories (EC 2019g). Examples include the United Kingdom's Air Passenger Duty and Germany's Air Transport Tax.

The European aviation sector faces some carbon pricing via the EU ETS, but the majority of the sector's emissions remain exempt. Since 2012, aviation emissions have been included in the EU's Emission Trading System but only for domestic and intra-EEA flights (accounting for roughly 40 percent of European aviation emissions). Reflecting aviation's relatively higher abatement costs, ETS prices to-date have not been enough to drive emission reduction within the sector, with emissions expanding by about a quarter since 2013 as opposed to the 15 percent reduction observed in other ETS sectors over the

[32]International provisions of the 1944 ICAO Chicago Convention do not explicitly prohibit the taxation of jet fuel intake.

[33]According to ICAO document 8632 the "normal practice with respect to the sale or use of international transport is to [apply a] zero [VAT] rate." The International Air Transport Association endorses' IACO's resolution and argues that a zero VAT rate should be applied because international air transport generally take place outside any tax jurisdiction.

same period.[34] Airline Ryanair features as an ETS top 10 emitter at an EU level. In the majority of member states, airlines feature as top 10 emitters, and in four countries they register as the largest emitter.

Progress in agreeing a global policy covering international aviation has been slow, but some progress has been made in recent years. National emission targets specified in the Kyoto Protocol and in the Paris agreement pledges explicitly exclude international aviation (and shipping) emissions.[35] In 2016, the International Civil Aviation Organization agreed on a global offsetting scheme for international aviation (CORSIA scheme), that was designed to require operators to purchase offset credits to cover emissions growth above 2019–20 levels (with the collapse in air travel in 2020, the baseline was changed to 2019). The scheme was expected to start in 2021, be voluntary until 2027, and end in 2035. The initiative does not include a long-term objective for in-sector emission reduction and will need to be based on robust rules to deliver genuine emission reductions (CCC 2019a). It remains unclear whether European countries will implement CORSIA in a complementary manner or substituting elements of it to the current framework (the ETS). Should European authorities assess the CORSIA initiative to be ineffective, they should consider extending EU ETS coverage from intra-EU flights to all flights to-and-from the EU (as originally envisioned).

[34] In 2018, about half of the aviation emissions covered by the EU ETS were accounted for by freely allocated allowances.

[35] Recent domestic commitments in certain countries (for example, UK 2050 net zero pledge) do include emissions from international aviation and shipping.

Box 2. Road Transport in the EU ETS?

One way to strengthen carbon pricing in transport would be to include it in the EU ETS. Another is to have higher country-level fuel taxes.

- Expanding the EU ETS to include transport is technically feasible. For instance, road fuel suppliers could be responsible for surrendering CO_2 permits, with costs ultimately passing through to final consumers. Examples outside the EU include California, Quebec, New Zealand, and Nova Scotia. Within the EU, Germany will introduce in 2021 a domestic cap-and-trade system covering the transport and building sectors.
- All else equal, the current ETS permit pricing (€25/tCO_2) would amount to additional six cents per liter of fuel, or a 4–5 percent increase in retail prices. However, this impact could in principle be undone if matched with a proportional reduction in other tax instruments.[1] This could be prevented if the increased carbon pricing is set explicitly as an addition to other transport taxes (such as VAT or excise taxes set to pay for road maintenance). As discussed in the main text, a case can be made that road fuel prices in the transport sector are not high enough to account for all externalities despite being more heavily taxed than other sectors.

[1]As an example, the carbon tax rate in Portugal (which is tied to the average EU ETS allowance price in the preceding year) nearly doubled in 2019. However, in anticipation of this increase, the government reduced the tax on gasoline by more than double the amount of the carbon tax increase.

Chapter

4 Residential Housing Sector

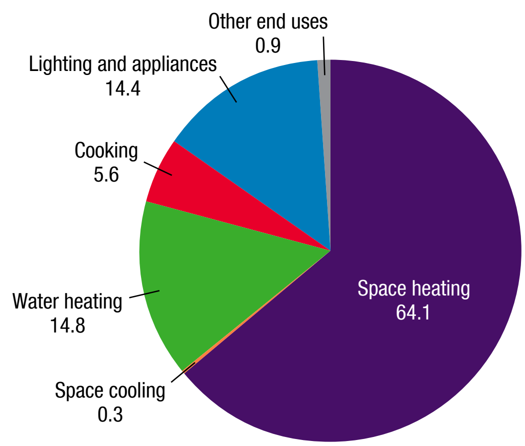
Overview of Emissions and Drivers

Residential housing accounts for about a quarter of the energy usage and a fifth of GHG emissions in the EU (Pirelli and others 2020).[1] These emissions comprise three main sources: (1) *indirect* emissions (about 10 percentage points), (2) *direct* emissions (about 6 percentage points), and (3) other emissions, which arise from construction and building materials, as well as household waste and water treatment (about 4 percentage points). Direct emissions refer to on-site fossil fuel use for heating and cooking. Indirect emissions are embedded in the generation of electricity to run appliances, such as electric space heating or cooling, cooking, and lighting. This chapter will mainly focus on heating, which dominates total energy usage and is the largest source of direct and indirect emissions (Figures 27 and 28).

Lower emissions due to higher energy efficiency and a cleaner energy mix were partly offset by population growth and a reduction in household size over the last three decades. The emissions reduction in the residential building sector from 1990 to 2017 is close to the overall emissions reduction in the EU (21 percent vs. 23.5 percent). Decomposing historical changes in emissions shows that—except for Malta—cleaner energy generation (GHG emissions per unit of energy consumed) was the key driver of emissions reduction in the EU residential building sector (at 28 percent on average) (Figure 29). In addition, energy intensity (energy consumed per building) has declined in the EU by 19 percent, as nearly all countries have experienced energy efficiency improvements. These gains were partly offset by an 8 per-

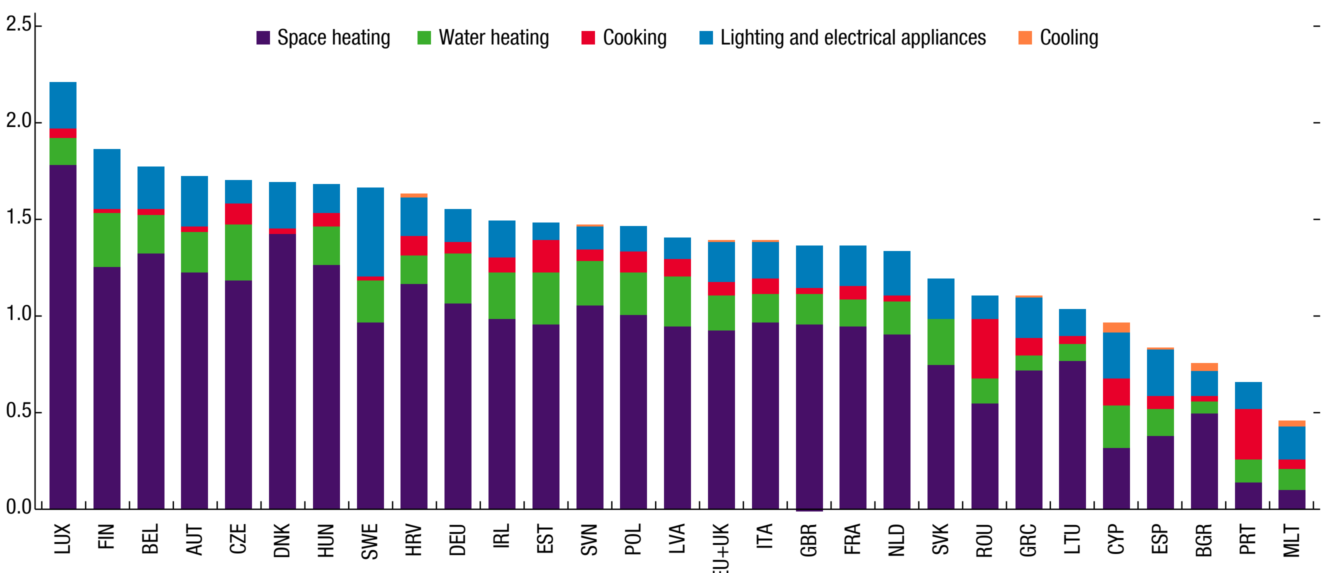
[1]The analysis of energy systems efficiency as well as household appliances is outside the scope of the section. Similarly, public buildings and commercial buildings are not covered. While abatement channels are similar in these two cases, policies differ to residential housing and a discussion is beyond the scope of this chapter. For further information on the nonresidential sector, see for instance, EC (2019d).

Figure 27. EU+UK: Final Energy Consumption by Households, 2017
(Percent)



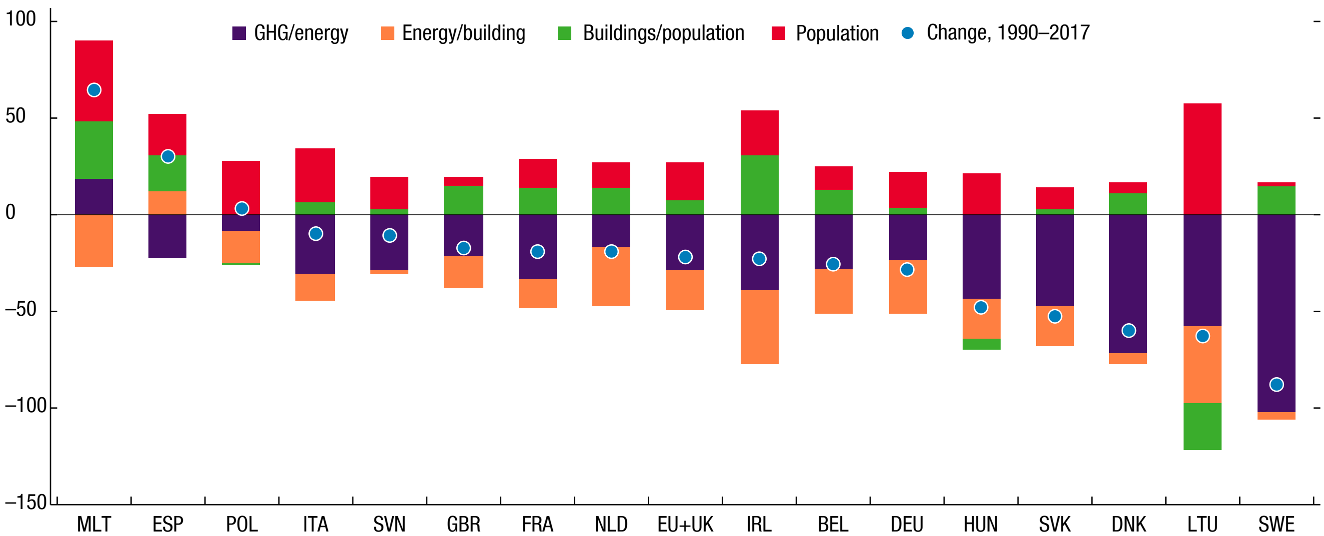
Source: Eurostat.

Figure 28. EU+UK: Households—Energy Consumption by End Use
(Tonnes of oil equivalent [toe] per dwelling)



Sources: European Environment Agency; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 29. EU+UK: Decomposition of GHG Emissions in Residential Housing
(Growth in percent; contributions in percentage points)



Sources: Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. GHG = greenhouse gas.

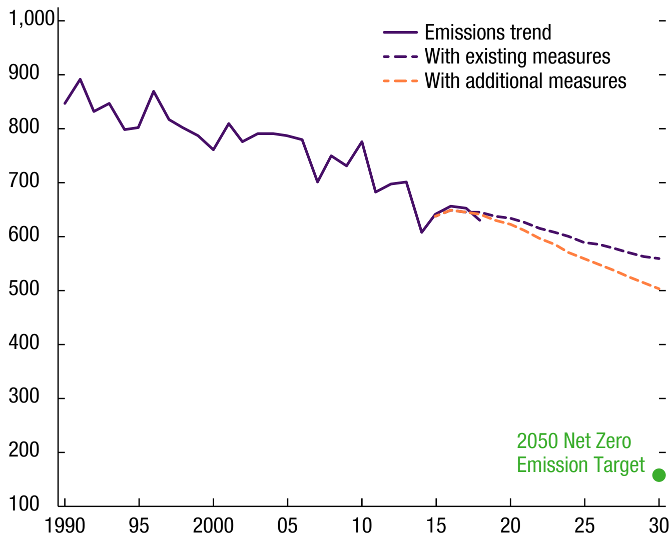
cent increase stemming from population growth, and a 20 percent increase due to fewer persons per households.[2] Variations across countries are large and for some countries (for example, Luxembourg, Malta, Spain) emissions from residential buildings increased.

The energy-efficiency improvements have been supported by various EU initiatives, including high energy-efficiency standards for new buildings. The full de-carbonization of the energy sector, and energy-efficient construction and renovation of buildings, are core planks of the European Commission Green Deal (2019). The European Commission (2015b) estimated that savings from adopting the highest minimum energy performance standards (MEPS) in the EU by 2030 would range from €37 to €55 billion (or 7–11 percent of estimated energy use) per year, of which one-third would be attributable to energy-efficient buildings.[3] Under the *2020 Climate and Energy Package*, the EU aims to achieve energy savings of 32.5 percent by 2030. The Energy Efficiency Directive in 2012 (EED) and the Energy Performance of Buildings

[2]In addition (and not shown in this decomposition of emission reductions due to more limited data availability by country), the average floor area of the housing stock has increased by 14 percent since 1990, which has slowed the potential reduction of energy use per building.

[3]Minimum energy performance standards (or minimum energy efficiency requirements), are regulatory measures applied in a country or region specifying performance requirements for an energy using device. They effectively limit the maximum amount of energy that may be consumed by a product, or the minimum level of efficiency, in performing a specified task.

Figure 30. EU+UK: Buildings—Effort Sharing GHG Emissions and Projections
(Mtonnes of CO_2 equivalent)



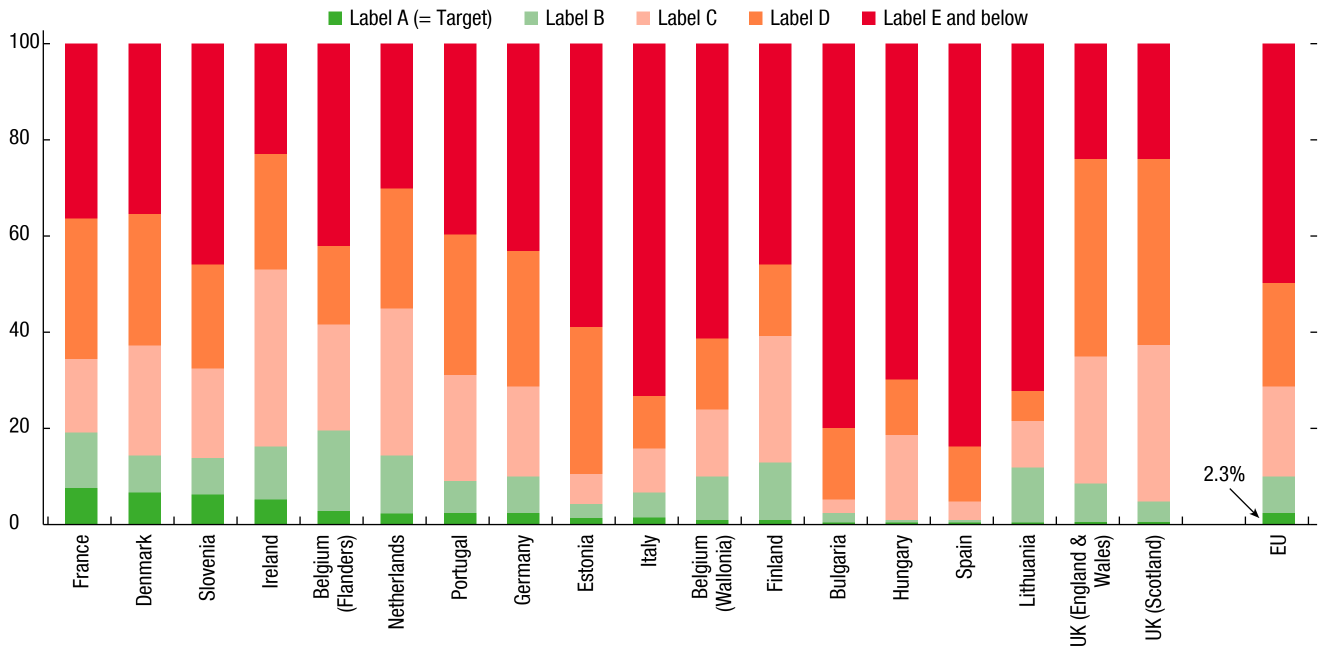
Source: European Environment Agency.
Note: GHG = greenhouse gas.

Directive (EPBD) in 2002 and 2010 form the main EU legislation for reaching these goals. Article 7 of the EED requires each member state to develop an *Energy Efficiency Obligation* (EEO) scheme to achieve cumulative energy saving targets from 2014 to 2020, which are at least equivalent to 1.5 percent of the annual energy sales to final customers of all energy distributors.[4] Nearly zero-energy buildings (NZEB) regulation will apply to all new buildings from end-2020 (new public buildings were subject to this regulation already since end-2018).

Under existing policies, the residential sector is expected to fall short in delivering on the 2030 efficiency and emission targets (Figure 30). At present, about 35 percent of the EU's buildings are more than 50 years old and more than 90 percent of the building stock is energy inefficient.[5] The average energy efficiency varies significantly across countries, with a large share of highly inefficient buildings in Southern and Eastern European countries (Figure 31). Countries expect emission reductions from heating and cooling in the building sector to continue as a result of further implementation of existing measures (in particular, the fuel switch away from oil heating and the promotion of clean energy) and the introduction of additional measures,

[4]The sales of energy, by volume used in transport may be partially or fully excluded from this calculation.
[5]See https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf.

Figure 31. EU+UK: Distribution of Building Stock by EPC Class[1]
(Percent of dwellings)



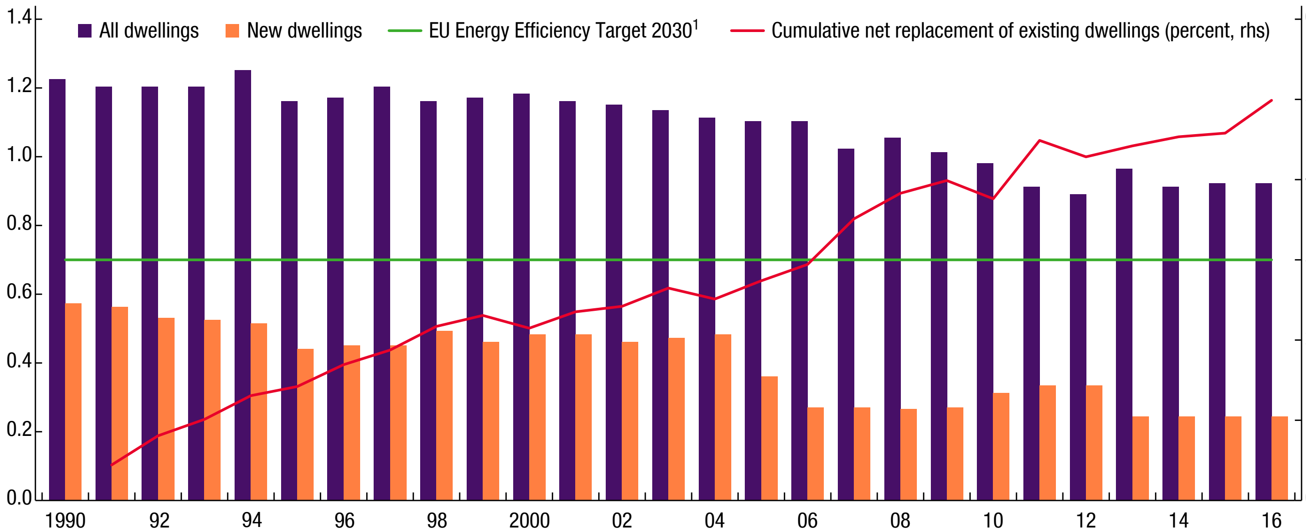
Sources: Building Performance Institute Europe; Central Statistics Office Ireland; European Environment Agency; Eurostat, *EU Building Stock Observatory*; and IMF staff calculations.
Note: EPC = Energy Performance Certificate.
[1]Countries with no central database (for example, Poland) or with limited information (Czech Republic, Romania, Slovak Republic) are not included.

including increasing the renovation rate in residential buildings. However, current energy use is still far above the EU energy efficiency target of 0.7 tons of oil equivalent (toe) per unit by 2030.[6] At the current rate of new construction and renovation activity, it would take more than half a century for the EU housing stock to become fully energy-efficient (Figure 32).[7] While the energy-efficiency level consistent with the 2030 emission reduction target is within reach, the EU-wide renovation rate should be about 7–8 percent per year to meet the 2050 net zero emission target (Figure 31).

[6]This threshold was derived from energy reduction target, which translates into a primary energy consumption of no more than 1,273 Mtoe and a final energy consumption of no more than 956 Mtoe in 2030, of which 18 percent is attributable to residential buildings.

[7]The construction of new dwellings of about 1.1 percent of the existing housing stock each year has resulted in an average annual net replacement rate of older dwellings by only about 0.2 percent since 1990 (as the housing stock has increased by 27.2 percent). The net replacement rate is calculated as the difference between the annual increase of the construction of new dwellings and the increase in the total housing stock for a given year relative the housing stock in the previous year. At the same time, only 0.4–1.2 percent (depending on the country) of the building stock is renovated each year.

Figure 32. EU+UK: Households—Energy Consumption for Heating
(Tonnes of oil equivalent per dwelling)



Sources: European Environment Agency; Eurostat; and IMF staff calculations.
[1]Assuming long-term trend growth of housing stock (units and average floor size) and based on energy consumption target for buildings (households and services) by 2030. In 2016, final energy consumption reached 1,108 million tonnes of oil equivalent (Mtoe) in the EU+UK. Buildings (households and services) consumed about 40 percent of this final energy (26 percent for households and 14 percent for services), and heating accounts for about two-thirds of energy consumption of households. Thus, for a projected EU target of total energy use for 2030 of 956 Mtoe, the target threshold of energy use per dwelling would be 0.7 toe (for a building stock of 215 million buildings as of end-2016).

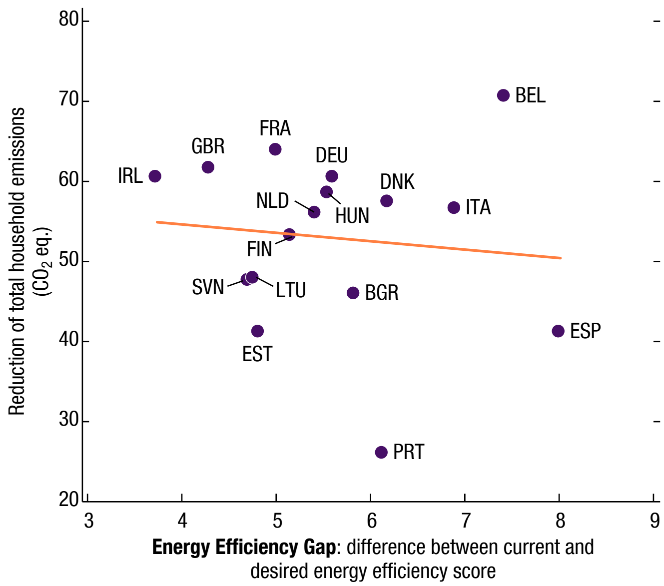
Abatement Channels

Abatement measures aimed at lower and cleaner energy use in residential housing are self-financing at current prices and technologies. Increasing energy-efficiency of buildings through better insulation, and cleaner and more efficient heating/ cooling equipment, is the main channel through which households can reduce emissions. Other energy-reduction channels such as energy-efficient lighting and digitalization to “smart” homes (for example, optimal automatic adjustment of heating temperatures) and renewable energy-based water heating systems can provide further sources of energy savings (GlobalABC 2019), but have more limited abatement potential owing to their lower energy shares.

Deep building renovations are the main channel of reducing emissions due to lower energy use (under current technologies).[8] Given a largely energy-inefficient overall housing stock, the potential for energy savings is

[8]Renovating the EU’s building stock for improving its energy performance will save €80 to €153 billion of investment costs into the power system by 2050. The savings, estimated after deep renovation, are at grid and production level.

Figure 33. EU+UK: Households—Potential Emission Reduction from Renovation/Retrofitting (Complete Upgrade to EPC = A)
(Percent)



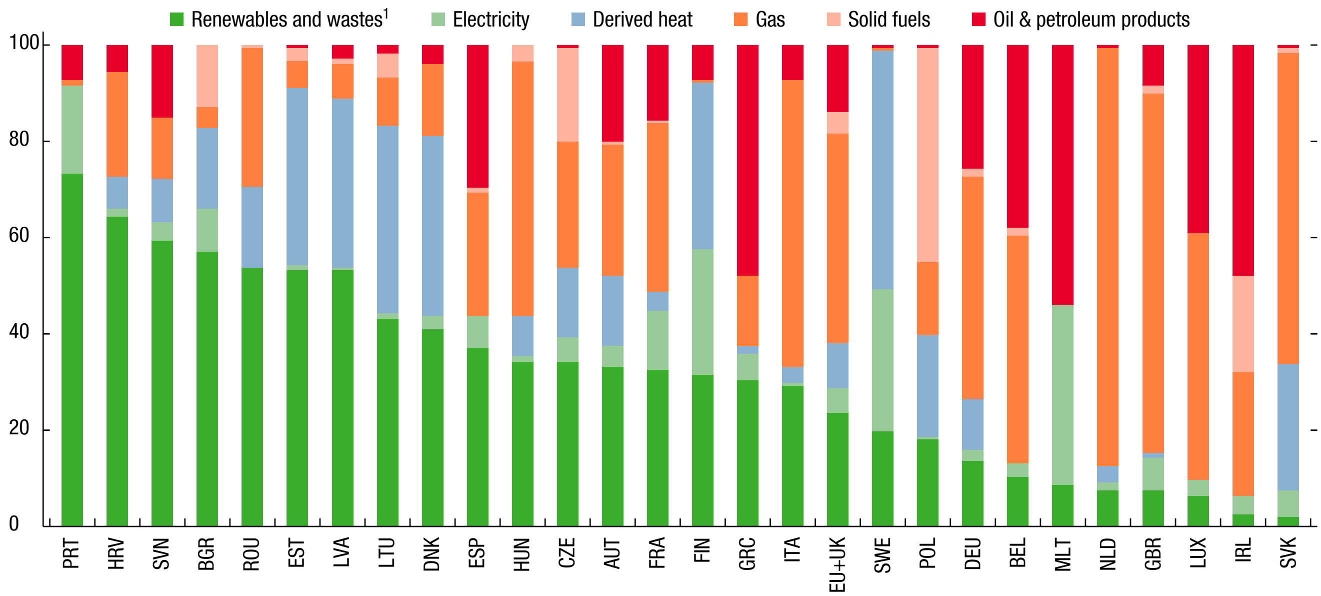
Sources: European Environment Agency; Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. EPC - Energy Performance Certificate.

considerable. A shift from a low energy-efficiency rating (Energy Performance Certificate (EPC) of "E" or less, which accounts for about 50 percent of the EU housing stock), to the highest rating of "A" (which covers less than 5 percent) could reduce energy consumption by about 85 percent on average, with slightly higher energy savings in Southern and Eastern European countries due to lower energy efficiency and smaller dwellings.[9] Combined with the country-specific household energy consumption mix, the emission reduction potential is estimated at above 50 percent for the EU, with the highest potential in Belgium, France, Ireland, and the United Kingdom (where households tend to use more fossil fuels for space and water heating) (Figures 33 and 34).

Reaching the net-zero emission target by 2050 requires a transformational shift through electrification and use of clean energy. Even in the best of

[9]Values are obtained by calculating the weighted average of existing energy efficiency ratings as a multiple of the average energy consumption of a three-bedroom semi-detached house (with a floor size of 100 m^2 and a monthly energy cost of €380) in each country and comparing it to the scenario where all houses are upgraded to the highest level of energy efficiency (EPC=A). The values are additionally adjusted for the country-specific average floor size of residential housing.

Figure 34. EU+UK: Households—Energy Consumption for Space Heating by Fuel Type, 2017
(Percent of total)



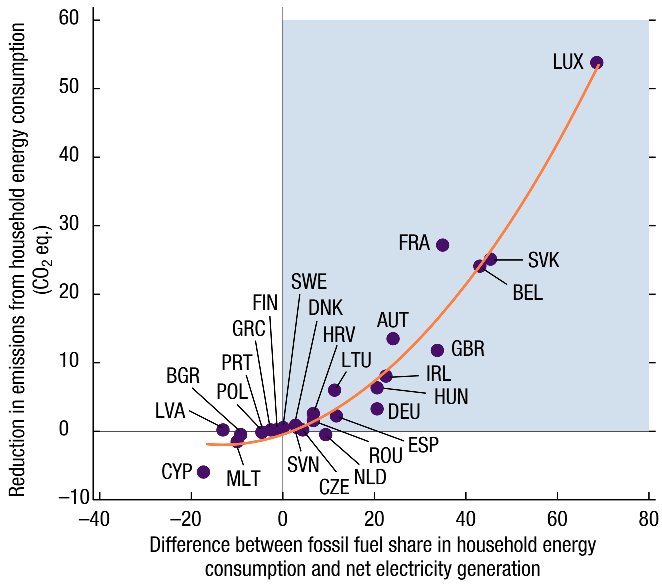
Source: Eurostat.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Predominantly solid biofuels, for example, biomass.

circumstances, when all energy-efficiency potential has been realized, energy will be needed to cook, heat, cool, or use electrical appliances. Hence, attaining a zero-emission target would require full electrification (for example, replacing gas-burning with electric stoves and gas heating with electric heat pumps) accompanied by a switch to non-emitting electricity generation.[10] The full potential of this mitigation channel will be realized once all energy is generated with non-emitting technology, over the longer-term (Chapter 2). In selected countries, the existing energy mix already implies emission reduction potential from electrification (Figure 35). The emission savings potential depends on the share of renewables and other low-carbon energy sources in overall power generation, compared to the emission intensity of fuels used for space and water heating. In some economies (Belgium, France, Luxemburg, Slovak Republic), the switch could reduce emission by 20–50 percent.[11]

[10]In principle, residential-based renewable energy, for instance through solar panels, could accommodate the remaining household energy demand, but based on current marginal cost curve estimates this appears less cost-efficient than a shift to nationwide clean energy generation.

[11]Estimates are derived by approximating the difference in lifecycle emissions associated with residential energy consumption based on existing energy sources and lifecycle emissions associated with the same energy consumption level but based on the countries' electricity mix in percent of total residential emissions. Since

Figure 35. EU+UK: Households—Potential Emissions Reduction from Complete Electrification
(Percent)



Sources: Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

The combined effect of greater energy efficiency through renovations and electrification could more than halve the current emissions from residential housing. Under the baseline simulations (with renovations achieving a complete and optimal energy-efficiency upgrade of the entire residential housing stock), current GHG emissions could be reduced by about 55 percent on average (Figure 36).[12] For individual countries with a high carbon-intensity of energy use, the combined effect could result in an emission reduction of more than 60 percent (Belgium, France, Germany, Ireland, United Kingdom).

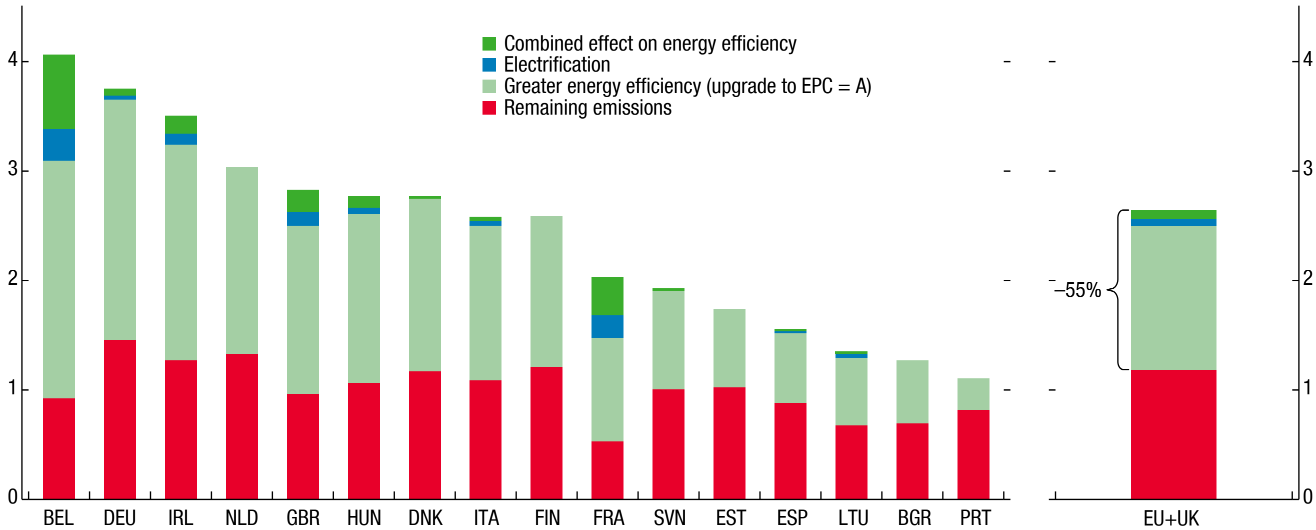
The required investment is large but has positive financial returns over the medium term. Implementation of all deep retrofitting renovations and electrification would entail high investment cost of about 40–50 percent of GDP.[13] Renovation cost estimates vary in line with country-specific labor

some economies rely heavily on coal and fossil fuel energy production, electrifying could even end up increasing GHG emission under the current energy mix.

[12]Allowing for an upgrade to “only” EPC=B level still implies an emission reduction of about 46 percent.

[13]Estimates are subject to uncertainty, reflecting possible variation in underlying assumptions. The estimate does not account for the moderate saving of about 1 percent of GDP at aggregate EU level due to lower investment needs in the electricity grid due to the implied reduction in energy need in the residential sector.

Figure 36. EU+UK: Potential Emission Reduction from Renovation/Retrofitting (EPC = A) and Electrification
(tCO_2 per capita, UN mean lifecycle emission projection per GWh)



Sources: European Environment Agency; Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. EPC - Energy Performance Certificate.

cost and scope of needed investment.[14] Despite the high price tag, under current technology standards and prices, energy cost savings are expected to broadly offset the investment for upgrading technologies and renovating buildings, although at very different horizons across countries (Figures 37 and 38).[15] With energy prices likely to increase in the future due to higher carbon prices, higher savings will make renovations even more cost-efficient.

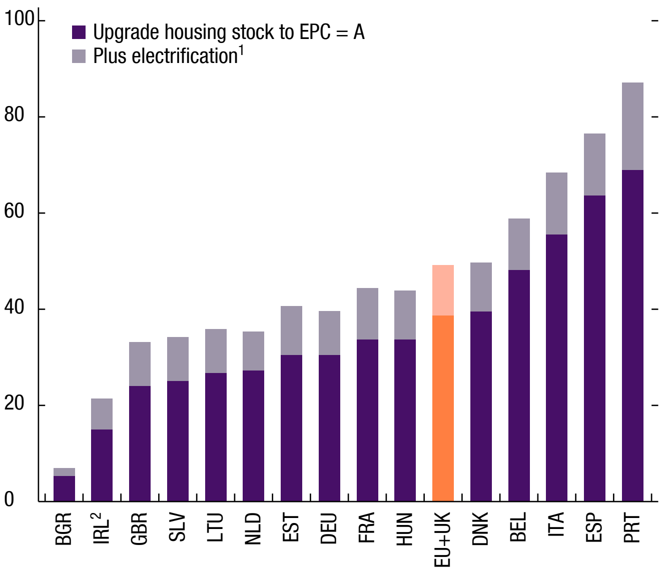
Challenges

The limited progress on emissions reduction in the residential building sector is partly explained by a lack of financing and inadequate price incentives. Incentivizing renovations and a shift to greater electrification are core ele-

[14]Investment costs for retrofitting/renovation are calculated using the estimates provided in Zachariadis and others (2018) and Paulou and others (2014) for Cyprus and Estonia, respectively. Country estimates are calculated using the composition of the housing stock by average EPC rating and corresponding level of investment needed to upgrade to EPC=A, adjusted by differences in average floor sizes across countries. Costs estimates are adjusted based on the GDP per capita. For instance, the average cost of retrofitting/renovation (including roof/wall/façade insulation and window frame system upgrade) for reaching the highest energy efficiency ranges from €8,457 to €44,427.

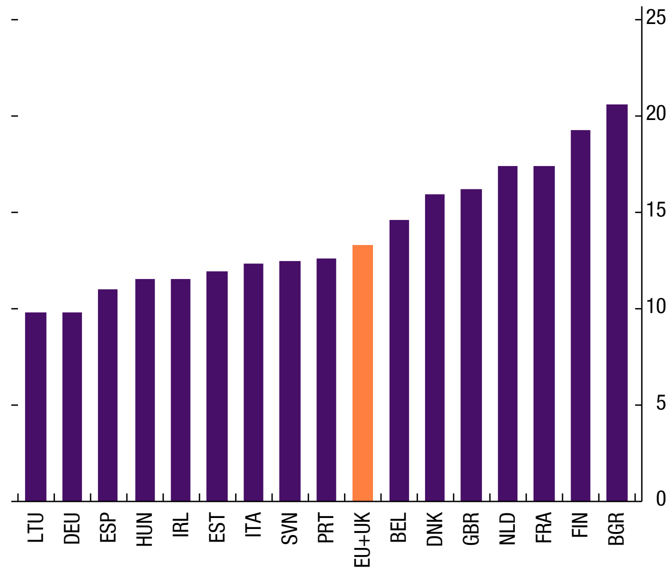
[15]The amortization time is estimated for each country using the cost of investment to upgrade the average energy rating in the country to EPC=A, and corresponding utility bills savings (adjusted for country specific data on energy prices incl. taxes). The time discount factor is assumed to be uniform at 2 percent.

Figure 37. EU+UK: Total Investment Needs for Retrofitting and Electrification
(Percent of GDP)



Sources: Central Statistics Office Ireland; European Environment Agency; Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. EPC - Energy Performance Certificate.
[1]Includes cost for eletric heatpump only.
[2]Percent of GNI.

Figure 38. EU+UK: Amortization Time of Investment in Renovation/Retrofit (EPC = A)
(Years)



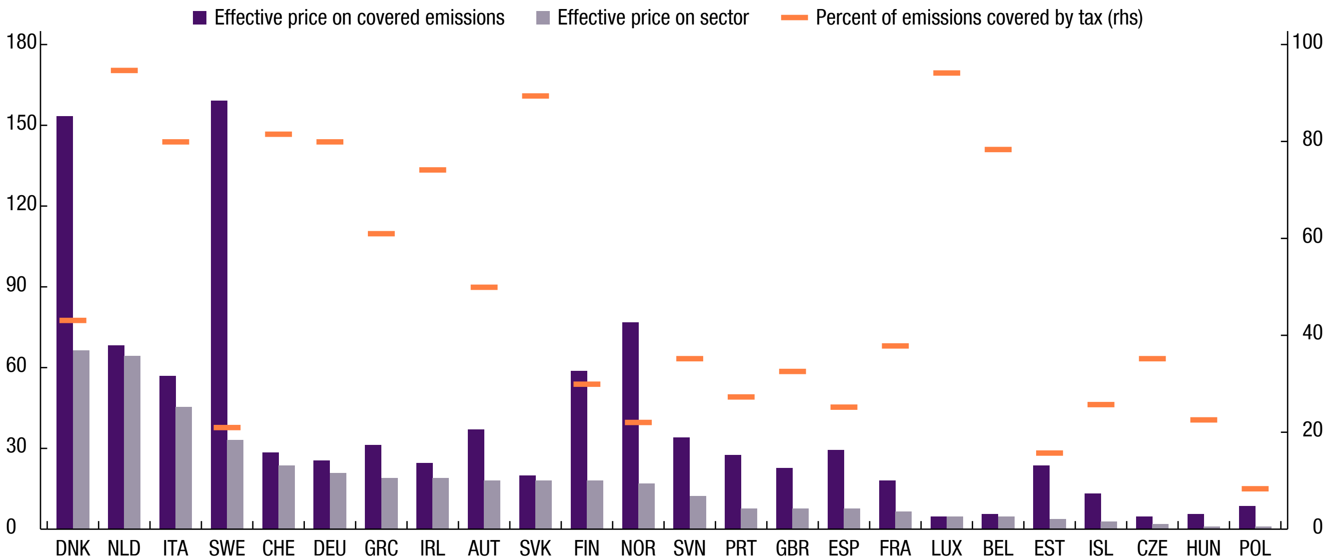
Sources: Building Performance Institute Europe; Central Statistics Office Ireland; European Environment Agency; Eurostat, *EU Building Stock Observatory*; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. EPC = Energy Performance Certificate.
[1]Median income level for each country is assumed.

ments of the abatement policies in the residential housing sector. Renovations cut energy bills and can reduce energy poverty. However, increasing renovation rates is a challenge. Higher renovation rates are not only held back by a lack of financing but also by market failures (including the investment and benefits disconnect between owners and users of housing) and inadequate price incentives (including uncertainties about future climate policies and carbon prices).

Partly due to the large share of indirect energy use, the residential housing sector is among the sectors least covered by environmental taxes. Current environmental taxes in the EU housing sector consist mainly of excises and, in a few cases, limited carbon taxes.[16] Thus, the housing sector has one of the highest "carbon pricing gaps," as only about 50 percent of related emission are covered by taxes, with an implied average effective price on covered

[16]This discussion abstracts from the taxes embedded in the electricity bill and focuses on *direct* emissions from the combustion of energy sources in homes.

Figure 39. Residential Emission Price
(EUR per tonne CO_2)



Sources: Organisation for Economic Co-operation and Development; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

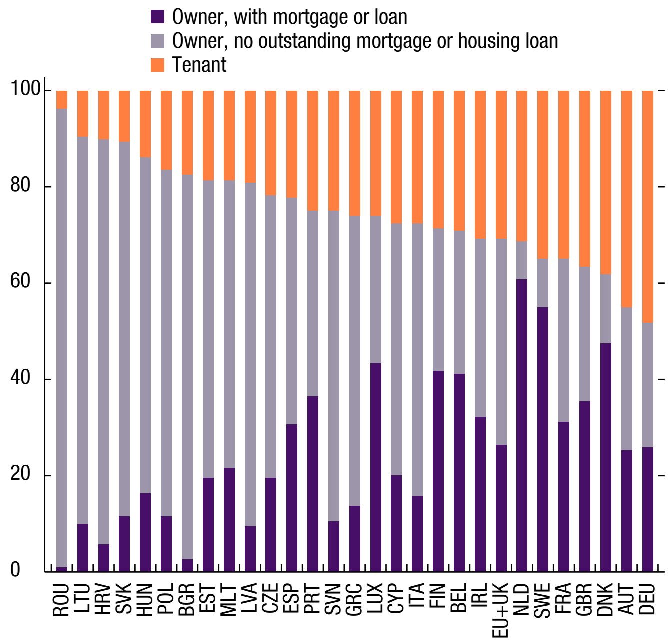
emissions of €18 per tCO_2 (OECD 2018b; Figure 39).[17] This puts coverage of emissions in the housing sector below all other sectors and results in an effective tax rate well below that of transport. Furthermore, in most cases taxes are not specifically targeted at the CO_2 content. Nevertheless, by applying environmental taxes to household consumption for fossil fuels (mostly for heating and cooking), several countries cover more than 50 percent of direct household emissions. France, Finland, Ireland, Sweden, and Switzerland are the EU countries with the highest share of an explicit carbon tax in residential emission taxes (OECD 2019).

Price-based policies alone may be insufficient to bring about needed investment and the targeted emission reductions for 2030 and beyond. There are several market failures that may need to be addressed via non-price measures:

- **Investor/user barrier:** Where renters are predominant, the energy savings would most likely be realized by them, giving homeowner limited incentives to invest in energy efficiency (unless it translates into higher rental

[17]The gap is the difference between a benchmark carbon price consistent with emission reduction targets by 2020/30 and the effective tax rate implied by existing carbon pricing, specific taxes on energy and the emission permit price from the ETS. The OECD (2018b) report considers two benchmark rates: €30, a low-end estimate of carbon costs at the time, and €60, a midpoint-estimate of the carbon cost in 2020 and low-end estimate for 2030.

Figure 40. EU+UK: Share of Owner-Occupied Housing, 2018
(Percent)



Source: Eurostat.
Note: Country list uses International Organization for Standardization (ISO) country codes.

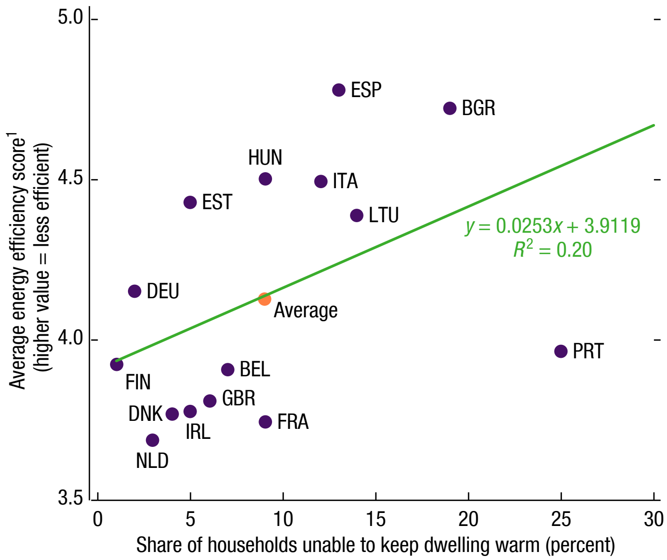
income).[18] Renters are less likely to invest themselves into a property that is not their own (especially if their expected rental period is short), except investments in low-cost, quickly amortizing investments, such as portable/limited life appliances like LED light bulbs. A similar mismatch between incurring the upfront investment cost and reaping its benefits arises from a fragmented ownership lifecycle, for example, when homeowners tend to move (and, thus, buy and sell) more often (Figure 40).[19]

- **Lack of (access to) financing:** Deep retrofitting or renovation measures require high upfront investment, which tends to exceed the available

[18]Several studies have shown this being the case to a certain degree (for example, in Ireland, a one-step increase in the energy efficiency of buildings increases rental income by 1.4 percent (BPIE 2014b)). However, information asymmetries remain too high to allow full returns on energy-efficiency investments by landlords.

[19]However, some studies on the relationship between buildings' energy performance and residential property prices indicate that the home value increases with its energy-efficiency, making the latter less of a concern. For instance, green building owners in the United States report a 7 percent increase in asset value due to a higher resale price than conventionally built homes, making them better collateral (Dodge Data & Analytics 2018). For Italy, Copiello and Bonifaci (2015) find that the market value of renovated houses with an original EPC=E increases by 7.6 percent. In the case of Ireland, a one-step increase in the building efficiency rating (BER) rating has been valued at a 2.8 percent increase in sale price.

Figure 41. EU+UK (Selected): Energy Efficiency of Housing Stock and Vulnerable Households
(Percent of households)



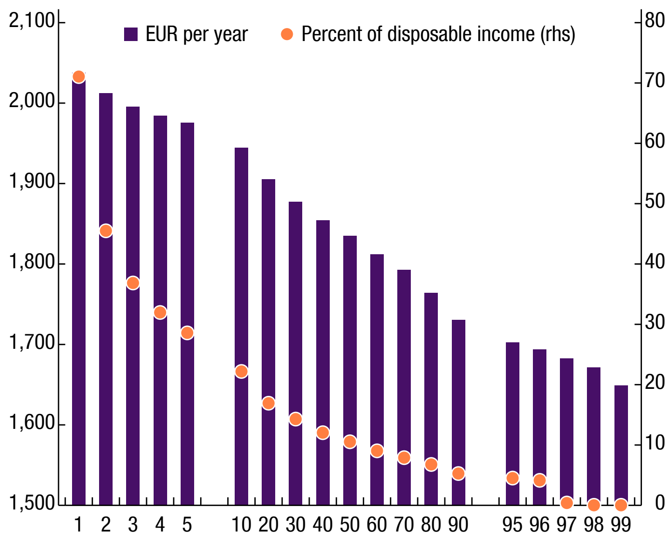
Sources: Building Performance Institute Europe; Eurostat, *EU Building Stock Observatory*; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]The energy efficiency score is the average EPC score of the existing housing stock.

savings of low-income households.[20] Even though the lower average floor size of dwellings occupied by low-income households generally requires less energy for heating and cooling, the benefits from retrofitting and renovation are likely to be larger (per square meter) due to lower energy efficiency and higher energy cost relative to disposable income (Figure 41). Raising the energy efficiency of social housing[21] resolves both challenges—financing constraints and investor/user barrier—and makes a strong case for direct policy intervention through public investment.

- **Energy savings awareness/uncertainty:** A low priority is often given by individuals to the cost of energy as it reflects a small share of the total residential building cost (Ürge-Vorsatz and others 2012). Furthermore, despite improvements in labelling on energy efficiency of appliances (which have short amortization periods), uncertain future energy prices make it unclear whether an investment is self-financing, especially where upfront costs are

[20]Household income and quality of housing tend to be positively correlated.
[21]Several EU countries (Belgium, Ireland, Malta, Netherlands) already include renovation of social housing in their 10-year integrated National Energy and Climate Plans (NECPs) for the period from 2021 to 2030 to meet the EU's emission reduction target in sectors that are not covered by the ETS.

Figure 42. Households' Estimated Energy Cost Savings from Retrofitting (Complete Upgrade to EPC = A), 2018
(Per household income percentile)



Sources: European Environment Agency; Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: EPC = Energy Performance Certificate.

large and implied energy savings are less certain (for example, deep retrofitting). At the same time, utility-bill savings from these changes could be particularly significant for low-income households (Figure 42).

- **Implementation complexity:** The larger the renovation the more counterparties will be involved, the higher the administrative cost and the riskier the project (for example, inadequate exaction of parts of the renovation project by contractors with suboptimal energy saving realization). In addition, adequate skills are required to ensure a high quality of renovations and upgrades. This complexity argues for policies that kick in at special points-of-entry where administrative upfront costs are already partly paid (for example, standardized mortgage "add-ons" to incentivize renovations offered by banks for any existing house purchase).

Policy Recommendations

A large-scale transformation is needed to make residential buildings more energy efficient and de-carbonize the energy use of households. Complementary mechanisms and instruments have been used in varying scope and intensity across EU members to encourage energy savings in residential housing, from which lessons can be drawn (Ürge-Vorsatz and others 2014):

(1) fiscal policies, including but not limited to taxes, (2) structural policies centering around energy efficiency standards, and (3) financial policies, including “green mortgages” and “green building insurance” (Box 3). Carbon taxes will help provide incentives to adopt abatement measures. However, some energy-efficiency measures (for example, deep retrofitting) imply significant upfront investment costs, which may require targeted fiscal/financial support. In contrast, for investments with limited cost and short payoff periods, structural measures, such as regulations and awareness campaigns, may be sufficient.

Electrification and building renovation have synergies that argue for parallel implementation. Absent renovation, the electrification of energy usage would translate into a significantly higher demand for electricity. Under the full electrification, net-zero emission 2050 scenario, demand for household electricity would increase by about 30 percent (which is about the share of direct energy use by households). Higher electricity demand in the future would require boosting renewable electricity production. To the extent that renovations would proceed in parallel and result in sufficient energy-efficiency improvements, potential energy demand for residential buildings might even decline (and create excess capacity for higher energy demand from other sectors, such as transportation and industry).

Amid market and regulatory failures hampering a faster and more effective renovation of buildings, targeted measures should draw from several policies:

- **Expand carbon tax coverage and increase the price of CO_2 emissions in the residential sector, including by phasing out support for emission-intensive energy source usage.** This would encourage households to use cleaner fuel sources through electrification and/or increase the share of sustainable generation from direct (for example, rooftop solar panels) or indirect (for example, district heating) sources. It will also add to incentives to invest in renovation. Price-based policies will need to be accompanied by adequate compensating measures for vulnerable households.
- **Set binding targets for energy efficiency improvements and support building renovation.** Amending the relevant EU directives (EPBD and EED) consistent with the provisions in the EU Green Deal (EU 2019c) would establish a clear path toward a low- and zero-emission building stock by 2050 and drive additional national commitments to support housing renovation. Under the Clean Energy for All Europeans Package, EU member states are already required to prepare national policy measures to de-carbonize buildings consistent with the previous target for 2030, but these national roadmaps may require amendment under the Green Deal’s higher level of ambition.

- **Harmonize and regulate energy efficiency ratings.** The certification process for EPCs varies significantly across EU member states. Introducing greater comparability through harmonization (without necessarily imposing identical standards across countries with different climates) will help reduce asymmetric information regarding ex ante energy savings and renovation cost and support.[22]
- **Increase availability and commercial relevance of building-efficiency information.** Ensure that the requirement for EPCs when a building is sold or rented (which has been implemented only in a few countries) is strictly enforced and expand current disclosure obligations to any bank lending collateralized by real estate; establish incentives for inspection schemes for heating and air conditioning systems (possibly supported by tax incentives).
- **Design energy-dependent property taxes.** Landlords need incentives for renovation due to the investor-user barrier. While transparency on energy cost is helpful to make a rental object more marketable, the still limited cost of energy compared to overall rent is unlikely to provide sufficient room for higher rental income to compensate for the initial investment. Thus, like feebate systems for lower emission vehicles, making real estate taxes progressive to EPCs would compensate for the investment in greater energy efficiency by landlords (and, thus, addresses potential market failure).
- **Expand options for "on-bill" financing of investments in energy efficiency.** The amortization of investment cost through future energy bills shifts repayment to the occupant (and energy user) rather than the owner of a building. It can help overcome the investor-user barrier by raising incentives for both landlords and homeowners with limited planned ownership-tenure to undertake investments. This "on-bill financing" practice is followed in some parts of the United States (Bird and Hernández 2012).
- **Enhance financial support through "green mortgages."** Increase funding and support for renovation—by mobilizing public and private financing and investment as well as strengthening long-term building renovation strategies; providing green-rebuild insurance coverage for investment in clean technologies and energy-efficient fittings (including renewable energy

[22]The certification price varies significantly across countries, which could impact the design and implementation of financial incentives for renovation. While transaction costs have fallen over time, they remain high and variable in several countries with a high share of buildings that are not energy efficient, such as the Czech Republic, Italy, and Slovenia. The Swedish system of certified experts provides a good example of how the transition to a market-driven price can be effectively managed. See http://bpie.eu/wp-content/uploads/2015/10/Energy-Performance-Certificates-EPC-across-the-EU.-A-mapping-of-national-approaches-2014.pdf.

facilities);[23] legislating the definition of energy-efficient mortgages (EEMs) based on recent initiatives, such as the current EMF-ECBC Initiative, to provide common standards for lower-cost "green mortgages" (Box 3) and offering means-tested low-interest loans or grants for renovation (modelled after existing national programs).[24]

- **Remove structural constraints.** Introduce certification and training programs for developers/contractors; amend vocational training in skill areas essential to energy-efficient renovation to prevent supply shortages. Drawing lessons from the failure of tax incentives for retrofitting in France, observers have noted that industrial/structural policies have a key role to play. The challenge is to expand and restructure the supply side to create an industrial sector that can provide retrofitting solutions that are understandable for owners and tenants and that can sustain high rates of retrofitting. This includes factors such as the provision of a skilled workforce, cooperation between different trades, and the creation of certifications and advisory structures.
- **Raise greater awareness of energy efficiency benefits.** Awareness campaigns (for example, including information on energy usage of comparable houses of higher energy standards and associated savings in the energy bill) have the potential to increase energy saving investments at relatively low cost. Furthermore, to overcome informational barriers and asymmetries, one-stop shops and integrated offers (loan, advice and service providers) could be helpful.
- **Ensure inclusive transition via supportive policies.** Recycling some carbon tax revenues can help combat energy poverty by providing means-tested grants to vulnerable households to reduce their energy bills and support the renovation and improved energy performance of older buildings, with a focus on social housing.[25]

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[23]Several large insurance companies (for example, AIG, Allianz, Aviva, and AXA) have started offering "green homeowners policies," which contain "green" upgrade features covering costs incurred to repair and replace damaged property to conserve natural resources, reduce energy or water consumption, reduce emissions of pollutants, or otherwise minimize environmental impact. There are also insurance policies covering homeowners for the loss of re-sellable energy (for example, solar) in case of accidents or damage to the property/equipment.

[24]Germany's development bank, Kreditanstalt für Wiederaufbau (KfW), provides long-term financing of investments in the modernization and construction of energy-efficient buildings at low interest rates on behalf of the Federal Ministry of Economics and Energy. See https://www.kfw.de/KfW-Group/Newsroom/Latest-News/Pressemitteilungen-Details_472512.html.

[25]Ireland plans to use one-third of its revenues from higher carbon taxes for "just transition" measures, such as housing upgrades and social protection.

Box 3. Green Mortgages

Green mortgages are becoming an important financing channel for improving the energy performance of Europe's building stock and can contribute positively to achieving the EU climate goals consistent with the Paris Agreement. A green mortgage (or energy efficient mortgage, EEM) provides incentives for borrowers to either acquire energy-efficient residential homes and commercial buildings or upgrade conventional construction by installing energy-efficiency improvements to enhance its Energy Performance Certificate (EPC) level. Lower operating costs due to energy savings of green buildings allows borrowers to direct more of their income toward mortgage payments, which strengthens the debt repayment capacity. This allows lenders to either (1) offer these mortgages at below market interest rates and/or (2) increase the loan amount at origination due to a lower cost of risk. In a recent Bank of England study on micro-level data of UK residential mortgages, Guin and Korhonen (2020) find that energy efficiency is a relevant predictor of mortgage defaults. Mortgages against energy-efficient properties are less frequently in payment arrears than mortgages against energy-inefficient properties. This result is robust when controlling for other relevant determinants of mortgage default, including borrower income, location, and the loan-to-value ratio of the mortgage.[1]

In response to the urgent requirement for climate-friendly buildings, many European banks have started offering green mortgages. The European Mortgage Federation (EMF), in concert with a consortium of mortgage lenders, has piloted a new scheme that could help develop a pan-European standard approach for green mortgages under the Energy Efficient Mortgages Initiative (EEMI), which will both assemble and analyze more data as well as developing a green mortgage design (Table 3.1).[2]

An example below provides a cost-benefit analysis of a green mortgage relative to a standard mortgage. Assuming an average cost of efficiency measures of €24,448 for a semi-detached dwelling (€300,000) and an average EU floor space of 96m^2 at EPC=A, the monthly payment for a 30-year green mortgage would be €1,225 (and slightly higher than for a standard mortgage even if the borrower benefits from a small interest discount of 25 basis points). However, the cost of owning an energy-efficient home

[1]The Institute for Market Transformation and the UNC Center for Community Capital (2013) find that banks in the United States and Europe enjoy a default rate of up to 33 percent lower from green home buyers.

[2]According to the EEMI, green mortgages are intended to finance the purchase/construction and/or renovation of both residential (single family and multifamily) and commercial buildings where there is evidence of: (1) energy performance which meets or exceeds relevant market best practice standards in line with current EU legislative requirements and/or (2) an improvement in energy performance of at least 30 percent. This evidence should be provided by way of a recent EPC rating or score, complemented by an estimation of the value of the property according to the standards required under existing EU legislation.

Box 3. Green Mortgages *(continued)*

Table 3.1. Cost-Benefit Analysis of a Green Mortgage
(Monetary units unless specified otherwise)

	Standard Mortgage	Green Mortgage[1]
Base Purchase Cost	300,000	300,000
Energy Efficient Measures[2]	—	24,448
Down Payment (20%)	60,000	60,000
Loan Amount	**240,000**	**264,448**
Monthly Mortgage Payment	1,146	1,225
Rate[3]	4.00%	3.75%
Term	30	30
Utility Cost Savings (Energy)[4]	—	155
Monthly Cost of Home Ownership	**1,146**	**1,069**
Bank Income (one year)[5]	**13,750**	**14,696**

Source: IMF staff estimates.
[1]For the financing of a retrofitted/energy-efficient dwelling.
[2]EU average for semi-detached dwelling with an average floor space of 96m^2 with EPC=A, estimated based on the implied (additional) cost for the construction of a net-zero energy building (NZEB) or a deep renovation, including roof insulation, wall/façade insulation, window frame system upgrade, and upgrading lighting and electronic appliances; for existing dwellings, the average energy efficiency for dwellings occupied by households at the median income level is assumed (EPC=D).
[3]Banks typically offer cashbacks, partial principal forgiveness, and a significant interest rate discount for green mortgages—in this example, a discount of 25 basis points is assumed (which is conservative, given that rate discounts can be as high as 75 basis points).
[4]Assuming that the weighted-average, purchasing power-adjusted annual energy cost for space and water heating are EUR3.1 per m^2.
[5]This does not include additional benefits from potentially lower loan loss provisioning and lower capital requirements due to lower expected and unexpected losses.

drops significantly below that of a standard home (–7 percent) after accounting for the estimated utility cost savings of €155 per month. Since also the bank benefits due to higher mortgage payments, this arrangement results in a win-win situation for both borrower and lender by making the economic implications of energy efficiency explicit in the green mortgage contract.

CHAPTER

5 Manufacturing Sector

Overview of Emissions and Drivers

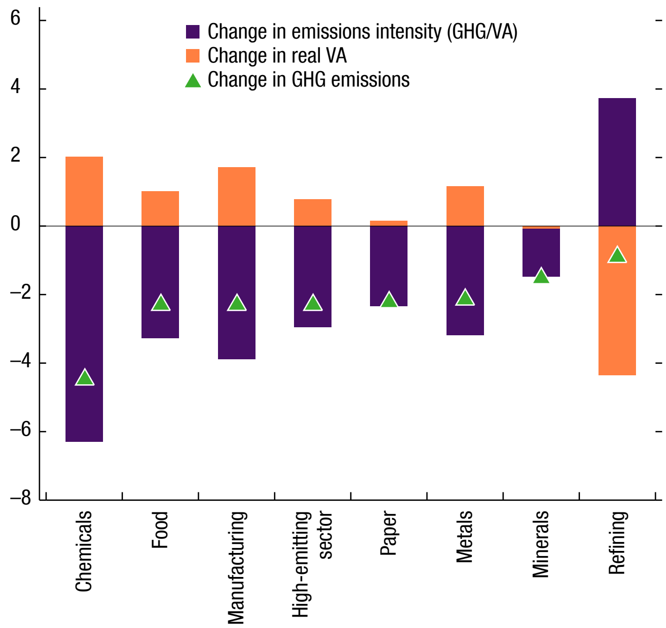
EU manufacturing GHG direct emissions are concentrated in a few sectors and are largely related to fossil fuel combustion.[1] Industrial emissions intensity in Europe is lower than in other large economies, possibly reflecting a mix of product specialization and efficiency. In absolute terms, EU's direct emissions from the manufacturing sector are large compared to those of other advanced economies but are lower than China's emissions. They account for nearly one-fifth of total EU GHG emissions, and stem mostly from six high-emitting industries (mineral, metal, petroleum refining, chemical, food, paper). Together, these industries account for more than 90 percent of total manufacturing emissions (the latter reaching 870 $MtCO_2e$ in 2018) but only about 45 percent of manufacturing value-added and employment (Eurostat, Air Emissions Accounts). Two-thirds of emissions come from the sector's use of energy via fuel combustion; one-third originates from production processes.[2] This accounting does not include indirect emissions due to the use of electricity.

There has been significant progress in reducing EU manufacturing emissions in recent decades (Figures 43 and 44). Manufacturing emissions declined by 38 percent since 1990, while total economy emissions dropped only by 23 percent. At the same time, value added in the manufacturing sector increased. For comparison, manufacturing emissions declined only by about 20 percent in Japan, Russia, and the United States during the same

[1]This chapter considers manufacturing industry emissions, unless otherwise specified.

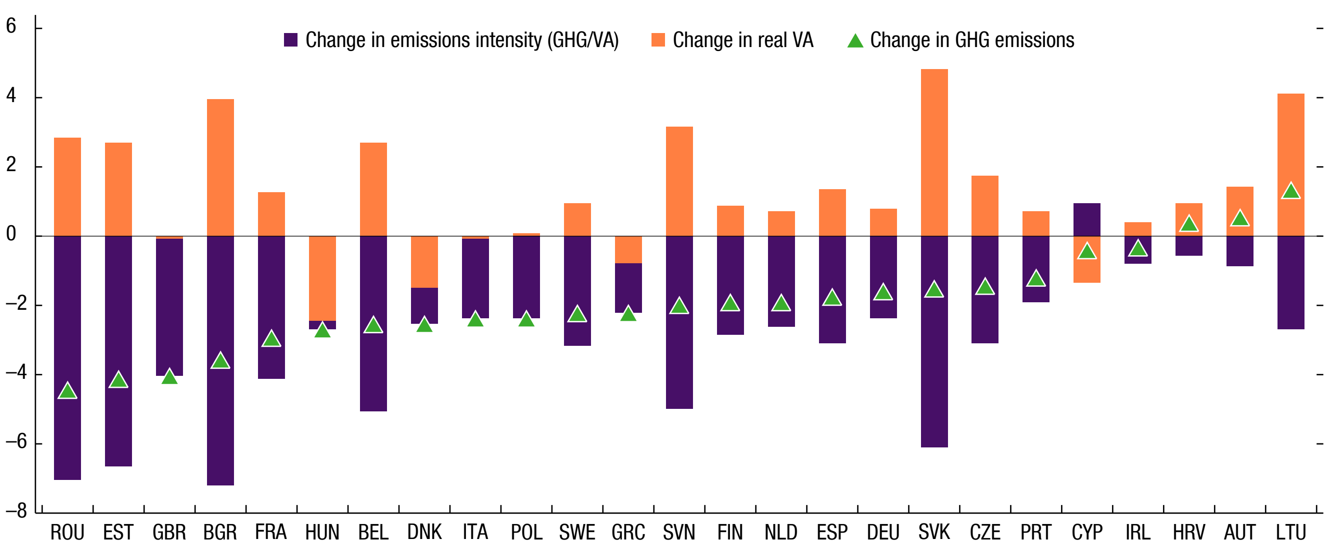
[2]Process-related emissions are a result of the industrial process itself, not of the energy input needed to start the process. For instance, most existing techniques in steelmaking use raw materials (for example, natural gas) that set CO_2 free as oxygen is removed from iron ore. Source: UNFCCC and IMF staff estimates.

Figure 43. EU+UK: Manufacturing Industry—Change in GHG Emissions
(Percent per year, 1995–2015)



Sources: Organisation for Economic Co-operation and Development, Structural Analysis database; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Total manufacturing includes sectors classified as "low emittors in the EU." Data is available for a subset of EU countries. GHG = greenhouse gas; VA = value added.

Figure 44. High-Emitting Manufacturing Industry, Change in GHG Emissions
(Percent per year, 1995–2015)



Sources: Eurostat; Organisation for Economic Co-operation and Development, Structural Analysis database; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. GHG = greenhouse gas; VA = value added.

period (UNFCCC).[3] EEA (2011) finds that between 1990 and 2008, direct industrial emissions from energy consumption declined mainly due to lower energy intensity of production, while other factors (carbon intensity, share of fossil fuel in fuel combustion, and use of indirect energy sources) contributed only marginally. Reduction in process emissions accounted for half of the decline in total emissions.

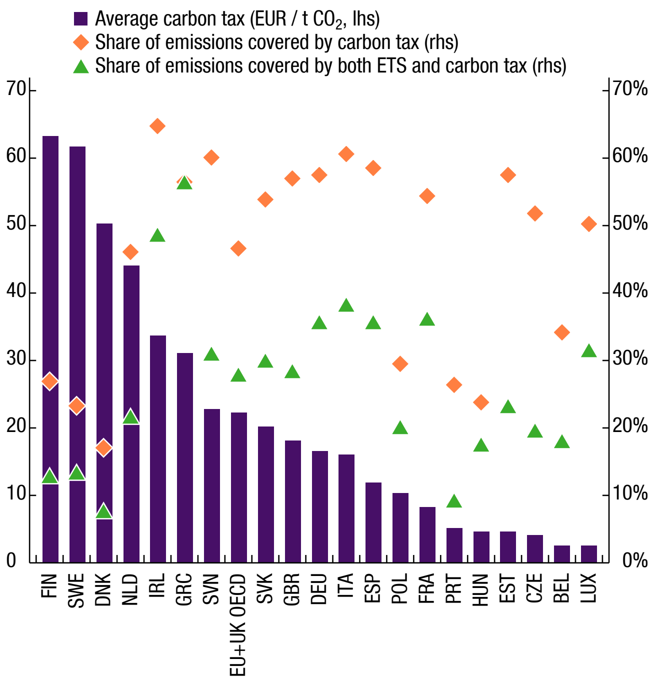
The main EU policy instrument for reducing emissions in the manufacturing sector is the European Trading System (ETS). The ETS covers about 65 percent of manufacturing emissions.[4] The rest of the emissions come from non-covered products, small plants, and gases (CH_4, HFC, NF_3, SF_6). Dechezleprêtre and others (2018) find that EU ETS has been effective in reducing emissions between 2005 and 2012. Some member states complement the ETS with national-level carbon and energy pricing instruments leading to different levels of carbon taxation and coverage within the EU (Figure 45). However, manufacturing firms often enjoy exemptions and reduced rates. For example, Sweden has a high carbon tax, but manufacturing firms covered by the ETS are fully exempt from the carbon tax and pay only 30 percent of the energy tax. The Netherlands has proposed an industry carbon tax which would apply on top of the ETS (Government of the Netherlands 2019). Such national policies would be more efficient at cutting EU emissions if the available ETS permits are adjusted downward to prevent a waterbed effect (where cuts in emissions in one country lower the carbon price and hence incentives to reduce emissions in another country).

Non-price policies have also helped reduce industrial emissions mainly through the adoption of cleaner production processes (Box 4). Several initiatives have been adopted and enforced at the EU level. There are various EU-wide minimum requirements for the efficiency of processes and products (Ecodesign Directive, Energy Efficiency Directive, Industrial Emissions Directive). Improved producer (energy-efficiency audits) and consumer (energy labelling) information have increased transparency. The EU's Best Available Techniques reference documents have helped facilitate the diffusion of best practices and technology. The EU also supports R&D for example through the EU Sustainable Industry Low Carbon (SILC) Initiative and the Innovation Fund. However, the cost-effectiveness of some of these non-price policies compared to carbon pricing is not clear (see companion paper). The non-price policies do not raise revenues for the public sector and in some cases may undermine the impact of the ETS. Additional initiatives have been taken to reduce industrial emissions at the national level.

[3]At the country level, the largest reductions in manufacturing emissions between 1990 and 2017 occurred in Luxembourg, Estonia, Latvia, Romania, and the United Kingdom; while smallest reductions or even increases occurred in Spain, Poland, Ireland, Austria, and Cyprus.

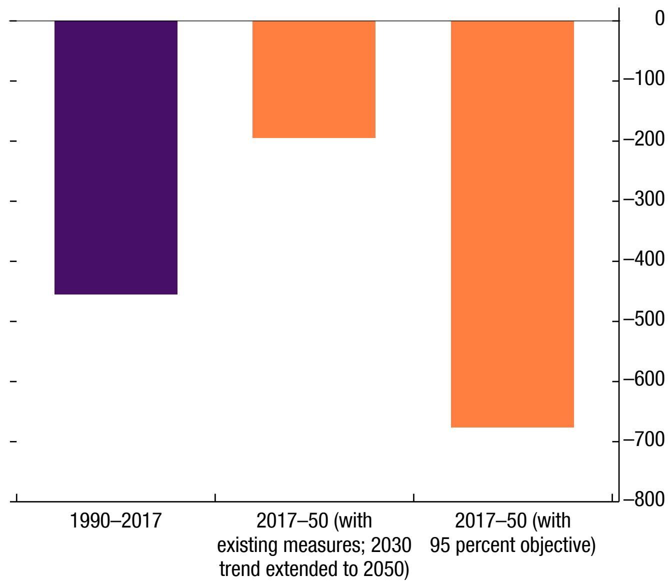
[4]Source: Eurostat, EEA and IMF staff estimates.

Figure 45. Industry: Carbon Taxes and Share of Emissions Covered, 2015
(Energy use)



Sources: OECD (2018b) Taxing Energy Use; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes. ETS = emissions trading system.

Figure 46. EU+UK: Change in Manufacturing Industry GHG Direct Emissions
($MtCO_2e$)



Sources: European Environment Agency; United Nations Framework Convention on Climate Change; and IMF staff calculations.

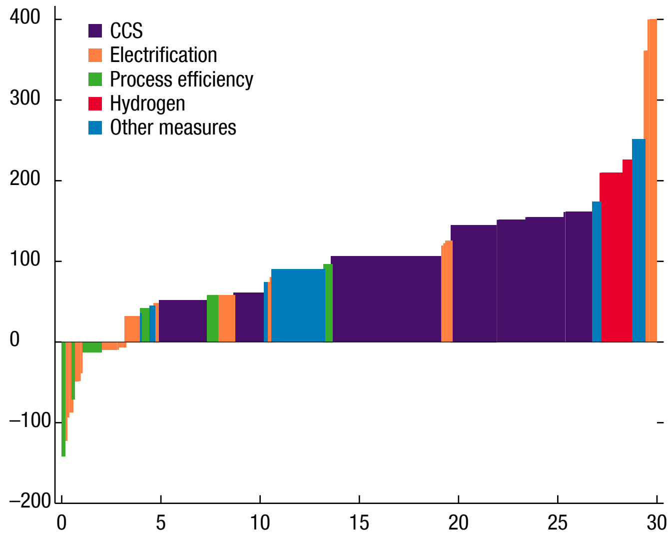
Going forward, meeting the Green Deal goals will require significant further efforts. While the European manufacturing sector made commendable progress in the past, emissions are projected to fall short of the current 2030 ETS target (43 percent reduction vs. 2005) under existing policies.[5] A linear reduction of emissions toward –95 percent in 2050 (close to net neutrality) would imply a needed reduction of industrial emissions of 53 percent by 2030 vs. 2005 (Figure 46).

Abatement Channels

Further improvements in industrial emission efficiency will be needed to meet the Green Deal's targets. Engineering experts and business associations have identified a number of potential technical solutions to reduce direct

[5]Estimate based on GHG emissions projections submitted by member states to the EEA.

Figure 47. Example of an Industrial Emissions Cost Abatement Curve in the Netherlands at the 2030 Horizon
(Cost effectiveness, €/ton CO_2)



Source: Based on PBL (2019).
Note: Estimates of cost abatement curves are highly uncertain as they depend among others on future energy and CO_2 prices and interest rates.

emissions.[6] There are some relatively cost-effective options, others that are not cost-effective at today's carbon prices, and some that are not yet ready to be scaled up and require further technological progress. Promising options include electrifying processes, switching to low emission feedstock such as hydrogen, and capturing and storing carbon (Figure 47).

Energy-related emissions can be reduced by increased energy efficiency as well as by fuel switching. Some processes use electricity as input, either directly or in the production of hydrogen. Many low-temperature heat processes have already been successfully electrified, while high-temperature processes are more difficult to electrify. Biofuels and biogas as well as biomass are low-emission fuel alternatives which could be used where electrification is challenging.

Process-related emissions can be reduced through new processes and improved material efficiency. For instance, new processes in steel-making build on existing technologies but use hydrogen instead of coke or natural gas to remove oxygen from iron ore, eliminating carbon from this step. Scrap in some manufacturing processes can be significantly reduced by adopting

[6]The material in this section is based primarily on Elkerbout and Bryhn (2019); Wyns, Khandekar, and Robson (2018); and Material Economics (2019).

current best practice. The recycling of materials bypasses the process emissions of new production. However, some recycling processes are costly and not yet commercially viable. For example, chemical recycling requires large amounts of energy input.

Carbon Capture and Storage (CCS) will need to play a role. Without CCS, zero-carbon products in some industries (for example, steel and cement) are not feasible. CCS technology is already at an advanced stage but not yet ready for large scale industrial application.[7] Nonetheless, the analysis underlying the Dutch 2019 industrial plan projects that half of the country's industrial emissions reduction by 2030 would be achieved by CCS. Making CCS solutions feasible would require some reconfiguration of production processes and significant infrastructure investments, including of transport.

The Effectiveness of EU Climate Policies for the Manufacturing Sector

The EU has so far largely compensated its industry for rising carbon costs. To address competitiveness concerns and risks of carbon "leakage," carbon price policies have often been designed in tandem with schemes to reduce the cost of carbon faced by the industry. For example, within the EU ETS framework, the manufacturing sector has received most of its emission allowances for free since 2005 (Figure 48).[8] While in theory, due to opportunity costs, incentives to reduce emissions are not undermined by free allowances, in practice, the empirical literature suggests that this might not be the case. For example, Dechezleprêtre and others (2018) find that installations which received more free allowances reduced emissions by less on average (possibly due to transaction costs, imperfect competition and behavioral reactions).

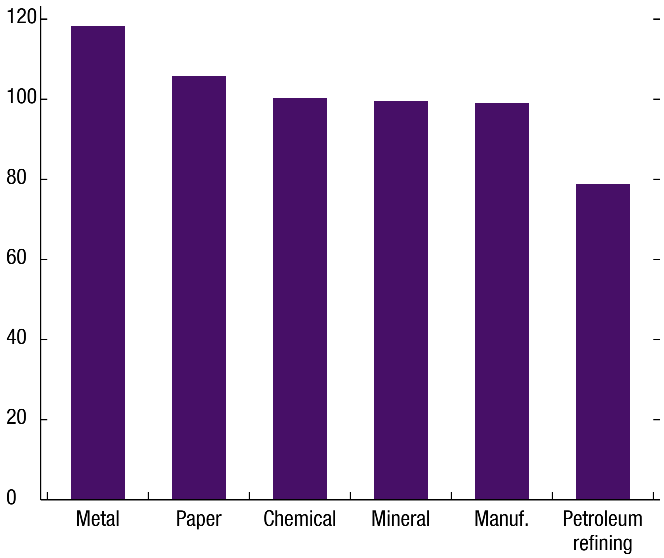
Member states also often provide partial compensation to their industries for carbon and energy costs. Some countries have schemes that effectively compensate firms for the cost of carbon emissions.[9] Large industrial electricity consumers often benefit from lower electricity prices than the average-size plant, thanks to a variety of tax reductions and price rebates (Figure 49). For instance, in many member states energy-intensive industries are exempt

[7]Importantly, CCS faces some public backlash over the question whether a permanently safe storage can be guaranteed. There is a tail risk of earth tremors when storing CO_2 on land, as well as the hazard of ground water acidification should any CO_2 escape (Elkerbout and Bryhn 2019).

[8]The European Commission draws up the list of sectors considered to be at risk of carbon leakage with the agreement of member states and the European Parliament. Most other jurisdictions that have cap-and-trade systems like the ETS also make use of free allowances. While the mechanism for free allocation will change in Phase 4 of the ETS, it is expected that the manufacturing sector will continue to receive allowances for free.

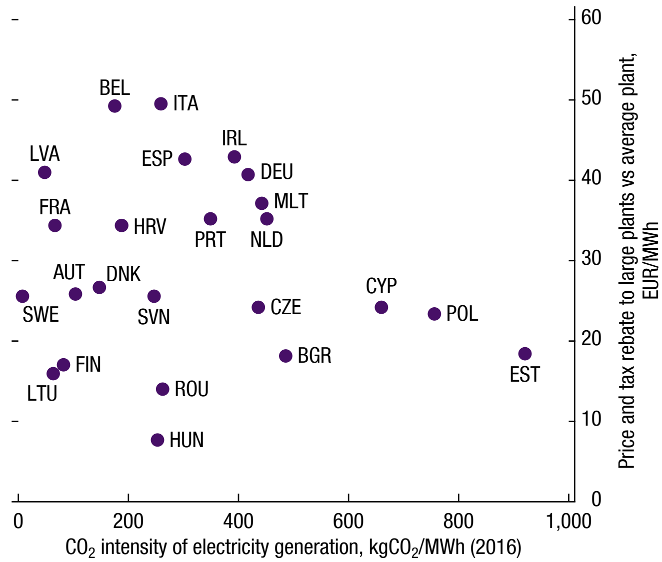
[9]Member states transfer part of their revenues from ETS auctions to the industry, ranging from less than 5 percent in Lithuania to 30 percent in France and 50 percent in Luxembourg (EC 2019e). These compensations were not always driven by an economic rationale (Roques and Laroche 2020).

Figure 48. EU+UK: Free Allocated as a Share of Verified Emissions, 2017
(Industrial installations)



Sources: European Union Transaction Log; and IMF staff calculations.

Figure 49. EU: Industry Electricity Price Rebates to Large Plants, 2017



Sources: European Environment Agency; Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

from energy and national carbon taxes, and network access duties are also often lower.[10] While electrification is a promising avenue to reduce industrial emissions, electricity price discounts and tax rebates have not been limited to countries in which electricity is generated with a climate-friendly mix (Chapter 2).

High-emitting industries invest less in R&D than the rest of manufacturing, despite the very large investments needs to meet climate targets. In countries where data are available, R&D investment is lower in high-emitting industries (1 to 6 percent of value added) than in the rest of manufacturing (10 percent of value added in top-performing countries). In most countries, some high-emitting sectors (mineral and metal) also invest less in equipment for pollution control and cleaner technologies than the rest of manufacturing, at about 0.4 percent of value added. According to the EC (2018), additional investments needed to reduce emissions by 80 to 100 percent (compared to 1990) will range from €2–25 billion per year between 2030 and 2050

[10]For example, in Sweden, the manufacturing industry covered by the ETS has been exempt from the carbon tax since 2011. In Germany, the cement sector is exempt from specific electricity taxes, and benefits from lower excises for the access to the electricity network. In addition, the EU manufacturing industry also receives subsidies for petroleum products, fossil fuel, coal, and lignite (EC 2019f).

(depending on climate targets and technologies used).[11] Industry electricity demand would rise considerably (it could double; Wyns, Khandekar, and Robson 2018), implying additional investments needs in the energy sector.

Toward a More Consistent Green Policy Package for Industry

Strengthening the EU ETS to improve the signaling effect of carbon pricing is critical to decarbonize the EU manufacturing sector (see companion paper). A clear and predictable price signal will incentivize investment in cleaner technologies. It will be equally important to find an alternative policy to the free allocations to prevent leakage since these allocations limit the price signal and revenues available to governments. In the absence of global carbon pricing, some form of Carbon Border Adjustment Mechanism could be considered as a second-best option to ensure a global level-playing field.

Complementary carbon pricing policies can be introduced provided that ETS allowances are reduced in parallel. For example, revenue-neutral feebates could be introduced at a sectoral level to strengthen pricing without affecting average producer costs.[12] In addition, member states can adopt carbon pricing of industrial emissions at national level.

Complementary policies are necessary to address market failures limiting investment in clean technologies. The following policies could be envisaged:

- **Increasing public R&D and support private R&D in green technologies:** Public support could compensate for knowledge spillovers that are not fully captured by the original investors. Green technologies may be particularly prone to spillovers because of their highly experimental nature and the substantial risk involved (Rodrik 2014). See the companion paper for further discussion.
- **Remove existing regulatory hurdles:** For example, stakeholder consultations have cited the current standards for a minimum cement content in concrete as limiting improvements in emission intensity (Material Economics 2019).
- **Improving market transparency:** Transparency helps address information failures arising from uncertainty about carbon intensity of products and the EU's Green taxonomy for sustainable investments is an important step.

[11]The EU decarbonation trajectory based on current policies would lead to 64 percent reduction of GHG emissions by 2050 and require investments of €11 billion per year.

[12]Such schemes involve a sliding scale of fees on products with above-average emission rates and a sliding scale of rebates for products with below-average emission rates.

- **Addressing coordination failures:** Changing processes within a value chain involves multiple actors which can have different incentives and not be able to contract all aspects of their relations. Policies can provide a space for discussions between industries, such as the EU Circular Economy Strategy.
- **Addressing investment constraints:** Mobilizing green investment, through the European Green Deal Investment Plan, is rightly at the core of the EU Green Deal. Its aim to mobilize at least €1 trillion to support sustainable investments over the next decade is commendable and can provide important support for the needed transition of EU industry. For example, guarantees for large, capital-intensive projects with a proven potential (provided by experienced lenders such as the European Investment Bank) could help them reach a commercial scale. The Investment Plan's aim to improve the investment framework for private investors, for instance through the EU taxonomy for sustainable activities will be crucial. One radical idea would be an EU-backed insurance mechanism to compensate investors for abrupt climate-policy reversals that render projects unprofitable. While not without similarities to the World Bank's Multilateral Investment Guarantee Agency, such an insurance may be riddled with practical complications and limitations.

Decarbonization objectives could be promoted through the fiscal stimulus and state aid measures put in place to help the economies recover from the pandemic. Low-carbon conditionality, as discussed in parts of the transport sector (for example, aviation and automotive) should be envisaged for support granted to the emissions-intensive manufacturing sector. At the same time, banks need to commit to more detailed disclosure of climate risks in their lending and investment portfolios.

Box 4. EU Green Industrial Transitions: Sectoral Case Studies

Large sustained declines in emission intensity of production have been recorded in some sectors, driven by a combination of technology, regulations, and ETS pricing. The chemical sector has made impressive progress in reducing GHG emissions (Figure 4.1). The 57 percent decrease in emissions between 1991 and 2017 is remarkable given that production in the EU chemical sector, including pharmaceuticals, expanded by 84 percent (CEFIC 2019). The mitigation was achieved mainly through reductions in process emissions, especially of non-CO_2 greenhouse gases such as N_2O, but also through a reduction in fuel and power consumption via new production processes such as increased use of biomass waste (Boulamanti and Moya 2017). These positive developments have been driven in part by EU regulations of emissions, industrial processes, and energy use (Maroulis and others 2016).[1]

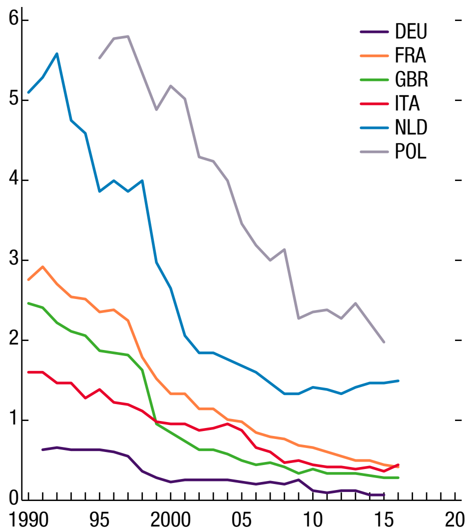
In the cement sector, the reduction in emission intensity compared to 1990 levels reflects improvements in energy consumption (Figure 4.2). The CO_2 intensity of production was reduced through efficiency improvements and increased use of biomass (Wyns and Axelson 2016). Large decline in GHG emissions were observed during the 2008–09 global financial crisis, a time at which construction industry collapsed, but in most of those countries, the emissions intensity of value added declined as well. In Germany, the efficiency of cement production has improved through the use of modernized plants, the increased use of alternative fuels, and the use of municipal waste as combustion input (Supino and others 2016). The German cement industry committed to reducing energy demand by 20 percent during 1987–2008 in exchange for a partial exemption from the state environmental tax and lower levels of regulations.

Past industrial green transitions have not had an adverse effect on employment. Staff analysis based on episodes of sustained declines of direct manufacturing GHG emissions in the EU since 1990 shows that the episodes were characterized by significant improvements in the emission intensity of processes and a large decline in energy-related emissions, while there have been no significant adverse effects on employment.

[1]These include regulations on the EU ETS, the Industrial Emissions Directive, Integrated Pollution Prevention and Control, Volatile Organic Compounds, Large Combustion Plants Directive, Best Available Techniques reference documents, Waste framework, Seveso, renewable energy, energy taxation, and energy efficiency.

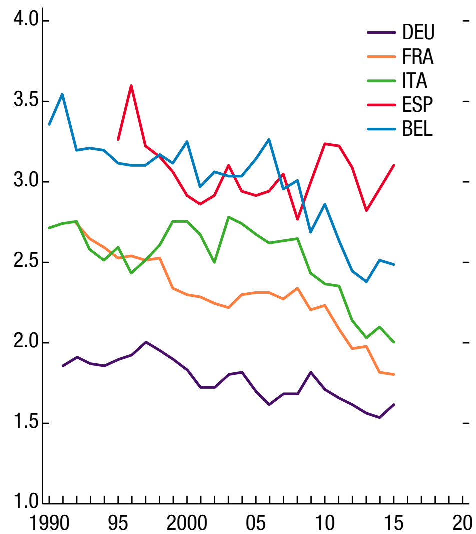
Box 4. EU Green Industrial Transitions: Sectoral Case Studies *(continued)*

Figure 4.1. EU+UK: Chemical Industry—GHG Emissions per Unit of Value Added
(KgCO_2e per unit of VA)



Sources: Eurostat; Organisation for Economic Co-operation and Development, Structural Analysis database; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: GHG = greenhouse gas; VA = value added.

Figure 4.2. EU+UK: Mineral Industry—GHG Emissions per Unit of Value Added
(KgCO_2e per unit of VA)



Sources: Eurostat; Organisation for Economic Co-operation and Development, Structural Analysis database; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: GHG = greenhouse gas; VA = value added.

Chapter

6 Agriculture Sector

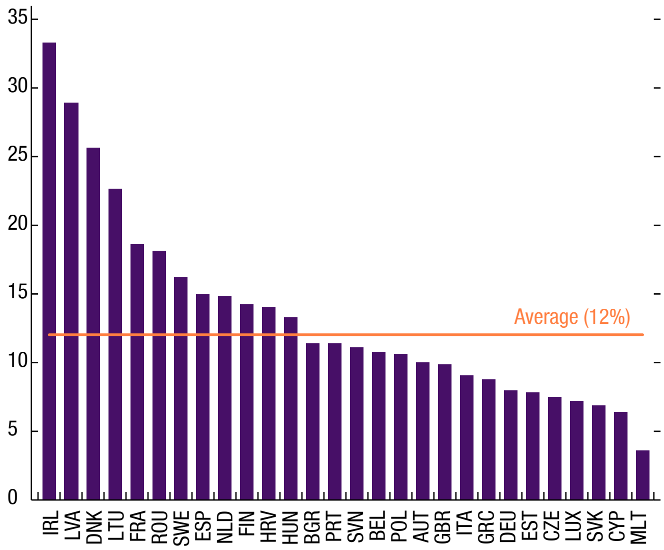
Overview of Emissions and Drivers

Agriculture accounts for nearly 10 percent of total greenhouse gas emissions in the EU and the United Kingdom, with large cross-country variation.[1] Agriculture's share varies significantly by country with the highest share, at 33 percent, in Ireland). In absolute size, the four largest euro area economies—France, Germany, Italy, and Spain—account for nearly half of all emissions from agriculture (Figures 50 and 51).

Most emissions from agriculture occur due to natural processes. While agriculture-related emissions are small relative to other sectors, they are largely biogenic and are difficult to reduce. There are two primary sources of emissions: crop cultivation and livestock production (Figure 52). Livestock, predominantly ruminant animals (cows and sheep), has the largest impact due to methane emissions from enteric fermentation (44 percent of agricultural emissions) and the decomposition of manure under anaerobic conditions (Takle and Hofstrad 2008), which often occurs in intensive farming (for example, dairy farms, beef feedlots, and pig and poultry farms). Nitrous oxide emissions from manure storage and spreading as well as the use of mineral fertilizers on croplands account for 15 and 37 percent, respectively. Emissions from fossil fuels used in agriculture amount to less than five percent of the total. Both methane and nitrous oxide are potent GHGs with 50–60 and 300 times the heat-trapping power of carbon dioxide, respectively; however, they disintegrate fast in the atmosphere (within 10–15 years). The conversion of wetland and peatbogs into arable land is another factor

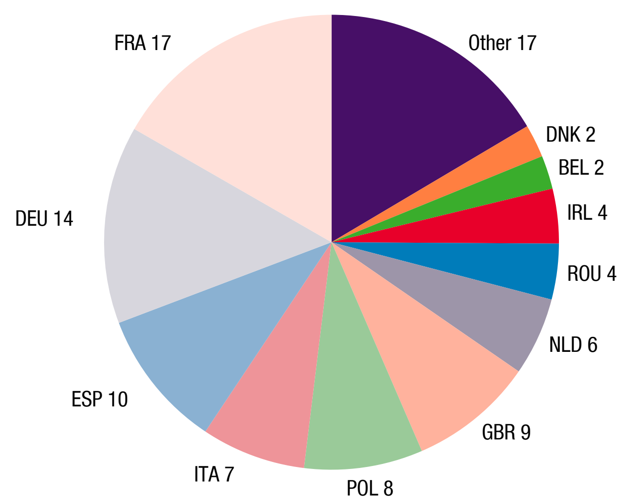
[1]Since emissions from land use related to agriculture represent the largest component of emissions from land use land use change, forestry, and fisheries, the share of agriculture increases to 12 percent if these are included in total EU emissions. However, attributing forestry, which is emission-negative, to agriculture would substantially reduce the emissions from the sector.

Figure 50. EU+UK: Agriculture—Share in National GHG Emissions, 2017[1]
(Percent of total)



Sources: European Environment Agency; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Includes land use, land use change, forestry, and fisheries (LULUCFF).

Figure 51. EU+UK: Agriculture—National Share of GHG Emissions, 2017[1]
(Total = 520 $MtCO_2$eq., percent)



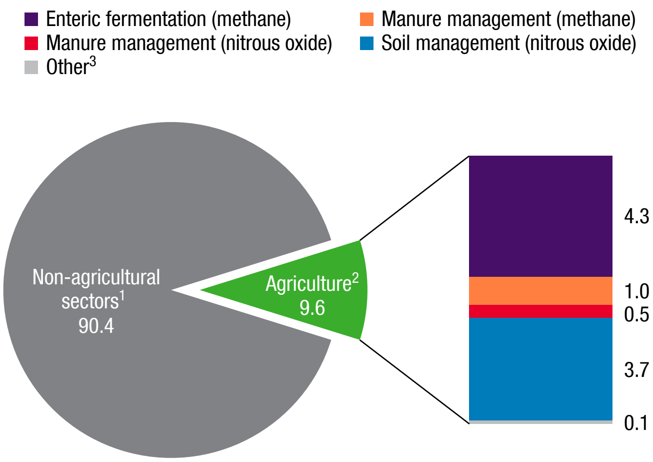
Sources: United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Includes land use, land use change, forestry, and fisheries (80.9 $MtCO_2$eq.).

of growing emissions, and cropland soil respiration, especially after tillage, releases carbon dioxide. Emissions from agriculture relative to arable land are particularly high in several smaller countries, where livestock density is generally higher (Figure 53).

Given its high exposure to changing weather patterns, agriculture stands to benefit most from effective climate change mitigation. The impact of changes in temperature and precipitation is highly specific to crop selection and varies by location, with potential knock-on effects on agricultural supply chains and food security. Within Europe, agricultural land in the south will be most seriously and adversely affected by climate change due to rising temperatures, greater risk of drought, more heat stress and declining arable land. While other regions could benefit from longer growing seasons and the potential for more varied crops, drier summers combined with more storms and floods could reduce crop yields and make the overall crop cycle less predictable. Changes in weather patterns could also facilitate the spreading of pests and diseases.

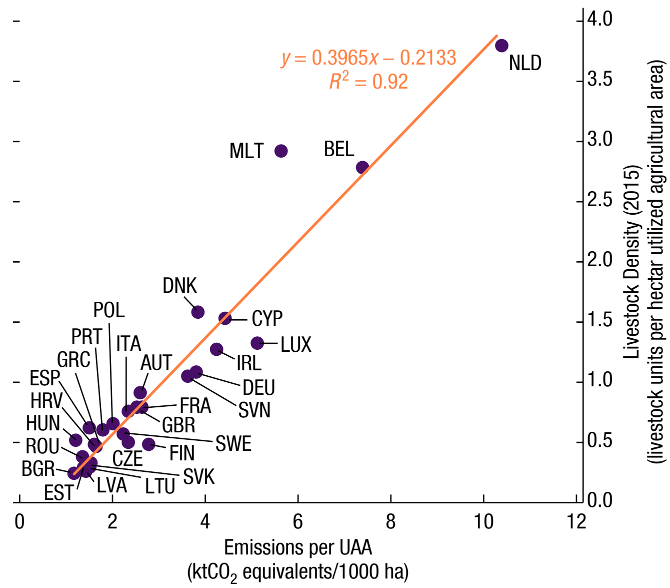
Agricultural emissions have declined by 20 percent since 1990. Most of the reduction happened in the 1990s due to lower methane emissions from

Figure 52. Total Emissions and Share of Agriculture, 2017
(Percent; agriculture total = 439 $MtCO_2$ equivalents)[1]



Sources: European Environment Agency; and IMF staff calculations.
[1]Excludes land use, land use change, forestry, and fisheries (80.9 $MtCO_2$eq.).
[2]Excludes agricultural transport and energy use.
[3]Includes rice cultivation and field burning.

Figure 53. EU+UK: Agriculture—Livestock Density and Total Emissions, 2015[1]



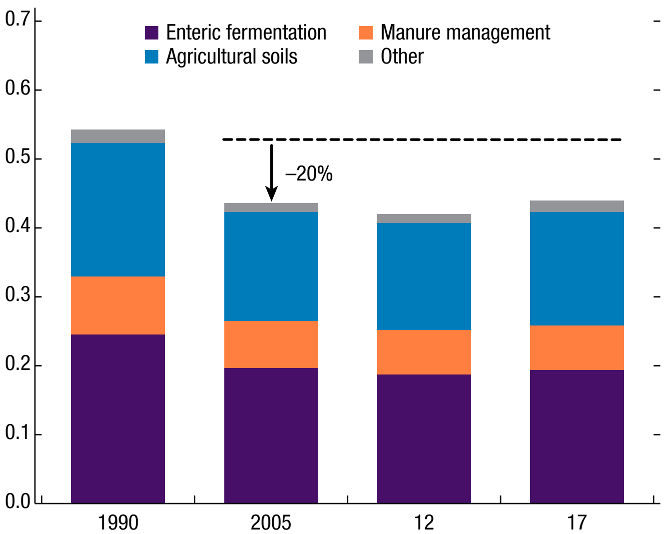
Sources: European Environment Agency; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Emissions from agricultural transport and energy use are excluded, as these sectors are not defined as part of the agricultural sector by the current IPCC reporting guidelines (IPCC 1997, IPCC 2000). Data also exclude emissions/removals from LULUCF, cultivation, field burning of agricultural residues and other sources.

livestock and reorganization of agricultural practices in Central and Eastern Europe (Figures 54 and 55). The EU Common Agricultural Policy (CAP) reforms, such as milk quotas and single farm payments, played an important role, resulting in more cost-effective intensification of agricultural production through higher livestock and crop yields. Changes in farming practices and optimized use of fertilizers helped reduce nitrous oxide emissions.

However, since 2005, overall EU emissions have changed little, as falling emissions intensity has been offset by growing agricultural output in most countries. Most countries, have increased the intensity of farming, usually resulting in higher emissions per hectare of arable land and per bovine population.[2] In this balancing act, some countries were more successful than others, and changes varied significantly across livestock and soil management (Figure 56). In a few Western European countries, emissions have declined

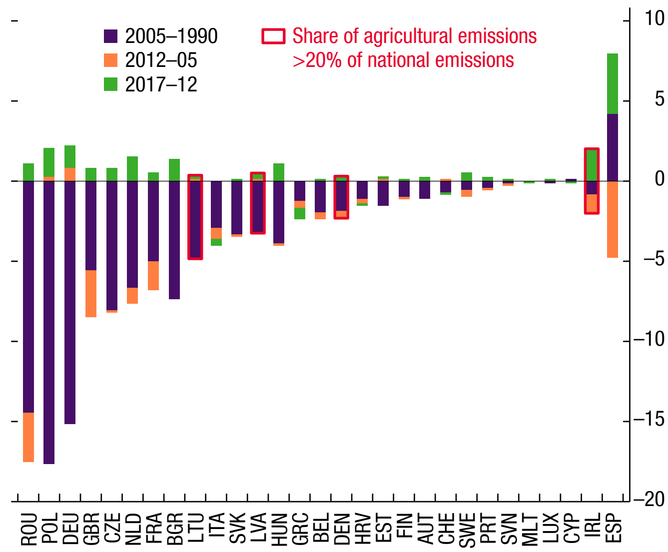
[2]Livestock density is associated with pressure on the environment as well as deteriorating air and water quality. It intensifies fodder production and imports of animal feedstuffs to meet the feed requirements. Such imports are an external source of nutrients and generates additional emissions and nutrient surplus of soils.

Figure 54. EU+UK: GHG Emissions in Agriculture, 2017[1]
($GtCO_2$ eq.)



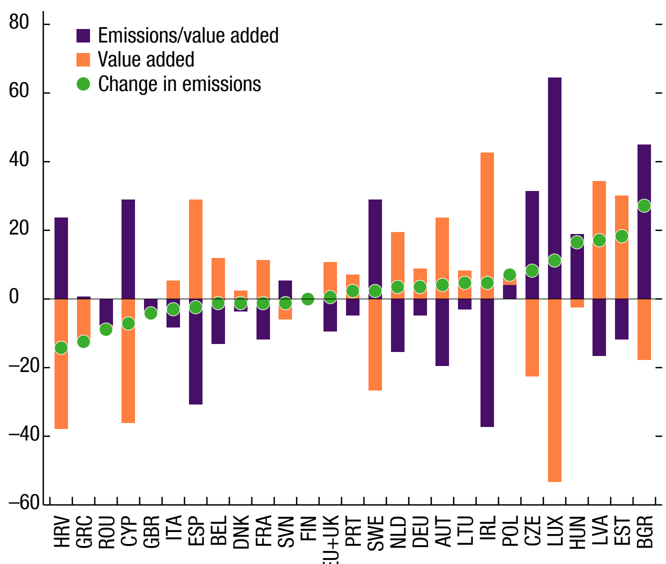
Sources: United Nations Framework Convention on Climate Change; and IMF staff calculations.
[1]Excludes forestry and fisheries (80.9 $MtCO_2$eq.).

Figure 55. EU+UK: Change in Agriculture Emissions
($MtCO_2$eq.)



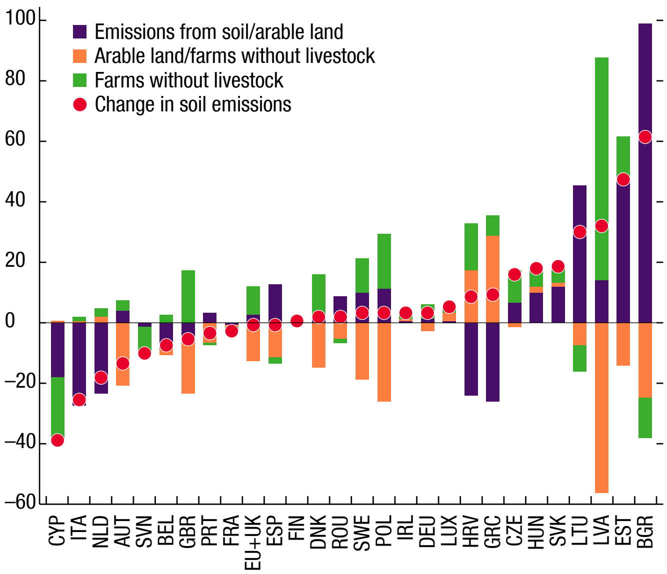
Sources: Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 56. EU+UK: Decomposition of GHG Emissions in Agriculture, 2005–17[1]
(Growth in percent; contributions in percentage points)



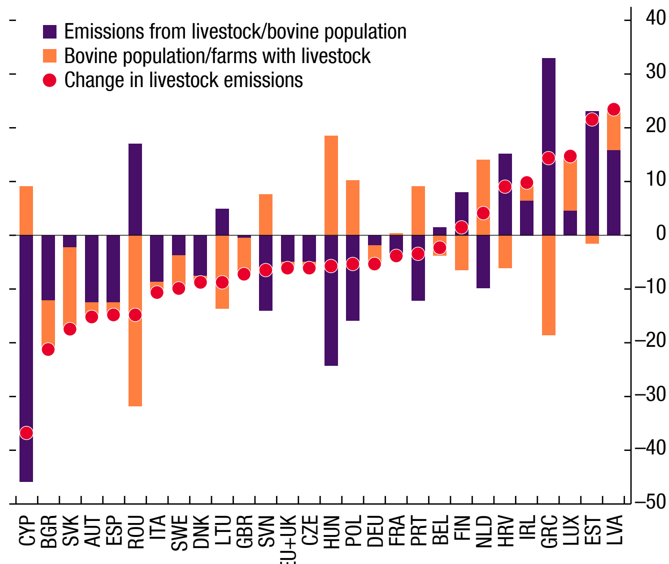
Sources: Eurostat; and IMF staff calculations.
Note: Growth rates are computed as change in logs. Country list uses International Organization for Standardization (ISO) country codes.
[1]Includes forestry and fisheries.

Figure 57. Agriculture (Soil)—Decomposition of Change in Emissions, 2005–17
(Percentage points)



Sources: Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

Figure 58. Agriculture (Livestock)—Decomposition of Change in Emissions, 2005–17
(Percentage points)



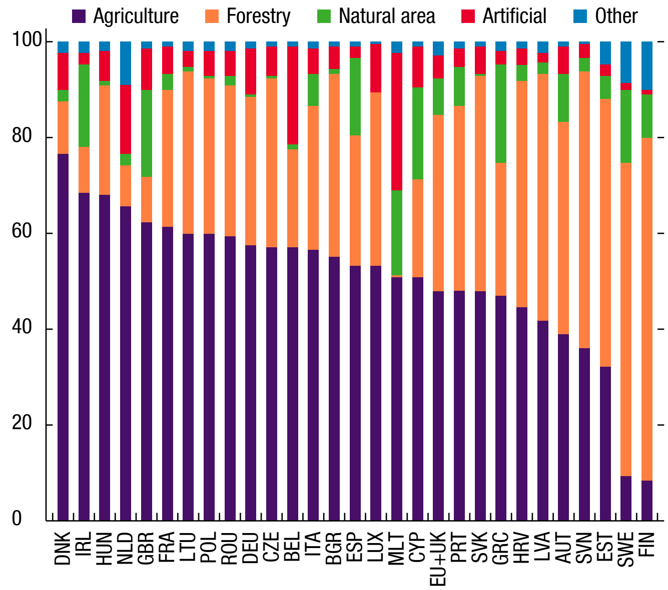
Sources: Eurostat; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

despite higher productivity. Conversely, in most CESEE countries in the EU, emissions from soil management increased despite a shrinking agricultural sector. Most of the decline in livestock emissions is explained by a shrinking bovine population and fewer livestock farms rather than in emissions per animal (Figures 57 and 58). The Effort Sharing Decision of 2012, which determines the minimum emission reduction of member states until 2020 (see companion paper), does not appear to have altered the stagnation of emissions. In fact, the emissions have increased since 2012 due to agricultural output growth in most countries outpacing the improvements in emission intensity.

In contrast to other sectors, agriculture offers significant potential for carbon sequestration. Croplands, which occupy more than half the territory of the EU (Figure 59), can stock massive reserves of carbon via agronomic measures, such as non-tilling to support roots growth, maintaining permanent pasture, and protecting grassland and/or agro-ecological infrastructure. For instance, the "negative emissions" from sustainable land use, land use change, and forestry could halve the overall emissions from agricultural activities through halting the conversion of wetlands into arable lands and protecting forests.[3]

[3]Sustainable land use, land use change, and forestry reduce total EU emissions by 5 percent.

Figure 59. EU+UK: Land Cover
(Percent)



Sources: European Commission; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.

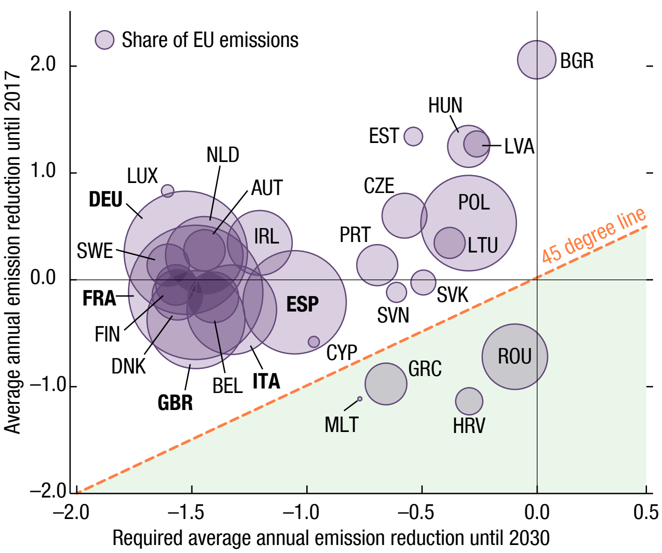
Forests and trees also prevent soil erosion and water contamination, protect land and soil fertility, and avert landslides and floods.

Under existing policies, agriculture is expected to contribute little to meeting the effort sharing target by 2030. Under the EU Climate and Energy Framework 2030, member states have committed to meet nationally defined emissions reduction targets in sectors not covered by the ETS, including transport, households, and agriculture.[4] However, half of EU countries have increased agricultural emissions since 2005. Only four countries have achieved a significant reduction in emissions (Croatia, Greece, Malta, and Romania). Most countries would need to make significant progress in the next 10 years or compensate via larger reductions in other sectors. Projections indicate that countries plan rather low emission reductions in this sector. Only a few countries (Finland, Germany, Ireland, Lithuania, Spain), reported reduction effects in 2030 (Figures 60 and 61).

The high-emission intensity of agriculture relative to its contribution to total output in the EU raises the stakes for effective mitigation. In the EU, the

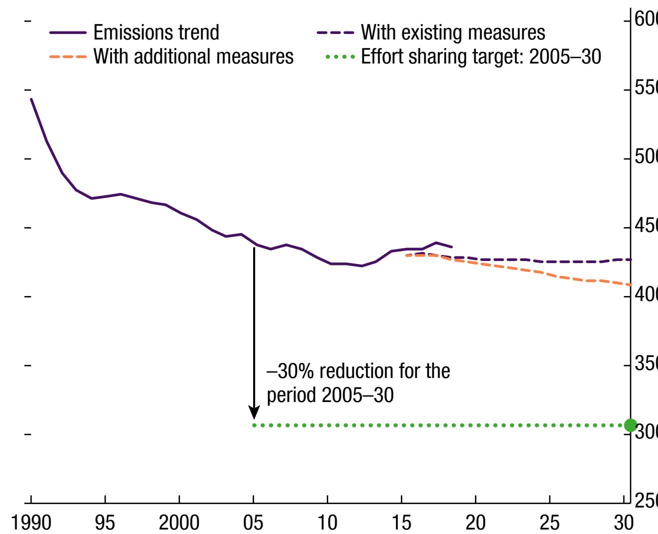
[4]Measurement challenges of agricultural emissions and the focus of the EU's Common Agricultural Policy (CAP) on food security and protecting farmers' income are key obstacles to the inclusion of agriculture in the ETS.

Figure 60. Agriculture: Actual vs. Required Emission Reduction for 2030 Target[1]
(Percent; relative to 2005 target)



Sources: Eurostat; United Nations Framework Convention on Climate Change; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Includes forestry and fisheries (80.9 $MtCO_2$eq.).

Figure 61. EU+UK: Agriculture—Effort Sharing GHG Emissions, Targets, and Projections, 1990–2030
(Mtonnes of CO_2 equivalent[1])



Source: European Environment Agency.

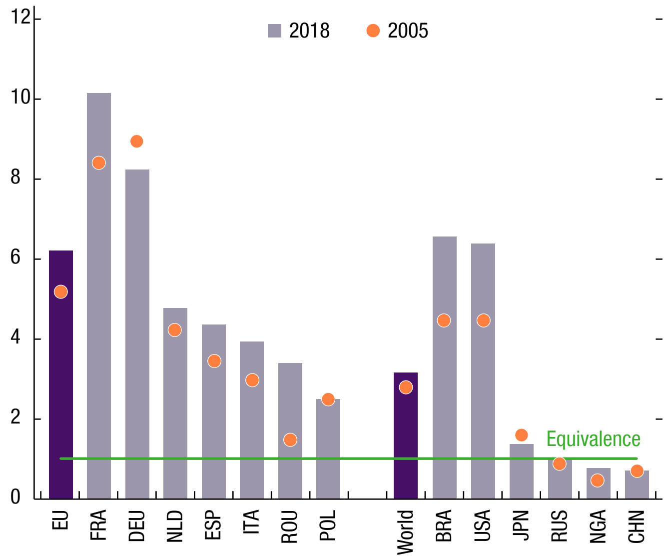
share of agriculture in total emissions is about six times the share of its value added, similar to that in Brazil and the United States but double the global average. This multiple has increased steadily since 2005 and is even larger for France and Germany (Figure 62). The rising emissions intensity of agriculture suggests that the required level of ambition in reducing emissions from agriculture will need to become higher over time relative to other sectors (if the marginal abatement cost is similar).

Abatement Channels

Potential abatement measures on the supply side vary in cost-effectiveness:

- *Enhancing soil management is cost-efficient and could deliver significant emission reductions over the near term.* The implementation of the 2003 EU Fertilizer Directive has already led to a significant reduction of soil emissions through precision farming and the optimization of application rates

Figure 62. Agriculture: Ratio between Share of Emissions and Share of Value Added[1]
(Multiple)



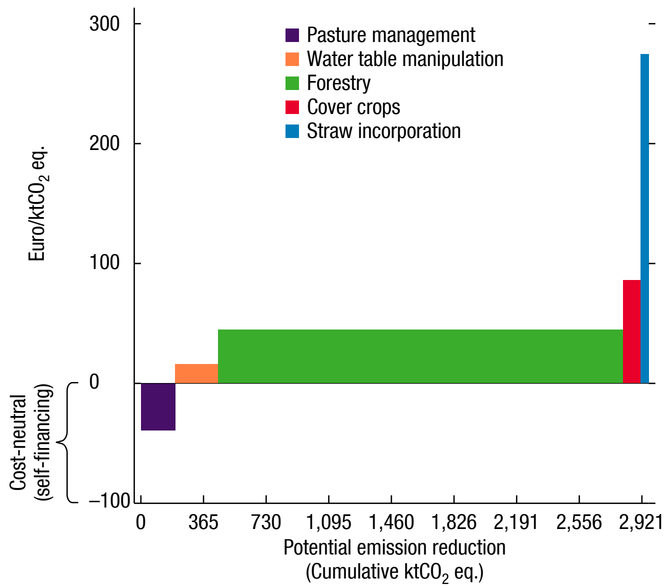
Sources: United Nations Food and Agriculture Organization; United Nations Framework Convention on Climate Change; World Bank; and IMF staff calculations.
Note: Country list uses International Organization for Standardization (ISO) country codes.
[1]Data on emissions and value added as of end-2017 for Japan, the United States, and the world; agriculture includes forestry and fisheries.

of nitrous fertilizers.[5] The high abatement potential of additional agronomic measures, including manure application on cropland, crop rotation and greater use of cover crops, can reduce emissions from soil respiration.

- *Reducing livestock emissions will not be self-financing but remains essential to achieve the effective emission reduction in agriculture needed to meet the EU's climate neutrality target by 2050.* While biogenic emissions from enteric fermentation (and subsequent manure management) are inherently difficult to measure and control, livestock measures offer significant abatement potential. Methane emissions from livestock (especially if not grass-fed) could be reduced by diversifying away from beef production toward non-ruminant animals (such as pigs and poultry), and to some extent, by applying enhanced farm management practices and new technologies, such as food

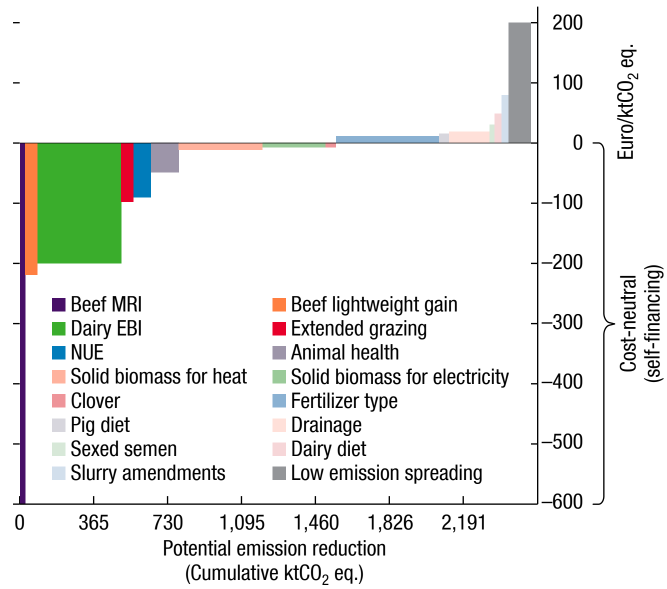
[5]In May 2019, the EU approved a new regulation, which harmonizes the requirements for fertilizers produced from phosphate minerals and from organic or secondary raw materials, which creates more opportunities for companies to develop innovative fertilizers. Regulation (EC) No. 2016/0084 will come into force by 2022 and includes all types of fertilizers, including mineral, organic, biostimulants, growing matters, and industry by-products.

Figure 63. Ireland: Land Use and Land Use Change



Source: Lanigan and others (2019).

Figure 64. Ireland: Livestock and Soil Management



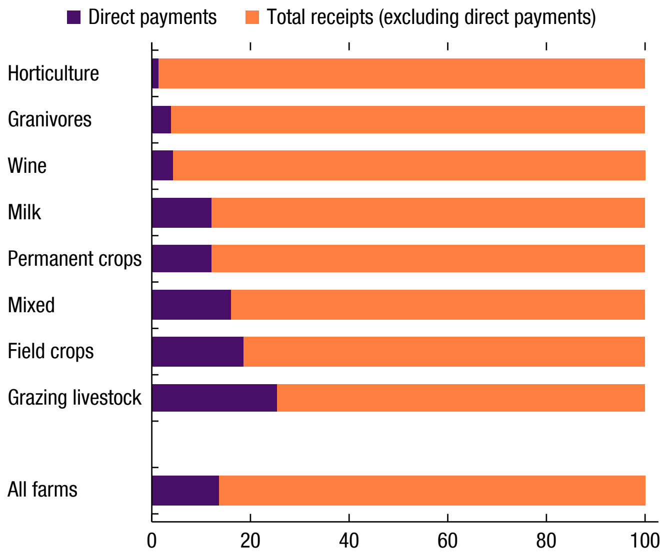
Source: Lanigan and others (2019); SEAI (2017); Schulte and others (2012); and IMF staff calculations.
Note: EBI = economic breeding index; MRI = Meuse-Rhine-Issel, a breed of cattle; NUE = nutrient use efficiency.

additives, breeding programs, barn modernization, and animal healthcare. Methane digesters can turn manure into biogas to substitute the direct and indirect energy use of farms; and, if implemented at scale, could also contribute to more sustainable overall energy generation.

- *Conservation farming—in combination with maintaining permanent pasture and protecting grassland—can boost the sequestration of carbon.* Better land management and agricultural practices could enhance the ability of soils to store carbon. Even though sequestering carbon in soil is relatively safe and economical, it is also slow, potentially reversible (due to changes in temperature and the extent to which carbon is stored near the surface), and significantly depends on soil type.[6] The sustainable intensification of agricultural production also implies reducing the conversion of land into agriculture. The growth of new trees planted on harvested areas and protecting forests offers an equally safe and effective way to achieve meaningful carbon dioxide removal from the atmosphere and provides a permanent carbon sink (Figures 63 and 64).

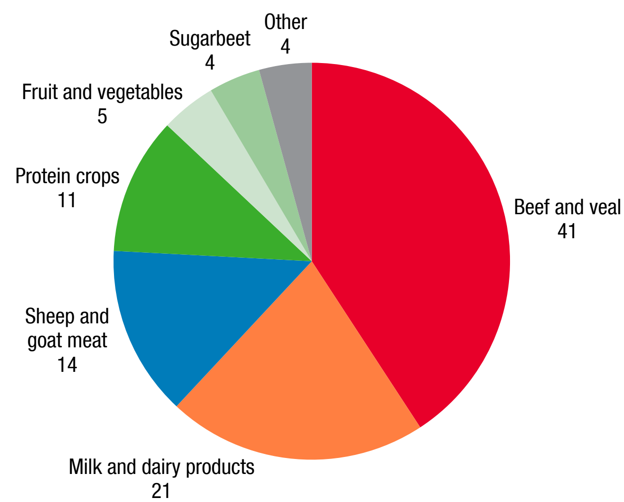
[6]Also more time is needed to better estimate the soil carbon sink potential as precise measurement remains challenging (Batini 2019a).

Figure 65. EU+UK: Direct Payments
(Percent of total farm receipts)



Sources: European Commission; and IMF staff calculations.

Figure 66. Agriculture—Coupled Premiums for Selected Agricultural Products, 2017[1]
(Millions of EUR, percent)



Source: Chemnitz and Becheva (2019).
[1]Coupled premiums account for about 10 percent of all direct payments (Pillar 1) under the EU Common Agricultural Policy Framework.

Existing financial support to farmers, measurement challenges, and costly investments make it difficult to incentivize targeted emission reductions through price adjustments. Some abatement measures can be self-financing due to savings from lower fertilizer use, greater crop efficiency, and less transportation of external feedstuffs (due to improved animal production efficiency). However, initial investments required for these measures might exceed the financial capacity of most farmers, who operate on low margins and depend on CAP support. Agricultural support depends on the size of farmland, which determines the amount of direct payments; this has a greater impact for arable farming and livestock grazing (as opposed to less carbon-intensive pig and poultry production where land is not important or wine and horticulture (Figure 65), where the value of output per hectare is very high, see Sarzeaud, Dimitriadou, and Zjalic 2007); at the same time, most "coupled premiums," which represent about 10 percent of direct payments, are still heavily targeted towards high-emission livestock (Figure 66). Most efforts with a large-scale and long-term mitigation impact, such as managing biogenic emissions through fermentation facilities for biogas generation, are not self-financing and require significant upfront investments. In addition, price-based measures are hampered by the absence of a comprehensive and reliable system of measuring methane and nitrous oxide emissions from manure and soil at the farm-level. Environmental taxes are limited to excises, which cover only the energy use in agriculture, while the sector is not covered by the ETS. Considering that more than 85 percent of all emissions are due to livestock and soil management (methane and nitrous oxide), this puts the coverage of emissions in the agriculture sector below that of all other sectors.

Further, the effectiveness of abatement measures in agriculture can be undermined by high carbon leakage. Fellmann and others (2019) show that the application of non-uniform national emission reduction targets to agriculture in the EU (in line with NDCs) will significantly increase imports from non-EU countries.[7] The authors show that higher imports of beef and other animal products will result in more than 90 percent of any emissions reduction being reflected in higher emissions outside the EU. These findings underscore the importance of multilateral commitments for agriculture and the need for mitigation measures on the consumption side.

Demand side measures have large potential for reducing emissions in agriculture. Inelastic demand for food constrains the extent to which carbon-intensive supply can adjust to marginal changes in price and puts the focus on shifting consumer preferences away from land-intensive food (for example, beef).[8] Emission intensity varies significantly across agricultural products and possible shifts in diet with variations in the consumption of meat, milk, and egg products[9] as well as minimizing losses in the food supply chain and consumption could reduce emissions from agricultural production significantly (Batini 2019b; Batini, Lomax, and Mehra 2020). The dietary changes would entail health benefits as well as public spending savings.[10]

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[7]Mainly in Africa, Asia, and South America, because the EU grants free-market access to developing countries in Africa and Asia and the established trade relations with South America.

[8]This argument also applies, to some extent, to agriculture-based energy commodities. For instance, the dedicated use of land for biofuel crops crowds out arable land for food production and typically entails a loss of biodiversity and soil degradation due to monoculture (with a higher use of pesticides and fertilizer).

[9]M'Barek and others (2017) estimate that removing CAP subsidies increases producer prices in agriculture by 5 percent while reducing production by 6 percent with wide variation across the product groups—dairy prices to increase by 11 percent, while poultry and beef experiencing small change in prices but large drop in production, with the degree of import substitution being one of the determining factors.

[10]The health risks of red meat consumption are widely documented in the literature, for example, Richi and others (2015) and Wang and others (2016). Unhealthy diet is a health main risk in Europe. According to the World Health Organization, more than half of all Europeans are overweight, and nearly one-quarter are obese. About 10 percent of the EU's GDP is spent on healthcare (OECD 2018a). Up to 80 percent of this spending goes toward treating noncommunicable diseases, many related to unhealthy diets and harmful alcohol use. The question how agricultural policy shapes consumption patterns has been insufficiently studied.

Policies

Mitigation measures would need to be anchored in the current policy framework. Abatement policies need to be multi-pronged and well-calibrated, considering their social and political impacts and the central role of agriculture in food security. Greater coordination at the EU level could generate economies of scale and lead to sharing best practices across member states. In addition, given challenges of reducing emission from natural processes, the high marginal abatement cost in agriculture requires continued balanced cross-sectoral approach in meeting the emission reduction target.

Within the CAP framework, several non-price policies have already been used in varying scope and intensity across EU members to encourage emission reduction in agriculture. Several CAP reforms over the years have tried to deal with challenging environmental problems; however, measuring and monitoring emissions in the design of support measures remains challenging. The current CAP structure includes various forms of climate action, but in some cases the impact of such measures is still uncertain. Both pillars of the current CAP include climate change mitigation measures, such as “green payments” (First Pillar) and organic farming as important elements of rural development policies (Second Pillar) but lack specific measures for emissions from ruminant livestock and a cross-country effort on leveraging the sequestration potential of soil management. In addition, a greater focus on sustainability could be achieved through (1) widening the mandate of the CAP to supplement the primary objectives of supporting famers and ensuring food security with environmental goals and (2) legislative initiative in general climate policies, such as an extension of the ETS to potentially include biogenic emissions from agriculture.

The development of the new CAP planning period (2021–27) offers an opportunity to step up “green” incentives and formulate more consistent and effective measures supporting technology, agroecology, and conservation. Several targeted measures would help repurpose agricultural support to foster a more effective transformation of the agriculture sector (Box 5):

- *Widen the scope of the First Pillar to include explicit livestock measures, possibly through an EU-wide target for reducing and taxing methane emissions to incentivize investment in emission-efficient meat production and biogas generation.* Most biogenic emissions (methane and ammonia) are difficult to measure accurately or to capture effectively for biogas generation without significant investments in new technologies and manure management. In addition, most mitigation measures for emissions from livestock, including generating biogas from anaerobic manure handling facilities, are very capital-intensive and are not self-financing; they would greatly benefit from financial support through the direct payment mechanism of the First Pillar of CAP, especially for smaller firms (Ory 2020), which is largely focused on agronomic measures and not emissions from livestock.[11] Once adequate measurement methods are established, price-based policies to support investment could be modelled after the ETS (accompanied by adequate compensating measures under the CAP). Linking direct payments to methane emissions under an EU-wide emissions limit would reward more carbon-efficient meat and milk production while mitigating the risk of carbon leakage from agricultural production within the EU (since emission reduction targets are set at the national level).[12] This could also entail pivoting from the economywide approach to emission reduction to a sectoral approach, current methods for determining carbon tax coverage of methane emissions in the oil and gas industry could provide guidance.

- *Provide more "green payments" in the First Pillar for sequestering carbon in agricultural soils*. Mitigation measures should be fully linked to emission-efficient farming (within an expanded mandate of the CAP). Farmers who receive direct payments must observe some basic rules (called compulsory "cross-compliance"), such as legislative standards related to protection of the environment, food safety, animal and plant health, and animal welfare.[13] Since the 2013 CAP reform, 30 percent of this support is allocated as a "green payment," for which farmers must fulfil a set of obligations designed to improve the environment and encourage climate action. However, there is no direct payment mechanisms for boosting carbon sequestration. So far, enhanced land management measures are covered in the Second Pillar upon application and at limited scale (see below).
- *Expand support for regional farming under the Second Pillar to strengthen the circular economy.* Imports from the EU account for 7 to 10 percent of global crops and livestock products associated with deforestation, such as soy for animal feed (FAO 2016). Connecting animal food systems

[11]Almost all direct payments are not linked to specific measures and, thus, generate an implicit bias toward emission-intensive farming that require a lot of arable land (for example, beef and milk).

[12]Enteric fermentation (methane) could be monitored consistent with existing systems for energy generation. Similar mechanisms could be installed for developing more effective binding targets for emission reduction from soil management. An annual consolidated nitrogen balance (post-harvest) at farm level should become a mandatory tool.

[13]Existing cross-compliance measures for climate change mitigation include crop diversification, protection of permanent grassland, and ecological focus areas (EFA) but lack specifics on the introduction of leguminous plants on arable land; "coupled support" for protein crops remains optional, and crop rotation is still low in many countries with poor record of reducing soil emissions (such as Croatia and Greece). Under crop diversification, farmers must cultivate at least two different crops if they have more than 10 hectares of arable land; the main crop may cover no more than 75 percent of the arable land, and the two main crops no more than 95 percent. Maintaining an ecological focus area means that at least 5 percent of the arable area of the holding on farms with more than 15 hectares of arable land are not used (excluding permanent grassland and permanent crops).

to local and regional production (by encouraging a circular economy of agricultural biomass and shorter supply chains), such as the development of viable technologies for creating nitrogen fertilizer and animal feed from agricultural waste, is key to achieving environmentally-friendly and resource-efficient farming.[14]

- *Align risk mitigation measures under the Second Pillar with climate action.* Risk management tools form an important part of rural development programs aimed at ensuring sustainable management of natural resources and climate action.[15] However, in many countries, support for crop insurance inflates the price of farmland and locks producers into a low-risk, low-reward system. Integrating greater diversity of insurable crops and rewarding periodic set-aside areas in insurance programs (consistent with the EU's forthcoming taxonomy on sustainable activities in agriculture) overcome this structural disincentive to more sustainable farming.
- *Scale up important financial and structural policies under the Second Pillar to support a shift toward renewable energy.* Funding for climate change mitigation requires also greater focus on substituting renewable energy for gasoline, diesel fuel, and natural gas used on farms and increasing the generation of electricity from wind and other renewable sources.

Fiscal policies at the national level could effectively complement amendments to the CAP and put additional focus on demand-side policies. For instance, removing tax expenditure favoring products with emission-intensity (for example, some countries have reduced VAT rates for dairy/meat products) (Cline 2020; FAIRR 2017) and providing financial support to R&D initiatives on emission reduction and carbon capture in agriculture. Taxing emission-intensive foods, and aligning public procurement practices, education programs toward better diets would be important steps in this direction. Structural policies could include standards and regulations as well as measures to raise awareness (for example, requiring CO_2 footprint labels). Financial policies should aim to facilitate green financing for smaller farmers to supplement EU-wide funding systems (such as the Young Farmer Scheme).

[14]For instance, a promising initiative is to use insects as high-quality protein for use as animal feed in lieu of fish meal or soy cake imports, which would not only lower emissions but also improve the nutrient balance and provide a natural stimulant of the immune system.

[15]The proposed "Next Generation EU" recovery package also includes a significant scale-up of rural development, which provides an opportunity for funding climate action under this pillar of CAP.

Box 5. Administrative Improvements to the First and Second Pillar of the EU CAP

In addition to widening the scope of climate mitigation through agronomic techniques and manure management in both pillars of the CAP, there are also several operational areas for addressing regulatory shortcomings:

Establish greater linkage between the First and Second Pillar for climate action. Both Pillars have climate-related measures but there is no clear linkage between the cross-compliance of "green payments" in the First Pillar and the eligibility of programs aimed at supporting climate change mitigation measures for rural development under the Second Pillar. Given the powerful push incentives under the First Pillar, the lengthy, application-based and member state-driven process under the Second Pillar risks fragmenting climate change mitigation in soil management across national boundaries. In addition, the new planning period of CAP should prioritize the protection and enhancement of carbon sinks on farms.

Close existing implementation gaps in the First Pillar. Some cost-neutral abatement measures that fall within the current scope of the First Pillar might still require additional financing, which could be achieved by reorienting available funding toward "green payments" to bridge liquidity constraints in financing their application. In addition, the First Pillar still has some gaps, such as the specification of greening equivalency measures by member states, which could be very effective in enhancing the mitigation potential at farm level; however, the lack of greater specification and quantification of equivalency, risks undermining their positive climate impact.

Remove administrative hurdles in the Second Pillar by lowering the eligibility threshold for climate change mitigation measures. The EU's rural development policy under the Second Pillar provides member states with greater flexibility in designing and implementing programs to achieve three main objectives: (1) fostering agricultural competitiveness, (2) ensuring sustainable management of natural resources and climate action, and (3) achieving balanced territorial development of rural economies and communities. These programs need to combine measures from a "menu" of 16 options ("European Menu"), which is detailed in the Rural Development Regulation (Regulation (EU) No 1305/2013) and co-financed by the European Agricultural Fund for Rural Development (EAFRD).[1] This menu also includes two measures for climate change mitigation: (1) restoring, preserving and enhancing ecosystems dependent on agriculture and forestry, as well as (2) promoting resource efficiency and supporting the shift toward a

[1]The EAFRD is the funding instrument of the second pillar of the CAP and is one of the European Structural and Investment Funds (ESIF). The EAFRD aims at strengthening the EU's agriculture, agro-food, and forestry sectors, as well as rural areas in general.

Box 5. Administrative Improvements to the First and Second Pillar of the EU CAP *(continued)*

low-carbon and climate-resilient economy in the agriculture, food and forestry sectors.[2] Like any other program, climate actions need to meet at least four out of the six priorities derived from the three main objectives mentioned above.[3] However, many specialized mitigation measures are likely to be focused on only a couple of these priorities, and, thus, are unlikely to satisfy this condition within the current scope of the Second Pillar.

[2]At least 30 percent of the EAFRD budget in each member state needs to be allocated to climate and environmental actions.

[3]The other four out of six priorities are (1) fostering knowledge transfer in agriculture, forestry and rural areas; (2) enhancing the competitiveness of all types of agriculture and enhancing farm viability; (3) promoting food chain organization and risk management in agriculture; and (4) promoting social inclusion, poverty reduction, and economic development in rural areas.

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