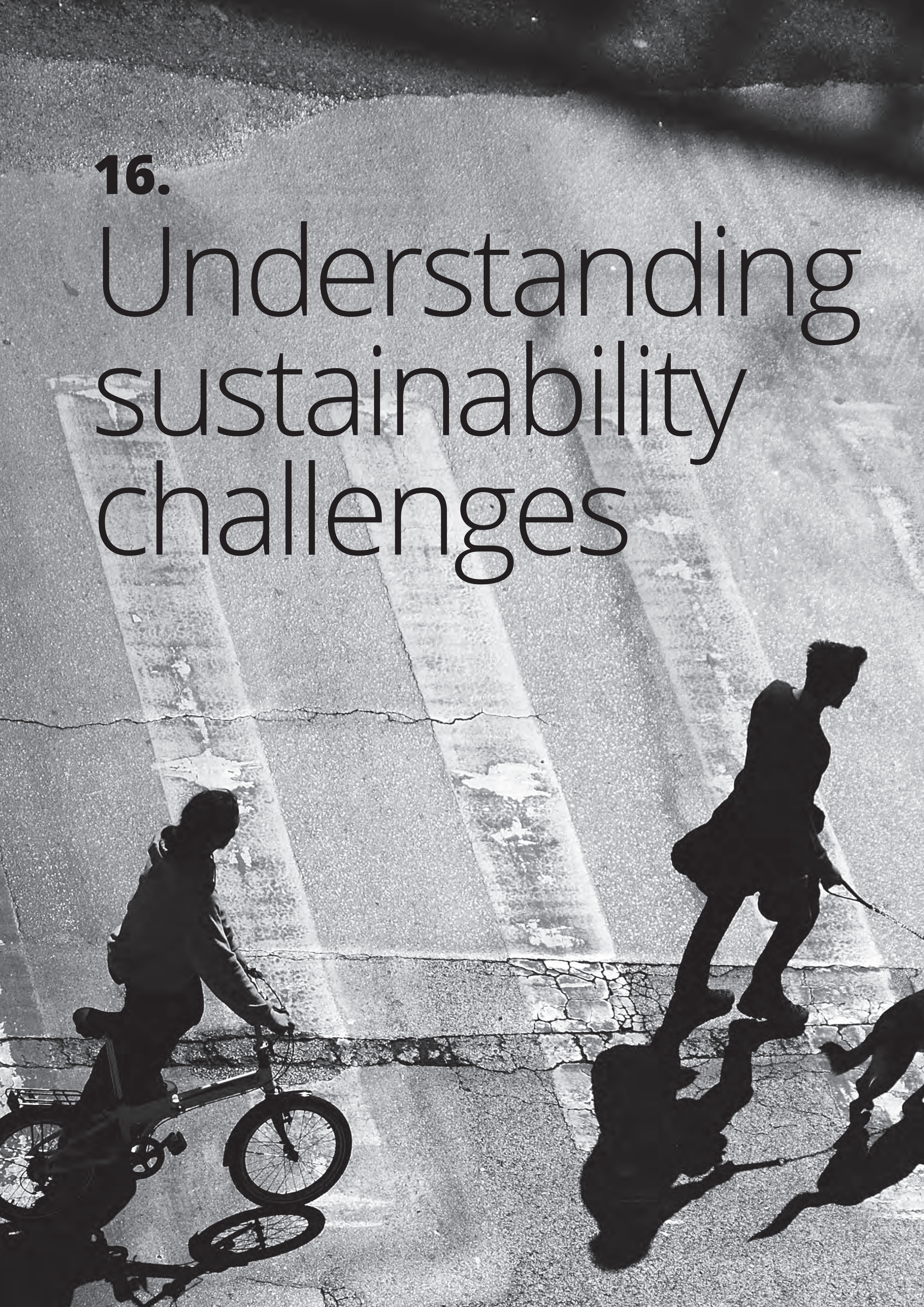
16. Understanding sustainability challenges



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Summary

- European consumption is tied to economic growth and living standards but also drives environmental impacts across the world. Europe's environmental footprint is much higher than the global average.

- The food, energy, and mobility systems account for much of Europe's pressures on the environment and health, and are linked to many dimensions of human well-being. These systems must be transformed to achieve Europe's sustainability objectives.

- In production-consumption systems, the co-evolution of system elements — technologies, regulations, infrastructures, behaviours, etc. — creates lock-ins and other barriers to change.

- Links between production-consumption systems create additional challenges. Addressing problems in one system may shift the burden or produce other trade-offs or unexpected outcomes — partly because the systems rely on a shared natural capital base.

- The resource nexus approach can help understand the combined pressures from production-consumption systems, manage system interactions within environmental limits and promote policy coherence.

- Production-consumption systems vary greatly across Europe, implying that actions must be tailored to local realities. Technology-focused measures should be complemented with approaches addressing consumption levels and behaviours.

- Drivers of change at different scales present challenges and also opportunities for transitions. Production-consumption systems will undergo transformations in coming decades. Europe can either be carried along by these events or it can actively shape them.

16.
Understanding sustainability challenges

16.1 The need to transform European consumption and production

The EU has achieved unprecedented levels of prosperity and well-being during recent decades, and its social, health and environmental standards rank among the highest in the world. These achievements are considerable. Yet, as outlined in Chapter 15, Europe today needs to achieve urgent and fundamental changes in its core systems of production and consumption if it is to sustain and enhance its progress to achieving sustainability goals. Building on that assessment, this chapter provides a more detailed analysis of the need for sustainability transitions and the challenges that this entails.

Europe needs to achieve fundamental changes in core systems of production and consumption.

16.1.1 Europe's economy and its environmental implications

Europe has gone through a series of major industrial transformations during the past two and a half centuries. In recent decades, the structure of the European economy has progressively shifted from an industry-intensive structure towards a service economy. This shift has been more rapid since the 1990s, although there is significant variability between European countries (OECD, 2019; Eurostat, 2018g). The service sector now accounts for some three quarters of EU gross value added (GVA), with agriculture, industry and construction accounting for the remainder (Eurostat, 2018g). A similar distribution can be observed for employment (Eurostat, 2018c). Agriculture accounts for only 2 % of GVA and employment but contributes significantly to environmental pressures (Chapter 13).

Trade has always been fundamentally important for the European economy, reflecting its open character and high dependence on natural resources from around the world (Section 1.5). Internationally, the 28 EU Member States (EU-28) represent the second largest exporter and importer of goods, accounting for 16 % of global exports and 15 % of global imports (extra-EU) by value in 2018 (Eurostat, 2019b). In physical terms, the EU imports mainly raw products (more than 60 % of total imports), such as biomass, metals, non-metallic minerals and fuels, as inputs to production. It exports primarily finished goods for final and industrial consumption (more than 50 % of all physical exports) (Eurostat, 2018j).

The EU is highly dependent on metal ores and fossil fuel resources from the rest of the world. Reliable access to critical raw materials has become a growing concern, as many are used in high-tech products and emerging innovations such as information and communications technology (ICT)-related and renewable energy technologies (EC, 2018e; Chapter 9). For fossil fuels, the heaviest reliance is on oil, hard coal and natural gas, making Europe vulnerable to supply and energy price shocks. At the same time, fossil fuel combustion is the major source of greenhouse gas (GHG) emissions and air pollution, and it contributes significantly to ecosystem degradation.

Imported raw and intermediate products such as iron and steel, rubber and plastics result in emissions of toxic substances, as well as a significant use of energy over their production cycle (Nuss and Eckelman, 2014). Overall, they represent the largest contributors to impacts on human and ecosystem health associated with European imports (Sala et al., 2019). Imports of solid biomass, biofuels and bioliquids contribute directly to deforestation and forest degradation (Olesen et al., 2016) and indirectly through conversion of non-agricultural land such as forests, wetlands and peatlands (EC, 2019d). This mechanism, known as indirect land use change, could also negate some or all of the GHG emission savings of individual biofuels (EC, 2012).

European citizens today enjoy high material standards of living compared with other world regions. Household adjusted disposable income is among the highest in the world (Eurostat, 2018l). Although significant differences still occur across countries and regions, the EU-28 also recorded the highest expenditure on social protection, and the lowest poverty and inequality rates across G20 regions (Eurostat, 2018l).

Despite the 2007-2009 economic crisis, EU household consumption expenditure increased by 38 % between 1996 and 2016 (Eurostat, 2018f). In 2017, almost half of EU-28 household consumption expenditure related to food, transport and housing (including water, electricity, gas and other fuels) (Eurostat, 2019a). In recent years, Europeans have spent relatively less on basic needs such as food, clothing and furnishings, and more on ICT (a four-fold increase in spending), recreation and culture, and health.

Europe's rising levels of affluence drive existing environmental pressures and create new ones.

An average European citizen in the EU-28 spends 3.4 times more on goods and services than the world average (World Bank, 2018), while energy consumption per capita is almost twice the global average (OECD/IEA, 2014). In the EU-28, there are more than 500 passenger cars for every 1 000 inhabitants, which is almost four times the world average (Eurostat, 2018m).

As in other regions, Europe's demand for goods and services is growing in proportion to rising levels of affluence (Sala et al., 2019). These trends are driving existing environmental pressures and creating new ones. The goods and services purchased in Europe are characterised by very different resource inputs and emissions. Increasingly globalised and complex supply chains mean that consumers have limited awareness of the full social, economic and environmental implications of their purchasing decisions (EEA, 2015). According to recent estimates, food products, in particular meat and dairy products, are among the largest contributors to environmental impacts associated with consumption, in terms of acidification, eutrophication, climate change, and land and water use (Beylot et al., 2019a). Manufactured products and raw materials contribute most to human and ecological toxicity (Beylot et al., 2019b).

Purchases of services (e.g. health, education, restaurant meals and hotels) account for 25 % of EU expenditure (Eurostat, 2018h) and for a significant share of impacts associated with EU-28 final consumption. Such services rely on large inputs of products from other sectors, such as food, machinery or electricity. This means that their overall environmental footprint (i.e. the direct and indirect environmental pressures generated by the consumption of goods and services) is often higher or much higher than that associated with manufacturing (EEA, 2014b).

16.1.2 Environmental footprints, trends and decoupling

Taken together, European consumption patterns are associated with substantial environmental footprints. Carbon, water, land and material footprints per capita are between 1.5 and 2.4 times higher in the EU than at the global level (Tukker et al., 2016; Wood et al., 2018).

For the period 1995-2011, Europe's environmental footprint showed mixed trends. Pressures such as acidification and eutrophication decreased significantly, while others such as land, energy use and GHGs were either stable or grew. The water use footprint grew steadily over the period, while material use increased overall, despite a significant reduction around the time of the 2008 economic crisis. Early estimates for 2012-2015 indicate that overall environmental footprints have further stabilised or slightly decreased (NTNU, 2018).

The decoupling of economic growth from resource use and environmental impacts remains a priority objective for EU policy. Overall, the economy of EEA member countries has grown faster than all environmental footprints since the 1990s (Stadler et al., 2018). Acidification and eutrophication have decoupled in absolute terms, meaning that, although GDP has increased, emissions of pollutants contributing to acidification and eutrophication have decreased. GHG emissions, energy, water and material consumption decoupled from gross domestic product (GDP) only in relative terms during the same time frame, meaning that they grew more slowly than GDP.

These reductions in emission intensity were primarily the result of regulation-driven technological improvements in Europe during the period 1995-2007 (EEA, 2013a, 2014a). Subsequently, the economic crisis and consequent structural changes have been the main driver of reduced consumption and related environmental footprints (EEA, 2015). More recently, factors such as macroeconomic changes, shifts in consumption and trade patterns, and eco-efficiency in the production of goods and services have combined to stabilise some environmental footprints.

Structural change in the European economy, such as the shift towards services and the reduction in some industrial activities, has been shown to increase reliance on imports of industrial goods, especially energy-intensive ones, and consequent outsourcing of harmful emissions (Velasco-Fernández et al., 2018; Baumert et al., 2019; Jiborn et al., 2018). In recent years, material efficiency trends observed for Organisation for Economic Co-operation and Development (OECD) countries have been mainly driven by technological improvements occurring in non-OECD countries (Ekins et al., 2017; Wood et al., 2018). Within Europe, the decline of the construction sector after the financial crisis also had an influence (Chapter 9).

16.1.3
Food, energy and mobility systems

The need to transform Europe's consumption and production is well recognised and is increasingly crystallising into a focus on particular systems. As indicated in Chapter 15, the analysis in the coming sections focuses on three systems in particular — those meeting European demand for food, energy and mobility. This selection partly reflects the key functions that these systems perform and their related prominence in EU policy. In part, it reflects the findings of scientific studies, which identify consumption categories such as food, mobility and housing as key drivers of environmental pressures (Tukker et al., 2006, 2010; Ivanova et al., 2016; EEA, 2013a, 2014a). Environmental pressures associated with energy use are assigned to the different end use categories, with mobility and housing accounting for a large proportion.

16.2
The food system

16.2.1
The food system at a glance

Food systems have evolved greatly in recent centuries from predominantly local systems of exchange into complex global networks of production, consumption and trade (EEA, 2017b; UNEP, 2016). They are shaped by many factors: economic, environmental, political, technological and social, including cultural norms and lifestyles. A food system can be defined as all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and to the outputs of those activities, including socio-economic and environmental outcomes (HLPE, 2014b). Food system actors include those directly involved in food chain activities, as well as governments and civil society, which set the wider policy and societal contexts (EEA, 2017b). The main purpose and function of the food system is to provide food and nutrition security but, depending on its characteristics, it can either enhance or degrade ecosystem health.

The food system is characterised by considerable diversity in Europe, because of variations in climate and morphology and diversity of soils, landscapes and seascapes, socio-economic conditions, technical skills and levels of investment. For example, the structure of farms varies substantially across countries in terms of physical and economic size. The proportion of the national population dwelling in rural areas in the EU-28 ranges from less than 1 % to up to 20 % (EC, 2018j). Producing and processing fish as food in the EU is still largely dependent on small and medium-sized businesses, and this sector plays an important role in many coastal communities (EEA, 2017b). While the agriculture and fisheries sectors have declined in relative importance economically over the last 50 years, the wider food and drink industry is one of the largest manufacturing sectors in the EU in terms of employment, turnover and value added.

In addition to meeting various societal needs, the food system is responsible for a vast array of impacts on the environment through emissions of pollutants, depletion of resources, loss of biodiversity and degradation of ecosystems in Europe and beyond (IPES Food, 2019). Agricultural production, processing and logistics are the phases contributing most to environmental impacts arising from the food system (Crenna et al., 2019). Moreover, a significant share of food is wasted in Europe because of inefficiencies across the value chain. This leads to significant burdens on the environment (Corrado and Sala, 2018; Scherhaufer et al., 2018), as well as ethical concerns.

The European food system is characterised by wide use of technologies, high external inputs (e.g. fossil fuels, fertilisers and pesticides), low labour inputs, and long and often complex supply chains (EEA, 2017b). It is also diverse, with many small-scale family-based producers operating alongside large, globalised food companies and suppliers. The global dimension increasingly influences the food system in Europe, as international markets, technological developments and transport systems have made it possible to connect food production and consumption globally (EEA, 2017b). This offers larger market opportunities for EU production and consumption but exposes EU primary production to the high price volatility of global agricultural commodities and strong competition. Global financial markets are increasingly influencing land transactions, agricultural production decisions, rural credit provision, risk insurance, commodity pricing, and food distribution and retail (HLPE, 2014a).

Europe is a net exporter of meat, dairy products, cereals and wine. It is a net importer of tropical fruits, coffee, tea, cocoa, soybean products, palm oil, and seafood and fish products. Imports of fish and aquaculture products meet 55 % of European demand (EUMOFA, 2015). In 2015, Europe had a negative trade balance in physical terms (kilograms) (Eurostat, 2016a); the difference between trends in volume and in value reflects the relatively low monetary value of some imports, e.g. soybeans and palm oil, compared with the higher value of exports such as processed foods, chocolate and wine. Nevertheless, the majority of food consumed in the EU is still produced within the EU and most EU trade in food and drink products takes place between EU countries (EEA, 2017b).

How the food system is structured and organised has implications for consumption patterns and levels, including diets. Food consumption patterns also vary substantially across European countries. For example, meat consumption ranges between 100 and 160 g/day, fish and seafood between 10 and 60 g/day and milk and dairy product consumption between 170 and 520 g/day (EFSA, 2008). The share of household expenditure attributed to food and non-alcoholic beverages in the EU-28 varies between 8 % and 28 % (Eurostat, 2018i).

88 million

tonnes of food is lost along the supply chain or wasted at the household level.

In the EU today, five of the seven biggest risk factors for premature death — high blood pressure, cholesterol and body mass index, inadequate fruit and vegetable intake, and alcohol abuse — relate to how we eat and drink (EC, 2014; EEA, 2017b; IPES Food, 2019). Up to 7 % of EU health budgets is spent each year directly on diseases linked to obesity, with additional indirect costs resulting from productivity losses (EC, 2014). The average European per capita consumption of animal protein is now 50 % higher than in the early 1960s and double the global average (PBL, 2011). The amount of food consumed outside the home has increased, while the amount of time devoted to cooking and eating food at home has fallen (Trichopoulou, 2009). There has also been a shift towards the consumption of energy-dense but low-nutrient processed foods (IPES Food, 2016).

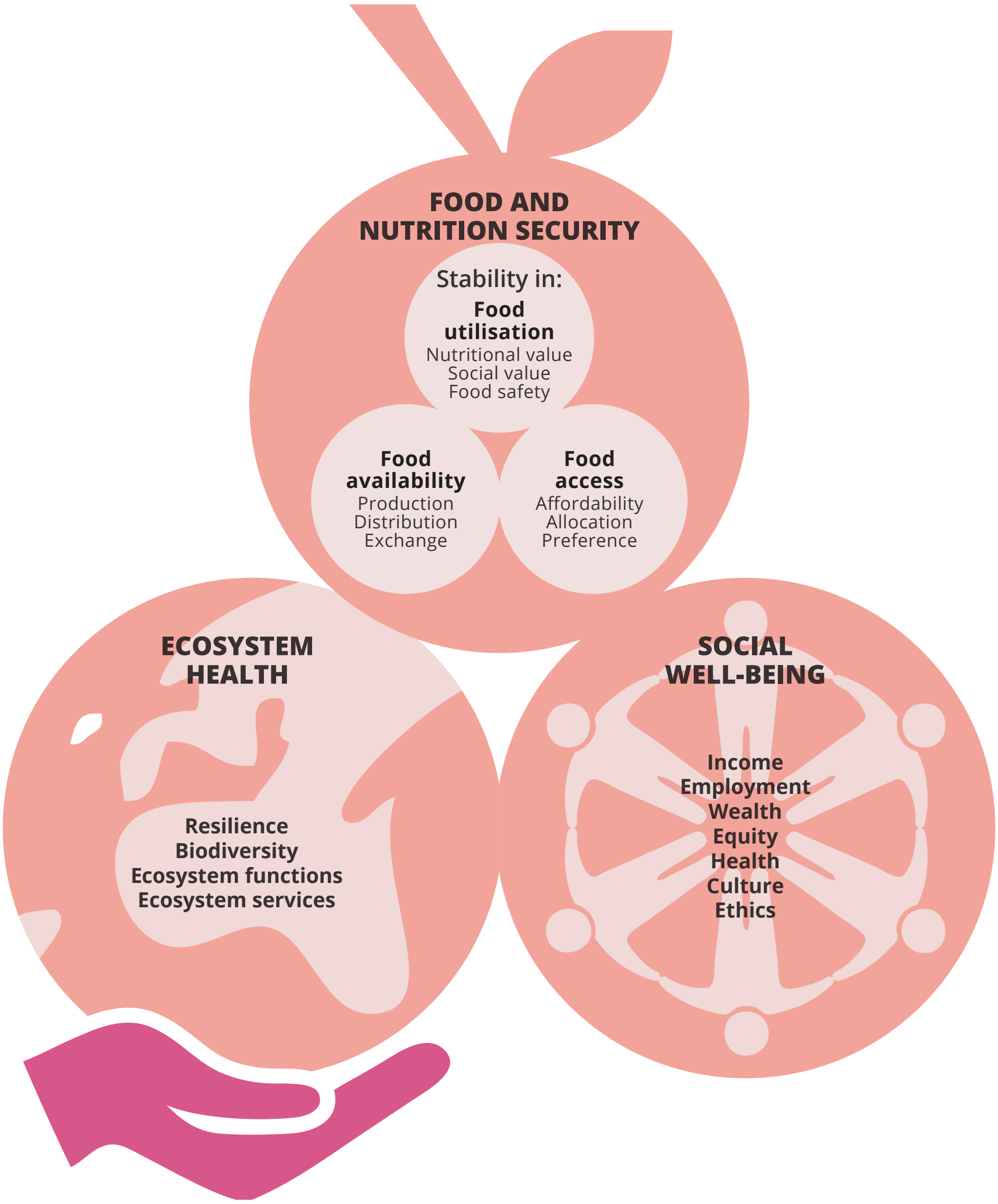
Moreover, increased consumption of food and drink products 'on the go' is expected to contribute further to littering and leakage of plastic waste — a growing environmental concern (EC, 2018c).

Overall, food production and consumption in Europe has environmental, social and economic impacts beyond European borders, including concerns regarding access to food worldwide. European production has particular impacts through imports of feed used in both livestock and aquaculture production. In 2013, Europe imported (net) some 27 million tonnes of soybeans and soybean products, largely from South America, the vast majority of which were genetically modified and not permitted to be cultivated in Europe (EEA, 2017b). This type of trade has been responsible for losses of habitat and biodiversity as well as land use conflicts (EEA, 2014a).

16.2.2 Trends and prospects

Overall, progress towards sustainable outcomes (Figure 16.1) is still limited in the food system. Unhealthy diets contribute to increasing levels of obesity, and more than half of the EU's population in 2014 was estimated to be overweight (Chapter 1). On average across the EU-28, 16 % of adults were obese in 2014 (OECD and EU, 2018). Agriculture still has high impacts on the European environment, while several fish stocks remain depleted in some European seas as well as worldwide (Chapter 13). Food consumption in Europe is generating increasing environmental pressures abroad (Chapter 1). Food waste is also excessive. Annually in the EU around 88 million tonnes of food is lost along the supply chain, or simply wasted at the household level, with corresponding estimates as high as EUR 143 billion (FUSIONS, 2016).

FIGURE 16.1 Food system desired outcomes



Source: EEA (2017b).

As illustrated in thematic and sectoral analyses in Part 2 of this report, current prospects indicate that, without fundamental changes in the food system, the outcomes will not be in line with achieving sustainability goals. The food system depends on healthy ecosystems and their services in Europe and worldwide. Key policy frameworks such as the EU common agricultural policy and the common fisheries policy have limitations in their effectiveness regarding environmental outcomes, such as protecting natural capital (Chapter 13). The food system in Europe is increasingly threatened by such losses as well as by climate change impacts, as it relies on relatively stable climatic and ecological patterns to perform its functions (Chapter 7).

There have been warnings of a potential global collapse of entomofauna (Hallmann et al., 2017; Sánchez-Bayo and

Wyckhuys, 2019). Moreover, an expanding bio-based economy in Europe is expected to increase demand for feedstock and shift agricultural production from food to non-food crops as industrial sectors seek substitutes for chemicals based on fossil resources. Similarly, the demand for bioenergy, including new energy crops, is expected to increase as a result of decarbonisation efforts (EC, 2018g). This could lead, in turn, to further competition for land use, increased use of biomass and risks of higher exploitation of natural capital in Europe, including the use of forests and other semi-natural areas in Europe, further challenging conservation and protection efforts envisaged by the EU biodiversity strategy.

In response to global developments, such as a growing global middle class and increased demand for land, food and bioenergy (Chapter 1), the European food system could develop in different ways — each involving synergies and trade-offs. If long-term trends continue regarding economic growth, technology, employment and trade in the agri-food sector, and without additional policy interventions, it is likely that the food system would be shaped by increased competitiveness and export orientation, rather than meeting health, environmental and economic goals together. Increased competitiveness in the agri-food sector would be likely to increase the trend towards fewer, larger and more capital-intensive farms (Chapter 13; IPES Food, 2019), lead to more nutrient pollution due to surpluses of livestock biowaste and increased use of fertilisers.

A move towards increasing export orientation could further consolidate the current 'high volume and low margin' model, based on high-tech and intensive agriculture. The increased reliance on digital technologies and appliances (e.g. drones, sensors, satellite images) also envisaged by the common agricultural policy and EU research programmes

An expanding bio-based economy in Europe is likely to increase competition for land use.

(EC, 2018h; IPES Food, 2019) could possibly reduce direct demand for fertilisers, pesticides, water, etc., per unit of land or product, but it is also likely to increase the need for machinery and appliances and energy infrastructure, potentially generating new environmental burdens. At the same time, the current innovation paradigm in EU policies locks the food system into a vicious cycle of 'techno-fixes' and short-termism that reinforces 'trends towards intensive, large-scale monoculture-based production', despite their demonstrable harm and trade-offs across environmental and socio-economic issues, (IPES Food, 2019). For example, the 2017 renewal of the license for glyphosate, was characterised by controversies concerning negative effects on soils and water and led to public reactions against the decision, as precautionary principle and protection of human health were perceived to be side-lined against economic interests (see IPES Food, 2019).

Alternatively, a combination of low-input agriculture in Europe and increased import dependency could ensure the supply of raw materials to the food industry and subsequent export of processed food. In this case, environmental pressures could be reduced in Europe, but they are likely to be externalised to other countries through trade. Another pathway would see food production systems turn towards low-input models, with short supply chains and reduced imports, in conjunction with lower consumption levels in the EU. The implications of such developments on jobs in the agri-food sector are not clear.

The barriers to a more sustainable configuration of the European food system are numerous. They are largely due to the interdependence between the food system and many other economic sectors (e.g. processing, retail), the concentration of power in large, globally networked and vertically integrated companies, and the consequent shift in influence from primary producers to actors downstream in supply chains (EEA, 2017b; UNEP, 2016). Sunk costs associated with large-scale processing plants, as well as with investments in research and development (R&D) and advertising — a prominent feature of the European food and drink industry (Galizzi and Venturini, 2012) — may create further barriers to change.

16.2.3 Towards system change

There is a wide range of potential actions to transform the food system to deliver more sustainable outcomes, including changes in production practices, dietary changes, improvements in technologies and management, and reductions in food loss and waste (for the livestock sector, see Buckwell and Nadeu, 2018; Springmann et al., 2018).

Changes in production practices may create opportunities to reduce environmental pressures. However, emphasis on increasing yields, productivity and efficiency has led to negative consequences for the environment (IAASTD, 2009). Instead, shifting towards practices such as precision farming, agroecology, or low-input and organic agriculture is often indicated as a potential way of reducing pressures on the environment and human health through reduced inputs and improved management practices.

Efficiency gains could, however, lead to lower costs and, in turn, to increased demand for food products, thereby offsetting environmental benefits. Innovative technologies and processes often raise concerns regarding their ethical and social implications and may create new, unexpected and unintended environmental challenges (EEA, 2013c). Therefore, changes in production practices would be more effective if combined with reduced consumption levels and changes in patterns of demand.

In contrast, it has been demonstrated that following the principles of agroecology and fully recognising agricultural multifunctionality, e.g. by maintaining and enhancing biodiversity within agricultural systems, may reduce the trade-offs between food production and ecosystem health, as well as creating a more resilient food system (FAO, 2014; Liere et al., 2017). Production processes that require lower inputs may be associated with reduced yields, however, thus requiring more land to be converted to production to fulfil overall demand, unless other measures are also implemented, such as reduced food wastage and use of animal products (Muller et al., 2017).

Changing habits and behaviour are also fundamental levers for transforming the food system. Diets ‘inextricably link human health and environmental sustainability’ (Willett et al., 2019) and can act as levers for change. Sustainable diets have lower environmental impacts and contribute to food and nutrition security as well as to healthy lives for present and future generations. Achieving a sustainable food system for everyone, according to the EAT-Lancet Commission on Food, Planet, Health, would require major improvements in food production practices, reduced food waste and substantial shifts towards healthy dietary patterns (Willett et al., 2019). The latter would entail an ‘appropriate caloric intake, based

> Changing habits and behaviour are fundamental levers for transforming the food system.

on a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars’ (Willett et al., 2019). It has been demonstrated that reducing animal-based food, especially beef, can significantly decrease environmental pressures (Conijn et al., 2018; Sala et al., 2019). However, savings associated with reduced consumption of meat and dairy products may lead to a shift in expenditure to other goods and services (e.g. transport) or increased resilience on imports with higher production impacts, thus offsetting the environmental benefits associated with dietary change. Apart from health considerations, a wider set of ethical concerns expressed by citizens and consumers on aspects such as animal health and welfare or support for the local economy, could also contribute to shaping the food system.

There is no overarching policy addressing the food system in Europe; rather, there are multiple policies across many different domains. Current European policies establish a common framework for governance and action, define incentives and direct research and innovation (EC, 2016a; EEA, 2017b; IPES Food, 2019). Several actions included in the circular economy action plan (EC, 2015), including commitments to reduce food wastage (Chapter 9), the expected ban on ‘single-use’ plastics (EC, 2019a), the revised waste legislative framework and the proposed fertiliser products regulation (EC, 2016d), are expected to improve the performance of the food system in the years to come by reducing waste and increasing reuse and recycling (EC, 2019c).

However, the broad range of policies relevant for food has to respond to many competing forces and vested interests, often leading to conflicting goals. For example, commitments to align policies with climate and development goals run in parallel with initiatives encouraging meat and dairy producers to seek new export markets (IPES Food, 2018, 2019). The main targets of key policy measures are generally farmers, fishers and consumers. While these food system actors are the largest in numbers (EEA, 2017b), they do not necessarily have the most power or influence to bring about change. Other food system actors such as suppliers, retailers and service providers actively shape the ‘food environment’ — the physical, social and economic surroundings that influence what people eat. For example, the 10 biggest retail companies in the EU have a combined market share of over 50 % (Heinrich Böll Stiftung et al., 2017), exerting a large influence over both producers and consumers. Influencing the food environment could be an important lever for change with regard to dietary composition, reducing food waste and supporting more sustainable production (EEA, 2017b).

European policies and initiatives could make better use of leverage points in the food system to bring about fundamental changes in the system as a whole (Meadows, 1999, 2008). For example, targeting more actions to the food industry, including suppliers, retailers and the distribution sector, could help accelerate progress towards sustainable pathways (EEA, 2017b). Moreover, incentives, such as direct payments to farmers, could be redesigned to better reflect the principles of agroecology and reward provision of public goods (IPES Food, 2019).

The development of a common policy framework for the food system could turn into a fundamental enabler of system change and promote transitions to sustainability by realigning sectoral policies across production, processing, distribution and consumption (IPES Food, 2019). Developing a systemic policy framework for food — connecting across the Sustainable Development Goals and EU policies — can also mobilise and guide contributions from many policy areas and provide a basis for a broad range of stakeholders to explore pathways for the system's transition.

16.3 The energy system

16.3.1 The energy system at a glance

The energy system is shaped by a multitude of forces related to the production, conversion, delivery, and use of energy, including economic and political forces as well as broader societal ones, such as cultural norms and lifestyles (Allwood et al., 2014). The energy system spans all resources, infrastructures, activities and actors directly and indirectly involved in meeting European demand for energy, as well as in the final consumption of energy. It includes the energy sector (i.e. the sector of the economy responsible for extraction, production and distribution of energy carriers), as well as major resource users such as buildings and construction, industry and households.

The energy system is characterised by significant diversity across Europe and its regions, particularly concerning aspects such as the energy mix, market liberalisation, the age of the energy infrastructure, carbon intensity and consumption levels. The choice of fuel type varies significantly across Europe; some countries meet their energy needs by relying on a broad range of primary sources, including renewables and nuclear energy, while others rely almost exclusively on fossil fuels (EEA, 2017d). This influences the carbon intensity of electricity production, with countries registering values from as high as 800 g CO_2/kWh to as low as 15 g CO_2/kWh (EEA, 2018e). The structure of the electricity market shows significant variations too. A handful of EU Member States are still characterised by a complete monopoly, and in five EU countries the largest generator accounts for at least 70 % of the market. In the majority of cases, however, the share of the largest incumbent ranges between 14 % and 50 % (Eurostat, 2018b). Regional diversity can also be seen in the age of energy infrastructure (installed capacity) (EEA, 2016d).

The use of fossil fuels for energy purposes is the principal cause of environmental impacts from the energy system.

Energy use in the household sector differs for of a number of reasons: climatic, structural (e.g. state and age of the building stocks), socio-economic and behavioural (e.g. household appliances, heating/cooling and cooking habits, uptake of energy-efficient technologies). In 2016, per capita energy consumption in the household sector of the EU-28 ranged from 0.2 tonnes of oil equivalent (toe) per capita in Malta to 1 toe/capita in Finland (EEA, 2018c).

Access to clean, secure and affordable energy is a vital service in Europe as well as globally. In Europe, rising awareness of the energy system's impacts on the planet have led to sustainability becoming the third key pillar of EU energy policies during the 1990s. In 2013, the Seventh Environment Action Programme set the direction for the European energy system of the future, with climate change being a particularly relevant driver of system change.

The production and consumption of energy creates a wide range of pressures on the environment and on public health. As half of EU energy consumption is satisfied through imports (Eurostat, 2018d), pressures arise at both the local level and globally. The use of fossil fuels for energy purposes remains the principal cause of environmental impacts across the energy system, causing adverse human health effects and harming crops, forests, water ecosystems, buildings and infrastructures (Chapter 7, 8 and 12). Nuclear energy also entails risks to health and ecosystems, especially nuclear waste management and potential accidents. Renewable energy technologies are also contributing to environmental pressures on land, ecosystems and human health, and depletion of resources across their full life cycle, especially if local and regional environmental conditions are insufficiently addressed during the project design and implementation phases.

Overall, the EU and its Member States are all net importers of energy carriers. In absolute terms, the EU is the largest energy importer in the world, with imports meeting 54 % of its energy needs in 2016. More specifically, 87 % of all oil products, 70 % of all natural gas and 40 % of all coal consumed in the EU were imported (Eurostat, 2018d). The import of solid biomass, biofuels and bioliquids to meet the needs for Europe's demand for energy carriers, is associated with significant impacts on biodiversity (Section 16.2 and

Chapter 1). The EU's dependence on imports has increased since 1990 as domestic fossil fuel production continues to decline due to depletion of resources and economic factors. Despite this, the increase in energy dependence stabilised around 2005, against the backdrop of increased production from sources of renewable energy. Although imported energy is essential for the EU's economy to function, significant amounts of money leave the EU economy in exchange for energy resources.

The call to phase out inefficient fuel subsidies and environmentally harmful subsidies is put forward by organisations, such as the World Bank, the International Monetary Fund and the OECD, and by the leaders of the G7 and G20 economies as well as by the European Commission (EC, 2011a; EU, 2013). Their elimination 'could raise government revenue by USD 2.9 trillion (3.6 percent of global GDP), cut global CO_2 emissions by more than 20 percent, and cut pre-mature air pollution deaths by more than half' (Coady et al., 2015).

Overall, energy consumption ([1]) fell on average after the economic crisis and has been on the rise since 2014. In 2016, gross inland energy consumption in the EU-28 (1 640 million tonnes of oil equivalent, Mtoe) was 2 % less than in 1990, and about 10 % less than it was during the peaks in consumption of 2005 and 2006. Oil, natural gas, and coal together supplied 71 % of the EU's gross energy needs. Equal shares of nuclear energy and renewables met the remaining consumption. The final energy consumed by end-users was only 2 % higher in 2016 than in 1990. A similar pattern is observed when the energy footprint of final consumption in Europe is analysed, a metric that combines both direct and indirect use of energy to satisfy final demand (e.g. energy embedded in products consumed in Europe), although the data are for a shorter time series and of lower quality. The transport sector demanded most energy, equalling one third of the total, followed by households and industry, accounting for one quarter each (Eurostat, 2018e). Non-energy uses of energy resources (fuels used as raw materials in various sectors) represented only 9 % of the final energy use in 2016 in the EU (Eurostat, 2018e; Figure 16.2).

The EU is the largest energy importer in the world, with imports meeting 54 % of its energy needs in 2016.

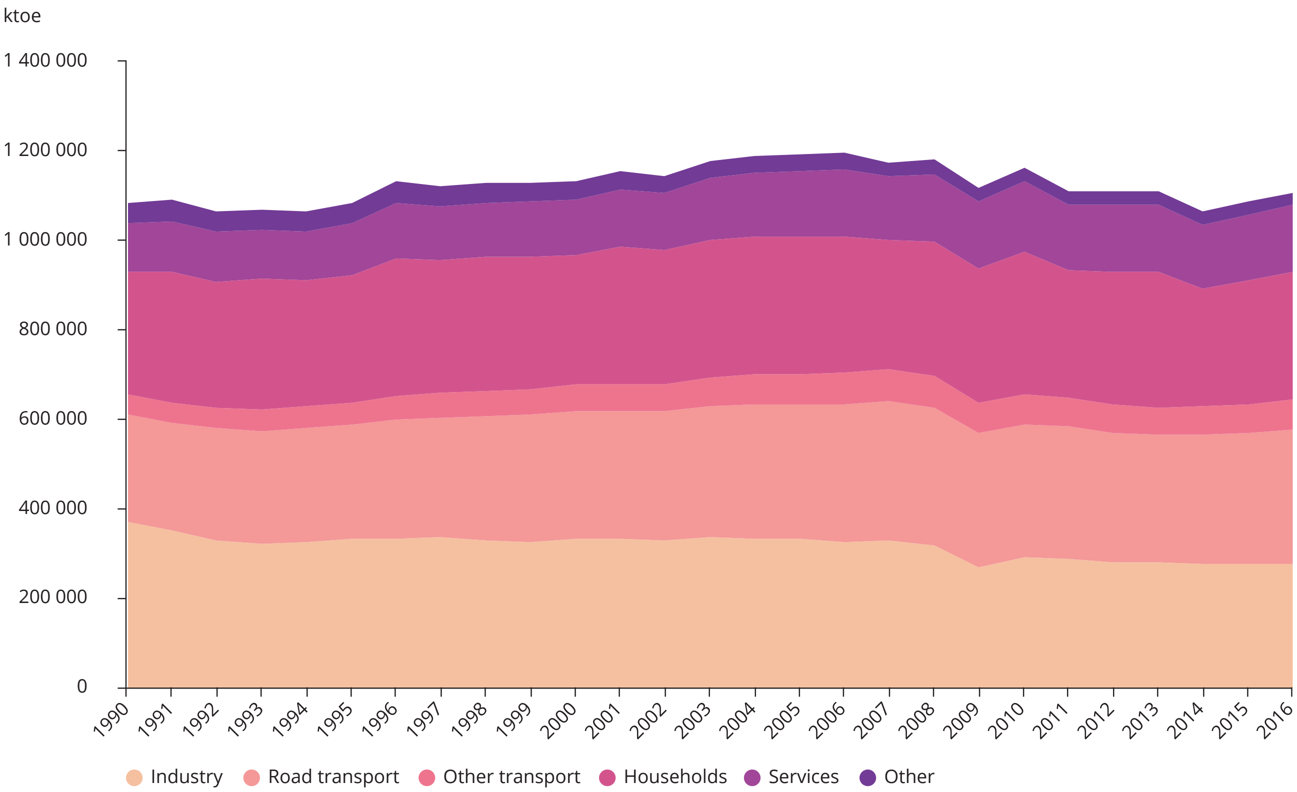
Combustion-based installations generating power and producing heat are still dominant, but shares of renewables are growing, driven by economies of scale, incentives and technological progress. Much of the EU's coal-based power capacity is more than 40 years old and is being operated at or near the end of its planned lifetime. In contrast, gas-fired power plants across Europe are younger (EEA, 2016d). Nuclear energy still plays an important role in half of the EU Member States, but its overall share in electricity generation across Europe is declining. The development of low-carbon and low-pollution energy technologies has been a major R&D and policy endeavour for several decades. A few technologies, in particular wind turbines and solar photovoltaic (PV) panels have seen substantial reductions in cost and are expected to become cost-competitive within a few years in the current EU energy market system. Renewable energy sources are used most widely in the heating and cooling energy market sector, in which the use of biomass (in district heating plants and in small-scale residential boilers and stoves) dominates all other renewables. In 2016, renewables accounted for the overwhelming majority (86 %) of new EU electricity-generating capacity for the ninth consecutive year (EEA, 2017c).

16.3.2 Trends and prospects

Trends concerning the energy system indicate that progress has been made towards reducing energy demand and increasing renewable energy shares. The EU energy system is changing rapidly, but it is still highly dependent on imports of fossil fuels, heightening the risks to supply and adverse impacts on climate, biodiversity and health. The electricity sector is currently driving the change, and other sectors such as heat and cooling, and transport show limited improvements. Europeans also consume less energy than they did 10 years ago. Efficiency gains, structural shifts in the economy towards less energy-intensive sectors such as services (EEA, 2018b), policy interventions (e.g. targets on energy efficiency — see Chapter 7), and the recession of 2008 have all contributed to reducing the demand for energy. In contrast, the demand for energy from road and air transport has continued to increase since 2009 (EEA, 2018b).

([1]) It is important to distinguish between 'final energy consumption' and 'gross inland energy consumption', as they have different meanings and implications for policy. Final energy consumption covers all energy supplied to the final consumer's door for all energy uses. In contrast, gross inland energy consumption is the total energy demand of a country or region and represents the quantity of energy necessary to satisfy the inland consumption of the country or region under consideration.

FIGURE 16.2 Final energy consumption by sector



Source: Eurostat (2018e).

Demographic and lifestyle changes may increase demand for energy, land and infrastructure.

The future of the European energy system will also depend on global and regional drivers of change. Trends in demography and lifestyle changes in Europe are likely to entail shifts towards smaller households requiring a higher floor area per individual, as well as increased demand for land and infrastructure (EEA, 2014a), larger stocks of household appliances and consumer goods (EEA, 2012), and personal electronic devices associated with the digitalisation of all aspects of life. All these trends potentially increase the demand for electricity. Projected impacts of climate change could have negative effects on the security of energy supply (EEA, 2019).

The energy system in Europe is likely to be increasingly exposed to the effects of price volatility, associated with the risk of disruption in supply due to potential conflicts and instability in exporting countries, trade and protectionism (EPSC, 2018), increased global demand and competition (OECD/DASTI, 2016), and a lower return on energy investments in newly discovered oil fields and oil tar sands (Murphy, 2014). In the short term, this trend may encourage the extraction of unconventional fuels in Europe (e.g. Neville et al., 2017). To counter the effects of energy price volatility and meet EU and global climate ambitions, the EU and its Member States aim to accelerate the transition to an efficient, renewables-based energy system. EU governing bodies are expected to introduce stronger policies on energy efficiency, including policies for energy demand management and to incentivise the substitution of carbon-intensive fossil fuels technology with renewable energy technologies.

The rise of 'prosumers' — private citizens who both consume and produce electricity, often by installing household solar PV panels — is recognised as a rapidly growing phenomenon (Sajn, 2016). This trend could significantly change the electricity system towards increased decentralisation as cities and neighbourhoods become more important in making collective decisions about energy production, supply and consumption, which has implications for the governance structure of energy networks. There are still many technological barriers and unknowns associated with such shifts. Some renewable energy technologies, such as solar PV and wind, are characterised by intermittent production patterns, which, if considered on a small scale and alone, will not meet the continuous demand for electricity from industry and households given the current infrastructure. For this reason, renewable electricity supply is currently backed up by non-renewable energy technologies such as coal and nuclear power plants or natural gas (Smil, 2016). The future development of energy storage technologies will be central to the transformation of the energy system (Verzijlbergh et al., 2017).

Integrating electricity grids would help the EU to achieve a well-functioning, secure and climate-compatible electricity market with a high share of variable renewable electricity production. Seventeen Member States are on track to reach their 10 % grid connectivity target by 2020 ([2]) (EC, 2017b). In the light of the further rapid growth expected in renewable electricity, continued progress in grid and market integration is needed (EEA, 2016d; EC, 2016c; Grossi et al., 2018). Enabling intermittent energy sources such as renewables to meet the continuous demand for energy will require additional storage capacity (i.e. batteries). These investments are not negligible in terms of demand for energy and materials and GHG emissions when considered over their life cycles (see Di Felice et al., 2018).

However, the recently negotiated recasts of the Electricity Directive and Electricity Regulation are expected to enable consumers to participate actively in the move towards a less centralised energy system (EC, 2019b), to facilitate 'cross-border trade', to allow for more flexibility to accommodate an increasing share of renewable energy in the grid and to 'drive the investments necessary to provide security of supply' (EC, 2019b).

The future of the European economy and its structure will also play a fundamental role in the energy system. Along with economic development and prosperity in Europe, a shift has taken place, away from energy and labour intensive domestic activities and towards high end production, complex and globalised supply chains (e.g. the car industry) and delocalisation of heavy industry (e.g. steel production in China) alongside other manufacturing sectors (e.g. clothing and textiles, ICT).

The continuing of this trend in Europe may facilitate the uptake of electricity, hydrogen or e-fuels in industry and manufacturing and may progressively phase out energy and labour intensive industrial processes for which substitute low-carbon technologies are not readily available to scale, in this way keeping both opportunities and challenges within certain social and economic domains. Yet, there are several technological and economic barriers associated with deploying such technologies to scale, not least their dependence on large quantities of renewable energy. Moreover, environmental impacts associated with their life cycles need to be better understood across both production and consumption phases.

From a climate perspective, it would be a missed opportunity if globalisation merely shifted emissions across geographical boundaries, resulting in increasing externalisation of emissions associated with Europe's demand for goods and services (Chapter 1) without reducing GHG emissions at the planetary scale.

16.3.3 Towards system change

The pace of the EU's progress towards climate and energy targets is not fast enough to meet its commitments to the Paris Agreement (Chapter 7). Increased efforts are needed to meet the EU's climate and energy targets for 2030, and the scale of change required to reach its 2050 objectives is even greater (EEA, 2018i, 2018h) — all the more so to reach the goal of climate neutrality set out by the European Commission in its long-term strategy (EC, 2018f). Continuing with the current structure of and trends in the energy system would not allow the EU to reach either 80-95 % decarbonisation or climate neutrality by 2050.

Several options have been proposed in the literature, enabling countries to develop specific strategies that take into account national circumstances (IPCC and Edenhofer, 2012; IPCC et al., 2014; IPCC, 2018; EC, 2018g). These include mitigation options such as combinations of low-carbon technologies (e.g. wind power, solar PV systems, bioenergy for heat and power, and biofuels), infrastructure development (e.g. electricity transmission lines, cross-border interconnections and storage), increased efficiency and savings (e.g. from energy-intensive industries and final consumption), carbon capture and storage, land restoration, changes

([2]) In 2014, the European Council called on Member States to aim to achieve interconnection of a minimum 10 % of their installed electricity generation capacity by 2020.

in consumption and lifestyles, and governance approaches.

The European Commission's proposed 'long-term vision for a prosperous, modern, competitive and climate neutral economy' (EC, 2018f) indicates that an economy with net-zero GHG emissions could be achieved by combining strategic building blocks such as maximising energy efficiency, including zero-emission buildings; deploying renewables and electricity to fully decarbonise Europe's energy supply; embracing clean, safe and connected mobility systems; developing competitive industry and the circular economy; developing a smart network infrastructure and interconnections; developing the bioeconomy and creating and enhancing essential carbon sinks; and tackling remaining CO_2 emissions with carbon capture and storage. It also suggests an enabling framework for the long-term transition (Chapter 17).

The transition towards a low-carbon energy sector can itself create new risks and dependencies that need to be anticipated. These include new raw material dependencies for high-tech renewable energy technologies and cybersecurity risks as a result of increasing ICT applications (Chapter 9). Moreover, fundamental changes in how energy is produced are likely to reshape the prevailing set of societal and geopolitical interactions and impacts (WEF, 2018b), potential disruption of the labour market (WEF, 2018a), as well as through new opportunities for employment in growing clean technology sectors.

Such changes will also lead to trade-offs with conservation of natural capital and likely effects on food and water security. Tackling climate change by upscaling the deployment of bioenergy without sufficiently strong safeguards has attracted criticism of its overall sustainability and effects in mitigating climate change (European Parliament,

The transition towards a low-carbon energy sector can itself create new risks and dependencies that need to be anticipated.

2015; ECA, 2016). In short, bioenergy — depending on source and type — can result in a range of trade-offs with other environmental issues, such as land use, biodiversity and ecosystem functioning, water, and nutrient and carbon cycles, and can even result in additional GHG emissions (EEA, 2013b). To minimise some of these environmental impacts, the Renewable Energy Directive (EU, 2009) sets sustainability and GHG emission-saving criteria for biofuels and bioliquids, which have subsequently been complemented by the 2015 Indirect Land Use Change Directive (EU, 2015). For the period 2021-2030, the recast Renewable Energy Directive (EU, 2018) strengthens the existing criteria and expands the application of sustainability criteria to all uses of biomass for energy, i.e. also for heating and power.

All the scenarios considered by the long-term vision rely on a substantial use of biomass for energy and point towards trade-offs with land use and protection of natural capital in Europe and beyond. Overall, substituting fossil fuels with renewable energy requires an increase in land use for PV panels, wind farms and biofuel production, the extent of which depends on the envisaged energy mix. If the demand for biomass is met through production in Europe, it might entail competition for land and trigger energy use by the agricultural sector. Although importing the feedstock from outside Europe might ease domestic competition for land, it would generate direct and indirect land use change in other parts of the world, which has potential implications for global loss of biodiversity.

Removing CO_2 from the atmosphere by enhancing natural carbon sinks or engineering technologies is also advocated as an option for the long-term reduction of GHG emissions (EC, 2018f). The land use, land use change and forestry (LULUCF) sector in Europe is today a net sink, as forest land alone compensates for net emissions arising from all other land covers; however, its future contribution to reducing GHG emissions is expected to decrease, mainly because of forest ageing and increased use of forest biomass (EC, 2018f). As recently indicated by IPBES (2018), land restoration and avoided degradation of forests, wetlands, grasslands and croplands could contribute significantly to the climate mitigation efforts needed at the global scale and in a cost-effective manner (Seddon et al., 2019).

Contrary to high-disturbance management systems (e.g. monocultures, fast-rotation forests), nature-based solutions are expected to contribute to multiple goals (Sections 13.4.3 and 17.3.1). In addition to carbon sequestration and consequent climate regulation, protecting natural capital would also lead to other important co-benefits for society, such as improved health and well-being (ten Brink et al., 2016). In contrast, carbon capture and storage (CCS) technologies have so far failed to develop at the expected rate, even with supportive EU regulation and co-funding opportunities (EC, 2018a). No large-scale commercial CCS plant is currently operating in Europe. This technology would need to overcome several economic and social challenges, including public acceptance, if it is to be deployed at the continental scale. Among other technical challenges, CCS-equipped power plants are estimated to require approximately 15-25 % more energy, thus needing more fuel than conventional plants. This would lead to increased direct emissions of air pollutants from CCS plants, including particulate matter and nitrogen dioxide (EEA, 2011a).

Overall, the energy system has the most developed and comprehensive EU policy framework, which covers aspects ranging from energy security to the internal market and to climate and environmental considerations. It concerns aspects of both production and final consumption. However, options for achieving net-zero carbon emissions, such as those envisaged by the long-term climate-neutral strategy (EC, 2018f), largely focus on technology options and expected efficiency gains across all sectors of the economy. There is much less focus on other levers such as behaviour and lifestyles (e.g. less carbon-intensive diets and modes of transport, limited demand for air transport, reduced demand for heating and cooling). Research on climate change tends to focus on mitigation and supply-side technological solutions, while a better understanding of behaviours and norms that determine households consumption is often overlooked (Creutzig et al., 2018).

Achieving change requires engaging several actors within the energy system, as well as taking advantage of multiple leverage points. The EU institutions and Member States define policies, regulate the functioning of the energy market, ensure security of supply and have the final choice over the national energy mix (EU, 2012). They are also responsible for creating enabling conditions for new entrants to the energy market, limiting market dominance and the power of incumbent system operators and strengthening the rights of individual consumers. Although they promote energy efficiency and new and renewable forms of energy production, and also influence energy policy indirectly by mitigating climate and environmental impacts across the energy system, they are just one among the many actors influencing citizens' choices and lifestyles.

Policies for achieving net-zero carbon emissions often focus on technology and efficiency gains rather than behaviours and lifestyles.

A broader set of actors, such as non-governmental organisations, energy service companies, grassroots platforms, think tanks, academia, innovation centres, sponsors and the media, will potentially enable the conditions for creating policy and converting regulation into practice (Backhaus, 2010). Most importantly, they are well suited to promoting changes in norms, habits and practices in ways that can reduce consumption of direct and embedded energy. Changes in these aspects should be deployed, together with stronger policy instruments, such as taxing unsustainable energy carriers and their emissions, and removing fossil fuel subsidies. Such measures would promote cross-sectoral and demand-side changes towards a more sustainable configuration of the energy system.

16.4 The mobility system

16.4.1 The mobility systems at a glance

The mobility system spans all resources, structures and activities involved in moving physical objects, including both people and goods. It is a complex system shaped by a multitude of forces — including economic and broader societal ones, such as cultural norms and lifestyles — evolving over long time scales. The transport sector addressed in Chapter 13 is just one of these components, albeit a fundamental one.

The transport sector is generally defined as an economic activity (see Eurostat, 2018o) and described in terms of GVA, employment, number of enterprises, etc. In contrast, the mobility system includes aspects that go beyond economic activity, such as personal mobility and individual behaviour, infrastructures, urban and regional planning, investments, policy and regulatory measures, as well as a multitude of actors such as producers, users, policymakers and civil society.

For the purpose of this assessment, the boundaries of the system are defined by the geographical focus on Europe and its global transport links. The specific properties of different modes of transport (road, rail, aviation and maritime, walking, cycling), such as capacity, speed and infrastructural requirements, define the supply side of transport and have a strong effect on mobility choices. In addition, mobility-related industries account for a significant share of the EU's economy and employment. For example, the production of motor vehicles alone accounted for 2.4 million jobs in 2015 (Eurostat, 2018a).

The mobility system shows marked diversity across Europe, concerning aspects such as network infrastructure and connectivity, modes of transport, share of renewable fuels, car ownership and overall demand (EEA, 2018j; EC, 2018l; Eurostat, 2018n), as well as socio-economic and geographical variations. For example, an increase in levels of car ownership, resulting in bigger car fleets, has been observed, particularly in countries joining the EU since 2004, alongside an expansion in the demand for transport in tandem with a stagnating or declining share of the more environmentally friendly modes of transport, such as rail transport (EEA, 2018f). This has been indicated as a key reason for increases in the transport sector's GHG emissions (EEA, 2018g).

Mobility is a means of satisfying fundamental needs, be it for personal purposes or as part of the economy. Most EU citizens make mobility choices every day, for example to reach their workplace, go shopping and access the social infrastructure such as schools, libraries and hospitals. Lifestyle choices and behavioural aspects play an important role in determining the shape and environmental impact of the mobility system, as established patterns are hard to change, even if better, more environmentally friendly mobility options become available. It has been shown that the shape of the mobility system partly determines the form of the built environment, and vice versa (Zijlstra and Avelino, 2012). Shopping centres outside or on the fringes of urban areas, suburbanisation and the need for long commutes when working and living areas are separated can all result in dependence on cars (Guerra and Cervero, 2011).

Alongside personal mobility, the system also plays a central role in production and trade. Europe is a transport hot spot with a high concentration of infrastructure by international comparison. It connects different world regions through major airports and sea ports, and plays a central role in global transport of passengers and goods. Complex logistics chains are the hallmarks of economic globalisation, as they now connect different production stages within countries, across world regions and even globally. This is especially relevant for complex products such as electronic equipment and the car industry. Raw materials (e.g. iron ore, crude oil and coal) and agricultural products (e.g. wheat, rice and soybeans) are among the most transport-intensive goods.

Europe has had limited success in reducing transport emissions and shifting towards more sustainable transport modes.

The mobility system generates important negative impacts on ecosystems and health. Rising car ownership rates and the growing road network have led to dramatic gains in personal mobility, but they have also resulted in important economic, societal and environmental problems (Geels et al., 2012). The spectrum is broad and ranges from well-documented, direct impacts on the climate and air quality, noise pollution, loss of biodiversity and fragmentation of landscape and habitats to more indirect impacts such as urban sprawl and invasive alien species entering in the ballast water of ships (Chapters 3-13). Transport also creates indirect impacts by stimulating demand in a range of other economic sectors, including extraction of raw materials, production of infrastructure and vehicles, electricity generation, petroleum refining, and recycling and disposal of materials.

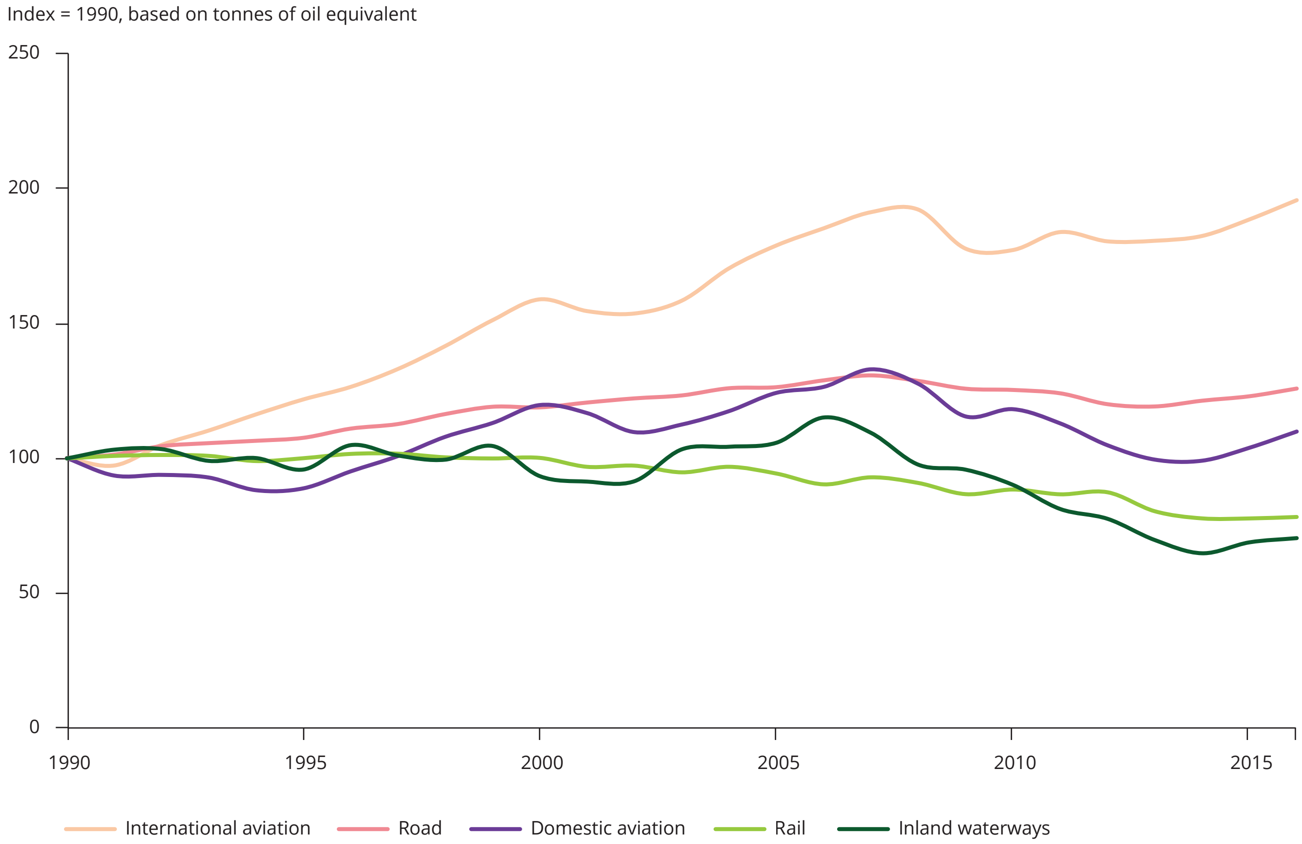
The EU mobility system is heavily dependent on imported oil; thus, it is intrinsically interconnected to the energy system. Transport accounted for 33 % of the EU's final energy consumption in 2016 (EC, 2018k) and only 7 % of the final energy used in transport came from renewable sources (Eurostat, 2018k). The remainder was largely made up of oil and petroleum products, of which 87 % were imported in 2016 (Eurostat, 2018k). Liquid fuels from fossil fuel sources have a high energy density, are relatively cheap, relatively easy to transport and handle, and are supported by a mature infrastructure. This creates a lock-in that keeps the petrol- and diesel-powered internal combustion engine the principal source of power for cars.

16.4.2 Trends and prospects

The mobility system has had limited success in reducing emissions and shifting towards more sustainable transport modes. While other sectors have already seen a certain reduction in emissions, GHG emissions from transport have increased by 26 % since 1990 (including international aviation but excluding international shipping). Following a peak in 2007, emissions decreased for 6 consecutive years. This largely coincides with a period of economic contraction, which had a dampening effect on transport demand. However, since 2013 emissions have risen again year on year. This puts the EU's mobility system in the spotlight. In future, it will need to run on much less carbon to avoid thwarting the EU's ambitions for mitigating climate change. Within the mobility system, road transport accounts for the biggest share (73 % in 2016), but aviation emissions have seen the strongest growth (Figure 16.3).

The political goal of shifting transport from more polluting modes towards less polluting modes has not had an obvious impact on demand or infrastructure development in the EU. Demand for passenger transport in the EU was at a record level of 6.8 trillion passenger-kilometres (pkm) in 2016. At 3.7 trillion tonne-kilometres (tkm), demand for freight transport was also close to its all-time high (EC, 2018k). The length of the EU's motorway network, for example, has seen uninterrupted growth over the last 25 years (EC, 2018k). Simultaneously, car ownership rates have kept going up — from 342 cars per 1 000 inhabitants in 1990 to 507 in 2016 (EC, 2018k). At the same time, the overall length of the rail

FIGURE 16.3 Energy consumption by transport mode



Source: Eurostat (2018e).

network has been shrinking, although more than half of it is now electrified (54 % in 2016).

Current prospects indicate increased demand for transport and mobility services in Europe and globally. According to the European Commission, passenger and freight transport are expected to have grown by about 42 % and 60 %, respectively, by 2050 compared with 2010 levels (EC, 2017a). Given similar trends in most other high-income countries and rapid growth in demand in low- and middle-income countries, it is likely that more people and goods will move around in the world in future than ever before. The shift in economic power towards developing regions and a fast-growing global middle class is also expected to increase trade with emerging economies, potentially requiring additional infrastructure at EU ports. In Europe, although some cities are experiencing a decline in their populations due to ageing and internal EU migration (UNDESA, 2018), others are expected to grow further (Eurostat, 2016b) and demand more mobility services, which may also occur as a result of the large number of infrastructure projects planned for the future (EEA, 2016c).

Demand for transport and mobility services is projected to grow in Europe and globally.

Another important development is the rapidly growing role of ICT across the mobility system. Real-time travel data, partly automated driving and the push towards autonomous driving can make the system more efficient and enable multi-modal, seamless transport services. The 'mobility as a service' approach seeks to detach mobility from vehicle ownership by bringing together all relevant means of transport to enable individual trips. It has the potential to reduce car ownership rates and improve capacity use across transport modes. Yet, the overall effect of ICT on the environmental pressures from the mobility system remains unclear, apart from having important social implications including personal data protection and privacy. The available research findings on automated and connected driving indicate that the technology can make vehicles more efficient and cut their emissions, but at the societal level it could also lead to additional demand for transport, longer commutes and rebound effects as a result of improved efficiency and lower costs (Taiebat et al., 2018).

Rapid progress in battery, fuel cell, bio- and electrofuel technology is starting to affect road transport, although uptake is limited. Regulatory pressure for more efficient cars and vans has already resulted in a small but rapidly growing share of battery electric vehicles (BEVs) and plug-in hybrids (PHEVs). However, with a combined share of 1.5 %, they represented only a small fraction of the new car market in 2017, which is still dominated by petrol and diesel cars (97 %). 2017 was also the first year that hydrogen cars became commercially available in Europe with 175 registrations (EEA, 2018a).

Alternative technologies and fuels are also starting to play a role in sea and air transport (e.g. 'advanced' biofuels and synthetic fuels ([3])), but market-ready technologies are not yet widely available and tend to suffer from poor cost-competitiveness, as well as low levels of energy efficiency. This is also due to weaker regulatory pressure as a result of the difficulty of agreeing binding rules at the international level. Batteries are also not universally suited to all transport modes. For international shipping, and especially for commercial aviation, their low energy density compared with liquid fuels is still an important disadvantage.

Achieving EU policy objectives will require urgent and large-scale change in the mobility system.

16.4.3
Towards system change

The scale of change in the mobility system required to meet EU objectives is large and the timeline is short. Changes are required not only to mitigate climate change but also to improve air quality, reduce exposure to traffic noise and address a broad range of other impacts. Measures concerning technological options, infrastructure, digital innovation, optimisation and societal and consumer choices are often advocated as ways of transforming the mobility system (see also EC, 2018g).

While efficiency gains and new technologies offer a range of opportunities, their viability and overall environmental and social effects at the system level are often less clear. The drive towards more efficiency appears to be driven by both markets and policies, for example the CO_2 emission regulations for cars and vans (EU, 2014). However, it mainly takes the form of incremental improvements in technology that are insufficient to put the mobility system on a trajectory towards achieving the EU's sustainability objectives. Incremental efficiency improvements are often offset by growth in demand or negated by countervailing market trends. For example, heavier and less aerodynamic cars, especially the trend towards so-called sport utility vehicles (SUVs), are partly offsetting progress in engine technology (EEA, 2018d). Moreover, the positive impacts of regulatory measures — even those already implemented — are often apparent only in the medium to long term because of the turnover in the vehicle fleet.

The results of research on the life cycle impacts of a typical battery electric vehicle in Europe show lower GHG emissions compared with conventional equivalents (EEA, 2018a). This is even with the EU's current electricity mix, which still contains electricity from coal (EEA, 2018a). Although the results are characterised by uncertainties and overall effects at the system scale, the benefits are expected to increase over time if the carbon intensity of the EU's electricity mix decreases. However, producing an electric vehicle is currently more harmful to the environment and human health than producing a conventional one owing to the extraction and processing of raw materials such as copper and nickel. Potentially strong synergies exist between mitigating CO_2 emissions in Europe and reducing other local environmental impacts, such as air pollution and exposure to noise. Electric vehicles offer benefits for local air

([3]) Synthetic fuels (also known as e-fuels) are produced by transforming electricity into synthetic gases (hydrogen, methane or other gases) and liquids. They can be stored and used in multiple applications, across different economic sectors (EC, 2018g). The technologies underpinning these processes are also known as 'power-to-X' technologies.

quality due to zero tailpipe pollution and less noise.

The technology-infrastructure-behaviour link is of central importance for driving change in the mobility system. The electrification of road transport is one example. Although it has gained momentum because of various incentive schemes and increasingly stringent CO_2 limits for the new car fleet, so far the uptake of this technology is still limited. The reasons for this are barriers and lock-ins that keep the system on its current path, including high prices, lack of a charging infrastructure, limited driving ranges and consumer attitudes (EEA, 2016e). The fact that the bulk of the traffic and refuelling infrastructure is already in place and will remain largely unchanged for decades because of its long life span, high investment costs and the overall duration of the infrastructure planning cycle impedes systemic change. Moreover, infrastructure development is often subject to conflicting demands, and environmental concerns do not always prevail. This aspect makes the mobility system subject to considerable inertia, and the effects of decisions taken today to reduce its impacts on the environment and health will usually take years and sometimes decades to materialise.

There is currently too much focus on technology and governance, and behavioural aspects tend to be neglected. The built environment, residential areas and the location of services are significant conditioning factors for how people make everyday mobility choices as well as for what options might become available (Wegener, 2004). Therefore, the transition of the mobility system is dependent on transitions in the built environment (EEA, 2016e). Spatial planning is a key issue in breaking the infrastructure lock-in. Investing more in infrastructure that facilitates walking, cycling and public transport is already driving change towards more sustainable urban mobility. Tackling regulations that drive urban sprawl (e.g. a building permit system that requires creating parking space) and changing taxation arrangements that make long commutes financially feasible could be suitable starting points. However, positive outcomes ultimately depend on accessible and attractive alternatives to individual motorised transport, as well as incentives to substitute physical transport with ICT, where possible, and to shift demand for transport to the most efficient modes.

Lifestyle choices and behavioural aspects play an important role in determining the shape of the mobility system, its impacts and its potential for reconfiguration. Decisions with profound environmental impacts, including car ownership, choice of vehicle and more generally mode of travel are linked to lifestyle. This insight can, for example, be used in public service campaigns encouraging sustainable transport (Thøgersen, 2018) as a leveraging point to change mobility behaviour, especially in urban areas. Taxation is an effective instrument to stimulate behavioural change, especially when well designed to take account of unintended regressive effects. Some European countries have announced their intention of reducing the tax differential between petrol and diesel, as a lower tax on diesel is not justified from an environmental perspective (Harding, 2014; see also Box 16.1). However, applying the principle in practice is often blocked by entrenched interests or by public concern about equity.

At the same time, the public discourse on mobility and its environmental effects is changing, as air quality problems linked to emissions from combustion engines, and diesel engines in particular, have become a major concern. A number of national governments have recently announced plans to phase out internal combustion engine cars. While implementing a phase-out in Europe would probably require a coordinated

BOX 16.1
Tax differentials, petrol versus diesel — examples of Belgium and France

Diesel is taxed at a lower rate than petrol in EEA Member States with the exceptions of the United Kingdom, where the two energy products have been taxed at the same rate since 2000 (EEA, 2016b), and Switzerland, where the diesel tax rate is higher than that on petrol. One of the reasons for the tax differential was to reduce fuel costs for hauliers, as diesel was mainly used as a fuel by commercial vehicles such as trucks and buses. However, the share of diesel-powered passenger vehicles has increased over the last two decades in Europe. The share of registration of new diesel-powered passenger cars increased from 23.1 % in 1995 to 56.1 % in 2011 in the 15 Member States that joined the EU before 1 May 2014. Since 2011, the share has dropped to 44.8 % in 2017 (ACEA, 2018).

Countries such as Belgium and France are in the forefront of reducing this tax differential. France set its tax on diesel at 71 % of the tax rate levied on petrol in 2010 and that increased to 88 % in 2018 (EC, 2019e). In Belgium, the diesel tax rate was set at 59 % of the petrol rate in 2010 but increased by 66 % in the period up to July 2018. In contrast, the petrol tax rate was reduced by 2.2 % during the same period, so that the tax rates on petrol and diesel are now equal. All changes are calculated based on nominal prices. ■

approach at the level of the single market and a long time horizon, clearly stating the political ambition can give direction to industry and consumers and be a leveraging point for achieving change.

To date there is no overarching strategy linking the mobility system in its entirety to all of the priority objectives set out in the Seventh Environment Action Programme. Nevertheless, with its three 'Europe on the move' packages, the European Commission 'has developed a comprehensive, integrated, and forward-looking approach to achieving clean, connected and competitive mobility for EU citizens' (EC, 2018e). Although the need to adopt a systems perspective to address challenges concerning GHG and air pollutant emissions is clearly acknowledged in several EU policies (EC, 2011b, 2018e) and policy proposals (EC, 2017c, 2018i), the emphasis is generally on technology pathways, efficiency gains and optimisation (e.g. digitalisation, automation, batteries), as well as related enabling factors (e.g. research and innovation, industrial leadership, multi-modal transport networks).

Europe is at the forefront of efforts to tackle the environmental impacts of the mobility system. Policies seek to maximise benefits for citizens by increasingly addressing decarbonisation and promoting the circular economy, safety, innovation, jobs and competitiveness (EC, 2018e). Nevertheless, impacts on natural capital, including habitats and biodiversity, and land and soil, are currently less prominently addressed. A broader understanding of the mobility system and its interactions, and increasing policy integration, is therefore crucial to achieve environmental objectives in Europe.

Progress towards sustainability transitions is hindered by a variety of systemic challenges.

16.5 Insights across the three systems

The assessment of Europe's food, energy and mobility systems in Sections 16.2-16.4 highlights some of the key challenges that Europe faces in achieving its long-term environmental and sustainability goals. Although there are signals of progress in food, energy and mobility, trends in environmental outcomes are not in line with meeting Europe's long-term environmental and sustainability goals. Moreover, a wide range of megatrends and emerging trends are likely to create additional challenges (Chapter 1 and Section 15.1).

Looking across the three systems, it is apparent that progress towards sustainability transitions in production and consumption systems is hindered by a variety of systemic challenges. The mechanisms that make the systems resistant to change are varied in nature, relating to the technological, economic and biophysical elements in the systems, as well as feedback mechanisms and cross-system interactions. Several of these challenges emerge as recurring features, although their characteristics differ across the food, energy and mobility systems.

First, the three systems are characterised by lock-ins and path dependency. In part, this reflects the fact that the system elements — technologies, regulations, infrastructures, user patterns, and so on — have co-evolved over decades to form relatively stable configurations. They are also multi-functional, implying that changes will result in a complex mixture of trade-offs.

Second, Europe's production and consumption systems are very often dominated by a small number of established actors. Moreover, there are marked differences in the roles and powers of actors along the value chain, for example between incumbents and new entrants. Such vested interests contribute to system inertia.

Third, achieving sustainability objectives is fundamentally dependent on individual and societal consumption choices — encompassing consumption levels, patterns and lifestyles. Local initiatives are emerging, offering new models of consuming and producing. Yet, the choices made by individuals and governments are still largely influenced by the dominant socio-economic paradigm, which generally promotes globalisation, consumerism, individualism and short-termism.

Fourth, it is also important to acknowledge the local heterogeneity of the food, energy and mobility systems. Each differs markedly across Europe and its regions, in terms of economic and infrastructural development and related consumption patterns, behaviours and lifestyles. Countries and regions also vary greatly in terms of their natural endowments and related biophysical limits (e.g. availability of natural resources, productivity, yields, but also technical efficiencies). This implies that responses must be tailored to local realities; there are no 'one-size-fits-all' solutions that apply across Europe.

Fifth, the three systems are highly interconnected with each other, giving rise to pressures and impacts across varied ecological systems and natural resources. They are also shaped by changes in the fiscal and financial systems. This interconnectedness across systems means that system reconfiguration is likely to lead to trade-offs among sustainability outcomes.

Sixth, policies can create enabling conditions to facilitate systemic change towards achieving sustainability objectives. Looking across the three systems, it is evident that thematic and sectoral policies increasingly reflect a systemic understanding of sustainability challenges. Several thematic policies cover aspects ranging from production to demand, often addressing impacts across the full supply chain, e.g. through life cycle thinking. Yet, the systems differ in terms of the ambition and coverage of the main policy frameworks. In contrast to the energy and mobility systems, there is currently no overarching policy on the food system in Europe. Moreover, even in the energy and mobility areas, the new frameworks are not comprehensive. Although issues such as security of supply, air pollution and climate are recognised in full across energy and mobility, other environmental aspects such as protecting natural capital are not sufficiently covered. Governance responses are likewise oriented towards a limited set of approaches, emphasising technologies and market-based instruments.

16.5.1 Societal lock-ins and barriers

The complexity and inertia that characterise Europe's systems of production and consumption arise in large part from the co-evolution of diverse elements over long periods. For example, the emergence of the car as the dominant form of land-based transport during the 20th century was accompanied by major private investments in the skills, knowledge and infrastructure for producing cars; public investments in the road infrastructure; the emergence of industries to manufacture and deliver fuel, tyres and other accessories; adaptation of urban design to suit the car; and changes in behaviour, expectations and cultural values linked to car ownership (Unruh, 2000).

The key idea is that the many interlinkages within and between complex systems mean that there are often strong economic, social and psychological incentives that lock society into particular ways of meeting its needs. Radically altering these systems is likely to disrupt established investments, jobs, consumption patterns and behaviours, knowledge and values, inevitably provoking resistance from affected industries, regions or consumers. The interactions between these diverse elements also mean that efforts to change complex societal systems can often produce unintended outcomes or surprises.

Looking across the three systems, a number of important lock-ins stand out, although their relative importance varies between systems:

- Emergence of a dominant design: Production costs for new technologies often drop significantly as output grows due to economies of scale and learning-by-doing, as well as network effects (Arthur, 1994). As a result, a technology (e.g. the internal combustion engine) can establish itself as the 'dominant design', enjoying significant price/performance advantages over subsequent innovations. A dominant design becomes further entrenched when supply chains and industry networks emerge to supply inputs, complementary technologies or infrastructure. This greatly increases the jobs, earnings and investments tied to the dominant design.

- Sunk costs: Public and private investments in infrastructure — particularly transport links and urban development — are often very substantial and long lasting (Figure 16.4). Businesses and employees likewise make major investments in manufacturing plants, knowledge and skills, which are geared towards particular modes of production. In the energy sector, for example, investments in upstream extraction (oil and gas rigs, coal mines), conversion (power plants, oil and gas refineries) and infrastructure (oil and gas pipelines, electricity grids, gas grids) are huge, constituting deep sunk costs that incumbent industries are likely to protect. The lifetimes of these assets and infrastructures are in the order of decades, further locking in existing systems.

- Jobs and earnings: Disruptive innovations threaten established businesses and can lead to structural economic change, resulting in job losses and even impacting whole regional economies. These effects are likely to create major resistance from industry groups and trade unions. For example, Europe's energy sector employs close to 2.2 million people, spread over 90 000 enterprises and representing 2 % of total added value (EC, 2016b). Some regions are strongly dependent on particular forms of energy production. For instance, many of the 180 000 European jobs in coal mining and 60 000 jobs in coal-fired power plants are concentrated in eastern Europe, which creates resistance to transitions in those areas. These realities are a key driver behind calls for a 'just transition' (ILO, 2015; UNFCCC, 2015).

- User practices and lifestyles tend to co-evolve with technologies and related infrastructures. Mobility, for example, is a 'derived demand', which supports other social practices such as leisure, visiting friends, shopping, commuting to work, business travel and taking children to school. For many of these activities, cars are often the most practical form of transport (in terms of travel time, carrying capacity, comfort), which is why many people choose this transport mode over others. Car use is also stabilised by long-standing positive cultural discourses, which associate cars with values such as freedom, individuality, power and success (Sheller, 2004). Cognitive biases such as


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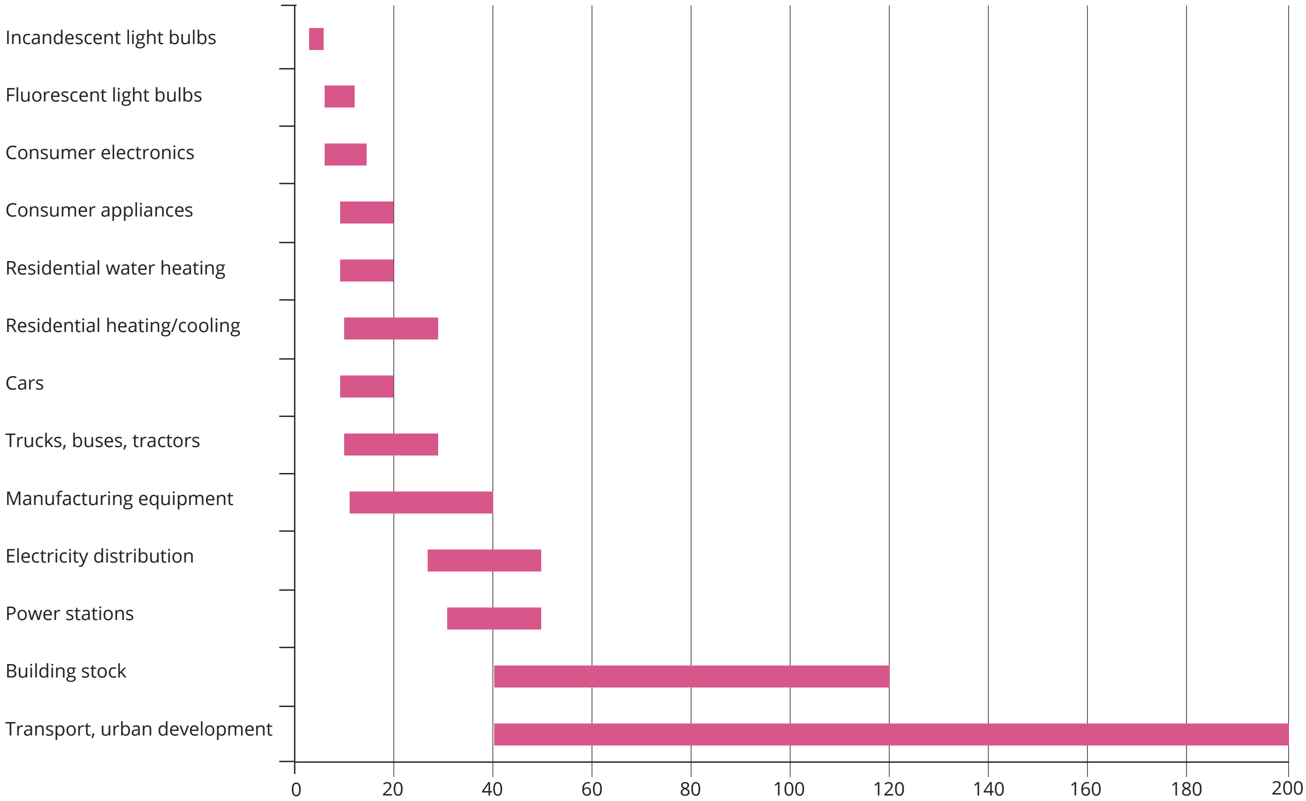
FIGURE 16.4 Average lifespans for selected energy-related capital stock



Source: Based on Philibert and Pershing (2002).

loss aversion, status quo bias and the endowment effect — whereby people overvalue something simply because they own it — can further deter lifestyle changes.

- Technological readiness and infrastructural development play fundamental roles too. For example, the 'carbon lock-in' in the energy system (EEA, 2016d) stems from a combination of the mechanisms described above. The shift towards a more distributed energy system increasingly reliant on renewable energy is likely to entail both stranded assets (e.g. fossil fuel power facilities), and expensive investments in new infrastructures to ensure a reliable supply of electricity. This looks set to include investments to increase the back-up capacity and extend grids to allow more trade in electricity (van Vuuren and Hof, 2018). Lack of technological readiness (e.g. carbon capture and storage, large-scale back-up batteries, power-to-X) is a fundamental barrier to decarbonisation.

Market prices often misrepresent the social and environmental costs of different modes of producing and consuming.

- Biophysical lock-ins are created by constraining factors, such as water availability, soil quality and the status of pollinators. These can affect opportunities for transformation, particularly in the food system (Oliver et al., 2018). For example, it may be hard to shift away from intensive farming practices if heavy reliance on specific crops and livestock leads to a loss of genetic diversity in other varieties, or if resulting soil degradation makes it hard to reduce chemical inputs.

16.5.2 Political and economic barriers

The effects of these lock-ins are often compounded by additional barriers linked to economic and political processes. The structure and organisation of modern production-consumption systems has been influenced to a large extent by market incentives. Because market prices often misrepresent the social and environmental costs of different modes of producing and consuming, this has contributed to systems that are harmful and unsustainable.

Unfortunately, governments are often constrained in their abilities to impose regulations and pricing instruments that are consistent with long-term sustainability goals. Groups with vested interests sometimes use corporate political strategies to shape policies in their favour (Hillman and Hitt, 1999; Levy and Egan, 2003). For example, powerful mobility-related industries (particularly the car industry) have been quite effective in lobbying against stricter environmental regulations and 'gaming' emission tests (Fontaras et al., 2017).

Policy interventions that remove environmentally harmful subsidies or put in place taxes to address externalities will create winners and losers. For example, taxing food, energy and mobility can have regressive distributional impacts — hitting poor people hardest because they spend a greater proportion of their income on such necessities (EEA, 2011b). It is also likely to have varying effects on urban and rural populations, young people and the elderly.

Electoral incentives can further discourage politicians from introducing measures that are likely to be unpopular in the short term but deliver long-term benefits for society. At the broadest scale, governments may be locked in to the economic growth paradigm that is known to be socially and environmentally harmful, partly because of the need to maintain employment levels and finance the welfare state (Kemp et al., 2018).

Altering sectoral policies (e.g. relating to standards for products or processes) can be difficult because producers and consumers make choices and investments based on them. The common agricultural policy (CAP), for example, is a cornerstone of EU policy that has helped to ensure stable access to affordable food for Europeans, supporting livelihoods in farming, and modernising European agriculture. But it is also criticised for its associated environmental outcomes (ECA, 2018). Attempts to reform it radically have proven difficult; the structural stability of the CAP policy framework encourages gradual adjustment of agricultural practices (Chapter 13).

The globalisation of production-consumption systems creates additional challenges. Consumers and producers (at different stages) are unaware of the socio-economic and environmental impacts of their choices and have limited influence over them. These same characteristics significantly constrain the efficiency of territorially based policy instruments, particularly as efforts to prevent an environmental or socio-economic problem in one location may result in substitution effects or relocation of production overseas (known as 'burden shifting').

Electoral incentives can deter governments from acting sustainably.

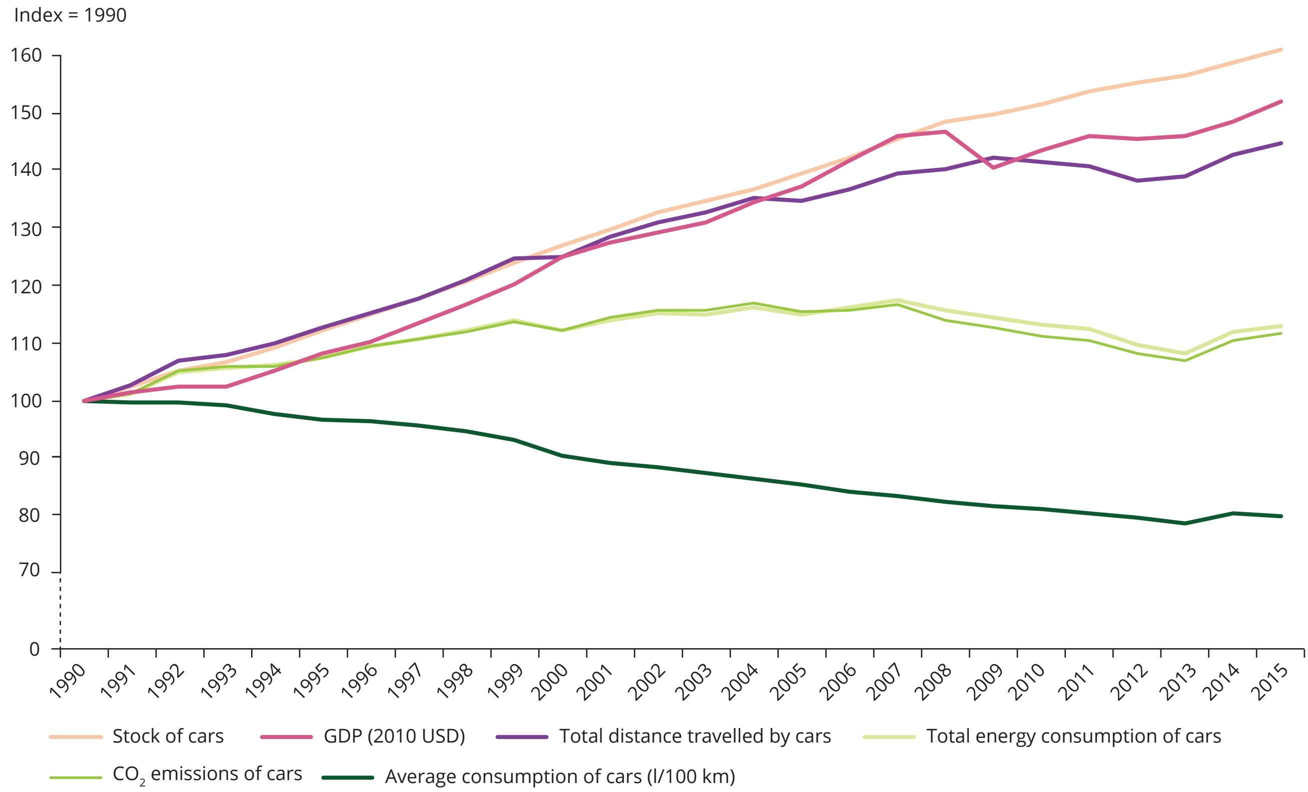
16.5.3 Rebound effects

The effectiveness of policy interventions can also be offset by feedback within systems. For example, technology-driven gains may be undermined by lifestyle changes and increased consumption and production, partly because improvements in efficiency tend to make a product or service cheaper and thus lead to increased production and consumption. This phenomenon is often referred to as the 'rebound effect'.

Examples of this challenge can be found across the food, energy and mobility systems. For example, increased water savings in agriculture have been associated with an expansion of irrigated areas, a shift to more intensive and higher value crops and more frequent irrigation events (Font Vivanco et al., 2018). The benefits associated with improvements in energy efficiency in buildings (e.g. thermal insulation, efficient boilers and lighting) are often offset at the macroeconomic scale by the resulting savings being spent elsewhere in the economy (Font Vivanco et al., 2018).

Improvements in fuel efficiency in cars have not led to a reduction in fuel consumption or GHG emissions because of increased car ownership and the distances driven (Figure 16.5). Similarly, the environmental benefits of replacing car journeys with cycling or reducing food waste will depend in part on whether consumers use the money saved to increase their consumption of other goods or services. In addition to highlighting challenges for governance, these examples highlight the importance

FIGURE 16.5 Fuel efficiency and fuel consumption in private cars, 1990-2015



Sources: Enerdata (2019); World Bank (2019).

of focusing on transforming whole systems, rather than seeking to alter aspects of production or consumption.

16.5.4 System interactions and the resource nexus

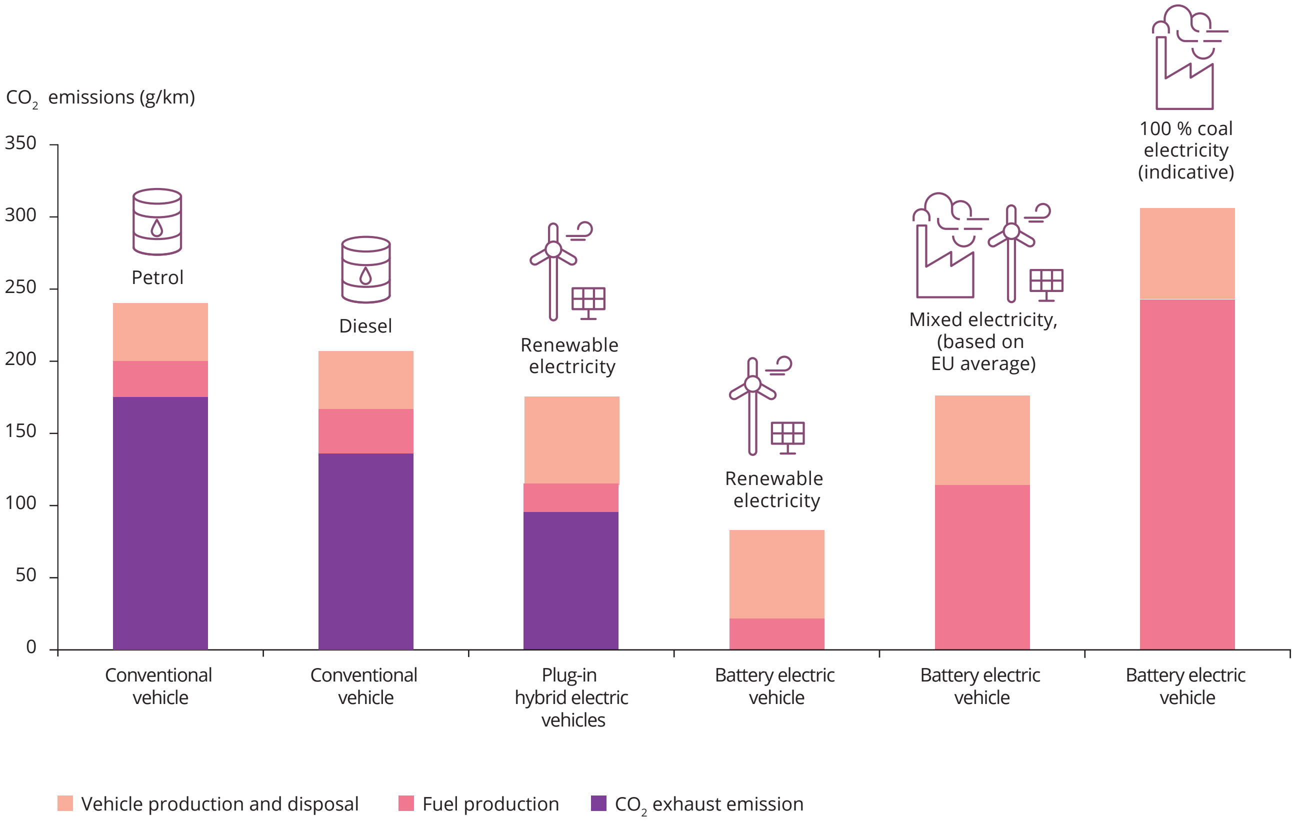
Analysing production-consumption systems in terms of their interlinked social, economic and environmental dimensions provides vital insights into the barriers to transforming them. Yet, focusing on individual systems understates the governance challenge. In reality, these systems (and others) are linked in complex ways, creating further lock-ins, trade-offs and uncertainties.

The food, energy and mobility systems are linked both directly and indirectly. Relatively simple interactions occur because the systems overlap in significant respects, implying that changes in one system have implications in others. For example, the shift to electric vehicles is likely to play an important role in reducing transport-related GHG emissions in coming years, but the benefits will depend heavily on the source of electricity used to charge vehicles (Figure 16.6). Investment choices in the electricity sector can therefore constrain or enable the transition towards electrical mobility.

The resource nexus

Less direct but very important links between the food, energy and mobility systems arise because of their shared reliance on natural systems, both as a source of resources and as a sink for wastes and emissions. As a result,

FIGURE 16.6 **Life cycle CO_2 emissions for different vehicles and fuel types**



Sources: EEA (2016a), drawing on TNO (2015).

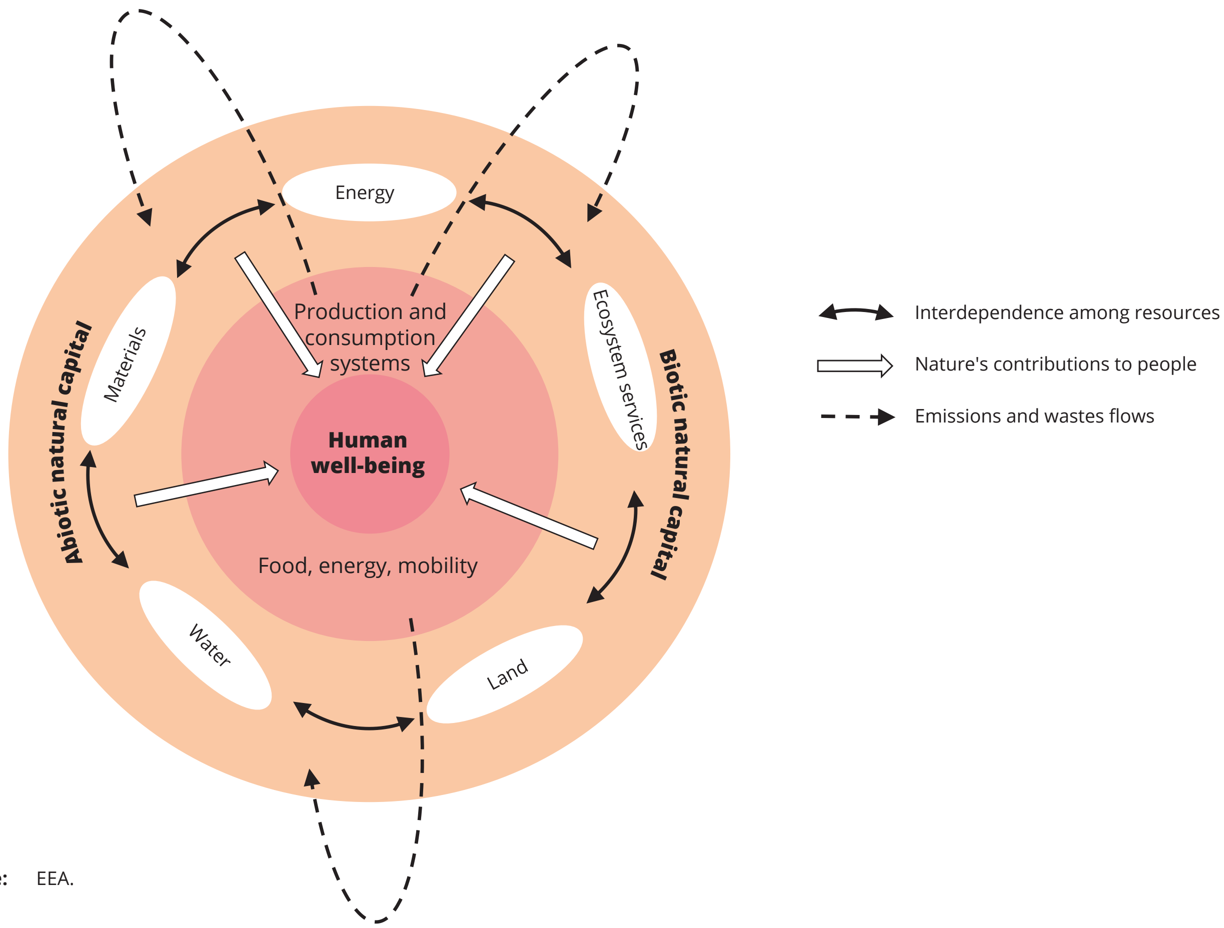
> The concept of the 'resource nexus' recognises that food, energy, water, land, materials and ecosystems are interconnected.

addressing problems in one area may simply shift the burden to other systems.

Choices regarding land use affect both the current outcomes of the food, energy and mobility systems and the potential for sustainability transitions. Such choices focus in particular on how land is used to produce food, fuel and biomass, to sequester carbon and to provide other ecosystem services. Agriculture, forestry and land use are recognised as important factors in meeting long-term climate goals because of the need to achieve negative emissions through carbon sequestration. Achieving this will require that the interlinkages across systems are considered and the trade-offs and co-benefits identified.

The concept of the 'resource nexus' essentially recognises that food, energy, water, land, materials and ecosystems (Figure 16.7) are interconnected across space and time (Hoff, 2011). It supports sustainability governance by helping to identify how best to balance socio-economic and environmental concerns. As the World Economic Forum (WEF, 2011) notes, 'any strategy that focuses on one part of the water-food-energy nexus without considering its interconnections risks

FIGURE 16.7 **The five-node resource nexus — water, land, energy, materials and ecosystem services — embedded in natural capital**



Source: EEA.

serious unintended consequences', such as externalisation of environmental pressures, burden shifting or distributional effects.

For example, analysis of 50 existing EU policies confirms that policy is normally framed within distinct sectoral mandates, e.g. for water, agriculture or energy (Venghaus and Hake, 2018). Interactions between these three domains have only recently become a focus for attention, primarily through informal statements of intent. The policy areas in which cross-sectoral thinking is most advanced are the agricultural and water sectors, because of agriculture's key role as a source of pressures on aquatic environments. Nexus thinking does not emerge prominently in policies regulating the energy sector, except in relation to the impact of biofuels and bioliquids on biodiversity, water resources, water quality and soil quality (Venghaus and Hake, 2018).

The low-carbon, circular, bioeconomy nexus

The emergence of broader and more systemic EU policy frameworks addressing the low-carbon economy, circular economy and bioeconomy offers the potential for more integrated management of natural resources. Yet these frameworks also rely on the same resource base, creating potential synergies and trade-offs, as well as raising questions about whether their cumulative impacts are compatible with protecting natural capital in Europe and globally. Considering current and future trends, there is a need to develop more knowledge of synergies and trade-offs and of how to reconcile economic activities, social needs and sustainable management of ecosystems (EC, 2018d).

The finite capacity of ecosystems to supply goods and services can also create biophysical lock-ins, potentially limiting opportunities for sustainability transitions. For example, potential tensions can be expected between the CAP, the low-carbon economy, the circular economy and the bioeconomy, linked to goals of increasing competitiveness and protecting local ecosystems. The EU's low-carbon economy, circular economy and bioeconomy policies all target increased use of biomass to replace fossil fuels, both to generate energy and as inputs to the chemicals and pharmaceuticals sectors. Yet, resource nexus analysis suggests that ecosystems cannot supply biomass and assimilate waste and emissions at the rate needed to meet these policy objectives.

Similarly, the need for new infrastructures and materials to support the transition to a low-carbon economy may be inconsistent with the goal of creating a more circular economy. A study by the International Resource Panel calculated that low-carbon technologies will require over 600 million tonnes of metal resources by 2050 to cover additional infrastructure and wiring requirements. Battery electric vehicles, for example, increase metal consumption by around 50 % compared with petrol vehicles (Ekins et al., 2017). If this demand is not dealt with in a circular manner, this will lead to higher GHG emissions.

At the same time, there are also important synergies between the frameworks. For example, recycling critical raw materials can help secure the resources, such as rare Earth metals, needed for renewable energy technologies. More broadly, circular strategies (e.g. reuse, recycling, product-service systems, sharing) reduce GHG emissions, either directly (e.g. avoiding transport) or because the strategy requires fewer materials and/or products to meet the same needs. This then avoids GHG emissions in the extraction, production, transport and waste processing phases of these (avoided) products. The implications are significant. In a review of four countries, the OECD found that materials management (production of goods and fuel, transport of goods, food production and storage, waste processing) accounted for 50-65 % of national GHG emissions (OECD, 2012). Another study estimated that implementing simple, already feasible, design options to extend the lifetimes of laptops, printers and washing machines in the EU could lead to savings in GHG emissions of over 1 million tonnes per year. This is equivalent to taking 477 000 cars off the road for a year (EEB, 2015).

In complex systems, policy interventions can result in 'risk migration', with successes in one area offset by the emergence of new risks elsewhere.

Finally, in a systemic context, policy interventions can also result in 'risk migration', in which successes in one area are offset by the emergence of new risks elsewhere. For instance, the circular economy package aims to minimise extraction of raw materials and energy use by keeping products for longer within the economy and by recycling. However, the limited ability to track chemicals in a circular economy could lead to the accumulation of hazardous substances in recycled materials and increase exposure to chemicals (EEA, 2017a; Chapters 9 and 10).

16.6 Challenges for governance

The need to transform how we produce and consume is now widely acknowledged in research and policy. Yet the analysis in this chapter highlights the extent of the challenge ahead. In seeking to transform societal systems, policymakers and other actors across society face diverse barriers and lock-ins, as well as substantial trade-offs and the likelihood of unintended outcomes.

The analysis of the food, energy and mobility systems illustrates that technology-oriented efficiency improvements alone will not be sufficient to achieve the very substantial and urgent reductions in environmental pressures that are required. Instead, there is a need to complement incremental improvements to established systems with other measures addressing the scale or patterns of consumption.

The 'avoid-shift-improve' logic provides a useful framework for guiding policies and actions towards reducing environmental pressures and addressing systemic challenges, as indicated by Creutzig et al. (2018). As illustrated in Table 16.1 for the mobility, energy and food systems, 'avoid' refers to the avoidance of unnecessary demand and overconsumption, 'shift' refers to moving consumption towards the mode/device/service with the least impact, and 'improve' refers to increasing the environmental performance of the process/product/service (e.g. production, use, end-of-life phases).

The resource nexus approach exposes another key governance challenge, highlighting the interdependence of production and consumption systems and their cumulative impacts on ecosystems. Transforming production-consumption systems inevitably produces trade-offs, as well as far-reaching and uncertain impacts. Yet established governance and knowledge systems are seldom

TABLE 16.1 **The 'avoid-shift-improve' framework applied to the food, energy and mobility systems**

System	Avoid	Shift	Improve
Mobility	Compact cities, integrated transport and land use planning, teleworking, sharing	Shift from car to cycling, walking or public transport	Eco-driving, smaller, lightweight vehicles
Energy	Passive houses or retrofitted, long-lasting devices, sharing machinery and appliances	Heat pumps, district heating and cooling, combined heat and power, recycled materials	Condensing boilers, insulation options, energy-efficient appliances
Food	Intake of calories and nutrients according to daily needs, reducing food waste	Shift to protein sources other than meat where appropriate	Fresh instead of processed food, product ecolabels

Source: Modified, based on Creutzig et al. (2018).

designed to handle this kind of complexity. Policies and actions at different levels of governance — from communities to international organisations — are often developed in silos addressing specific sectors or issues (Stirling, 2014; Wallis, 2015; Venghaus and Hake, 2018). Research is often similarly compartmentalised within disciplinary boundaries, while indicators and knowledge infrastructures are seldom developed and organised in ways that support a systemic understanding of challenges and responses. Collectively, these factors make it hard to achieve adaptive governance processes that can respond rapidly to new information about the barriers, opportunities, trade-offs and co-benefits associated with systemic change.

To achieve sustainable system outcomes, there is a need for policies that embrace the inherent interconnectedness of system components, interactions across systems, and links between economic, social and environmental goals. To anticipate potential implications and unintended consequences such interventions should be assessed against multiple criteria. These include feasibility against ecological and biophysical constraints, their viability for economy and society (e.g. effects on jobs, structure of the economy, import dependency), and their ability to meet multiple sustainability goals simultaneously, both inside and outside Europe (Giampietro et al., 2009; MAGIC-NEXUS Project, 2018; Ripa et al., 2018).

To achieve sustainable outcomes, there is a need for policies to embrace systems' interconnectedness and links between economic, social and environmental goals.

Looking ahead, the pressures on existing systems are set to increase. In addition to global demographic, economic and environmental trends, the emergence of a cluster of related technologies — including artificial intelligence, robotics, 3D printing, the Internet of Things, nanotechnology and biotechnology — threatens to disrupt economic and social systems in profound ways. According to Klaus Schwab, founder of the World Economic Forum, 'We stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before.' (Schwab, 2015).

The coming transformations are likely to be disruptive for industries, investments and labour markets, creating major challenges for societies. Yet, they also present opportunities to reshape societal systems in ways that are urgently needed. Chapter 17 explores these themes in more detail, examining how Europe's governments and societies can respond to sustainability challenges by finding ways to change production and consumption patterns in ways that can create a resilient and sustainable future.