The sustainability transition in Europe in an age of demographic and technological change

An exploration of implications for fiscal and financial strategies

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Contents

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Executive summary

EU policy clearly recognises that achieving long-term sustainability will require fundamental transformation of the core socio-economic systems such as the food, energy and mobility systems. This understanding forms a key pillar of the new European Green Deal, as well as the growing body of complementary goals, strategies and tools, including the Energy Union, the New Industrial Strategy for Europe, the just transition mechanism and the proposal for a European Climate Law.

In their different ways, these instruments all aim to enable society to meet its material and socio-economic needs while protecting and enhancing the environment in Europe and globally. Achieving this balance, as detailed in the European Environment Agency's recent five-yearly assessment, SOER 2020, represents a major governance challenge, characterised by widespread lock-ins, feedback loops, trade-offs and uncertainties. Achieving the sustainability transition will require that all areas and levels of government work together to enable the emergence and diffusion of new ways of living and working.

Fiscal and financial policy tools have a critical role to play in each phase — from enabling experimentation and innovation, and correcting market incentives, to ensuring a fair sharing of the costs and benefits across society. Yet Europe's financial and fiscal systems themselves face significant disruption and change over coming decades, resulting from the transformation of production-consumption systems, and closely intertwined macro-level processes, such as demographic and technological megatrends. Given the foundational role of the fiscal and financial systems in the functioning and governance of European societies, it is essential to understand how they will be impacted by ongoing social and economic change.

This report builds on recent EEA work around the green economy and the sustainability transition. It analyses two key drivers — demographic and technological transitions — and highlights their connections to, and their influence on, the key systems of production and consumption, the fiscal and financial sectors, and the environment, stressing the need for coherent integration of related policies.

Sustainability in an ageing Europe

In spite of many uncertainties, this report shows that population ageing is expected to directly affect the environment by leading to changes in the level and structure of consumption: for example, an older population is expected to consume more house and home-related services, but less transport-related services, with resulting changes in energy consumption and emissions. Population ageing (and eventual decline, as anticipated by the middle of this century) is also expected to result in decreased consumption levels, with a reduction of certain environmental pressures.

Population ageing can also create uncertain environmental effects through a number of indirect, systemic macro-level channels. The effects of an aging demographic on labour markets, along with adverse effects on fiscal balances, can have implications for the public and private purse, which can, in turn, influence strategies and hinder investment.

In short, demographic change has significant implications for the sustainability transition, challenging its human, technological, economic, social and policy elements.

The ambiguous role of the technological revolution

Technology can support economic growth in an ageing society by supplying the production capacity no longer provided by a shrinking labour force. However, technology-led productivity gains may also exacerbate labour substitution, thus increasing the pressure on public budgets through a shrinking tax base: automata, robots and artificial intelligence-based devices are not currently taxed in the same way as labour, their fiscal counterpart being the taxation of corporate profits.

Significant gains in resource efficiency and decarbonisation of the economy are expected to arise from technological innovations, especially in combination with organisational and social innovations, for example in the circular and sharing economies. However, effects on the sustainability transition can be ambiguous, because the technological transition is neither guided by nor so far primarily concerned with sustainability aims. For example, recent estimates suggest that technologies such as blockchain, self-driving cars and sharing platforms may require large amounts of additional energy, or have uncertain effects on the demand for resources, or they may also create congestion and rebound effects.

Key areas under analysis

Key aspects of the sustainability transition, in particular those of the collaborative economy such as sharing platforms, have ownership, labour, and cost-profit profiles that are not yet fully understood. This can influence fiscal sustainability and the availability of public resources for investment in the sustainability transition. This report highlights:

The limits of eco-innovation: Green technologies and eco-innovations exploit the same enabling technologies and platforms as the wider technological transition. The pace of development and diffusion of green technology in Europe is varied and slower than would be needed to meet the demands of the sustainability transition. Investing in eco-innovation is not sufficiently rewarded by markets, and policy instruments must be enriched and reinforced to create the appropriate incentives.

Fiscal competition for public finances and how this threatens the transition: The combined effect of an ageing population on increased public spending and reduced tax revenues, together with the fiscal uncertainties created by the new 'disruptive' technologies, can mean that the sustainability transition loses out when public resources are allocated: social spending will inevitably be the winner in any 'fiscal competition'.

Public budgets and private investment: At present, the environment accounts for only a small share of public spending in EU countries, and the share of expenditure on the environment has not increased in the last decade. Climate-related expenditure in the upcoming EU multiannual financial framework for 2021-2027, although significant, will not be sufficient on its own. Environmental taxation and other market-based instruments are necessary to trigger and drive responses from industry, technological and organisational innovations, and overall social changes to bring about resource efficiency, decarbonisation and a circular economy. While governments must be bolder in creating the right incentives and mechanisms for inducing the transition, the private sector will have to assume a key role in achieving the critical mass of investment required by the sustainability transition. An increasing number of companies are adopting sustainability strategies not only to prevent regulatory costs and risks but also because they perceive new market opportunities and economic returns from aligning themselves with the overall societal move towards sustainability. The expectation of private returns forms much of the basis for investment, and strong policymaking can reduce (perceived) risk.

The role of the financial sector: The financial sector has an important role to play. The recent surge in 'green' or 'sustainable' finance, can be seen as a game-changing step towards the sustainability transition, and the EU initiatives on sustainable finance are fundamental elements of a transition strategy. The increase in climate risk concerns among banks and financial regulators may be a critical change, which is resulting in climate risks being considered in funding decisions. A similar attitude is emerging for funding decisions based on the circularity of businesses and projects.

Three key factors for the sustainability transition: Consensus, incentives and finance

In the time frame required for the sustainability transition there will be fundamental changes in social structures, led by population ageing, and in the technological system, led by the IT-based revolution. These changes will have major consequences for the scope and direction of public policies, politics and governance.

The sustainability transition is vital to the Europe we want, but it cannot be utopian. It must embody these different transitions and bring them together on a single path. To this end, consensus, incentives and finance for investment will be key factors, and any framework to facilitate the sustainability transition will require policies and incentives that are clear, bold, stable, long-term and integrated.

Note regarding COVID-19

The main contents of this report were completed December 2019-January 2020, before the effects of the COVID-19 pandemic were felt. We do not anticipate that the pandemic would alter the findings and considerations contained within this report in any significant way. It does, however, reinforce certain notions further, and we would therefore note that:

- COVID-19 highlights the importance of societal protection, prevention, resilience, and vulnerability. Future pandemics will be part of the global risks we have to address, alongside risks associated with climate change, ecosystems and resource degradation, poverty, security and other risks.

- The IT-intensive technological revolution discussed in the report may well be intensified/accelerated by the COVID-19 crisis as, for example, options for physical communication are reduced, IT-reliant practices such as teleworking are extended, and systems designed to track people in response to contagion are deployed.

- Possible mismatches between sustainability policies — such as carbon neutrality targets — and the allocation of public budgets in EU countries (largely focussed on social spending) may be influenced by the COVID 19-crisis, by further exacerbating competition for public and private resources.

- Immense fiscal (deficit spending) and monetary efforts are being directed towards mitigating the economic shock resulting from the pandemic. Europe will also need a comparable effort to re-start a significant investment cycle to support the European Green Deal and the sustainable transition.

1 Multiple transition and EU policies

1.1 Background to and motivation for the report

A decade ago, the EEA drew attention to the urgent need for Europe to shift towards a much more integrated approach to addressing persistent, systemic environmental challenges (EEA, 2010). That report identified the transition towards a green economy as one of the four key environmental priorities required to secure the long-term sustainability of Europe and its neighbourhood and recognised that ecosystems, the economy, human well-being and their related types of capital are intrinsically linked (EEA, 2012).

In 2014, the EEA concluded that achieving the transition to a green economy requires (EEA, 2014):

- long-term thinking and actions;
- a widely applicable coherent framework that can drive profound changes in dominant structures and prioritises promoting innovation;
- the extensive recalibration of fiscal instruments;
- the design of innovative finance initiatives.

It argued for the rational integration of objectives across all policy areas, treating as equal the economic, social and environmental performance objectives of sustainable development.

A fundamental aspect of the sustainability transition process is merging the longer-term perspective of environmental policies with the relatively short-term focus of economic and social policies (EEA, 2015). Policies and politics give issues such as tackling unemployment greater emphasis, as society expects fast outcomes. Achieving environmental objectives, such as restoring ecosystem resilience and attaining a carbon-neutral Europe, by contrast require long-term policy measures that often incur short-term costs and often deliver less immediate and visible benefits to society.

Longer-term developments such as demographic changes and technological breakthroughs in the transition to a low-carbon, green economy will also contribute to eroding the current tax bases in European countries (EEA, 2016). These expected trends challenge the overall basis of current thinking on how to fund public spending on social welfare systems in parallel to the sustainability transition. Much more needs to be done to design resilient, long-term tax systems in Europe in the face of such systemic challenges (EEA, 2016).

Global megatrends, such as an ageing population and technological changes, are also crucial factors in determining Europe's environmental and sustainability outlook (EEA, 2015, 2019a and 2019b). They highlight the necessity for addressing multiple environmental, social and economic challenges from a more systemic perspective:

> We face urgent sustainability challenges that require urgent systemic solutions. This is the unambiguous message to policymakers in Europe and globally. The overarching challenge of this century is how we achieve development across the world that balances societal, economic and environmental considerations (EEA, 2019b, p. 9).

Fiscal and financial policy tools have a critical role to play in supporting solutions – from enabling experimentation and innovation, and correcting market incentives, to ensuring a fair sharing of the costs and benefits across society. Yet Europe's financial and fiscal systems themselves face significant disruption and change over coming decades, resulting from the transformation of production-consumption systems, alongside closely intertwined macro-level processes, such as demographic and technological megatrends. Given the foundational role of the fiscal and financial systems in the functioning and governance of European societies, it is essential to understand how they will be impacted by these change processes.

It is these considerations that have informed the thinking and logic for this new EEA report.

1.2 Overall political context and aims of the report

The political context

Achieving a sustainable Europe requires far-reaching societal change (EEA, 2019b). Key policy documents reflect this, such as the European Commission's long-term vision for a climate-neutral economy (EC, 2018a) and its Reflection Paper on the 2030 agenda for sustainable development (EC, 2019a). The current European Commission 2019-2024 (von der Leyen, 2019) emphasises the need for ambitious, transformative action by assigning top priority to the European Green Deal and the huge opportunities that it could create.

In December 2019, the European Commission presented the roadmap of the European Green Deal for making the EU's economy sustainable (EC, 2019b). The European Green Deal is the strategy aiming to turn climate and environmental challenges into opportunities and thereby making Europe the first climate-neutral bloc in the world by 2050. The European Green Deal encompasses all sectors of the economy and states that all EU actions and all policies will have to contribute to the European Green Deal objectives. The European Green Deal is 'the new growth strategy that aims to transform the EU into a fair and prosperous society (EC, 2019b)'. However, the Commission clarifies that 'economic growth is not an end in itself (EC, 2019c)' which can be seen as a paradigm shift in economic policy. Apart from the environmental and climate challenges, 'technological progress and demographic change are set to transform our societies profoundly (EC, 2019c)'.

It is articulated that the challenges Europe is facing are complex and interlinked requiring innovative and alternative methods as 'conventional approaches will not be sufficient (EC, 2019b)'. Furthermore, significant investments from public and private sources are required to finance the green transition. In 2016, the European Commission initiated a work stream on sustainable finance by establishing a high-level expert group on sustainable finance (HLEG) to provide advice on different topics including how to steer the flow of public and private capital towards sustainable investments. The recommendations of HLEG shaped the Commission's Action Plan: Financing Sustainable Growth (EC, 2018b).

In the context of meeting the objectives of the European Green Deal, investment is crucial and is recognised in the adoption of the Sustainable Europe Investment Plan in 2020 (EC, 2020a). The plan is the investment pillar of the European Green Deal and 'will mobilise through the EU budget and the associated instruments at least EUR 1 trillion of private and public sustainable investment over the upcoming debate (EC, 2020a)'. Through the Just Transition Mechanism, the Sustainable Europe Investment Plan takes into account significant challenges in terms of the required restructuring of economies as part of a transition process that should leave no one behind.

Setting the scene – the context of the report

The sustainability transition is seen as the route towards a sustainable society and is characterised by a deep, systemic transformation in the key societal systems of production and consumption that most affect the environment and climate ([2]). In essence, it is about moving from the society we live in to the society we want, and, for it to be successful, it is critically important to assess its interactions with other major transformational forces of our age such as demographic and technological change and the consequent changing priorities in the funding of public policies.

The report adopts a broad systemic approach by looking at the sustainability transition in this multiple-transition setting. It does so by exploring the characteristics of each specific transition and their multiple interactions. We should also take the existing and new targets/objectives of the EU's environmental and energy policies to 2030 and 2050, including those to be established under the European Green Deal (EC, 2019b), as a sound basis for implementation.

The report's focus on the connections between these multiple transitions aims to highlight major potential synergies and conflicts to better inform effective and successful EU policy design and decision-making for the sustainability transition (EC, 2019a). These interconnected changes are being increasingly picked up in EU policy discourse:

> The question is whether we are a victim of change, or whether we will embrace and guide it.

([2]) There are different definitions of the sustainability transition. For example, Grin et al. (2010) defines it as a 'radical transformation towards a sustainable society, as a response to a number of persistent problems confronting contemporary modern societies'. A definition focusing more on the environmental dimension is applied by the EEA (2019a): 'A fundamental and wide-ranging transformation of a socio-technical system towards a more sustainable configuration that helps alleviate persistent problems like climate change, biodiversity loss or resource scarcities.'

> Europeans are facing pressing challenges such as environmental degradation and climate change, demographic transition, migration, inequality and pressure on public finances (EC, 2019a, p. 2).

The report explores how demographic and technological change could potentially affect the environment, as well as how all of these changes and trends could influence public budgets and policy priorities.

In the case of fiscal sustainability, for example, if governments are not able to allocate investment and social spending for ensuring the well-being of their citizens, they will fail in their primary mission. These concerns focus on revenues and costs/spending programmes. For example, the ageing population is likely to lead to both reduced tax revenues and growing age-related expenditure — public pensions, health care and long-term care. Technological developments and uptake can lead to increased revenues from economic growth but also, potentially, higher unemployment, resulting in declining tax receipts, growing public expenditure and increasing inequality. Furthermore, although technological progress is increasingly recognised as environmentally friendly, it can also increase environmental pressures (EEA, 2019b; UN Environment, 2019a).

1.3 Report structure

Overall, the future outlook requires systemic thinking and actions but most policies are not adequate in this respect: dominant approaches to policy formulation address individual issues rather than the complex, systemic nature of many current issues, leading to suboptimal outcomes. Systemic thinking can help identify, assess and prioritise policy interventions to deliver the goal of sustainability, be it fiscal, economic, social or environmental. Figure 1.1 describes the overall logic and structure shaping this thinking.

Chapters 2 and 3 explore the two of the major macro-scale societal transitions — demographic and technological — and analyse their links with the environment and their effects on the public budget. The need for a balanced fiscal policy therefore imposes constraints and trade-offs on all public policies, including environmental policies and green investment. These aspects are examined in Chapter 4, which also includes a review of the need for investment and the potential role of the private sector in financing the transition.

Key to the added value of this report is the analysis of the interactions between an ageing population, technological transition and environmental policies — the latter viewed from the fiscal sustainability angle — and the feedback loops that might mutually influence them (Jackson and Victor, 2015; D'Alessandro et al., 2018). Assessing these complex interactions calls for the use of integrated models. Chapter 5 presents the results of two modelling exercises specifically developed to manage this complexity more effectively ([3]):

- a qualitative systemic approach using causal loop diagrams based on systems thinking to analyse the simultaneous impact of social, economic and environmental variables on a system's performance; and

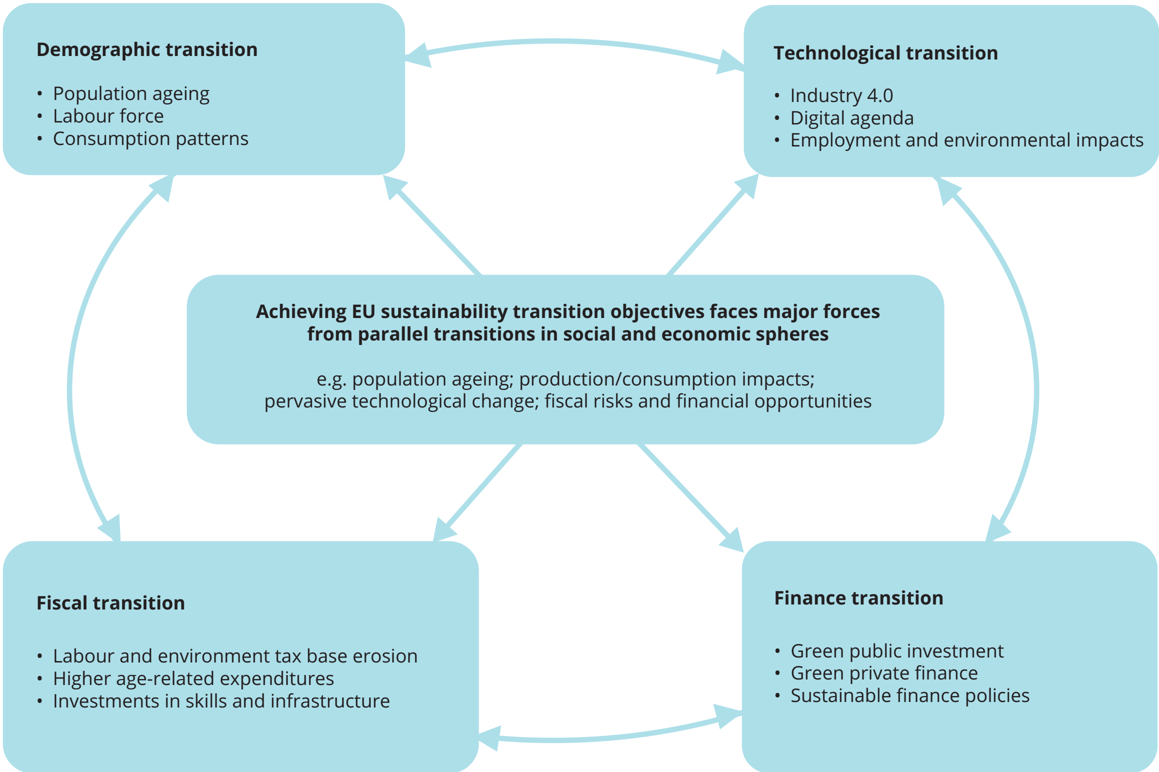
- a computable general equilibrium model to forecast the impacts of an ageing population, technological change and environmental policies on fiscal sustainability and macroeconomic performance.

The modelling approaches are used to understand and visualise the many and sometimes diverse outcomes of drivers and constraints, including the many — and sometimes unexpected — indirect effects. As for all models, the results should be interpreted with care and regarded as just part of the knowledge needed for decision-making.

Chapter 6 provides a summary and a more reflective analysis, including an overview of various fiscal policy options for putting public finances on a sound footing, thereby addressing some of the key points emerging from the report.

([3]) For a detailed discussion of the two modelling approaches and the findings, see ETC/WMGE (2020).

Figure 1.1 Connections in a multiple-transition setting



Source: EEA.

2. Demographic transition

Key findings

- The EU population is projected to increase to 2040, remain stable to 2050 and then decline to 2070.
- By 2050, the number of people aged 65 or above will have doubled to 29 % relative to 1990, leading to a 'demographic deficit' which is expected to have negative socio-economic implications, including disruption in the social contract between age groups.
- An empirical analysis of greenhouse gas footprints indicates that consumption expenditure and the footprint of food consumption as a share of total consumption increases with age. However, age-specific estimates of greenhouse gas footprints suggest that an ageing population can per se systematically reduce the footprint of final consumption.
- At the macroeconomic level, population ageing is considered a factor in potential 'secular stagnation' — a reduction in demand for a given income level.
- Most of the available studies indicate that an increase in the share of the population aged 60 or over decreases the growth rate of gross domestic product per capita.
- Ageing is expected to have a negative effect on fiscal sustainability because it can increase the need for spending on social protection and health, while also eroding the tax base through a reduced labour force.

2.1 Introduction

Demographic transition links population size with evolving patterns of birth rates, death rates and age structure. Much of Europe is in the mature phase of demographic transition, in which birth and death rates converge at relatively low levels towards a stable population and subsequently population decline, as predicted for the coming decades in many European countries (World Bank, 2016). This development is in contrast to the trend of global population which is projected to further increase (Box 2.1).

Box 2.1 Population growth

The recent report on global population by the United Nations Department of Economic and Social Affairs projects a further increase of global population from 7.7 billion in 2019 reaching 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100 (UN DESA, 2019). This projection reveals a declining annual growth rate from 0.9 % in the period between 2019 to 2030 to 0.2 % for the 50 years period from 2050 to 2100. The distribution of the increase in global population is different between regions as the largest part of the growth in population is projected in urban areas of developing countries. On the contrary, the population in developed countries, in particular in Europe but also in countries like South Korea and China, is projected to be stable or declining. For example, Eurostat projects a small increase in the population of the EU of 2 % between 2019 and 2050 but with a wide margin between EU Member States. The population in countries, like Luxembourg, Sweden and Malta, is projected to increase by more than 30 % during this period (i.e. a projection of the annual increase of more than 1 %) and on the opposite side countries, like Bulgaria, Croatia, Latvia, Lithuania and Romania, are projected a reduction in the population of more than 15 % in this period. Although the projected trend in the total population in EU Member States differ, all countries are confronted with an ageing population as the share of people aged 65 years and over will increase from 20 % of total population to 29 % in 2050 (see Figure A2.1 in the Annex and EEA, 2020).

Key uncertainties associated with possible population decline include fertility rates and migration, but a very reliable indicator of the transition to maturity is population ageing. Combined with lower fertility rates, ageing will result in an increase in the old-age dependency ratio, which will put pressure on fiscal budgets and labour markets. These trends towards population ageing and increasing dependency ratios also have wider socio-economic and environmental implications for the sustainability transition. The effects of demographic transition on environmental sustainability are traditionally looked at from the perspective of population growth; much less research and policy attention has been devoted to the possible environmental, economic, fiscal and social effects of an ageing population.

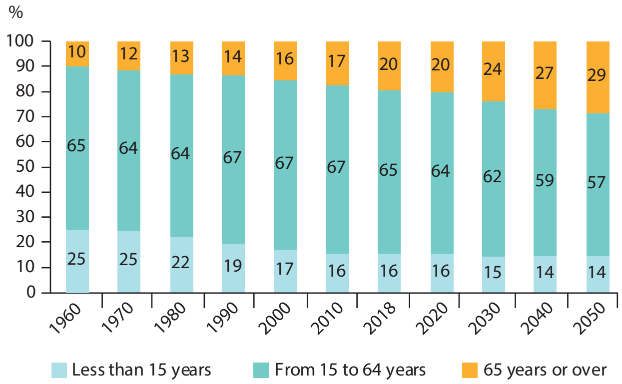
A review of the available literature on the environmental implications of population ageing (see ETC/WMGE, 2017) informed an empirical analysis of the effects of ageing on greenhouse gas footprints. From this analysis, 'what-if' scenarios for the greenhouse gas footprint of the EU in 2050 have been developed using demographic scenarios produced by Eurostat. The results suggest that an ageing population can overall result in a reduction in greenhouse gas emission footprints.

Population ageing also has major implications for economic growth and fiscal sustainability in Europe through its effects on labour markets, social protection and health spending, and fiscal revenues. Evidence suggests that the overall effects of ageing are negative, especially for fiscal sustainability, which is essential for mobilising public and private resources for investing in a transition to a green economy (see Chapter 4).

2.2 European population trends and projections

Most EU countries are completing their demographic transition, which started about two centuries ago, and will enter a post-transition phase in the second part of this century (ETC/WMGE, 2017). Population growth in the EU is expected to reach a ceiling in 2040 and then decline. There will be major changes in the age structure that will increase the cohort of those aged 65 and over from 20 % of the total population at present to 29 % in 2050 and increase the old-age dependency ratio from 30 % at present to 50 % in 2050 (Figures 2.1 and 2.2) [4]. Within this overall picture, individual Member States will experience different trends and some may be considered to have already entered a post-transition phase. Overall, completing the demographic transition in Europe will have far-reaching and pervasive consequences for society.

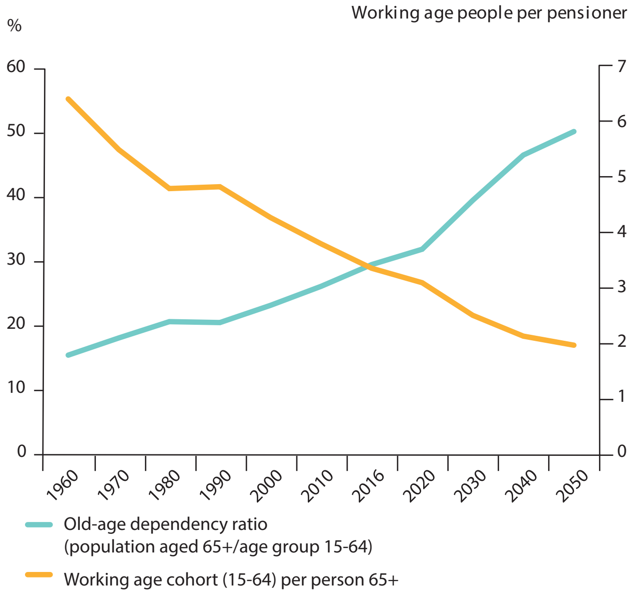
Figure 2.1 Trends in the age composition (%) of the EU population between 1960 and 2050



Note: 1960: no data for Croatia, Cyprus, Estonia, Latvia, Lithuania, Malta, Romania and Slovenia; 1970: no data for Croatia, Cyprus, Malta and Slovenia; 1980: no data for Croatia, Cyprus and Slovenia; 1990 and 2000: no data for Croatia.

Source: Eurostat.

Figure 2.2 Old-age dependency ratio (%) and number of working age people per pensioner in the EU, 1960-2050



Note: 1960: no data for Croatia, Cyprus, Estonia, Latvia, Lithuania, Malta, Romania and Slovenia; 1970: no data for Croatia, Cyprus, Malta and Slovenia; 1980: no data for Croatia, Cyprus and Slovenia; 1990 and 2000: no data for Croatia.

Source: Eurostat.

(4) See Eurostat (2019a) baseline population projection.

The demographic changes in EU Member States, Norway and Switzerland are diverse. Total population is projected to decrease in 15 countries and the working age population, those aged 15-64, in 20 countries (Annex 2.1). The sole common feature is the projected increase in the number of people aged 65 and over in all countries. This trend is likely to lead to disruption of the 'social contract' between age groups, as intergenerational relations work well when the shares of age groups remain relatively stable over time and the cost to the working age population of sustaining the young and old also remains approximately stable. The increase in the share of the 65 and over cohort will result in a 'demographic deficit', which is 'perceived to herald negative implications for both nations and regions. It is argued that this results in demographic decline leading to a fall in economic activity; and in demographic ageing resulting in an economic burden due to increased requirement for pensions and health care' (Harper, 2013).

Life expectancy at birth is increasing in all European countries, especially for men who generally have lower life expectancies than women. Increased life expectancy, however, does not always correspond to an increase in healthy life-years. When these are considered, healthy life-years are not only lower than life expectancy but they also decreased in some European countries in the last decade. In Denmark, for example, while male life expectancy at birth was 75.4 years in 2004 and increased to 79.2 in 2017, male healthy life-years decreased from 68.3 to 59.8 in the same period (Eurostat 2020a, 2020b). Similarly, in Austria life expectancy at birth for men increased from 76.4 to 79.4 years between 2004 and 2017 but expected years of good health dropped slightly, from 58.3 to 57.4 years. Other countries, including Estonia and Finland, have seen the opposite trend as both life expectancy and healthy life-years have increased.

Life expectancy and remaining healthy life-years at age 65 in the EU follow a similar pattern for both men and women: life expectancy at 65 increased between 2004 and 2017 for women by 1.5 years and for men by 1.3 years. There are, however, examples where life expectancy at age 65 is rising, but the expected number of healthy life-years is falling. In Greece, for example, the remaining healthy life-years for women aged 65 decreased between 2006 and 2017 from 10.3 to 7.8 years and in the Netherlands from 11.4 to 9.6 years. Nevertheless, the trend in the majority of EU Member States is that life expectancy and healthy life-years are increasing. These developments will have economic and fiscal implications, as they imply increased health expenditure in the future.

Table 2.1 Remaining life expectancy for men aged 65 living in different conditions in the United Kingdom

Life expectancy and influencing factors	Poor	Good
Remaining life expectancy (years)	12.0	23.0
Income level	Low	High
Retirement status	Ill-health retiree	Normal health retiree
Lifestyle	Unhealthy	Healthy

Source: Harper (2017).

Longevity also differs according to social and living conditions. According to Harper (2017), there is a clear evidence that people living in better social and economic conditions and in better locations, which may mean higher environmental quality, live longer. In the United Kingdom, the remaining life expectancy at age 65 of socially disadvantaged people is 12 years while it is 23 for those enjoying better economic and lifestyle conditions (Table 2.1).

Completing the demographic transition is also expected to contribute to a possible 'secular stagnation' ([5]) of mature economies, which will have major implications for the current pension systems in EU Member States and the overall fiscal and budgetary situation (Section 2.4 and Chapter 4).

2.3 Exploring the environmental implications of the demographic transition

The environmental implications of a growing population have been in the spotlight for many years – from Ehrlich (1968 — see Box 2.2.) through to more recent contributions (see, for example, O'Neill et al., 2010; Götmark et al., 2018). This is due to the well-established relationships between more people on the planet, growing affluence and consumption, and increased environmental degradation. Less attention, however, has been devoted to the environmental effects of a stagnating and possibly decreasing population (Clements et al., 2015). In particular, research on the

([5]) Secular stagnation refers to an economy with a chronic (secular or long-term) lack of demand. For a detailed discussion of the term see Eichengreen, 2015 and Summers, 2015 and 2016.

Box 2.2 Population and its impact on the environment

The simplest form for studying the environmental implications of population is the IPAT formula (Ehrlich and Holden, 1971) ([7]). It is based on an identity expressing environmental impact (I) as the result of three variables: population size (P), affluence (A) or the average income (GDP) of each person in the population, and technology (T), or the overall environmental intensity of the production in the country or region. An often used the mathematical formula is I = P*A*T, which is multiplicative in the driving variables. The formula is not universally accepted because of being simplistic and because of the likely correlation of the three variables, but it is often used to measure the contribution of P, A and T to the Impact.

The IPAT model (or the similar Kaya Identity) has been variously criticised, reformulated, and extended across a large base of theoretical and empirical literature (see, among many others, Fischer-Kowalski and Amann, 2001; Chertow, 2001; York et al., 2003).

One of the foci of this report is studying the environmental and fiscal implications of an ageing population by going beyond the consumption of an average person, and instead considering the consumption bundles of different age cohorts as the composition of the population will change over time (Liddle, 2011). The age structure of the population matters in so far as people in different stages of their lives consume different goods and services and are in different stages of their economic activity, i.e. being in education, receiving income during their working lives and being on a pension. Household expenditure data, such as the European Union Statistics on Income and Living Conditions (EU-SILC), show that environment-intensive goods/services like transport and residential energy consumption vary according to the age structure of the population (EC, 2008).

environmental effects of population ageing has been rather scant and inconclusive ([6]).

As people move through their lives, their consumer spending levels and consumption preferences change. A common finding is that consumption falls at retirement, a phenomenon known as the 'retirement-consumption puzzle' (see, for example, Bernheim, Skinner and Weinberg, 2001; Hurd and Rohwedder, 2003; Smith, 2004; Celidoni and Weber, 2020).

When it comes to expenditure on different goods/services, the share of food expenditure remains roughly constant for households in different age groups, while the share of expenditure on equipment, clothing and shoes is higher and increasing for young households up to the age of 35 and decreases after 50. As household members get older, they spend larger shares of their overall budget on energy and household services, expenditures which tend to increase steadily over a lifetime up to retirement, while spending on health in total expenditure increases from the age of 55. Conversely, the share of expenditure on (private) transport is higher for younger households and declines sharply after the age of 60. This general picture of consumption levels and expenditure as an inverted U-shape — with population cohorts in middle age having the highest income and the highest spending and consumption — is quite common across all national contexts.

The scant literature on the environmental implications of these age-related consumption pattern is, however, rather inconclusive, in particular in the case of energy consumption and related emissions. For example, empirical studies of different countries highlight the possibility of higher energy consumption and greenhouse gas emissions because of the consumption behaviours of older groups (Tonn and Heisenberg, 2007; Brounen et al., 2012; Kronenberg, 2009). Other studies, instead, provide evidence of the fact that population ageing will contribute to the reduction of energy use and GHG emissions (for example Dalton et al., 2008; Garau et al., 2013).

However, as discussed in EU (2013), EEA (2019b) and Sala et al. (2019a and 2019b), food, transport and housing-related consumption have the highest environmental burden and therefore the net environmental impact of consumption composition arises from the interplay between housing and food

([6]) For an overview of studies analysing ageing population and environmental implications see ETC/WMGE, 2017. See also EEA, 2020 for a discussion on population and ageing in the framework of megatrends and sustainability.

([7]) Ehrlich is also well-known as the author of the book 'The population bomb' (Ehrlich, 1968). The book alerts to the environmental consequences of rapid population growth following the ideas of Robert T. Malthus stating the disparity between exponential population growth and the linear growth of food supply (Malthus, 1798). Addressing these challenges, Ehrlich suggests taking into account population control measures. This aspect is also supported by neo-Malthusianism, which advocates human population planning including the use of contraception. Since its publication, Ehrlich's thesis has been criticised as being rather pessimistic and as representing a simplistic view on global change in line with those prevailing during the 1970s, whose predictions did not materialise. The present concepts of sustainability put people at the very core and are very concerned with people's well-being and social sustainability, including in less developed countries which are still undergoing rapid population growth, which is, however, bound to stabilise in time with the maturity of the demographic transition.

consumption increasing and transport consumption decreasing in parallel with people's age. In short, the demographic transition can have two main effects on the environmental impact of consumption:

- People of different ages have different levels of consumption expenditure per person; in general, older people consume less, and this can reduce environmental pressures;
- People at different ages consume different mixes of products and services that have different environmental footprints; therefore, an ageing society may change environmental pressures through the consumption-composition channel.

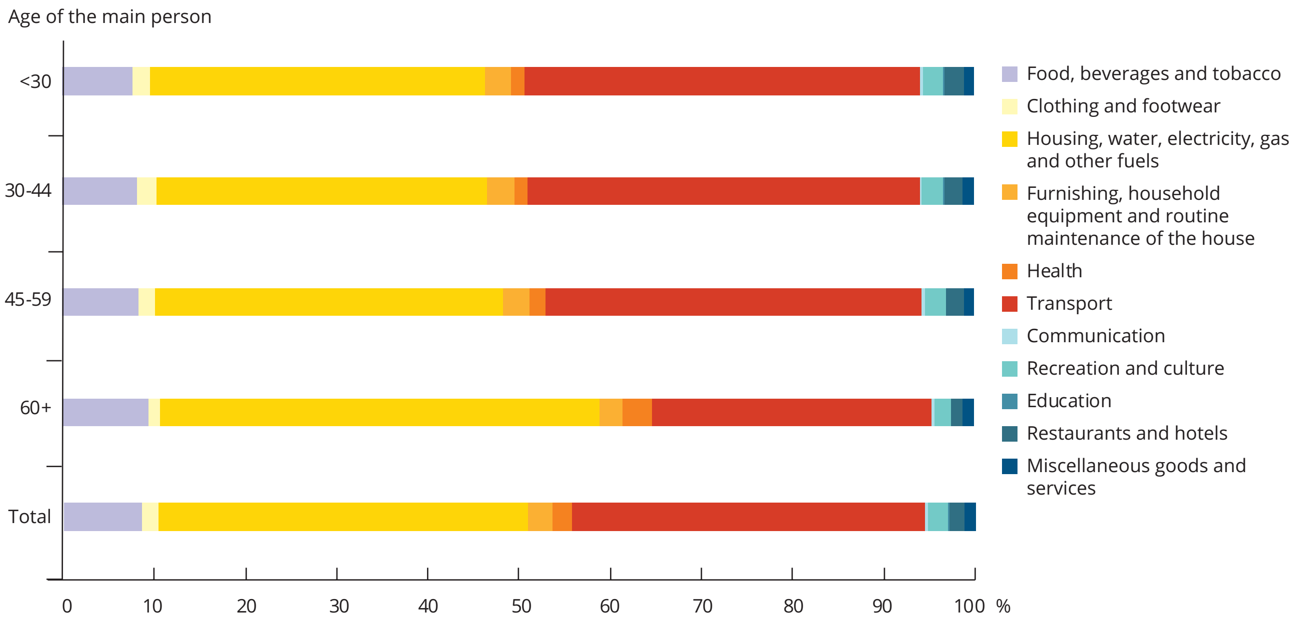
An original empirical exercise has been developed to explore the combination of these effects, taking greenhouse gas emissions as the reference environmental pressure, and following a two-level approach. First, the average greenhouse gas (GHG) footprint of different consumption categories (clothing and footwear, food, housing, etc.) is linked to household expenditure data by age. The age of the 'main person' in the household is used for this purpose. This person earns the highest income in the household. Second, the estimated greenhouse gas footprint per person is linked to population projections to see how population ageing can influence total greenhouse gas emissions in Europe. See Annex 1, Section A1.1 for details of the data sources and calculation methods ([8]).

2.3.1 Differences of greenhouse gas footprint by age

The age of the main person in the household was used to evaluate differences in age-related consumption expenditure and greenhouse gas footprint patterns, with a focus on the three consumption clusters — food housing, and transport — which contribute 55 % of households' final consumption and 93 % of the corresponding greenhouse gas footprint in the EU ([9]).

As a first result, the emission compositions by source are significantly different for the older age cohort driven by different consumption patterns (Figure 2.3). For example, in terms of GHG footprint, households with the reference person aged 60+ show a value 17 % below average.

Figure 2.3 Structure of greenhouse gas footprint of final consumption of households by aggregated consumption purpose (COICOP 1 digit) and age of the main person in the household, EU, 2011



Sources: Based on Exiobase 3.4 and Eurostat data.

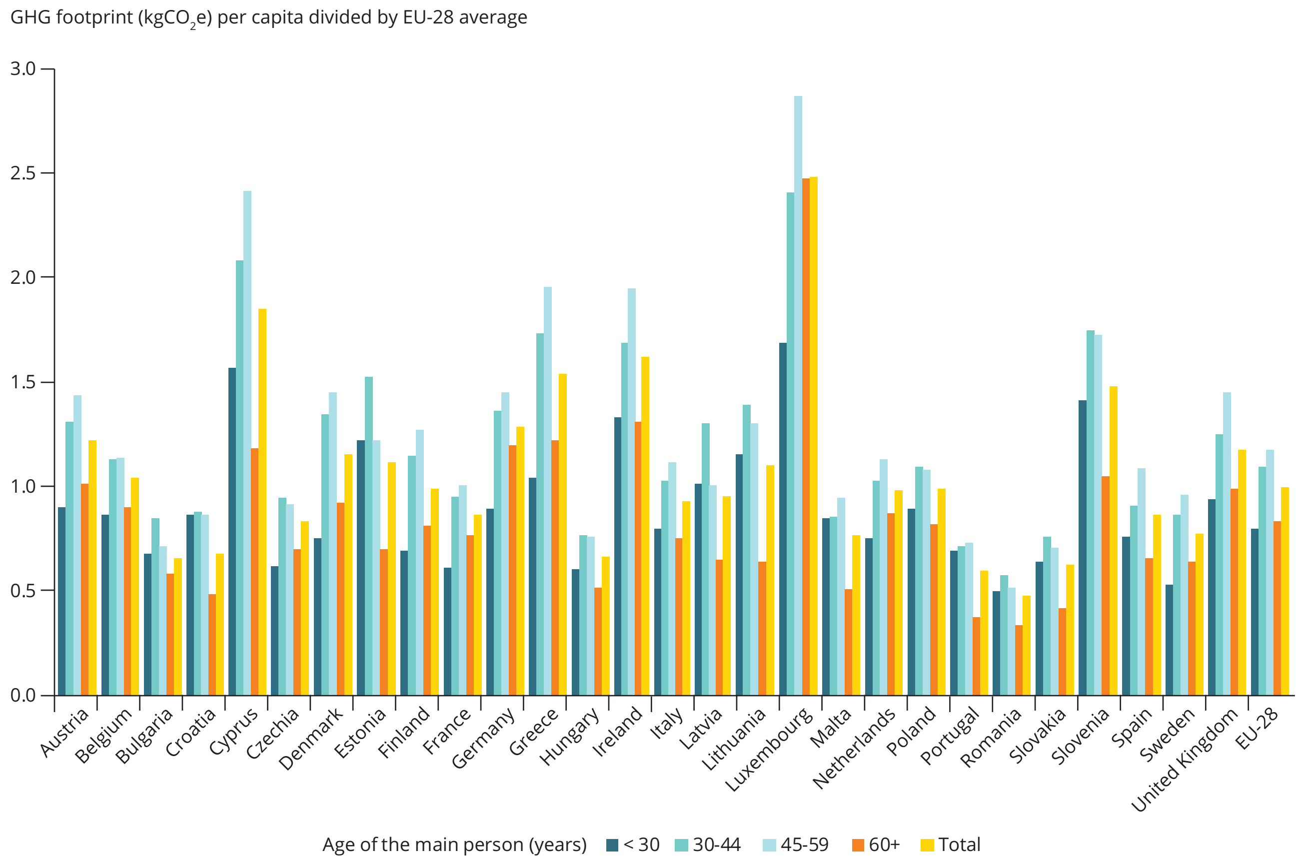
([8]) See Sala et al., 2019a, for the application of footprint methodologies to measure the environmental impacts of different consumption areas (food, housing, mobility, consumer goods, and appliances) over time.

([9]) The reference person of the household (or 'main person') is defined as the person that earns the highest income. If a household's reference person is older than average, that does not necessarily imply that all the household's members are (or the average household member is) older than average. For example, a one-member household aged 40 (average age: 40) will be on average older than a four-member household composed of father (50), mother (50) and two children aged 10 and 12 years old (average age: 30.5).

Within this, the greenhouse gas footprint of housing, in relative terms, is the largest for households with a 60+ main person: on average, housing accounts for 40 % of GHG footprint, but it accounts for as much as 48 % of the GHG footprint for households with a 60+ main person. The opposite happens for transport: households with a 60+ main person are characterised by a relatively small GHG footprint from transport, a 31 % share compared to the average across all households of 39 %.

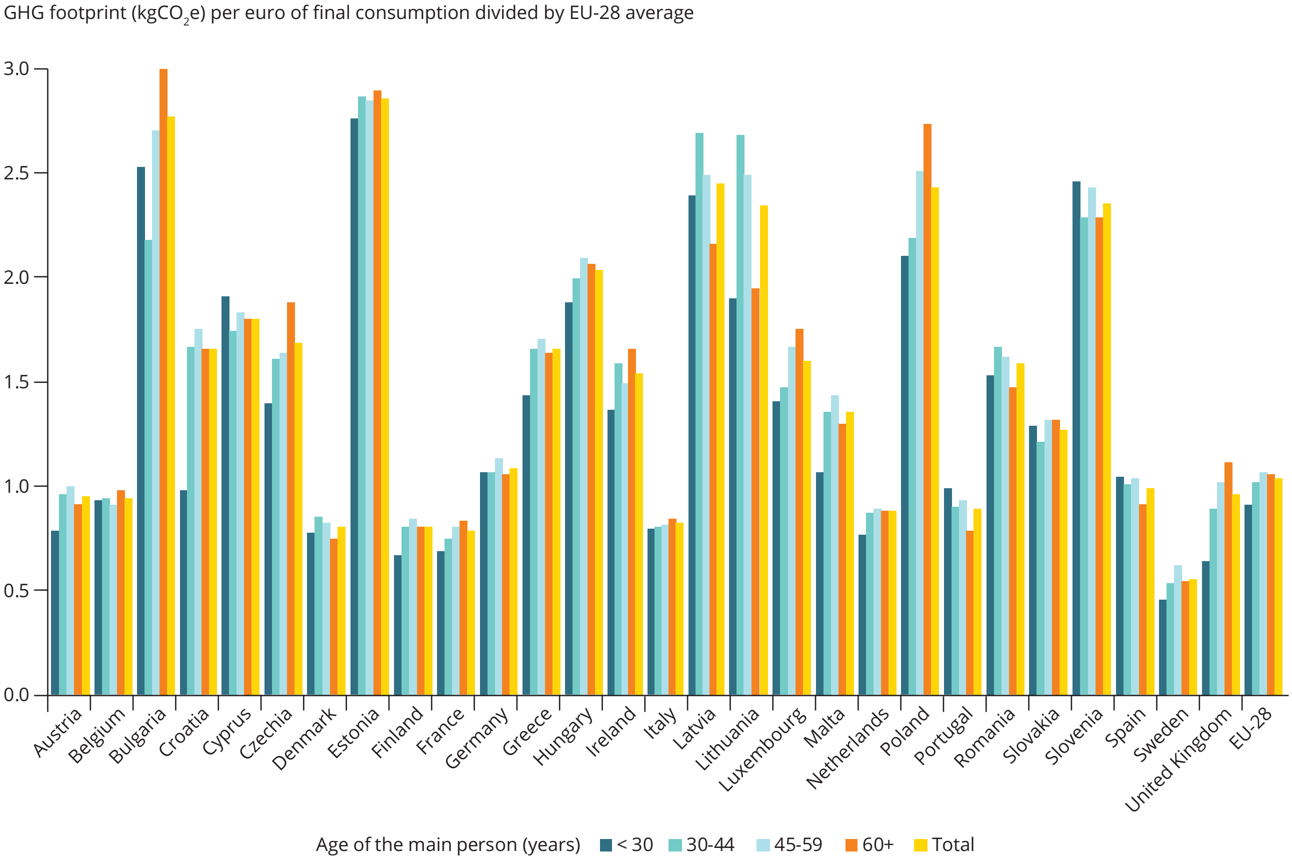
The corresponding patterns for GHG footprint per capita in EU countries are presented in Figure 2.4. The emissions per capita for the 60+ cohort are lower compared to the central cohorts. However, the emissions per Euro spent, that is the intensity of emission of consumption (Figure 2.5), is not significantly lower for the 60+ compared to the other cohorts. Indeed, in many EU countries the emission per euro spent is higher for the 60+ cohort compared to other cohorts. These results suggest that the different consumption structure of older households (e.g. higher share of housing and lower share of transport) does not always provide significant advantages in terms of intensity of emissions per euro spent. Rather, the effects of ageing on reducing emissions arise mainly from older households having a level of consumption lower than the average.

Figure 2.4 Average GHG footprint per capita by age of the main person in the household and country for year 2011. Average EU-28=1



Sources: Based on Exiobase 3.4 and Eurostat data.

Figure 2.5 **Average GHG footprint intensity of households' final consumption per EUR by age of the main person in the household and country for year 2011. Average EU-28=1**



Sources: Based on Exiobase 3.4 and Eurostat data.

2.3.2 Age-related greenhouse gas footprint with different population projections

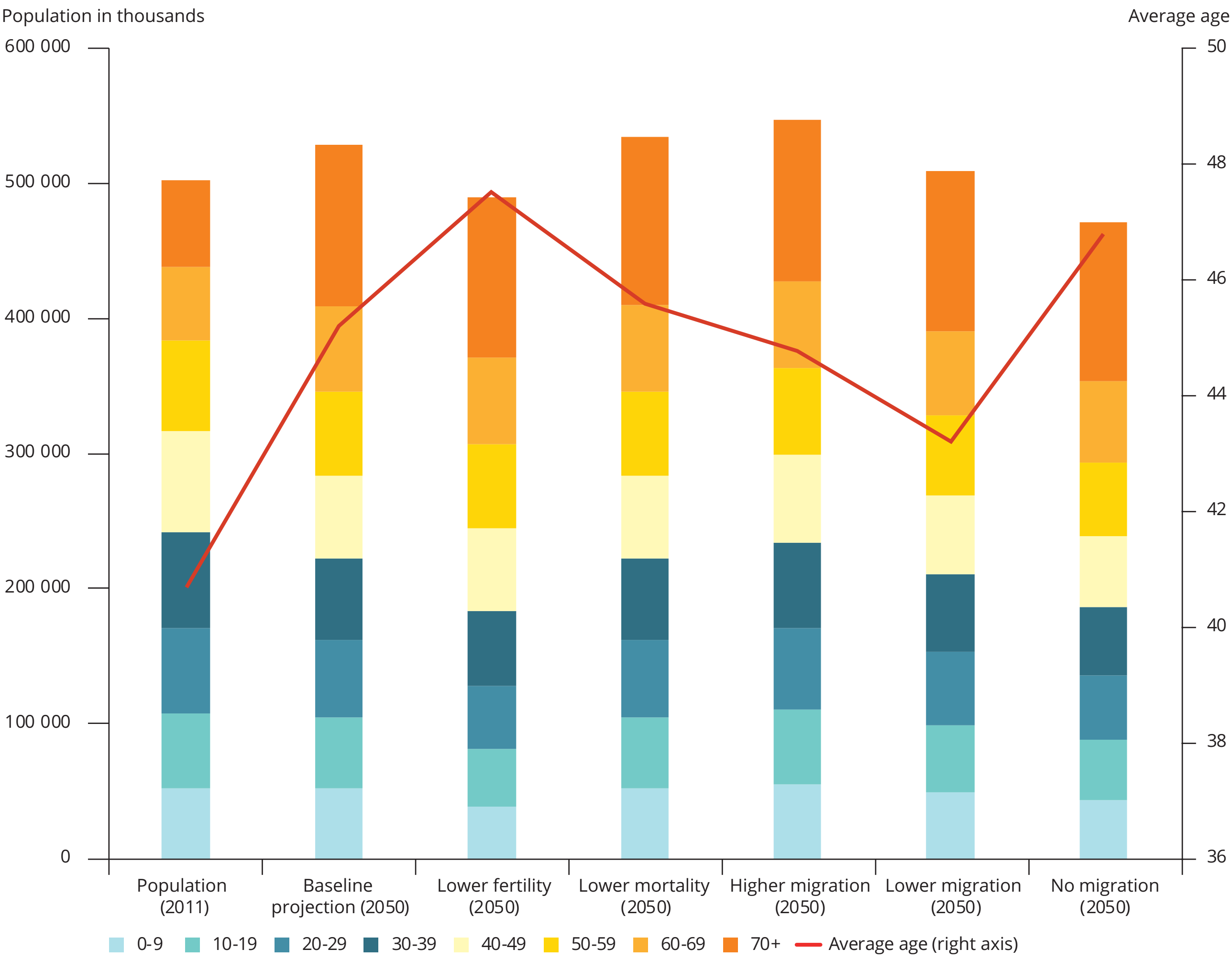
To evaluate scenarios for the possible future impacts of the demographic transition on greenhouse gas footprints it is necessary to allocate a footprint to the age of the person (rather than to the age of the main person in the household, as above). Then, a person-age analysis of the consumption expenditure and composition has been carried out by exploiting the European Union Statistics on Income and Living Conditions (EU-SILC) database and using the methodology described in Annex 1, Section A1.

Data show that, at the EU-28 level, the 50–59 cohort has the largest average greenhouse gas footprint per person, 11 % higher than the average, while those aged 70 or over have the lowest, 12 % below the average. With few exceptions, the results are similar across the EU countries, with the 50-59 age group having the highest footprint per person and older age groups having a lower footprint than the average.

These person-age-specific estimates have been used to estimate scenarios of greenhouse gas footprint according to different projections of population and age structure to 2050 produced by Eurostat ([10]). Figure 2.6 reports a summary of the different Eurostat projections in terms of level of population, its composition by age classes and average ages. Compared to the actual value of 2011 (first bar), all the projections indicate a substantial ageing of the EU population. Instead, when considering the level of population, only two projections, those for 'lower fertility' and 'no migration', show a reduction in the EU's population by 2050.

These official Eurostat projections have been used to compute 'what-if' scenarios for age-related greenhouse gas (GHG) footprints (Figure 2.7). Given the very long time horizon (2050), which makes it very

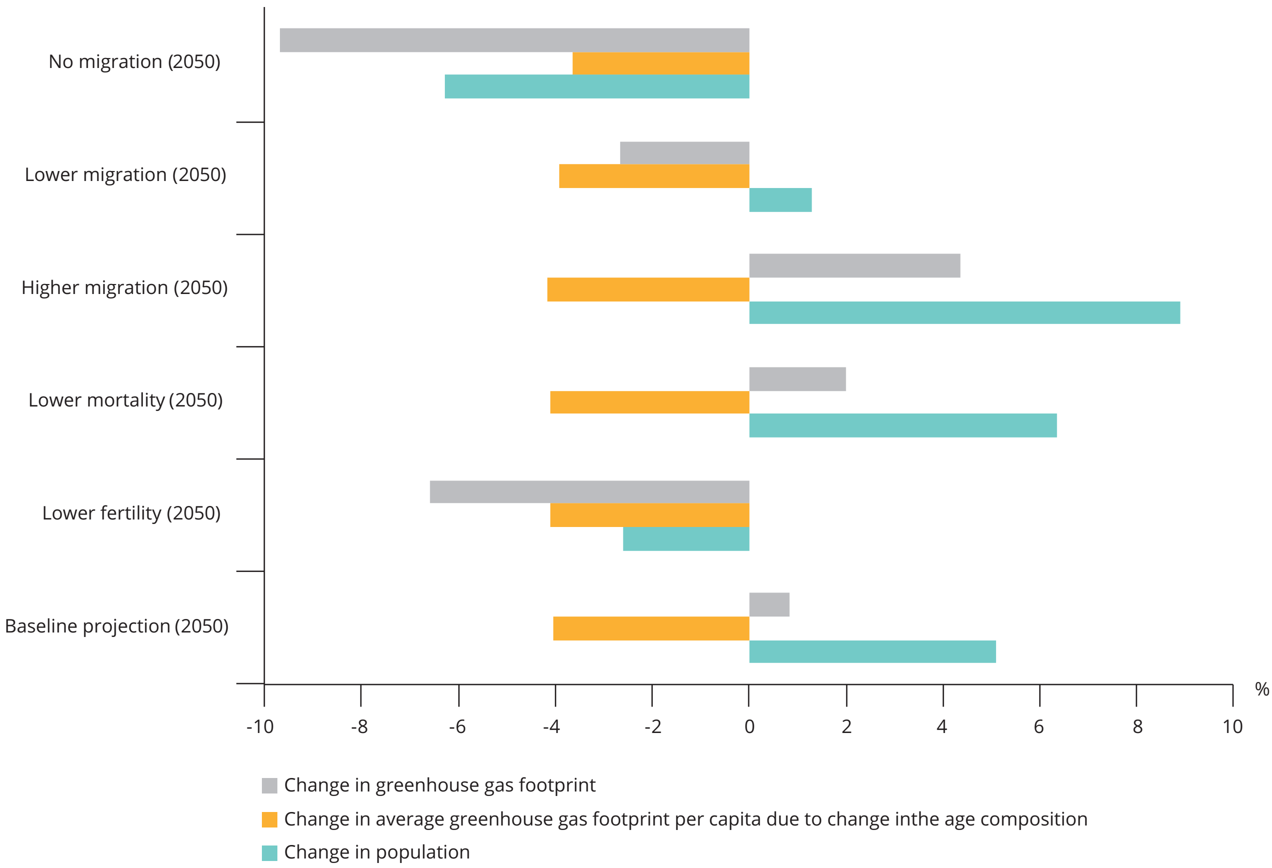
Figure 2.6 EU population projections by age group to 2050



Source: Based on Eurostat.

([10]) The Eurostat projections are: Baseline; Lower fertility; Lower mortality; Higher migration; Lower migration; No migration. For a detailed discussion on the link between population growth and migration, see: EEA, 2020.

Figure 2.7 **Projected change in greenhouse gas (GHG) footprint and average GHG footprint per person due to changes in population levels and in age structure, EU-28, 2011-2050**



Sources: Authors' own compilation based on data from Exiobase 3.4, Eurostat and EU-SILC.

difficult to predict technological change, economic growth, and social behaviours, these 'what if' scenarios are made under strong assumptions on the stability of some key variables, and attempt to answer the question: 'What would the effect of population ageing be on the GHG footprint (consumption footprint) of EU countries in 2050 under various demographic scenarios, assuming stable incomes, consumer preferences and technologies?' ([11]).

The results of the 'what if' scenarios are presented in Figure 2.7. The evolution of population composition by age, which is the main focus of this analysis (orange bars in Figure 2.7), contributes positively to reducing the average GHG footprint per person by about 4 % across all the scenarios – the greatest being 4.2 % in the 'higher-migration' scenario and the smallest being 3.7 % for the 'no migration' scenario.

These results are due to the systematically lower GHG footprint estimated for older people combined with a share of elders expected to increase in Europe in all the Eurostat projections (see also Figure 2.1). In terms of total emissions, however, this positive environmental contribution of population ageing is reinforced by population decrease in the 'lower fertility' and 'no migration' scenarios, whereas it is partly or more-than-fully offset by increases in the level of population in the other scenarios (positive blue bars in Figure 2.7).

([11]) In particular, the assumption behind the scenarios are: (i) the greenhouse gas footprint intensity of household consumption expenditure remains unchanged (i.e. no technological and organisational change); (ii) the level of household consumption expenditure by age of the reference person remains unchanged (i.e. no economic growth); and (iii) the consumer preferences are stable.

Summing up, while acknowledging the exploratory nature and limitations of these empirical exercises, the results show that:

- Households with the 'main person' older than 60 have a different consumption mix compared to other age cohorts, and, given the different emission factors of different categories of consumption, the mix of emission sources of older households differ from the other cohorts, in particular with a high relative importance of housing consumption as an emission source.
- The older households have levels of consumption and emission per capita which are lower than other cohorts, in particular the central cohorts (aged 30-44 and 45-59) both in the EU-28 as a whole and in the single EU countries. However, the emission intensity of consumption (emission per euro spent) is not significantly lower for the 60+ compared to the other cohorts, and it is even higher in some countries. Then, the different consumption structure of older households (e.g. higher share of housing) does not provide significant advantages in term of intensity of emissions per euro spent, and the effects of ageing on reducing emissions can arise mainly from the relatively lower level of consumption of older households.
- Looking instead at the estimates on consumption and emission per person in the EU-28 as a whole, the carbon footprint per person of those aged 60+ is the lowest across all age groups, and it is 12 % below the average; this applies also to the majority of single EU countries.
- When using these age-specific emissions data per person in building emissions scenarios based on Eurostat population projections to 2050, population ageing by itself could give a net positive contribution of about 4 % reduction in greenhouse gas emissions levels in all the scenarios.

Therefore, an ageing society could contribute positively to EU efforts to arrive at a carbon-neutral continent by 2050. However, this expected effect is not strong enough overall to justify a relaxed attitude to the transition efforts towards decarbonisation, in particular because the intensity of emissions per euro spent by older households is not substantially different from the one of other age cohorts.

At the same time, population ageing can have indirect effects on emissions and the environment through macroeconomic channels that will be addressed in following paragraphs and in Chapter 5 through a modelling approach ([12]).

2.4 Effects of ageing on growth and fiscal sustainability

Overall, population ageing will put pressures on fiscal sustainability (Nerlich and Schroth, 2018). In a European macroeconomic policy environment undergoing fiscal consolidation and needing to balance public budgets, fiscal sustainability emerges as a constraint on all public policies. The scenarios for fiscal sustainability become even more problematic with an ageing population, as potential competition for the public budget between social/health spending and other sectors, including the environment, becomes more likely in the future.

Ageing will also exert negative pressures on fiscal sustainability because of expected increasing scarcity of labour and its negative consequences for income taxation. Furthermore, the links between an ageing population in Europe and economic performance, on the one hand, and the fiscal and budgetary implications, on the other, are relevant given the unprecedented investments needed for the sustainability transition.

2.4.1 Demographic change and economic growth

As already discussed, population ageing is considered a factor behind the secular stagnation hypothesis, (Summers, 2014; Eggertsson and Mehrotra, 2014). This suggests a negative correlation between ageing and gross domestic product (GDP) per person and, under certain conditions, an imbalance between excessive savings and inadequate investment. Ageing per se is not the cause of low growth but, if there are macroeconomic conditions that make the equilibrium real interest negative and central banks have low inflation targets, nominal interest rates close to zero may occur. These macroeconomic policy conditions prevailed in Europe during the economic and financial crisis. The specific effects of ageing are reductions in demand bringing an excess in savings and subsequently a lower equilibrium income.

Key drivers of economic growth, such as productivity, labour supply and consumption are higher among working age adults than among those aged 60 or over. Other things being equal, a country with large cohorts

([12]) See also ETC/WMGE, 2020, and Costantini and Sforna, 2020.

of young and elderly people is likely to experience slower growth than one with a high proportion of working age people (Bloom et al., 2011).

Analysis of the economic effects of demographic changes have historically made a distinction between first and second demographic dividends (Lee and Mason, 2006). The first dividend 'is a direct and immediate consequence of the rise in the working-age share of the population' in which the economy has proportionally more people able to produce at the most productive stages of their lives. The second dividend can be seen as the result of higher economic growth rates when faster growth of the working age population leads to greater savings in the short run and higher investment in human capital and investment per worker in the long run (Cruz and Ahmed, 2016). It is not as clear whether the opposite effects would materialise as a population ages and declines, but studies over the past decade point to some interesting results (Box 2.3).

Overall, it is fair to argue that the ageing of the world's population introduces several major policy challenges (Bloom et al., 2011). A central one is the demographic transition's implications for future public and private savings, which will then influence investments and may therefore slow down future economic development, as savings are the main source of investments. If current policies prevail, then the increase in public pension expenditure caused by ageing will lead to a commensurate decline in public savings, and younger people will have to save significantly more and postpone retirement by a number of years to enjoy pension benefits similar to those of today's pensioners (Amaglobeli et al., 2019).

2.4.2 Fiscal and budgetary implications of an ageing population

Fiscal sustainability depends crucially on whether current fiscal policy can cope with expected

Box 2.3 Findings on the link between economic performance and the demographic transition

'We find that a 10 % increase in the fraction of the population aged 60+ decreases the growth rate of GDP per capita by 5.5 %. Two-thirds of the reduction is due to slower growth in the labor productivity of workers across the age distribution, while one-third arises from slower labor force growth. Our results imply annual GDP growth will slow by 1.2 percentage points this decade and 0.6 percentage points next decade due to population aging' (Maestas et al., 2016, p.2).

'Many empirical studies have found that GDP growth slows roughly one to one with declines in labor force and population growth — a disquieting prospect for both the United States and Europe. ... Whether population aging is good or bad for the economy defies simple answers. The extent of the problem will depend on the severity of population aging and how well public policy adjusts to new demographic realities' (Lee and Mason, 2017, p. 7).

'Per capita GDP growth is positively correlated with changes in the relative size of the working-age population, and negatively correlated with changes in the share of the elderly' (IMF, 2004, p. 143).

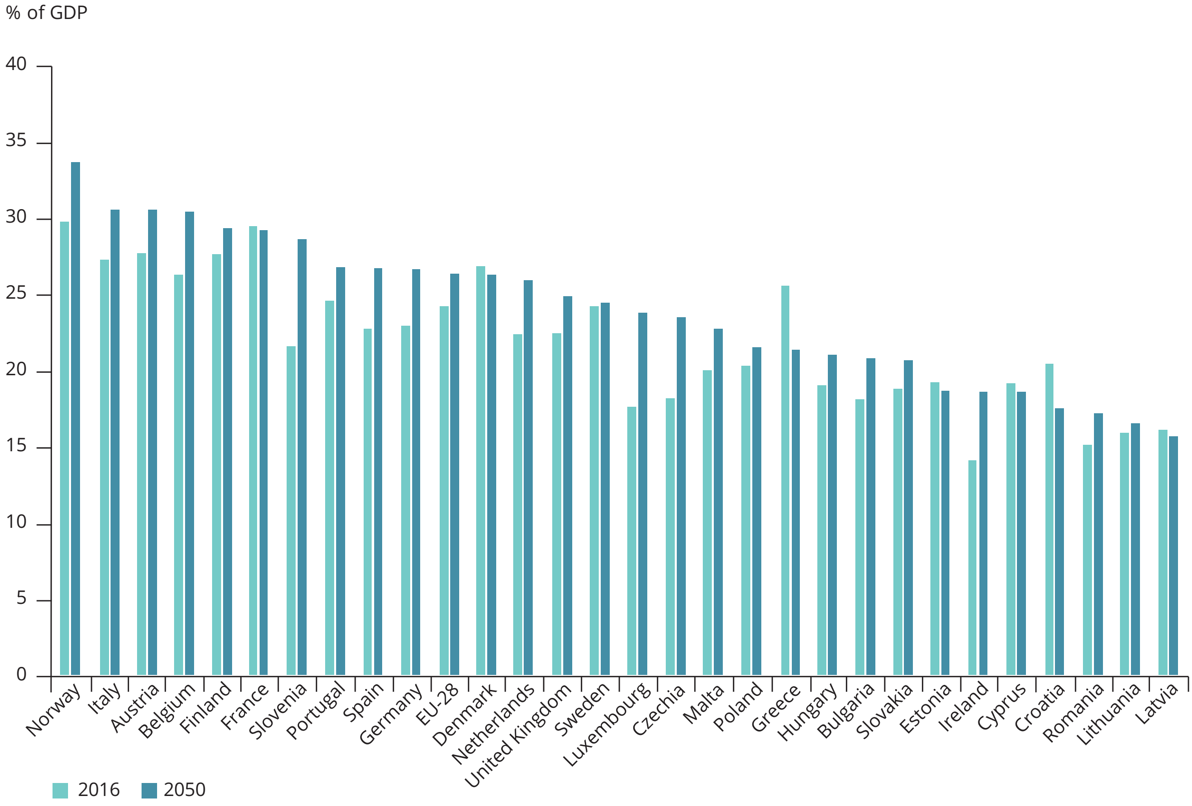
'Our research suggests that the combination of aging and shrinking will reduce potential growth in advanced economies by about 0.2 percentage points in the medium term' (Lagarde, 2016).

'Demographic change is one of the most important determinants of the future economic and social landscape. ... The channels through which demographic changes affect an economy typically include savings and investment behaviours, labour market decisions, and aggregate demand and supply responses. In the medium to long run, both changes in the labour supply and changes in productivity — either viewed as exogenous or caused by demographic changes — could significantly alter an economy's aggregate supply and thereby economic growth, since demographic changes affect the amount and combination by which its factor inputs are utilized. In the short run, demographic transitions are likely to affect aggregate demand, since the amount of consumption and investment would depend critically on structural changes in the population's age-earnings profiles. ... Despite the expected grave consequences on the economy, in many macroeconomic policy discussions or debates, demographic changes usually do not take centre stage' (Yoon et al., 2014, p. 4).

'Our research shows how developments in private saving drive changes in national saving. In emerging markets and low-income developing countries collectively, relatively young populations lead to increased private saving. In contrast, we expect private saving rates in aging advanced economies to contract sharply' (IMF, 2019).

'One view is that population aging in the developed countries is likely to have a large effect, reducing income per capita primarily through the fall in labour supply per capita that will accompany the reduction in the share of working-age population. However, even if this occurs, it may not be as harmful as it at first appears' (Bloom et al., 2011, p. 27).

Figure 2.8 **Trend in strictly age-related expenditure (pensions, health care, long-term care and education), EU-28 and Norway, 2016-2050, percentage of GDP (baseline scenario)**



Source: EC, 2018c.

long-term demographic challenges, particularly the rising cost of supporting an ageing population. The European Commission's 2018 Ageing Report (EC, 2017a and 2018c) includes estimates of the budgetary implications of demographic changes on government expenditure ([13]). Public age-related expenditure in the EU, includes pensions, health care, long-term care and education expenditure and is projected to increase as a share of GDP from 24 % in 2016 to 26 % in 2050 in the baseline scenario, with differences across Member States (Figures 2.8 and 2.9). Beyond 2050, age-related expenditure will not necessarily increase after 2050 as overall population starts to decline (EC, 2017a and 2018c).

Although an increase of about 2 percentage point of public age-related expenditure as a share of GDP projected for the year 2050 may be deemed to be achievable considering the uncertainties linked to modelling projections and the long-time frame of about 30 years. However, a recent report published by the EC's Directorate-General for Economic and Financial Affairs concludes that 'public finances in the EU face long-term fiscal sustainability challenges based on current policies and that there are intergenerational issues, entailing a larger adjustment for future generations' (Arévalo et al., 2019). Current policies in EU Member States with regard to the overall pension systems including the statutory retirement ages differ as for example, the statutory retirement age in 2050 varies between 65 year and 71.5 years (in EC, 2017a see Annex 2: Tables II.A.2.1 and II.A.2.2).

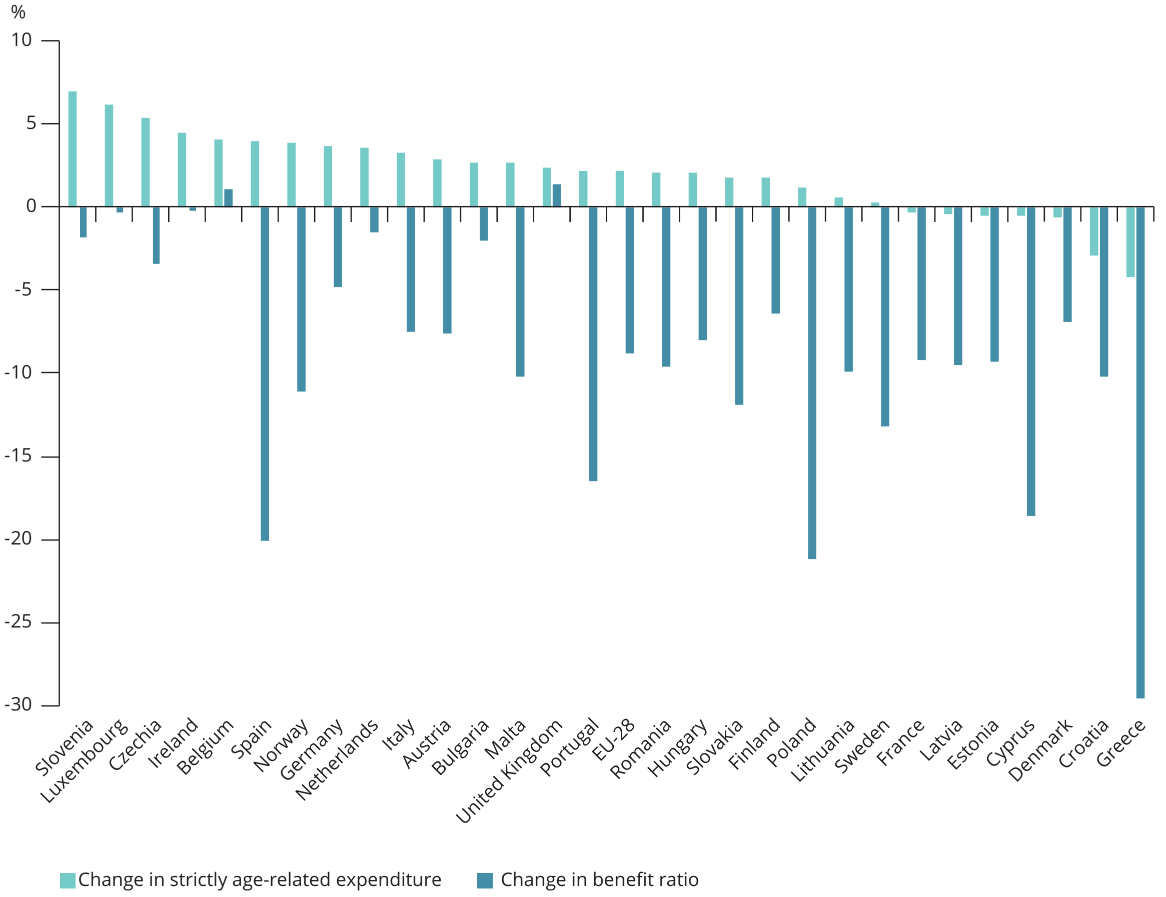
Revealing the dimension of the projected increase of public age-related expenditures, the projected amount can be related to the annual investment in energy related infrastructure in the

([13]) The regularly published ageing reports contain a comprehensive set of simulations projecting the trend in public spending on pension schemes and health, given the current regulations and reforms already implemented in EU Member States. These simulations are based on a set of assumptions related to demographic factors (fertility, mortality), economic growth including changes in total factor productivity (TFP), and labour market participation rates of individual age groups. Furthermore, the projections are based on the full implementation of pension reforms that will result from higher effective retirement ages, which are expected to rise to more than 70 for men and women in the second half of the 21st century in countries including Denmark, Greece and the Netherlands.

period 2031-2050 amounting to EUR 377 billion corresponding to 1.9 % of GDP (EC, 2018d), which is in the same range as today's investment in the energy system and related infrastructure (EC, 2018a). The future investment figure is only the baseline and the average additional annual investment for achieving a net zero GHG economy is projected to be about EUR 170 billion, approximately 0.9 % of GDP (EC, 2018d). This means that the increase in old age-related expenditure is projected to be about two times the additional annual investment needed for achieving a net zero economy. Furthermore, the increase in age-related public expenditure is to be covered by the public budget and future energy related infrastructure investment will be paid by the public and the private sector, which will be responsible for the majority of these investments (see also Section 4.4.2).

Within this overall picture, pension-related expenditure is projected to decrease as a result of pension reforms in nine EU Member States. However, these changes are often outweighed by the projected changes in health care and long-term care spending and point to how health issues could in future be a stronger focus for environmental policies and vice versa, as good environmental conditions can reduce the demand for public health services for vulnerable population groups such as the elderly.

Figure 2.9 **Changes in strictly age-related expenditure and the benefit ratio in EU Member States and Norway 2016-2050 (baseline scenario)**



Note: Age-related spending includes public pensions, health care, long-term care and education expenditure, as a percentage relative to GDP. The benefit ratio is the average pension relative to average wages ([14]).

Source: EC, 2018c.

([14]) The trend in the benefit ratio differs widely in EU Member States and Norway between 2007 and 2016 (EC, 2009, 2018b). The ratio increased in 10 Member States (no data available for Croatia in 2007) by up to 11.5 percentage points (Portugal) and by 8.9 percentage points (Cyprus) but dropped in the majority of Member States and Norway with the largest decline in Bulgaria (12.8 percentage points), France (12.5 percentage points) and Sweden (10.4 percentage points).

The average pension in relation to average wages in the EU is likely to decline from 44 % to 35 % between 2016 and 2050. This will very likely result in old-age poverty for many millions of Europeans in the coming decades. This trend 'could give rise to upward risks to the pension expenditure projections' (EC, 2018c), revealing potential future challenges in financing public welfare provisions (see Chapter 4). Projections of age-related expenditure in EU Member States and Norway for the period 2016-2050 (Figure 2.9) point to large variations: for example, a reduction in strictly age-related expenditure is projected in seven Member States — Croatia, Cyprus, Denmark, Estonia, Greece, France and Latvia — and an increase in the other 21 Member States and Norway. Furthermore, only in Belgium and the United Kingdom is an increase in pensions in relation to average wages predicted, while reductions of more than 20 percentage points are predicted for Greece, Poland and Spain.

It is crucial to take into account the overall pension system in the individual EU Member States as the decreases in the public pension benefit ratio may be compensated by private pension schemes. Private pension schemes are in place in the EU but the actual design differs between Member States, as well as whether they are occupational pension schemes or mandatory private or voluntary ones (EC, 2017a and 2018e). Closely linked to the discussion on pension reforms is the topic of poverty in old age, along with the increase in income inequality as the poorer part of the work force is rather constrained in contributing to private pension schemes. The risk of poverty and social exclusion in old age is happening in Europe, but varies widely between EU Member States and may increase during the coming decades ([15]).

2.4.3 Demographic transition and fiscal revenues

As previously discussed, the demographic transition can be expected to have profound impacts on tax revenues. The reduction in the working age population from 65 % to 57 % of the total EU population in the period 2018-2050 will reduce revenues generated from labour taxation, including social security contributions, as well as from value added tax (VAT).

Calahorrano et al. (2016) modelled microeconomic data for Germany to quantify changes in personal income tax and VAT revenues for the years 2030, 2045 and 2060 ([16]). The authors found that by 2060, when the German population is expected to be both smaller and older, personal income tax revenues could be 12-21 % lower and sales tax revenue 13-25 % lower. Beznoska and Hentze (2016) also modelled the effects of demographic change in Germany integrating all current policy measures relevant to labour taxation. That study estimates that personal income tax revenue will be about 7 % lower in 20 years' time (2036) because the reduction in the working age population will erode the tax base.

Sweden's National Institute for Economic Research has assessed government income and expenditure trends based on long-term scenarios. The Swedish population projection differs from the majority of other Member States with the overall population projected to increase to 2050 and with a relatively lower share of older people than the rest of the EU. Under these rather favourable conditions, and assuming an unchanged tax system, the study estimates that the government deficit will increase to -3 % of GDP in 2040 (NIER, 2016). This combination of favourable conditions and negative implications further underscores the need to design ageing-proof fiscal systems (see Chapter 4).

A study in Finland of potential societal developments during the next twenty to forty years, inter-alia, has concluded that when it comes to ageing, it will be difficult to replace a huge reduction in income tax returns with other forms of taxation. The authors argue for a new tax model to replace the diminishing tax base related to work (Hautamäki et al., 2017). Meanwhile a Danish study assessing the consequences for public finances of changes in age and household structures in Denmark over the period 2008-2037 has concluded the negative public budget effects of these changes could amount to 3.7 % of GDP per year (Jacobsen and Jensen, 2014).

Outside Europe, a US study has estimated that, if the US population in 2011 had already had the age composition that is projected for 2030, then 'tax revenue would have been lower by USD 8.1 billion, or 1.1 per cent' (Felix and Watkins, 2013). The authors also show that ageing alone, keeping all other factors such as income growth and tax structures constant, is expected to reduce income tax revenue by 2.4 % per person and sales tax revenues by 0.5 % per person by 2030 compared with a baseline of no demographic change (Felix and Watkins, 2013).

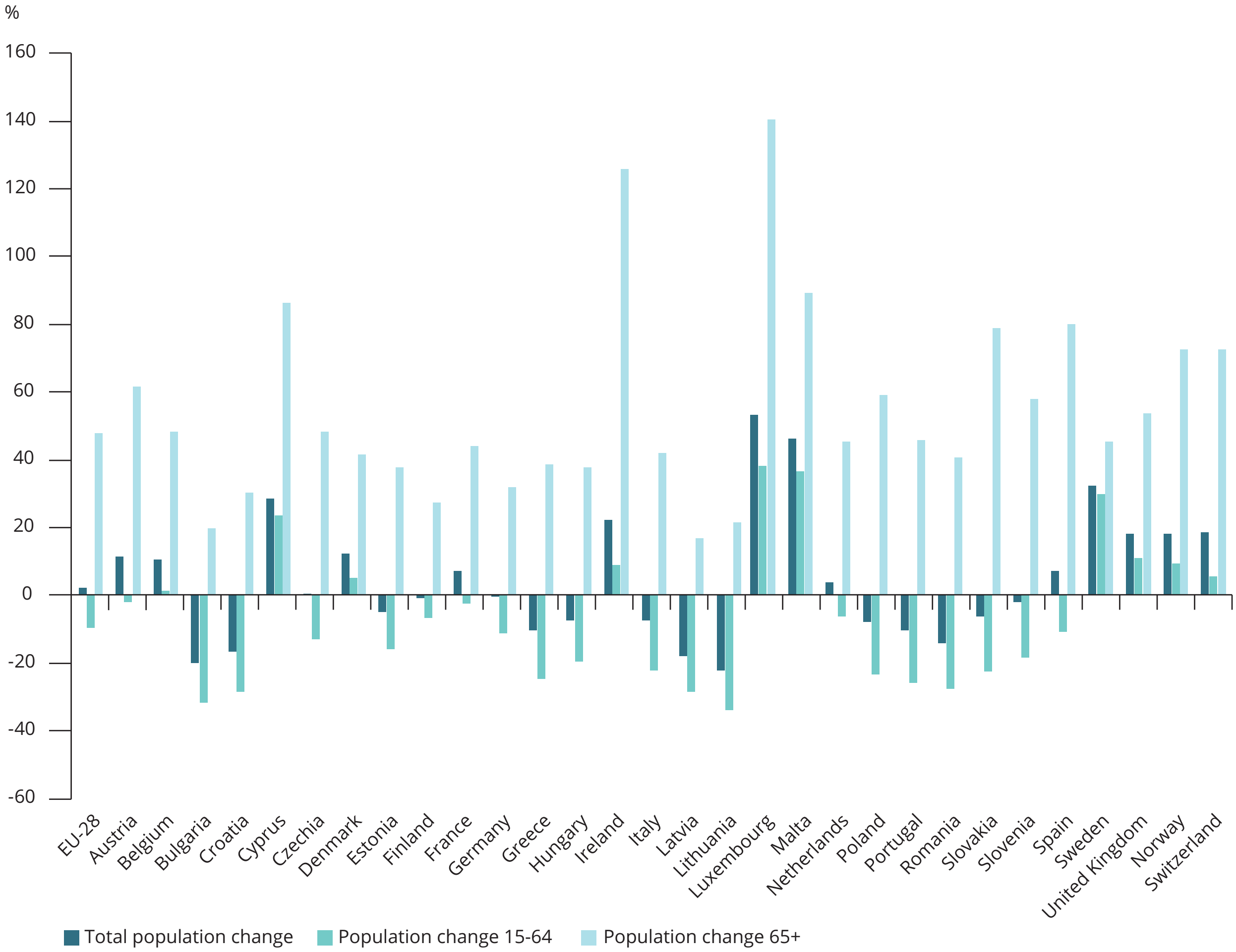
Ageing can also shift demand across products and sectors that are subject to different fiscal regimes. One such effect, which has implications for labour markets and then for fiscal sustainability, is that ageing

([15]) See EC, 2018e and OECD, 2019a for a detailed analysis of pension reforms and poverty at old age in Europe.
([16]) The simulation projects the effects on tax receipts between a baseline scenario without any demographic change and three variants of the official population projections of the German Federal Statistical Office.

is expected to trigger demand of home automation systems, health care and personal services, areas in which information and communication technologies (ICT), artificial intelligence and robotics are extensively applied (see Chapter 3). Such effects in turn highlight the need to assess the fiscal dimension of age-related changes in the final demand structure for how they may affect VAT revenues.

Together these results underline that income and spending patterns over citizens' lifetimes change and can have substantial impacts on fiscal revenue. Typically, earnings increase during workers' careers and then fall when they become older, as they reduce their working hours or retire. Consumer spending patterns tend to follow a similar trajectory, increasing as people move from early life to middle age and then declining when they retire. As income and sales/value added taxes represent a large share of total government revenue ([17]), however, the future implications for public budgets are clear. These pressures in turn raise various issues on alternative sources of revenue, including environmental taxation and trade-offs in the destination of public funding, including green investments. Fiscal policies could be adapted through, for example, a tax on robots, but developments are at an early stage and the trajectories unclear. These issues are discussed in more detail in Chapter 6.

Figure 2.10 Total percentage change in population (total age; those aged 15-64 and 65 and over) in the EU-28 and individual EU Member States, Norway and Switzerland, 2016-2050



Source: Eurostat.

([17]) At the EU level, taxes on labour, including social security contribution, contributed about 50 % and value added-type taxes about 18 % of total tax revenues in 2017, illustrating the crucial role of these taxes in the public budget.

3. Technology and innovation — drivers of the transition to sustainability?

Key findings

- The technological transition has the potential to fundamentally change the very nature of the co-existence and hierarchies between human intelligence and artificial intelligence.
- Techno-optimists envisage infinite economic growth based on extreme automation of the economy and society, but this outcome is uncertain, given that the technological transition is neither guided by nor primarily concerned with:
  - Sustainability: key IT-based sectors are resource and energy intensive and may result in significant rebound effects as prices fall and consumption rises.
  - Labour: the technological transition could cause unemployment, bias against specific groups such as older people, and changed social spending as fiscal flows are impacted by a shrinking labour force.
  - Environment: certain, supposedly green, technologies and innovations can actually result in net negative environmental outcomes. For example, recent estimates suggest that technologies such as blockchain, self-driving cars, and sharing platforms may require large additional amounts of energy and resources. This requires consideration in the design of policy.
  - Fiscal issues: significant uncertainties exist for taxation of, for example, immaterial businesses and the treatment of capital in IT-intensive businesses. Ownership, labour, and cost-profit profiles are also not yet fully understood and add further uncertainties to the fiscal sustainability transition.
- The uptake of green technology, key for delivering real-world effects, has fallen among European firms. These trends probably reflect the economic downturn and the prevailing low-investment regime in the EU and are a source of concern.
- Eco-innovation seems to have positive effects on employment and jobs, and the correlation between green patenting and employment is stronger in regions with lower levels of gross domestic product. However, green technology and eco-innovation do not currently play a sufficiently large role in the technological transition to significantly influence it.

3.1 Introduction

Innovation can help to address pressing policy and social challenges — including an ageing population, climate change, and numerous health and environmental issues (EIB, 2018, p. 95).

The current technological transition is driven by the acceleration in computational power, which has brought rapid growth in the use of information and communication technologies (ICTs) in production and consumption processes, the rise of the Internet of Things, cloud computing and big data, the development of artificial intelligence (AI), blockchain technologies, industrial automation and humanoid robotics. The deployment of these technologies, often defined as 'disruptive' and referred to as the basis of a fourth industrial revolution, or Industry 4.0, has gained considerable momentum.

This transition raises questions that are directly and indirectly relevant to the green economy and sustainability transition. For example, the expectation of positive economic impacts is high, but question are raised about their scale, speed and the distribution of economic, social and environmental benefits. Two central points of concern are the possibility of technological unemployment on a large scale, relevant for an ageing society (see Chapter 2), and the largely unknown fiscal implications of technologies behind the collaborative economy, relevant for fiscal sustainability (see Chapter 4).

Expectations of the environmental impacts of the technological transition are generally positive, for example through induced dematerialisation and decarbonisation outcomes, but the overall consequences for resources and energy remain unclear and the expected net benefits are increasingly questioned in some studies. The German Advisory Council on Global Change (WBGU) underlines these challenges of the digitalisation process in terms of further increasing energy and material consumption and an increase on ecosystems summarising that '[T]echnical innovation surges do not automatically translate into sustainability transformations, but must be closely coupled with sustainability guidelines and policies' (WBGU, 2019).

With this context in mind, several questions arise:

- What is the role of green technology and eco-innovation in the technological transition?
- Can they support the sustainability transition, despite unsustainable components of the wider technological transition?
- Can they guide the general technological transition and, if so, will their development and deployment have enough impact?

This chapter explores these questions by examining the changes induced by the wider technological transition on the economic growth regime and labour market, their effects on social and fiscal sustainability in an ageing society and the possible environmental implications of the wider transition. Chapter 5 explores the wider role of technological change in the sustainability transition using quantitative and qualitative system models.

3.2 Technology — the disruptive and creative engine: a new regime of growth and labour in an ageing society?

> Technological progress is a main driver of aggregate economic growth and improvements in living standards over the long term. It increases overall productivity, thereby boosting per capita income and consumption. While technological progress has mostly been incremental and gradual over time, on a few occasions, technological change has been revolutionary, transforming the organizational structure of societies and economies (UN, 2017, p. 1).

Current technological developments feature prominently in the public debate as a means of achieving environmental sustainability. Technological progress represents an important opportunity for reducing the impact of human activity on the environment, but it also creates challenges, especially at the social level. The unit cost of computation is collapsing, paving the way to hyper-digital economies and societies and possibly 'the singularity' (Nordhaus, 2015) ([18]).

ICT in combination with advances in materials science, biotechnology and nanotechnology is what defines a new technological transition. The policy counterpart of this is the increasing role of research and innovation strategies within economic and public policies in general and the strong convergence between innovation policy and industrial policy, as seen, for example, in Industry 4.0 (EP, 2015a; EC, 2017).

The transition to a regime dominated by disruptive technologies raises issues about the potential anthropological changes they imply and the possibility of maintaining a positive co-evolution between these technologies and human needs.

([18]) According to Nordhaus (2015), '[T]he idea here is that rapid growth in computation and artificial intelligence will cross some boundary or Singularity after which economic growth will accelerate sharply as an ever-accelerating pace of improvements cascade through the economy' and '[A]t the point where computers have achieved superintelligence, we have reached the 'Singularity' where humans become economically superfluous in the sense that they make no difference to economic performance'.

One question is whether the current technological transition will have results comparable to the three industrial revolutions of the past ([19]), with particular concern about the widespread implementation of technologies 'in areas where human abilities were once deemed indispensable, threatening to do for cognitive ability what machines did for muscle power' (UN, 2017). The outcome might be massive changes in labour markets that threaten jobs, as AI and robotics are rapidly learning to do what human workers do — and often faster, better and cheaper. However, it remains to be seen whether the final outcome will actually be massive unemployment, which was not the case with previous major technological revolutions.

These rapid technological developments also induce major structural changes in economies where, for instance, the digital transformation promotes new working arrangements and structures, mainly discussed in the context of digital matchmakers, such as Amazon, Airbnb and Uber, and often accompanied by an increase in non-standard, relatively insecure, gig jobs.

So far, all industrial revolutions have led to increases in productivity. This is also expected of the current technological transition. Nevertheless, the growth in productivity in advanced economies has been declining for several decades despite the ongoing technological transition.

There are differing views on why expected increases in productivity are yet to materialise. One suggests that technological revolutions never lead to immediate increases in productivity (Eichengreen, 2015). Brynjolfsson and McAfee (2011, 2014) are more optimistic; they argue that there is no slow-down of technological progress but that the full potential of this has yet to be exploited and organisational structures have still to adapt ([20]).

Others argue that new production processes and products do not have the same economy-wide productivity effects as key technologies from earlier periods (UN, 2017). One US analysis identifies 'six headwinds' that will impair the US economy in the future including demography, education, inequality, globalisation, energy/environment, and excessive consumer and government debt (Gordon, 2012). All these headwinds are also highly relevant for Europe. Similar views argue that the technological revolution cannot translate into equivalent economic growth because other socio-economic factors dissipate their effect (Klingholz and Slupina, 2017).

There seems, however, to be a consensus in the literature that it will take quite some time for extreme productivity dividends from digitisation to materialise. A recent analysis argues that it may take to 2045 for the full, worldwide diffusion of smart automation and AI technologies (McKinsey, 2019a). The idea that extreme productivity dividends may take a long time to be completely realised was already part of earlier productivity paradox debates surrounding the digital era ([21]) (Quadrio Curzio et al., 1994; Goldin et al., 2019).

The secular stagnation debate provides additional arguments for a possibly slow technological transition ([22]), as it points to a long-lasting stagnation in demand due to not only the expected ageing of the population but also increasing risk aversion and rising income inequality. These arguments are all particularly relevant for an ageing Europe.

In contrast, recent contributions, for example from Acemoglu and Restrepo (2017), highlight that the countries with older populations are showing stronger growth because, with an ageing population, they are the largest adopters of advanced technologies and the combined effect of ageing and substitution technology for older people can help prevent secular stagnation.

3.2.1 Technological progress and the labour market

The present technological trends are already generating deep changes in production processes and labour markets. According to the International

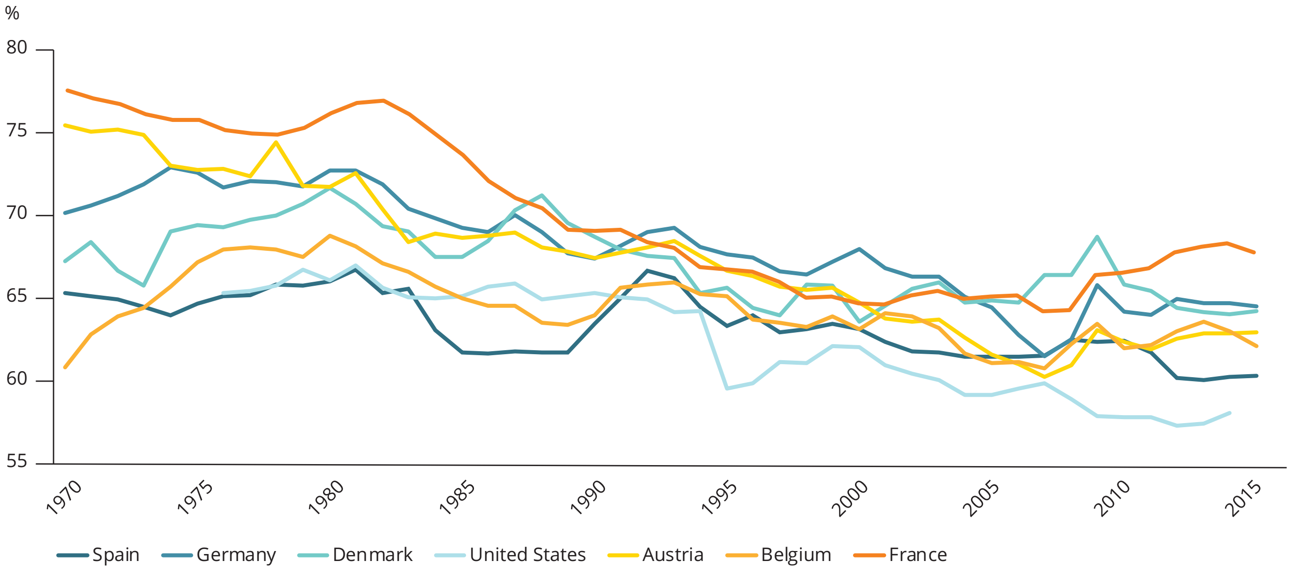
([19]) The first industrial revolution, c. 1760-1840, involved the transition from hand production methods to machines through the use of steam and water power. The second, c. 1870-1914, was a period of great economic growth, with increased productivity made possible by the development of extensive railway networks and the telegraph as well as factory electrification and the introduction of the modern production line. The third, in the second half of the 20th century, is also called the digital revolution and saw the development of communication technologies and extensive use of ICT in production processes.

([20]) There are ongoing discussions about the challenges associated with measuring productivity within national accounting frameworks. One of these concerns the measurement of gross domestic product (GDP), as some impacts of the technological transition, such as free communication services, are not reflected in GDP.

([21]) The productivity paradox, also called the Solow computer paradox, suggests that labour productivity may decline rather than increase following investment in IT. This phenomenon was first observed in the United States in the 1970s and 1980s (Rotman, 2018).

([22]) For political and economic scholars' discussion of different aspects of secular stagnation, see Teulings and Baldwin (2014).

Figure 3.1 **Trend in the labour share of national income (%) 1970-2014**



Source: Based on KLEMS data and calculated as labour compensation/(labour compensation + capital compensation).

Monetary Fund, in recent decades technology has been the single most important factor explaining the falling trend in labour's share of income in advanced and even less advanced countries (IMF, 2017a) ([23]). Labour's share of national income ([24]) has been on a downwards trend in many EU Member States and in the United States since the 1970s and 1980s (Figure 3.1), although the trend discontinued in some countries after the economic and financial crisis of 2008/2009. Capital's share of income increased because of the reduction in labour's share and, since ownership of such capital is typically concentrated among those with the highest levels of income, this trend tends to increase income inequality (Dao et al., 2017).

Automation may lead to a further shift of income to capital owners at the cost of labour income and possibly employment. Improvements in technology lead to lower prices of investment goods and thus possibly to an increase in the substitution of capital for labour ([25]). There are many studies assessing these relationships with rather different findings ([26]). For example, the European Commission acknowledges the divergence of views in the academic literature on the potential impact of technology on jobs, while signalling that, if existing new technologies were adopted in production processes, they could automate between 37 % and 69 % of today's tasks (depending on the Member State), leading to a significant change in the set of employees' tasks in many sectors (EC, 2018f).

The European Bank for Reconstruction and Development has reported that the average employment rate in 11 countries ([27]) declined by 1.5 percentage points between 2010 and 2016, while the average number of robots increased by 0.3 per 1 000 workers over the same period (EBRD, 2018). The analysis points to a substantial displacement effect: every additional robot per 1 000 workers reduces the employment rate by 0.7 percentage points. A similar finding has been reported in a study of the impact of industrial robots on employment in Finland, France, Germany, Italy, Spain and Sweden, in which the authors conclude that one additional robot per thousand

([23]) The International Monetary Fund discussed this trend in detail and summarised it as follows: '[I]n advanced economies, about half of the decline in labor shares [in income distribution] can be traced to the impact of technology. The decline was driven by a combination of rapid progress in information and telecommunication technology, and a high share of occupations that could be easily be automated' (IMF, 2017b).
([24]) The labour share of income is the share of national income paid in wages to workers.
([25]) A detailed analysis of the decline in the labour share in the United States can be found in a recently published report by McKinsey (2019b). The report also lists reasons for this trend, including automation and capital deepening as well as the emergence of superstars, and assesses the development at economic sector levels.
([26]) For the findings of empirical studies, see Frey and Osborne (2013), Arntz et al. (2016, 2017, 2019), PwC (2018a), Nedelkoska and Quintini (2018) and OECD (2019b).
([27]) The countries covered by this analysis were Bulgaria, Croatia, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

workers reduces the employment rate by up to 0.2 percentage points (Chiacchio et al., 2018).

Opposite outcomes are arrived at elsewhere in the literature. Some scholars at the International Monetary Fund have found increased robot density in manufacturing to be associated with greater productivity, alongside local gains in employment and wages (Schneider et al., 2018). The Organisation for Economic Co-operation and Development (OECD) argues that empirical analysis so far points to ICT and robotisation having led to economic restructuring but not to greater unemployment, rather a shift in overall demand for labour from manufacturing to services. OECD analysis indicates that '*technology and shifts in consumer preferences* have been the main drivers of losses in manufacturing jobs in advanced economies' (OECD, 2018a; italics in original).

That no clear-cut evidence emerges from an increasing number of studies points to well-known compensation mechanisms for, or indirect effects of, innovation on labour demand. Several studies suggest that product innovation generally stimulates growth in employment ([28]). However, the findings are less conclusive for process innovation, which may displace workers in the user industry but can increase employment in the new technology producing industry. Furthermore, the decrease in price associated with a reduction in the unit cost of a product due to new technologies can trigger new demand, eventually leading to an increase in production and employment — a rebound effect ([29]).

Labour substitution effects could be stronger for older people — who may experience selective technological unemployment — thus accelerating and exacerbating the pressure to exit the workforce and enter retirement. If this selective substitution prevails, the pressures of population ageing on public budgets and the pension system can be exacerbated while fewer people in the workforce could further reduce the tax base.

Automation can, however, also support an economy with a large share of the population outside the workforce. Such solutions are already emerging in health care systems, including home assistance, in particular for providing long-term care for older people. If these technologies save/complement labour in labour-intensive services, they could reduce the demands on the public budget in an ageing society.

That technological progress leads to changes in the labour market is nothing new. A key difference today is that machines are substituting both manual and cognitive tasks, so it follows that skill sets will have to adapt more radically as most occupations and jobs will undergo a fundamental transition (EC, 2018f; WEF, 2016, 2018). The World Economic Forum argued in 2016 that by 2020, across all types of occupations, on average more than one third of the core skills needed to perform most jobs would consist of skills not yet considered crucial to the job at the time (WEF, 2016). European firms already face this challenge as the availability of staff with the right skills is the most frequently quoted obstacle to investment in EU Member States (EIB, 2017, 2018), and this is listed as the largest obstacle in 18 EU Member States ([30]) (EIB, 2018).

In this technological transition, as happened in each of the previous disruptive industrial revolutions, skilled workers are favoured over unskilled ones ([31]). In Europe, the composition of the labour market changed between 2005 and 2018, as the employment of highly skilled workers increased in all EU Member States and the number of medium-and low-skilled jobs declined in the majority of countries (Figure 3.2), leading to the 'hollowing out' of medium-and low-skilled workers.

Although the trend presented in Figure 3.2 shows a decline in low- and medium-skilled workers, the actual situation shows labour market imbalances between the demand and supply of skills at all levels. The changes in the demand for skills can be attributed to technological progress, globalisation and demographic changes ([32]). It is worthwhile highlighting that shortage occupations are reported in all skill classes in Europe with cooks, plumbers and pipe fitters,

([28]) For a thorough literature review of the impacts of digitalisation and automation on the labour market, see Arntz et al. (2019). The authors conclude that computerisation did not lead to a decline in employment but stress that 'the question whether this holds true for the effects of further technological advances in the new future remains open.'

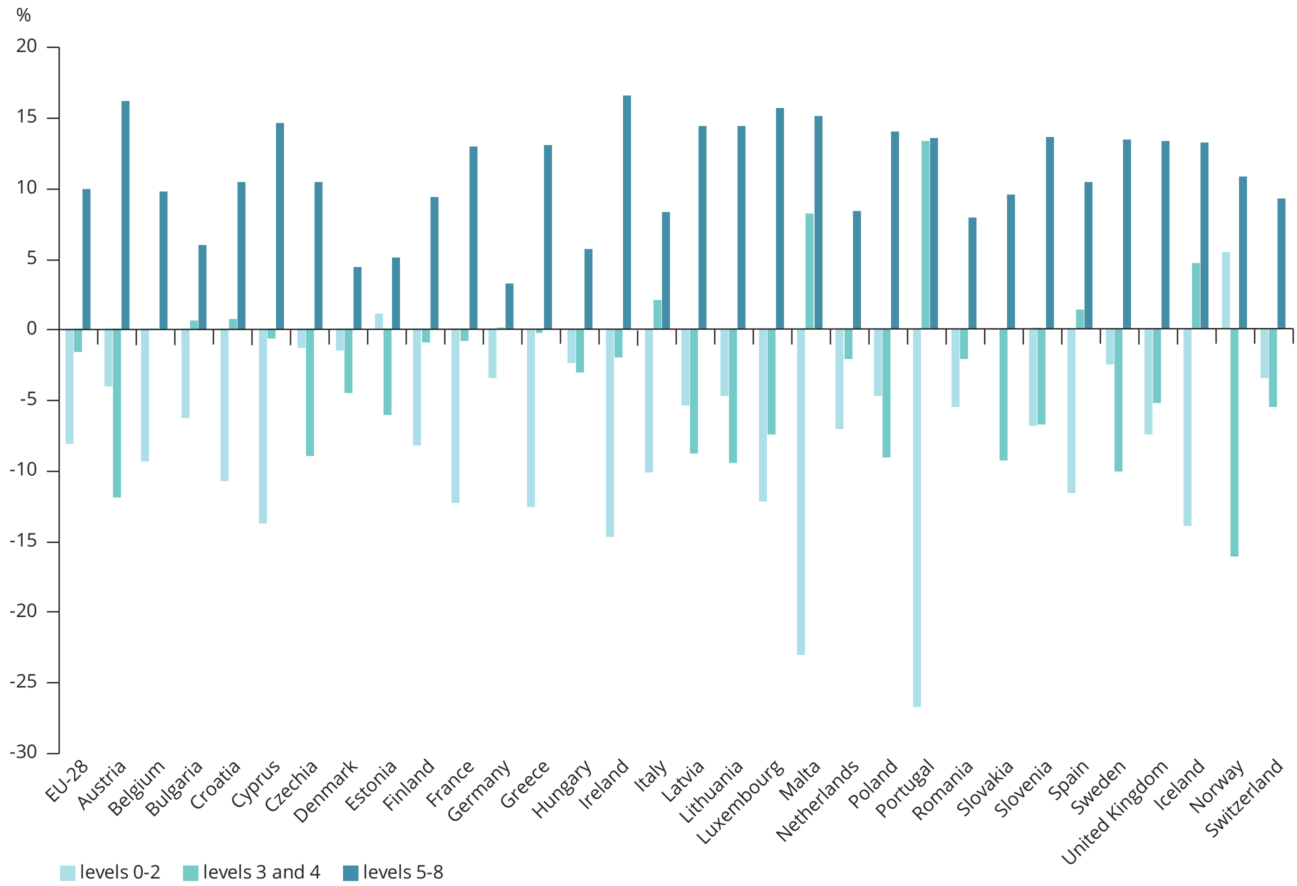
([29]) Increasing efficiencies can provide some gains in income — by a decrease in the costs of using resources — that are then spent on more consumption, for example, driving further in more fuel-efficient cars, so that not all of the expected gains in terms of reduced consumption will materialise. This fact is called the rebound effect and is also known as the Jevons paradox (Jevons, 1865) in the case when the rebound effect is greater than 100 %, i.e. outdoing the efficiency gains. For discussion of the rebound effect see Sorrell (2007) and Greening et al. (2000).

([30]) Based on data collected in the European Investment Bank's Investment Survey of Firms (EIBIS). The data reveal that 93 % of firms considered their current staff to be fully proficient in their actual job but felt that they would face difficulties in finding new staff. It is also worth highlighting that the lack of staff with the right skills is rated much higher as an obstacle than energy costs (EIB, 2018).

([31]) See the report published by the European Commission's Joint Research Centre for an assessment of the effects of new technologies on the future of work and skills (Gonzalez Vazquez et al., 2019).

([32]) See for a detailed discussion of factors affecting skill shortages and skill mismatches: Brunello and Wruuck, 2019.

Figure 3.2 Change in employment by educational attainment level in those aged 15-64 years in the EU, Iceland, Norway and Switzerland, 2005-2018



Note: Levels 0-2 — less than primary, primary and lower secondary education; levels 3 and 4 — upper secondary and post-secondary non-tertiary education; levels 5-8 — tertiary education. For France, the change in the metropolitan areas is shown and, for Switzerland, the change between 2010 and 2018 is shown.

Source: Eurostat.

generalist medical practitioners and welders and flame cutters on the top (EC, 2018g). The top ranked surplus occupations are general offices clerks, shop sales assistants, advertising and marketing professionals, bank tellers and related clerks, and sociologists, anthropologists and related professionals. The skills mismatch obviously affects low-, medium- and high-skill professions alike.

The implications of frontier technologies, such as AI and robotisation, are also controversial in terms of the taxation of both labour and capital. The present fiscal system favours capital intensification and automation over labour, with negative consequences for employment and economic inequality. Such concerns drive suggestions for the taxation of robots and industrial automation devices as a way of counterbalancing such negative externalities across society (see Chapters 4 and 5).

3.3 Environmental consequences of the technological transition: all good?

Previous industrial revolutions have led to environmental challenges, exemplified by air pollution/climate change and increased consumption of resource. The current disruptive technological transition, however, provides opportunities to deal with these challenges, steering countries to a low-carbon, low-pollution and resource-efficient future. For example, ICTs have become essential to measure and model environmental processes that improve the productivity of labour and capital as well as natural resources (Antonioli et al., 2018). Overall, ICTs have much more to contribute to the dematerialisation of economic activities.

However, the total environmental impact of ICTs, as well as the other innovations derived from the Industry 4.0 paradigm, such as autonomous robots, remain unclear because of the rebound effects. For example, new technologies can reduce environmental pressures during the use phase and can lead to substitution processes, for instance by increasing the use of autonomous vehicles at the expense of private and public transport, but they can also increase the demand for transport and hence resource use.

An expansion in the mobility-sharing sector will decrease negative environmental pressures because of the reduced number of individual vehicles and consumption of fossil fuels (McKinsey, 2017; Thomä et al., 2018). However, according to analyses by the International Energy Agency of the links between energy, transport and digital technologies, the overall environmental and climate implications are rather ambiguous. For example, under a best-case scenario of improved efficiency through automation and ride-sharing, road transport energy use could halve compared with current levels. Conversely, if efficiency improvements do not materialise and rebound effects from automation result in substantially more travel, energy use could more than double (Kamiya et al., 2018).

These changes in the mobility sector may lead to a significant reduction in oil consumption and CO_2 emissions (Thomä et al., 2018) and, at the same time, to potential job losses across the automotive sector's value chain. However, the findings of the studies assessing the implications of automotive sector digitalisation and decarbonisation for the labour market differ widely, some suggesting massive job losses (Erich and Witteveen, 2017; ifo Institut, 2017; IAO, 2018), whereas others suggest that new jobs will result (T&E, 2017; AIE, 2018). These findings are not too surprising, as the underlying assumptions differ in line with unpredictable future developments.

The transition to driverless freight vehicles will lead to a massive reduction in employment as well as a decrease in emissions, presenting a challenge for society in combining negative social impacts with positive environmental benefits (ITF, 2017). The complete loss of driving jobs will have negative fiscal implications, as revenues from labour taxes will fall, while the reduced demand for labour might be deemed positive in the longer run because of the demographic transition. Furthermore, because labour costs account for up to 35-45 % of costs in Europe's road haulage sector, driverless freight vehicles are likely to make the sector even more competitive relative to rail, inland navigation and other forms of transport, which will have negative environmental impacts if technology and the modal split remain unchanged.

More sharing economy companies, such as Uber, Lyft and Airbnb, are expected in the future. These companies' platform-based business models are probably some of the most disruptive innovations of the past two decades. Whether they lead to environmental benefits, however, cannot be stated unequivocally because of potential rebound effects. An analysis of San Francisco, for example, concludes that companies such as Uber and Lyft are the biggest contributors to growing traffic congestion (Erhardt et al., 2019). Between 2010 and 2016, hours of delay during the week increased by 62 % compared with 22 % in the absence of these companies, based on a counterfactual scenario ([33]).

Overall, the technological transition has great economic potential, but its social and environmental consequences need further analysis. For instance, the digitalisation of industrial processes focuses primarily on the potential effects on labour. There is much less public debate about the environmental costs and benefits in terms of reductions in environmental pollution and resource consumption (UNIDO, 2017).

The transition to a low-carbon economy can be a particularly material-intensive process, as clean energy technologies and systems are in fact significantly more material intensive than current traditional fossil fuel-based energy supply systems (World Bank, 2017). Others conclude that lower carbon technologies will increase the demand for metals by 2050, although it will be small compared with the background consumption of metals driven by the rest of the economy (IRP, 2017).

([33]) See also the article discussing potential benefits of the ride-hailing companies such as Uber and Lyft (Bliss, 2018), the European Parliament briefing discussing the consequences of these transport network companies (EP, 2015b) and the Öko-Institut study (Hülsmann, 2018).

([34]) An expected increase in the uptake of electric vehicles (EVs) will lead to increased demand for materials such as cobalt and lithium. The IEA (2019a) concludes in its Global EV outlook 2019 that '[T]he comparison of material demand for automotive batteries with the current levels of supply suggests that in the years ahead the supply of cobalt and lithium needs to expand to avoid shortages that may hinder the transition to electric mobility envisioned in the scenarios.'

Some experts summarise these trends as a Catch-22 dilemma — 'a shift to renewable energy will replace one non-renewable resource (fossil fuel) with another (metals and minerals)' (Vidal et al., 2013) — that will possibly continue for some time, as the current energy infrastructure is still based on fossil fuels ([34]).

However, technologies for a low-carbon economy, including low-carbon heavy industry, are available and if broadly adopted could enable a break away from the current unsustainable production processes. The transformation of the capital stock of heavy industries, such as those manufacturing iron and steel, aluminium, chemical products and cement, is essential because the output of these sectors is fundamental for transport, construction and food production.

A recent study suggests multiple options for achieving net-zero CO_2 emissions by 2050 in parts of the EU's heavy industry including steel, plastics, ammonia and cement production (Material Economics, 2019). The study spells out the need to accelerate innovation, enable early investment, support more costly production processes with low CO_2 emissions, overcome barriers to circular economy solutions, and ensure that companies can access the large amounts of clean electricity and other new inputs and infrastructure they need (Material Economics, 2019). The study also points out that all pathways to net-zero emissions require the use of new production routes with low CO_2 emissions, which cost 20-30 % more for steel, 20-80 % more for cement and chemicals, and up to 115 % more to achieve the cuts in some of the very 'last tonnes' of CO_2 emissions. The authors argue that these differences cannot be borne by companies facing both internal EU and international competition, so policies will be needed to support them (Material Economics, 2019).

Taken together, it is clear that public policies and resources are essential for transforming large parts of existing infrastructure. We will also need to recognise that economic growth, which is not very green, will be needed to finance the initial investment necessary for switching to an energy-, climate- and resource-friendly economy (Klingholz and Slupina, 2017).

The impacts of the technological transition on labour markets is a key social dimension of the transition process. Such dimensions are often referred to as part of the 'just transition', as in the new European Commission's programme and the European Green Deal (von der Leyen, 2019; EC, 2019b) ([35]).

Renewable energy technologies have created employment along the value chain, both upstream and downstream, amounting to about 11 million jobs at the end of 2018 (IRENA, 2019). This should be of no surprise, as building new infrastructure always leads to new jobs. A critical question in this discussion is whether these jobs are temporary or permanent. A snapshot comparison by the International Energy Agency of various power generation technologies suggests that employment for each new unit of electricity generated across a project's life cycle is comparable across technologies (IEA, 2017). Elsewhere, analysis points to the increase in renewable energy employment tending to outweigh the decline in employment in fossil fuel production, but overall employment levels in the sector may still fall (OECD, 2017a).

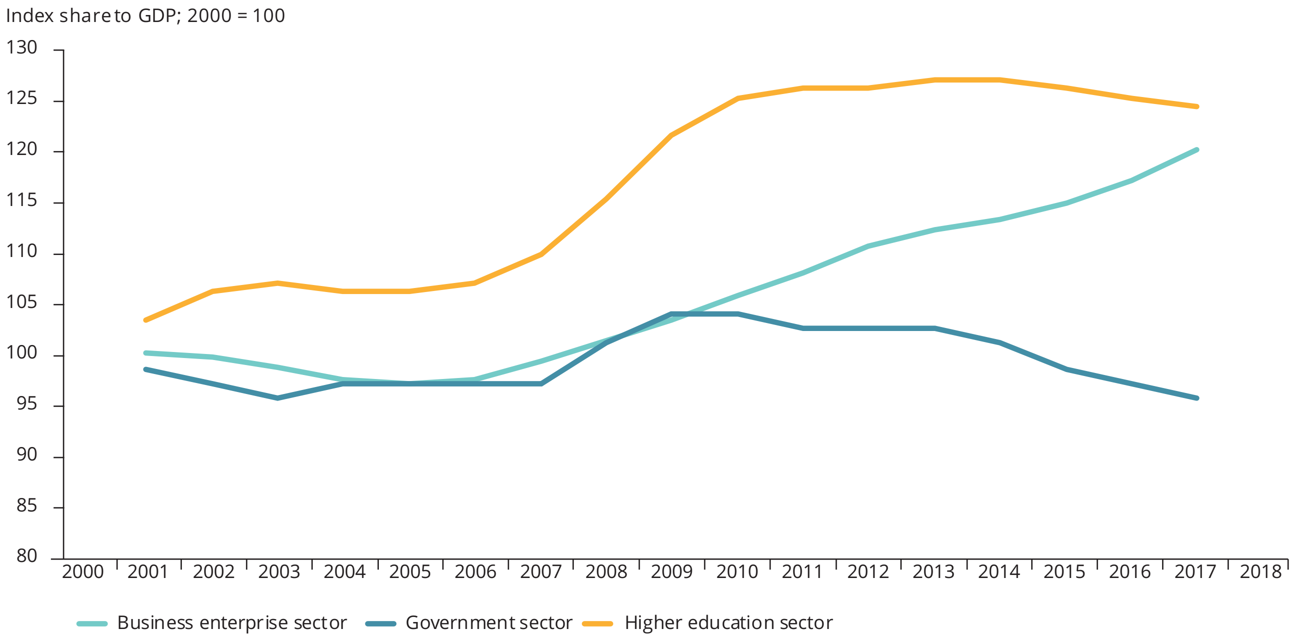
When it comes to policy measures, digitisation and Industry 4.0 developments often happen faster than new policies and regulations to govern them. Furthermore, the design and application of ICTs, AI and automation are not subject to specific environmental concerns and the net environmental effects of many new technologies are largely unexplored.

This missing connection between sustainability and innovation, including a large part of innovation policies, can drive ineffective or bad policy mixes. The development of digital currencies to fund climate finance programmes was, for example, envisaged in the Paris Agreement, but policy should stimulate the decarbonisation of the blockchain technology to encourage innovators to design financially rewarding blockchain technology that also achieves environmental goals.

Overall, technological innovation can be a blessing and a curse for the transition to a green economy, as it can provide some environmental benefits as well as have unforeseen negative effects on the environment. The economic and social implications are even harder to assess, as efficiency gains may lead to job losses. It is, therefore, advisable to take a systemic approach studying the whole spectrum of possible effects (Bock-Schappelwein et al., 2018) to assess the net implications of green technologies in the context of sustainability. Such approaches are often overlooked in policy design.

([35]) For a thorough summary of the just-transition concept, see JTC (2017).

Figure 3.3 Trends in gross domestic expenditure on R&D by sector in the EU, 2000-2018 (3-year average)



Source: Eurostat.

3.4 Eco-innovation and green technologies: how much do they influence the technological transition?

There are two main dimensions to the role of green technology and eco-innovation in relation to technological transition: (1) such technologies can reduce resource and environmental pressures; and (2) green technologies increasingly exploit wider IT enabling technologies and platforms ([36]).

Such technologies can be disruptive on their own by driving sustainability-focused change. The main question is whether the green technology and eco-innovation transition can be strong enough to have a central place in the wider technological transition — and even significantly influence it ([37]).

This section considers the strength and direction of developments in eco-innovation and green technology for the three conventional phases of the innovation chain: (1) research and development (R&D) expenditure; (2) invention (patents); and (3) adopting innovations at the company level. It also analyses evidence on the employment effects of green technologies and eco-innovation.

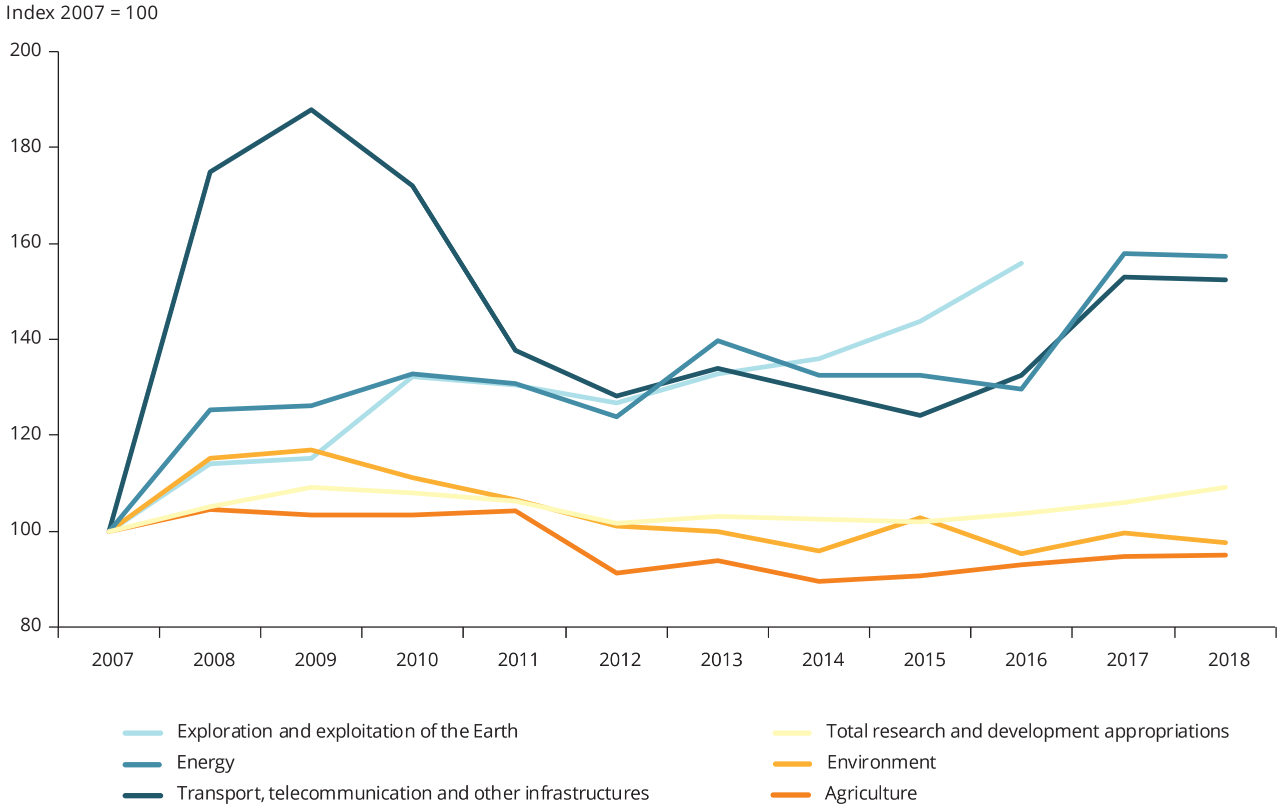
3.4.1 Environment-related research and development spending

R&D spending drives new knowledge creation processes. In 2018, gross domestic expenditure on R&D across all sectors in EU countries was EUR 336 billion, corresponding to 2.1 % of gross domestic product (GDP), a figure well below the 3 % target of the Europe 2020 strategy. The most dynamic sectors since 2000 have been higher education followed by business (Figure 3.3). The overall inability of the EU to achieve such an important target for its knowledge-based economy is in sharp contrast to the wider technological revolution under way across society.

([36]) For definitions and conceptual analysis, see Rennings (2000), Kemp and Pontoglio (2011), Mazzanti et al. (2016) and Kemp and Never (2017).

([37]) The increasing concern over the ethics of research and research responsibility, as exemplified by emerging concepts such as responsible research and innovation (see von Schomberg, 2013), can also play a role in emphasising the importance of sustainable innovation within general research and innovation processes.

Figure 3.4 **Government R&D spending for resource-related objectives and total R&D appropriations in the EU, 2007-2018, at constant 2010 prices**



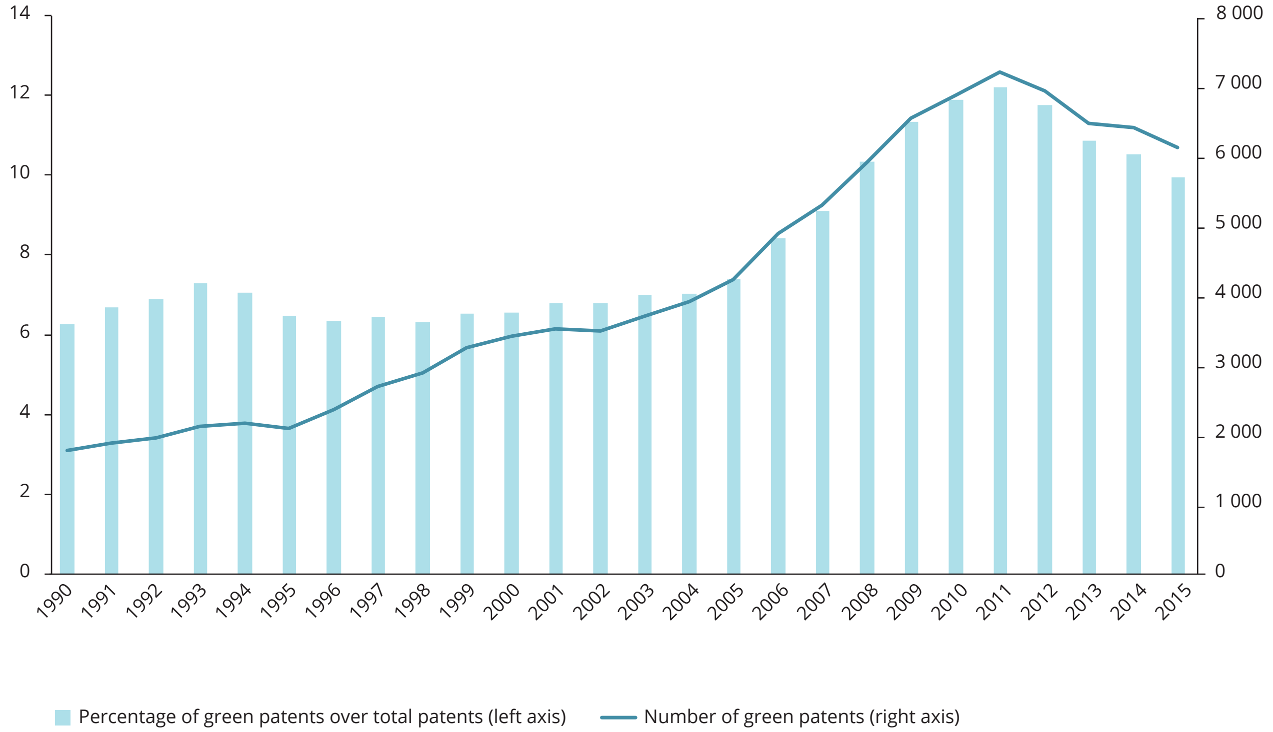
Note: Data on exploration and exploitation of the Earth not available for 2017 and 2018.

Source: Eurostat.

Government spending on R&D was EUR 102 billion across the EU in 2018. The trend in spending on R&D has oscillated, with a slight jump in the core years of the financial crisis, suggesting some countercyclical use of direct public R&D expenditure to support the economy. However, the ratio of government spending on R&D to GDP for 2018 was about the same as in 2007, at 0.64 % of GDP.

These figures suggest that R&D has been a decreasing priority in the direct allocation of public spending and the government policies of EU countries. Trends in spending since 2007 have favoured energy, transport and Earth sciences over the environment (Figure 3.4). Overall, environment- and resource-related R&D seems to increasingly rely on business and higher education research investment, as is the case for R&D in general, as well as on EU funding through significant allocations from the EU framework programmes for research and innovation.

Figure 3.5 **Number of green patent families and their share (%) of total patent families in the EU, 1990-2015**



Source: Authors' compilation using data from OECD Regpat version 2019 (OECD, 2020a; see also Maraut et al., 2008) and Patstat version 2019 (EPO, 2020). The technological domains are from the OECD Env-Tech report (Haščič and Migotto, 2015), updated in 2016 (OECD, 2020b).

3.4.2 Invention — green patents

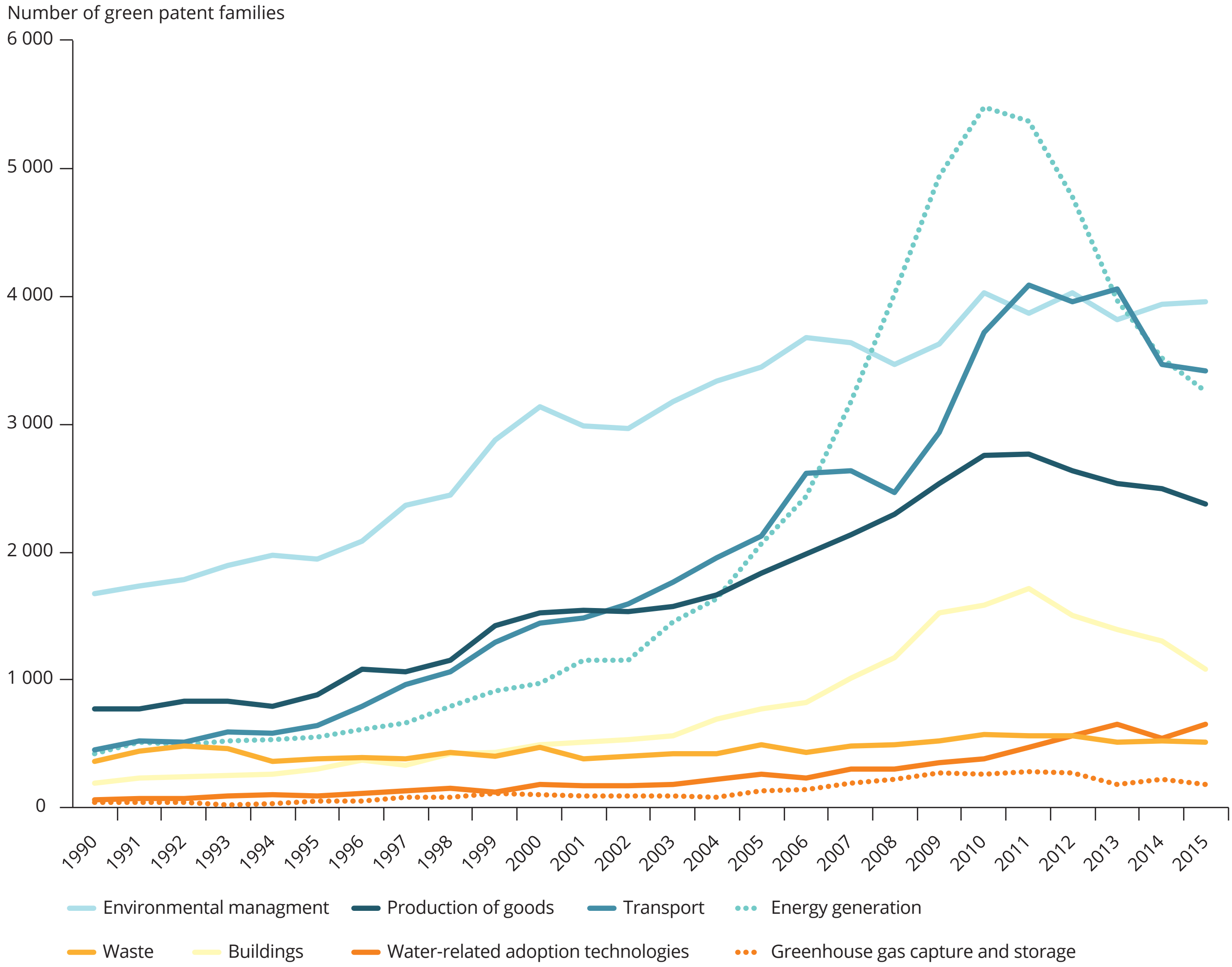
Patents are an extensively used indicator of the invention phase of innovation (Popp, 2005). From 1990 to 2015 in Europe green patenting activities steadily increased and the number of green patents grew faster than non-green technological inventions (Figure 3.5) ([38]). However, since 2012 the number of green patent families has decreased ([39]).

A similar trend characterises the share of green patents in total patents. Following a sharp increase from 2005 to 2011 in which the share reached 12 %, the percentage of green inventions decreased until 2015. Overall, Figure 3.5 suggests that green technologies are more firmly rooted within the European technological system and their relevance has increased over time, but their influence has waned in the most recent years for which data are available.

([38]) Trends in patent families — i.e. sets of patents taken in various countries to protect a single invention — have been analysed for the period 1990-2015. The reason for not reporting data for more recent years is the lag associated with the availability of reliable patent data. To build the time series the OECD Regpat database (version 2019) was used together with Patstat (maintained by the European Patent Office, spring 2019 version), from which information not included in Regpat (such as the patent family ID) was gathered. The 2019 version of Patstat is limited to years prior to 2015. This is due to the time required by the European Patent Office to publish patent applications — usually 18 months after the earliest priority date, but the lag is usually longer for European patent applications based on a patent application under the Patent Cooperation Treaty — and due to the time it takes to receive data, which are then elaborated and included in Patstat, from national patent offices. Therefore, data for recent years invariably mark a decrease in patents, which reflects this lag.

([39]) The result is in line with the findings discussed in an IEA (2019b) commentary.

Figure 3.6 Number of green patent families by Env-Tech technological domain

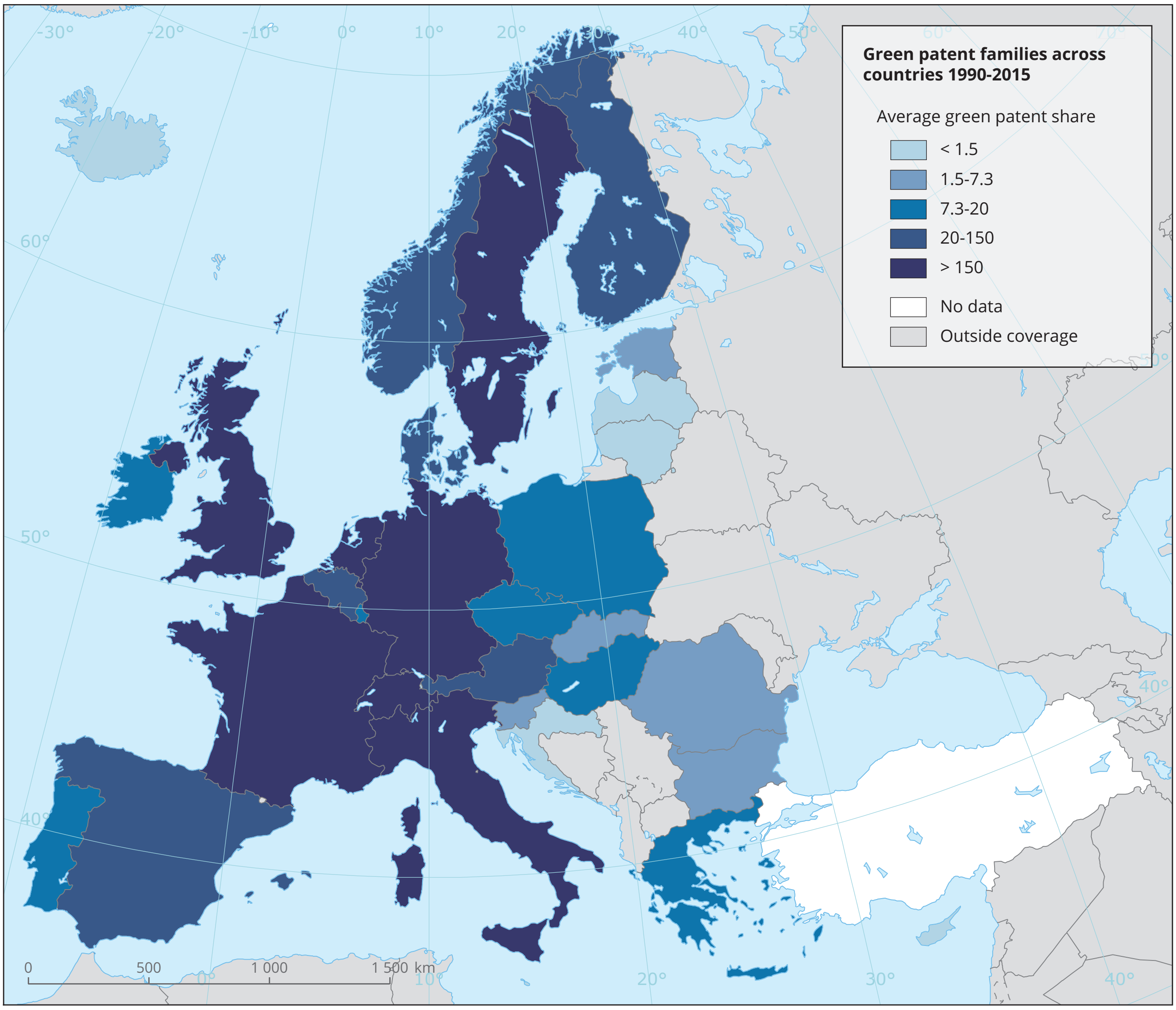


Source: Authors' compilation using data from OECD Regpat version 2019 (OECD, 2020a; see also Maraut et al., 2008) and Patstat version 2019 (EPO, 2020). The technological domains are from the OECD Env-Tech report (Haščič and Migotto, 2015), updated in 2016 (OECD, 2020b).

Figure 3.6 shows green patenting activities by technological domain with negative trends in recent years for low-carbon transport technologies, energy efficiency in buildings and production of green goods.

The technological domains showing more stable trends over time include greenhouse gas capture and storage, waste management and water-related technologies.

Figure 3.7 Distribution of average number of green patent families in the EU, Iceland and Norway, 1990-2015

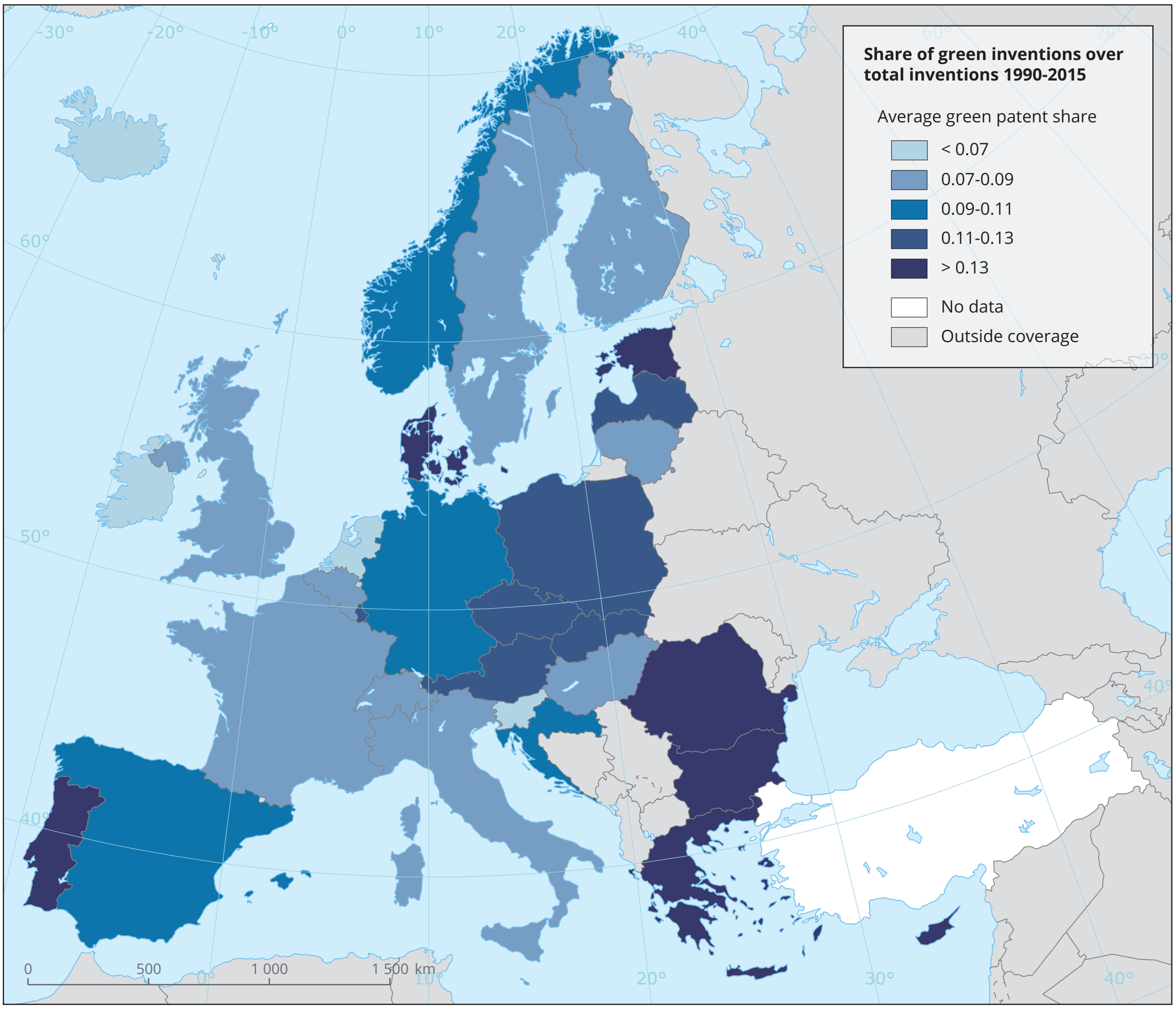


Source: Authors' compilation using data from OECD Regpat version 2019 (OECD, 2020a; see also Maraut et al., 2008) and Patstat version 2019 (EPO, 2020). The technological domains are from the OECD Env-Tech report (Haščič and Migotto, 2015), updated in 2016 (OECD, 2020b).

Looking at the distribution of green patents across Europe, three main country groups emerge. The first includes France, Germany, Italy, Netherlands, Sweden and the United Kingdom — all countries with strong manufacturing or high-tech sectors from which green inventions tend to emerge (Figure 3.7). Indeed, since the beginning of the 1990s, green patenting increased in the majority of these countries, mostly triggered by the implementation of various EU environmental policies.

The second group includes Austria, Belgium, Finland, Norway and Spain — countries that show good performance in terms of producing green inventions. The third group comprises those countries that lag behind in terms of absolute numbers of green inventions and includes Croatia, Iceland, Latvia, Lithuania, Portugal and Romania.

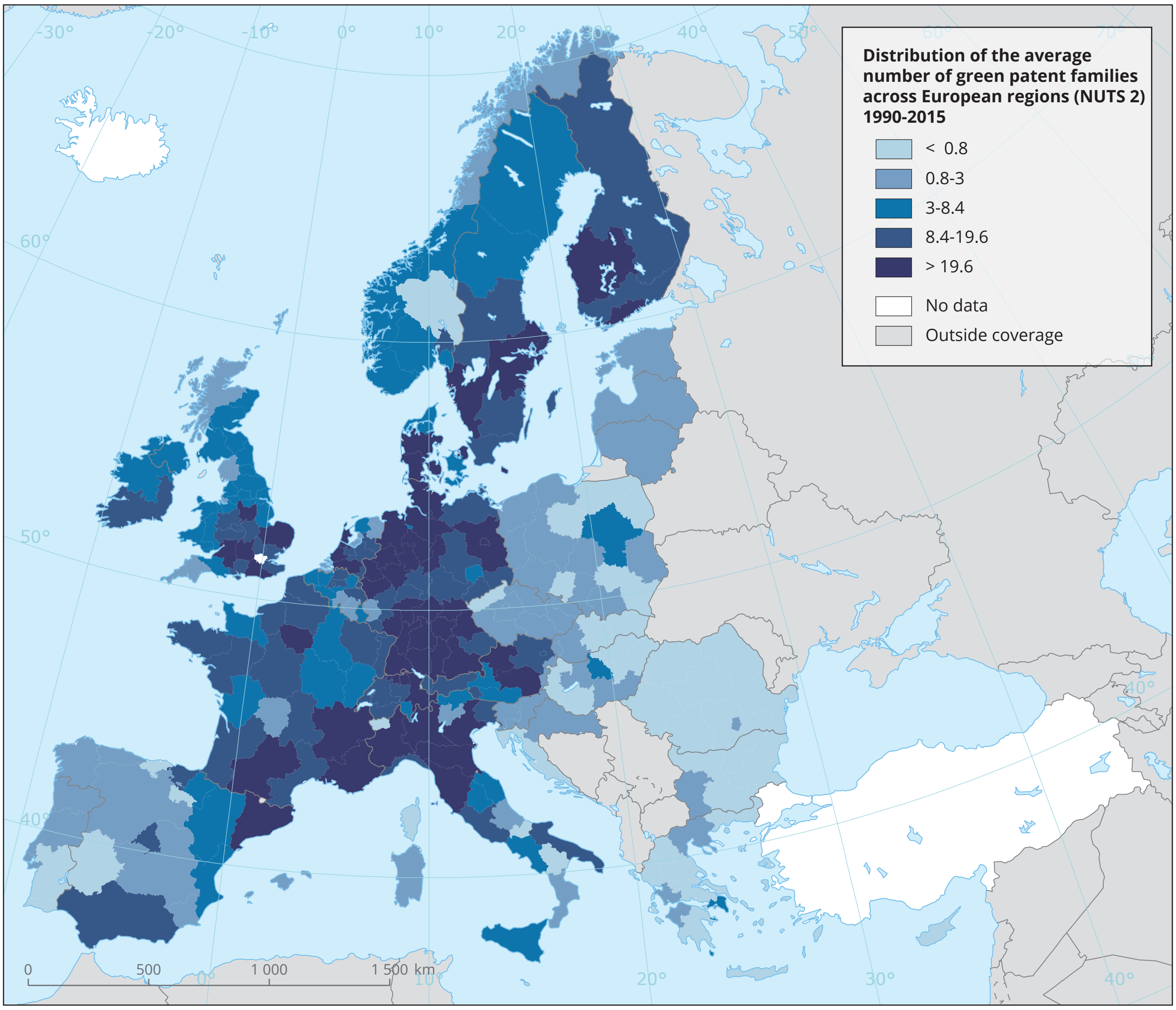
Figure 3.8 **Share of green inventions in total inventions (%) in the EU, Iceland and Norway, 1990-2015**



Source: Authors' compilation using data from OECD Regpat version 2019 (OECD, 2020a; see also Maraut et al., 2008) and Patstat version 2019 (EPO, 2020). The technological domains are from the OECD Env-Tech report (Haščič and Migotto, 2015), updated in 2016 (OECD, 2020b).

However, the countries that lag behind in terms of green patenting activities perform relatively better in their share of green technological activities in total inventions (Figure 3.8), for example Bulgaria, Estonia, Greece and Portugal. In recent years, these countries have experienced an increase in sustainability-related invention activity. This trend is also emerging in the countries in the second group such as Romania, Poland, Hungary and Latvia. Countries in the first group, however, such as Denmark and Austria perform well in terms of both patenting activities and the greening of their technological systems.

Figure 3.9 Distribution of the average number of green patent families across European regions (NUTS 2), 1990-2015



Source: Authors' compilation using data from OECD Regpat version 2019 (OECD, 2020a; see also Maraut et al., 2008) and Patstat version 2019 (EPO, 2020). The technological domains are from the OECD Env-Tech report (Haščič and Migotto, 2015), updated in 2016 (OECD, 2020b).

At the regional level (NUTS 2 ([40])), regions with higher GDPs and a significant share of manufacturing activities perform relatively better in the creation of new green technological knowledge (Figure 3.9). Three main clusters of high performers can be identified. The first includes regions in the north of Italy and the south of France. Southern German and northern Austrian regions constitute the second group and form a dense cluster in the centre of Europe. The last cluster covers northern European regions, especially those in Belgium, Denmark, Finland, northern Germany, the Netherlands and Sweden. Regions that lag behind include southern Italy, the north of Spain and eastern European regions. The geographical distributions of non-green and green inventions across regions (1990-2015 average) almost overlap, thus confirming that green inventions primarily emerge in highly innovative regions.

([40]) Nomenclature of Territorial Level for Statistics (https://ec.europa.eu/eurostat/web/nuts/background).

3.4.3 Adoption of green technologies by firms

Patents do not capture the extent to which inventions translate into innovations and their diffusion throughout the economy, rather they largely indicate the outcomes of larger firms' knowledge creation. Information on eco-innovation adoption and diffusion is more relevant for analysing potential improvements in the environmental performance of production systems.

The Community Innovation Survey (CIS) is the only official EU-wide source of information on the diffusion of eco-innovation, and it sits alongside specific national and regional survey-based analyses ([41]). Information from the CIS on the uptake of eco-innovation is available for two years: 2008 and 2014. Evidence is presented here on the energy-climate and waste-circular economy (our definition) domains ([42]).

Overall, eco-innovation adoption in the waste-circular economy domain shrunk in the EU between 2008 and 2014. In fact, data for 2008 show that the uptake of innovation by enterprises aiming to reduce resource use per unit of output ranged from 12 % to 40 %, while in 2014 the upper bound had fallen to 37 %. This evidence is consistent with Alquézar Sabadie and Kwiatkowski's (2019) findings, pointing to the decline in investment in clean technology, which peaked globally and in Europe in 2012.

The generally unfavourable macroeconomic trends in the EU over the period might explain the relative downturn. Material prices were also low over that period and therefore there were no price incentives to introduce such innovations. Furthermore, waste policies introduced back in the 1990s might have lost their power to encourage innovation (Mazzanti and Nicolli, 2011). Looking ahead, it would be relevant to test the effects of the EU's 2015 circular economy strategy on the diffusion of waste and circular economy innovation ([43]). Currently, the EU action plan for a circular economy and the revised 2018 waste directives are still too recent to assess their roles as drivers of eco-innovation.

The adoption of eco-innovation aiming to shrink the CO_2/energy footprints of companies was also lower overall in 2014 compared with 2008 according to the EU CIS, again consistent with the evidence on total eco-innovation adoption provided by Alquezar Sabadie and Kwiatkowski (2019). Beyond the aforementioned EU recession and stagnation that affected the period 2008-2014, the EU Emissions Trading System (ETS) allowance scheme had an impact whereby carbon prices stagnated at very low levels and increased again only since 2018. Furthermore, variations in national energy policies created heterogeneous stimuli on top of the regulatory-driven incentives of the EU ETS.

At the micro-level, the share of innovation with environmental benefits is relatively high when compared with European firms' general innovation activities, revealing that environmental concerns are taken into account in day-to-day business strategies. The analysis of CIS data shows that key driving forces for eco-innovation are environmental regulation, reduction of internal costs and companies' quest to have a 'green reputation'. Eco-innovation can combine environmental, social and economic values in a systemic way and, above all, European companies realise that environment can be a business opportunity (Alquézar Sabadie and Kwiatkowski, 2019).

Future analyses could attempt to correlate eco-innovation with firms' economic and environmental performance. Recently, for example, Horbach and Rammer (2019) used two waves of the German CIS to highlight some positive turnover and employment effects of adopting circular economy-oriented innovations.

The overall conclusion is that eco-innovations have not progressed homogeneously over time, due to unstable economic cycles, weak prices of oil and other resources, and expectations of policy stringency and credibility, all of which continued beyond the period considered, 2008-2014.

([41]) The analyses are based on aggregated micro-data, which are provided by Eurostat (2020c). Individual micro-data are often used for micro-econometric analysis (Rennings and Rammer, 2011; Mazzanti et al. 2016). Sector CIS data have been also used for econometric analysis (see Gilli et al., 2014). CIS data are a complement to other relevant projects aimed at conveying indicator settings such as the EU Eco-innovation Scoreboard, the OECD green growth indicators, the Asia-Europe Meeting Eco-innovation Index, the Cleantech Innovation Index (Grazzi et al., 2019). Diaz-Lopez (2019) provides evidence on international indicators such as environment-related R&D budgets, policy instruments in support of green technologies and the Global Cleantech Index.

([42]) Data on diffusion and adoption are particularly difficult to gather. The geographical coverage of these datasets strongly depends on the characteristics of the surveys.

([43]) It is worth noting what Alquézar Sabadie and Kwiatkowski (2019) stress about the effects of regulation on (total) innovation (adoption of at least one innovation). Based on the 2014 CIS, they observe that, as well as grants, subsidies, public procurement and financial incentives for environmental innovations, which are mild supporting factors, 'existing environmental taxation is also surprisingly not considered as a relevant factor. It could be explained by the fact that environmental taxation is very specific and punctual. Instead, regulations and taxes expected in the future are quoted slightly more frequently, meaning that companies are starting to anticipate future trends and to integrate them in their strategic management.'

Furthermore, fiscal measures alongside credible environmental policies, such as the European circular economy strategy and the Paris Agreement on climate change, can sustain these volatile and fragile eco-innovation trends. Proposals for green new deals recently emerged in the United States and the EU to tackle the climate crisis and economic stagnation. Such developments may provide stimuli for environmental innovation in the coming years.

3.4.4 Eco-innovation and employment

The literature exploring the effect of eco-innovation on employment is relatively scarce in sharp contrast to the many studies that investigate the employment effects of general technologies. Most studies find a positive relationship between eco-innovation and employment (Horbach, 2010; Horbach and Rennings, 2013; Licht and Peters, 2013). Some studies highlight a positive relationship between adopting green product innovation and labour demand (Horbach, 2010; Licht and Peters, 2013). They also argue that green and non-green innovation have similar effects on employment, although this relationship was not confirmed by Horbach and Rennings (2013).

The available evidence is less conclusive for green process innovation, with the majority of studies finding a positive association between environment-related process innovation and employment. A German study stresses that process innovation technologies initially reduce firms' need for employment, providing cost savings that improve competitiveness and lead to an increase in product demand and, eventually, an increase in labour demand. Nevertheless, this positive effect is found only for process innovations related to material resource and energy savings. Process innovation related to air and water are still characterised by end-of-pipe technologies that reduce employment. This confirms the findings of Pfeifer and Rennings (2001), which highlight how the transition from end-of-pipe green technologies to clean production processes increases employment.

Furthermore, a study of the green patenting activities of Italian manufacturing firms found that environmentally related innovative activities have a greater positive impact on growth in employment than non-green ones (Gagliardi et al., 2016). This study was extended to assess whether the effect of green and non-green patents varies according to a firm's pace of growth and found that environmentally friendly inventions have a greater impact on growth in employment than non-environmental ones, with the exception of firms that either grow very fast or very slowly (Leocini et al., 2017).

The substitution between technology and various types of jobs emerges as a feature of the impact of technological change on employment. Consoli et al. (2016) found that green jobs usually rely on higher levels of human capital such as education, work experience and on-the-job training. Furthermore, looking at the type of skills, they show that green jobs are more intensive in their use of cognitive and interpersonal skills.

The green economy programme developed by the Occupational Information Network (known as O*NET Online) emphasises that technology and green economy activities affect the labour market in different ways (Dierdorff et al., 2009; O*NET Online, 2020a). Other studies (O*NET Online, 2020b) focus on what workers do rather than on what they make and capture to what extent green economy-related activities pervade the labour market (Consoli et al., 2016; Vona et al., 2018; Vona et al., 2019). This approach overcome the dichotomous nature of green and non-green jobs by acknowledging that the transition towards an environmentally friendly economy is a gradual process that affects most occupations to different degrees.

3.4.5 How much can we rely on eco-innovation for the green economy transition?

Technology and eco-innovation play significant roles in policy strategies for the green economy transition. A case in point is the 2015 EU circular economy strategy, which has triggered unprecedented interest in the technological side of saving material resources. EU-funded investment in research and innovation since 2016 is estimated at EUR 10 billion. This is also the case with the decarbonisation strategy and in particular the strategy for a climate neutral economy (EC, 2018a). For example, the long-term strategy options proposed in support of the Commission's Communication *A clean planet for all* (EC, 2018a) rely on the introduction of technological innovations and the diffusion of existing technologies and on the economic self-sustainability, expected or alleged, of these options (see Box 3.1).

Box 3.1 Innovation — a tool for decarbonisation

Despite the very clear compelling case for decarbonisation proposed for years by scientists, intellectuals, associations and several political parties, decarbonisation is still happening at a very slow pace compared with what would be necessary for climate stability and what could be achieved. Decarbonisation also needs to accelerate if the race is to be won from the standpoints of the economy and the capacity for job creation. In this respect, innovation will accelerate the pace of transformation by making the costs of zero-carbon technologies equal to or lower than those of fossil fuel-based options, as is already the case for wind and photovoltaic energy in some parts of the world. This, in turn, will give economic advantage to the front runners in these new industries and technologies and will push fossil fuels out of the market, without the need to wait for an agreement on a global carbon tax (which would be very hard to achieve today) that would internalise the global warming externality.

Source: High-Level Panel of the European Decarbonisation Pathways Initiative (EC, 2018h).

Overall, the EU trends in R&D spending by governments, patents in the various realms of eco-innovation, and data on the uptake of eco-innovation by firms show that the strength of motivation and the pace of investment seems to be far from that required by a green economy transition. These point to the need for further triggers and drivers of eco-innovation.

For example, for some technologies the diffusion process over the last few decades has reduced their cost to levels competitive with their non-green counterparts, while others remain non-competitive given current energy and material prices. According to World Bank data (World Bank, 2020), the real energy price index was at the same level in 2017 as in 1980, and the non-energy materials price index was at 1960 levels in 2017. Weak market signals mean that policies are carrying the burden of boosting eco-innovation.

Stronger policy signals to support the creation of greater economic returns from eco-innovation include using economic instruments that tackle environmental pollution or 'bads'. In particular, carbon prices arising from carbon tax and emission trading schemes are very low, and more than half of the emissions covered by carbon pricing schemes in the world were priced below USD 10 per tonne of CO_2 in 2018 (World Bank, 2019), with the allowances of the EU ETS priced at EUR 10-28/tCO_2.

These prices are far from those recommended by the World Bank's High-level Commission on Carbon Pricing in 2017 to achieve the Paris Agreement's 2° C target (CPLC, 2017) — USD 40-80/tCO_2 by 2020 and USD 50-100/tCO_2 by 2030. The market and fiscal levers are too weak to trigger significant leaps in green technology, even with strong direct commitment from eco-innovation policy.

Furthermore, the introduction of new policies needs to be accelerated (see Quadrio Curzio and Zoboli, forthcoming). Weak policy instruments in contrast to ambitious targets cannot boost eco-innovation and can be a hindering factor in guiding the general technological transition towards sustainability.

4. Fiscal and financial transition

Key findings

- In a European macroeconomic policy environment undergoing fiscal consolidation and needing to balance public budgets, fiscal competition among public policy areas can arise.
- A sustainable transition will challenge 'fiscal sustainability' — which is an important policy objective in the EU. The transition will require:
  - Substantial interactions between fiscal and taxation systems, as well as public and private financial resources. Public spending on the environment in European countries is only around 1.5 % of total government expenditure and its share has not increased in the last two decades. Meanwhile, environmental tax revenues (which amounted to 6.1 % of total revenues from taxes and social contributions in the EU in 2018) are not guaranteed for the future, because meeting the EU's climate and energy targets will erode the tax base of current energy taxation systems.
  - Much greater public and even more importantly, private investment. Current levels of investment in areas contributing to the sustainability transition are too low, partly reflecting the generally weak investment climate across the EU. Governments need to work to create the right incentive structures and mechanisms to foster technological and social innovation.
- Institutional investors are increasingly seeking financial products that support sustainability, without compromising returns, liquidity or pricing.
- Mounting awareness around the risks of climate change for financing and insuring activities in the real economy can lead to discrimination against financing climate-risk prone activities compared to financing activities that are perceived as climate-risk 'free'.
- Financing the transition cannot be seen as independent from other factors, which are crucial for its overall evolution, such as technological change and an ageing population.

4.1 Introduction

Fiscal sustainability maintains macroeconomic stability and ensures effective allocation of public resources ([44]). Population ageing puts pressure on fiscal sustainability. European countries will face fiscal challenges because of reductions in the labour force, erosion of the income tax base and an increase in age-related expenditure (see Chapter 2).

In the short and medium term, the revenue-generating potential of energy/carbon taxes is still considerable, in particular when tax rates are progressively rising (OECD, 2019c). However, current efforts to implement stricter environmental and climate policy targets may impair the revenue-generating potential of current environmental taxation schemes in the long term. This can also affect the further implementation of tax-shifting programmes that increase the tax take for environmental pollution and resource consumption

([44]) The definitions and measures of fiscal sustainability are discussed in detail in Section 4.3.1.

while reducing it for labour (EEA, 2006; Ekins and Speck, 2011; EEA, 2016).

Countries are also facing a huge need for investment in the transition to a low-carbon and resource-efficient economy, but the amounts allocated to the environment from the public budget are low and have not increased in recent years. Nevertheless, public infrastructure investment will be required, while public funds will also play a crucial role in the 'just transition' towards sustainability.

Technological change can have fiscal consequences, as adopting new technologies and processes can lead to substantial changes in employment patterns, for example, resulting in an increase in non-standard employment and the emergence of the collaborative economy. These changes raise crucial issues for safeguarding stable public finances in the years to come (see Chapter 3).

This chapter analyses the revenue and expenditure of the public budgets of the 28 EU Member States (EU-28), bearing in mind the ageing population, technological changes and sustainability objectives. It considers how publicly financed investments can play a critical role in triggering and supporting the transition to sustainability in the coming decades.

4.2 Public budgets in European countries — past trends and future outlook

Environmental influences on public budgets include environmental taxes and emission trading schemes on the revenue side and investment in environmental protection on the expenditure side. Assessing their past trends allows the study of complex links between societal, technological, economic and fiscal factors. Assessing possible future developments can enhance our understanding of how public budgets can support the sustainability transition.

4.2.1 The revenue side of public budgets

The level of economic development varies across the EU Member States, Iceland, Norway and Switzerland (Table 4.1). Long-established EU Member States exhibit similar trends, with annual average economic growth rates of about 1-1.5 %. In contrast, newer Member States have achieved higher economic growth rates, many above 3 %.

Economic growth rates of 2-3 % were reported for France, Germany, Italy and the United Kingdom in the 1980s and 1990s (Klingholz and Slupina, 2017), but such high growth rates for these countries are over. For example, the European Commission uses an average EU annual growth rate of 1.4 % in its projections for the Ageing report (EC, 2018c). Such projections can probably be taken as the new normal for many EU Member States, although significant variations are observed: from 0.8 % in Greece and Italy to 1.9 % in Sweden. These trends also support the hypothesis that Europe could suffer from 'secular stagnation' in the coming decades (see Chapters 2 and 3).

The annual growth in total tax revenues was higher than growth in gross domestic product (GDP) in the majority of EU Member States, pointing to an increasing trend in tax-to-GDP ratio (EC, 2019d; see also Figure 4.3) ([45]). Labour taxation revenues, which include compulsory social security contributions, amount to roughly 50 % of total EU tax revenues (EC, 2019d). During the period between 2002 and 2018, the annual growth rate of labour tax was higher in 13 EU Member States than the growth rate of total tax revenues, and it was higher in 15 EU Member States than the GDP growth rate.

Revenues from environmental taxation

Environmental tax revenues increased substantially in several of the newer EU Member States during the period 2002-2018. This compares with countries such as Denmark, Germany, Norway and Portugal where revenues declined in absolute terms, mainly attributable to a reduction in energy tax revenues.

Energy taxes amount to some 75 % of all environmental tax revenues ([46]) and transport taxes contribute about 20 %, while the remainder comes from pollution and resource taxes. However, environmental concern is not the primary motivation for energy and transport taxes, rather it is revenue raising.

Figures 4.1 and 4.2 show the share of environmental taxes in relation to GDP and total taxation over time. The contribution of environmental taxes and emission trading schemes to overall fiscal revenue is rather

([45]) Taxes and social contribution payments make up about 90 % of total revenues across the EU (Eurostat, 2019b).
([46]) Revenues from taxes levied on transport fuels at EU level accounted for about 50 % of total tax revenues.

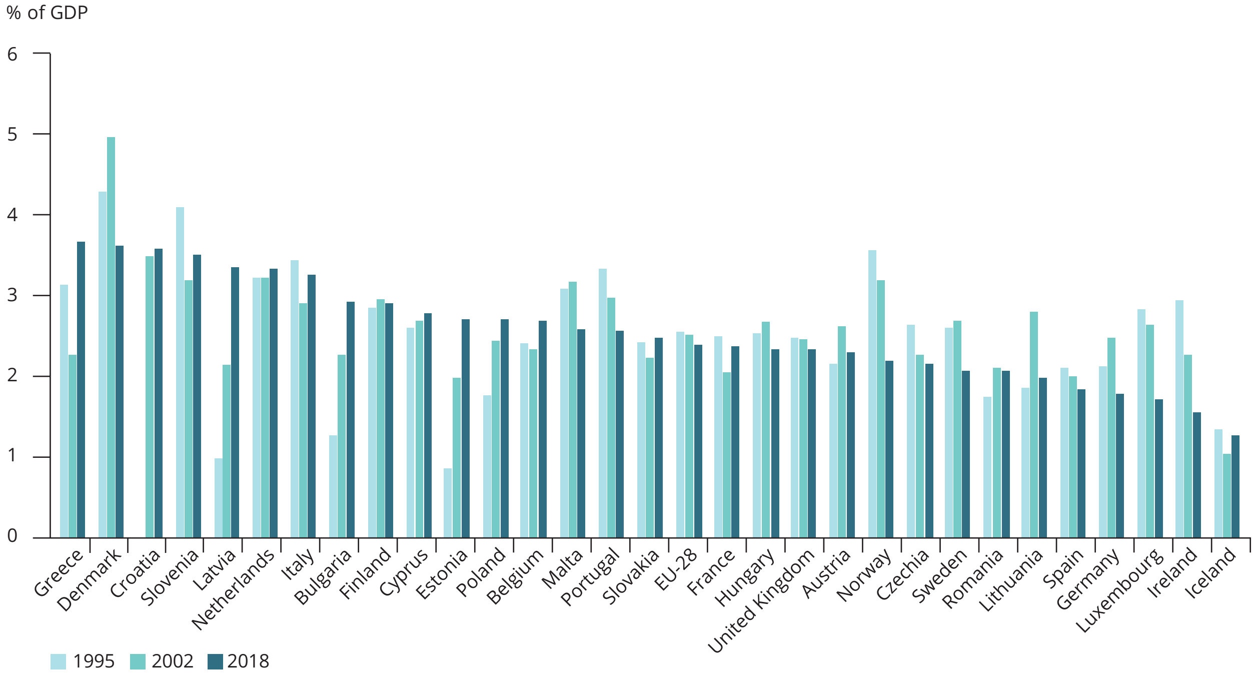
Table 4.1 Average annual growth in GDP and tax revenues in the EU-28, Iceland, Norway and Switzerland, 2002-2017 (constant 2010 EUR)

	GDP		Total tax revenues		Tax on labour revenues		Environmental tax revenues	
	Change 2002-2018 (%)	Average annual growth 2002-2018 (%)	Change 2002-2018 (%)	Average annual growth 2002-2018 (%)	Change 2002-2018 (%)	Average annual growth 2002-2018 (%)	Change 2002-2018 (%)	Average annual growth 2002-2018 (%)
EU-28	25	1.4	31	1.7	29	1.6	19	1.1
Austria	28	1.5	24	1.3	26	1.4	12	0.7
Belgium	29	1.6	30	1.7	19	1.1	49	2.5
Bulgaria	70	3.4	82	3.8	61	3.0	119	5.0
Croatia	28	1.6	31	1.7	26	1.4	31	1.7
Cyprus	37	2.0	65	3.2	76	3.6	41	2.2
Czechia	56	2.8	68	3.3	67	3.3	49	2.5
Denmark	23	1.3	18	1.1	17	1.0	-11	-0.7
Estonia	66	3.2	75	3.6	63	3.1	129	5.3
Finland	23	1.3	20	1.2	16	0.9	21	1.2
France	22	1.2	33	1.8	36	1.9	41	2.2
Germany	24	1.4	30	1.7	25	1.4	-10	-0.7
Greece	-7	-0.5	11	0.7	10	0.6	51	2.6
Hungary	40	2.1	39	2.1	27	1.5	22	1.2
Ireland	99	4.4	57	2.9	92	4.2	37	2.0
Italy	1	0.1	7	0.4	8	0.5	14	0.8
Latvia	67	3.3	85	3.9	69	3.3	162	6.2
Lithuania	79	3.7	87	4.0	92	4.2	27	1.5
Luxembourg	55	2.8	62	3.1	80	3.7	0	0.0
Malta	88	4.0	98	4.4	101	4.5	53	2.7
Netherlands	25	1.4	36	2.0	36	2.0	29	1.6
Poland	88	4.0	98	4.4	98	4.4	107	4.7
Portugal	9	0.5	19	1.1	32	1.7	-6	-0.4
Romania	85	3.9	74	3.5	83	3.9	81	3.8
Slovakia	87	4.0	94	4.2	99	4.4	108	4.7
Slovenia	41	2.2	38	2.0	32	1.8	54	2.8
Spain	25	1.4	30	1.6	33	1.8	14	0.8
Sweden	43	2.3	40	2.1	29	1.6	11	0.6
United Kingdom	30	1.7	37	2.0	29	1.6	24	1.3
Iceland	66	3.2	77	3.6	n.a.	n.a.	104	4.5
Norway	29	1.6	22	1.3	22	1.3	-11	-0.8
Switzerland	36	2.0	41	2.2	n.a.	n.a.	n.a.	n.a.

Notes: Environmental tax covers energy tax (including carbon taxes and revenues from the EU Emissions Trading System), transport taxes, resource taxes and pollution taxes. For further information, see EEA (2016).
n.a., not applicable

Source: Eurostat.

Figure 4.1 **Environmental tax revenue as a share of GDP in the EU-28, Iceland and Norway, 1995, 2002 and 2018**



Note: No data available for Croatia for 1995.

Source: Eurostat.

small, amounting to about 6 % of total tax revenues in the EU in 2018. Environmental taxes contribute almost the same share to the public budget as taxes levied on corporations' income.

The shares of environmental tax revenues in countries varied between 4.4 % in Luxembourg and 10.9 % in Latvia in the same year. The largest increases in environmental tax revenues occurred in, among others, Latvia, Estonia and Bulgaria between 1995 and 2018. In sharp contrast, environmental taxation as a share of total tax revenues declined in 17 EU Member States, most noticeably in Portugal, Luxembourg and Malta, as well as Norway, over the same period.

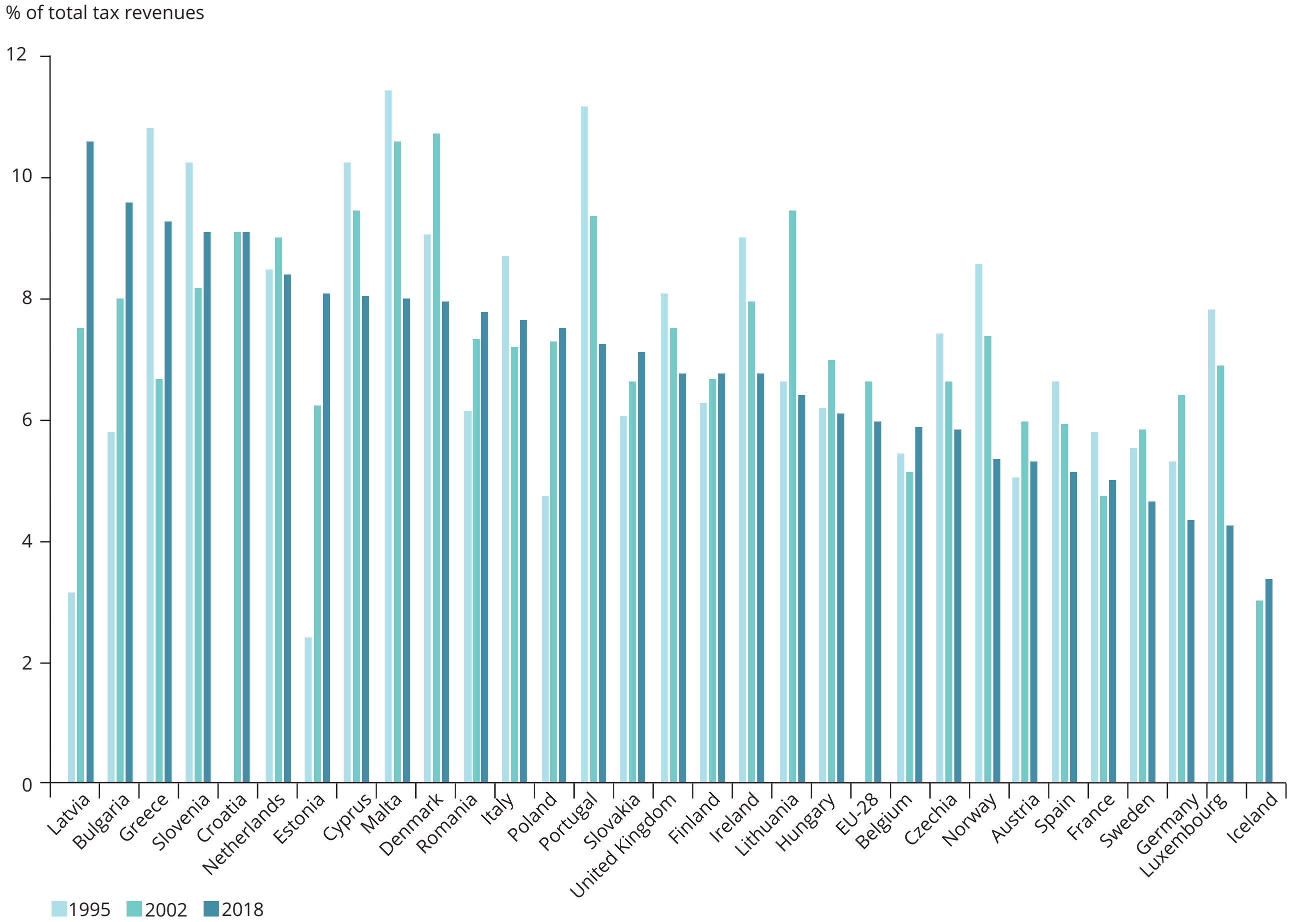
Overall, environmental tax revenues have fallen in recent years despite the growing importance of environment and climate issues in EU policy debates. One explanation is that environmental taxes are usually levied per unit of physical consumption (*ad quantum*), fixed in nominal terms, so their real value declines in the absence of adjustment for inflation (EC, 2011; EEA, 2016). In contrast, labour and consumption taxes, such as value added tax, are set *ad valorem*, meaning that the tax rate is set as a percentage of the tax base and is therefore immune to the effects of inflation.

The primary objective of environmental taxes should be to internalise external costs and thereby meet the objectives of environmental policy, such as reducing pollution and resource use (EEA, 2016), with revenue raising as an extra benefit. There are several options for using these revenues, among them to reduce other distortionary taxes, such as labour or capital taxes, or to finance green investment in, for example, energy efficiency.

Revenue-neutral tax-shifting programmes have been implemented in countries throughout the world, and Europe leads this policy approach (EEA, 2016). For example, the EU Seventh Environment Action Programme (EU, 2013) calls for a more systematic application of the 'polluter-pays principle' through phasing out environmentally harmful subsidies and shifting taxation from labour to pollution.

However, there is limited scope for environmental taxation to realise far-reaching tax-shifting programmes

Figure 4.2 **Environmental tax revenue as a share of total tax revenue in the EU-28, Iceland and Norway, 1995, 2002 and 2018**



Notes: No data available for the EU-28, Croatia and Iceland for 1995.

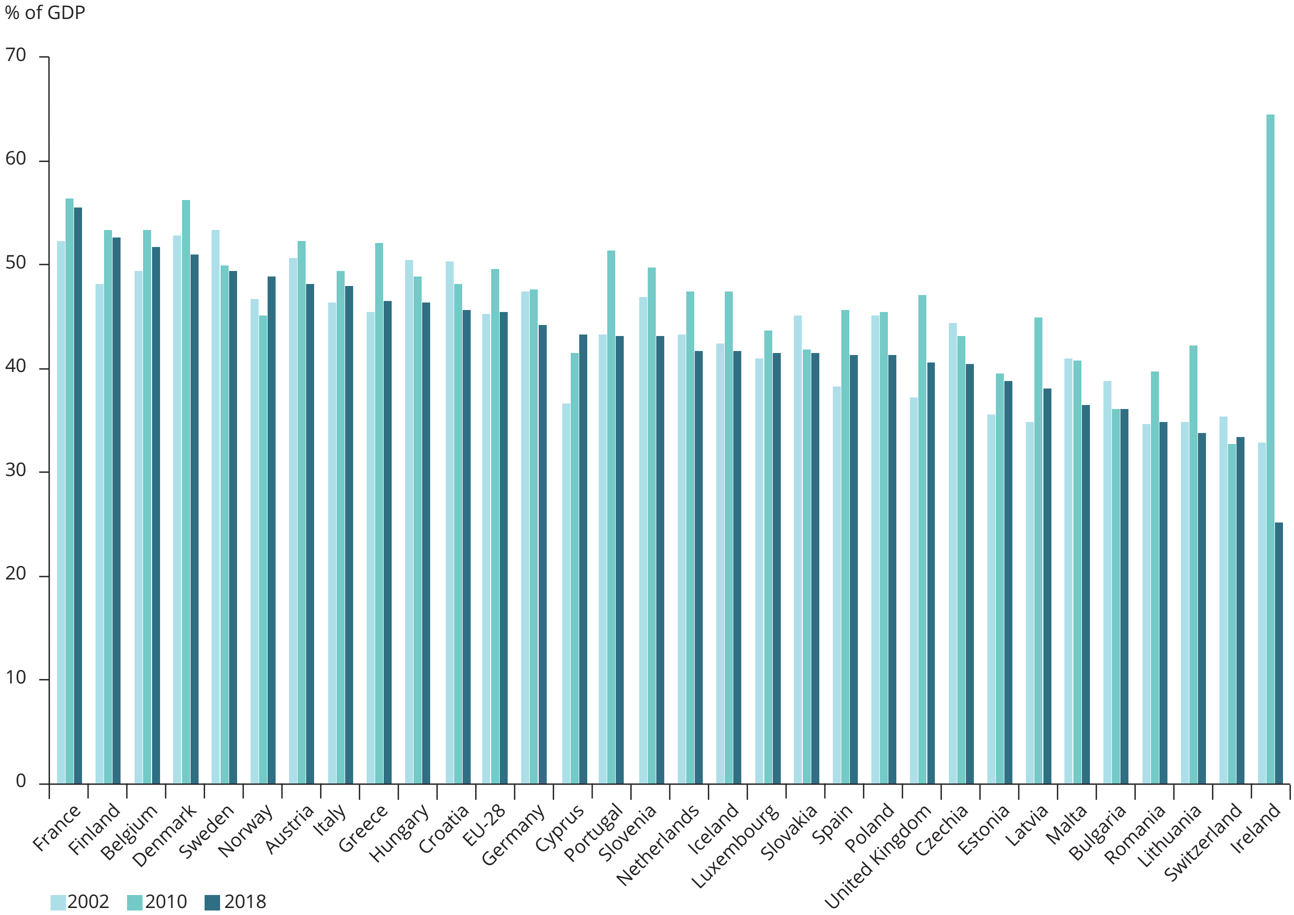
Source: Eurostat.

because of its relatively small base vis-à-vis labour taxation and the potential erosion of the tax base implied by EU Member States meeting their ambitious environment and climate targets in the coming decade. Shifting the tax burden from labour to environmental pollution and resource use should be seen as part of a policy package that aims to rebalance the countries' future fiscal burdens, given the fiscal challenges of an ageing population (Section 2.3) and the technological transition (Section 3.2).

4.2.2 The expenditure side of public budgets

Government expenditure differs widely between European countries, across policy domains and over time (Figure 4.3). Public expenditure increased notably in response to the economic and financial crisis of 2008/2009. After the crisis, there was a decrease in all EU Member States between 2010 and 2018, revealing large variations in the ratio of total government expenditure to GDP: from 25 % in Ireland

Figure 4.3 **Total general government expenditure as a share of GDP in the EU-28, Iceland, Norway and Switzerland, 2002, 2010 and 2018**

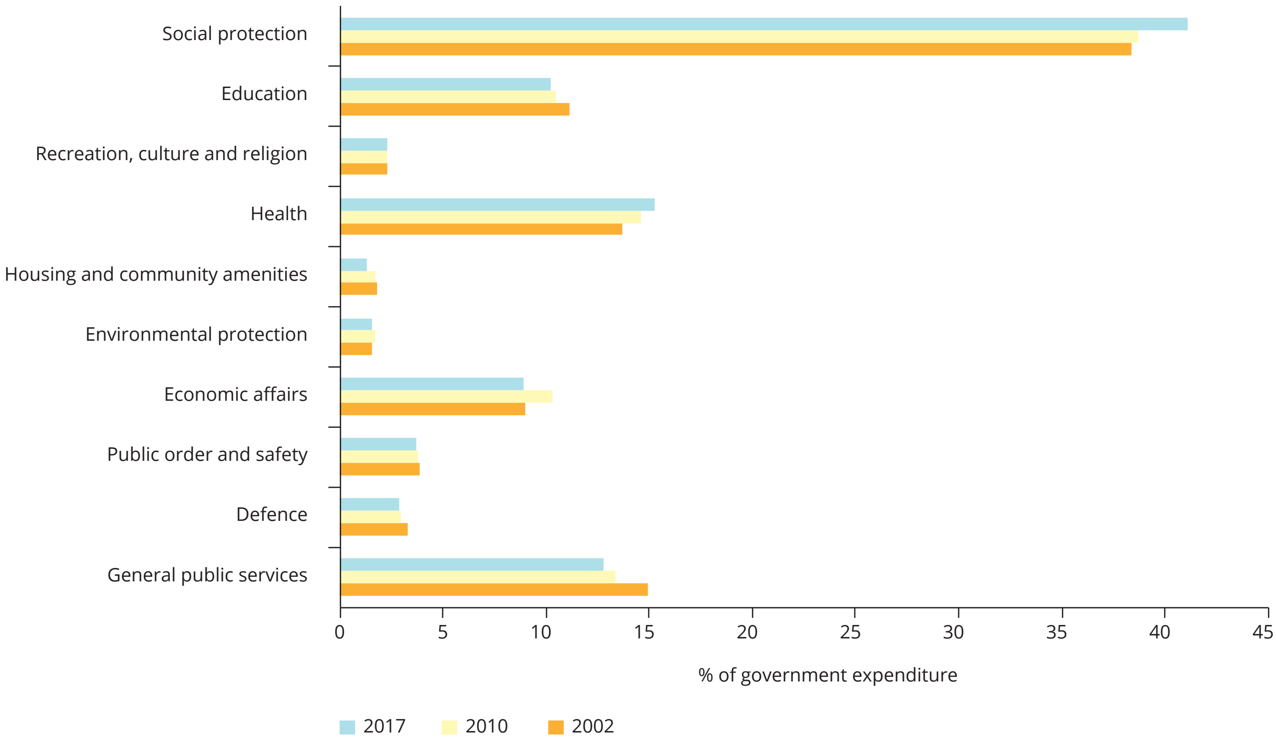


Source: Eurostat.

to 56 % in France in 2017. These differences also occur on the revenue side of the public budget, and again France had the highest ratio of total tax to GDP and Ireland the lowest in 2018.

The allocation of government expenditure to different public policy fields over time provides some interesting insights (Figure 4.4). The two biggest spending areas are social protection and health, and there has been a clear increase in government spending on both. Expenditure on social protection amounted to 28 % of GDP in the EU in 2016, some 2 % higher than in 2008. Between 2005 and 2016, expenditure on social protection relative to GDP increased in 23 EU Member States, with the highest increases in Finland (6.3 %), followed by Greece (5.8 %) and Spain and Italy (4.2 %). Norway also recorded an increase of 5.6 %. In contrast, Hungary, Ireland and Malta reported reductions in their ratios between 2005 and 2016.

Figure 4.4 **General government expenditure by function as a share of total expenditure in the EU, 2002, 2010 and 2017**



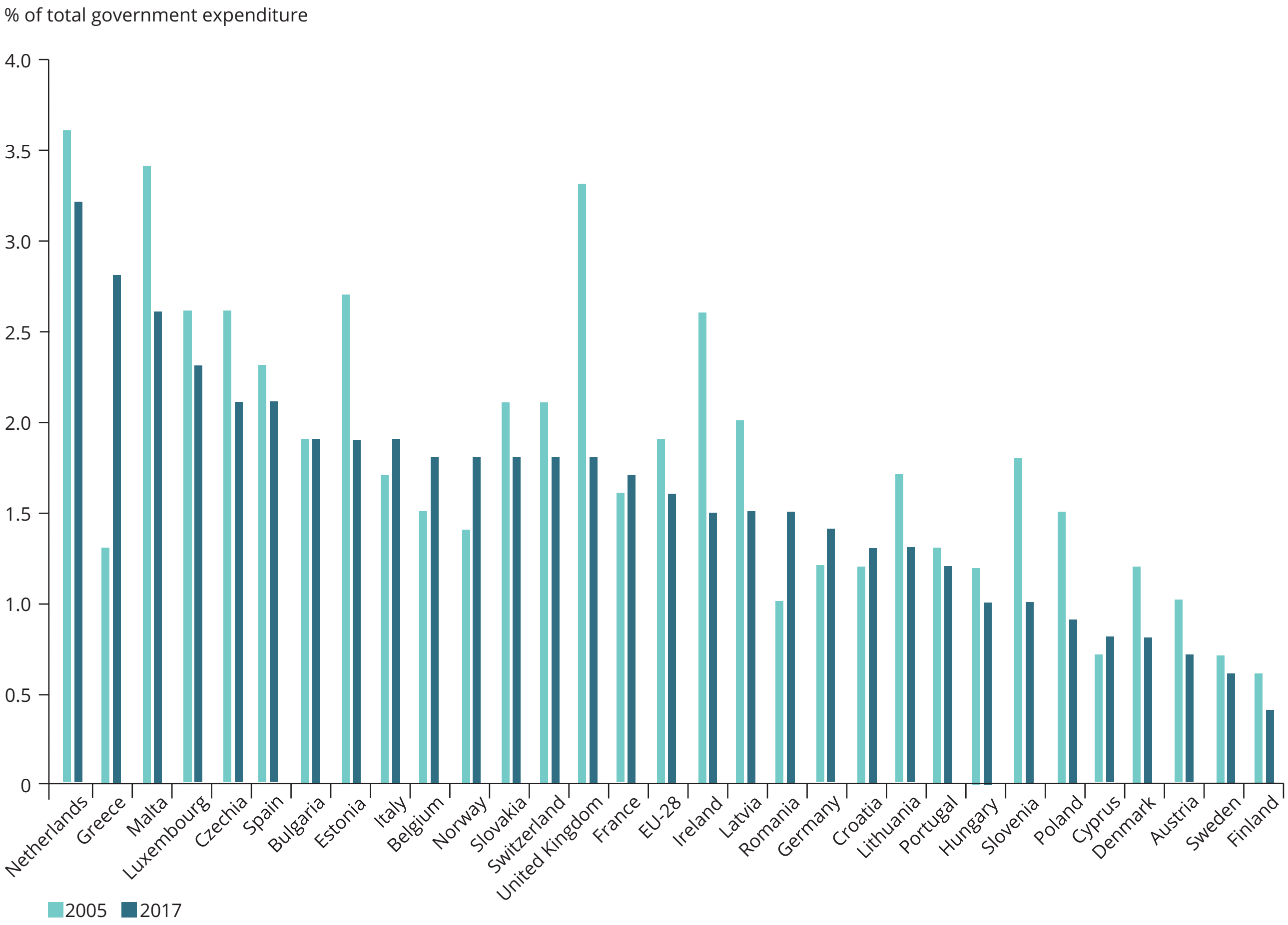
Note: Data are taken from statistics on 'general government expenditure by economic function' collected according to the international Classification of the Functions of Government (COFOG).

Source: Eurostat.

The financing of social protection also differs across European countries. Some draw on social security contributions paid by employers and by the people, individuals and households protected, others are financed by transfers from the public budget, general government contributions or a mixture of the two. Overall, in the majority of European countries the share of general government contributions to social protection has increased while the share of contributions from employers and the people protected has fallen (Annex 4.1; Mayrhuber 2016; Mayrhuber and Bock-Schappelwein, 2018). These changes in the financing of social receipts are significant for 19 EU Member States, and the largest increase, of 23 %, is recorded in Malta. The share of employers and workers' contributions in financing social security is still crucial, as it contributes more than 50 % of total social protection receipts in the EU as a whole.

These changes in the structure of financing social protection expenditure increase pressure on the public budget. The economic and financial crisis of 2008/2009 and demographic changes are the primary reasons for governments' increased contribution to social protection. Further increases in both social protection and health expenditure can be expected as the working-age population decreases and the number of pensioners increases steeply (Section 2.3.2).

Figure 4.5 **Government expenditure on environmental protection (COFOG GF05) as a share of total government expenditure in the EU-28, Norway and Switzerland, 2005 and 2017**



Note: COFOG GF05 — Environmental protection — includes waste management, waste water management, pollution abatement, protection of biodiversity and landscape, research and development in environmental protection and environmental protection n.e.c. (not elsewhere classified).

Source: Eurostat.

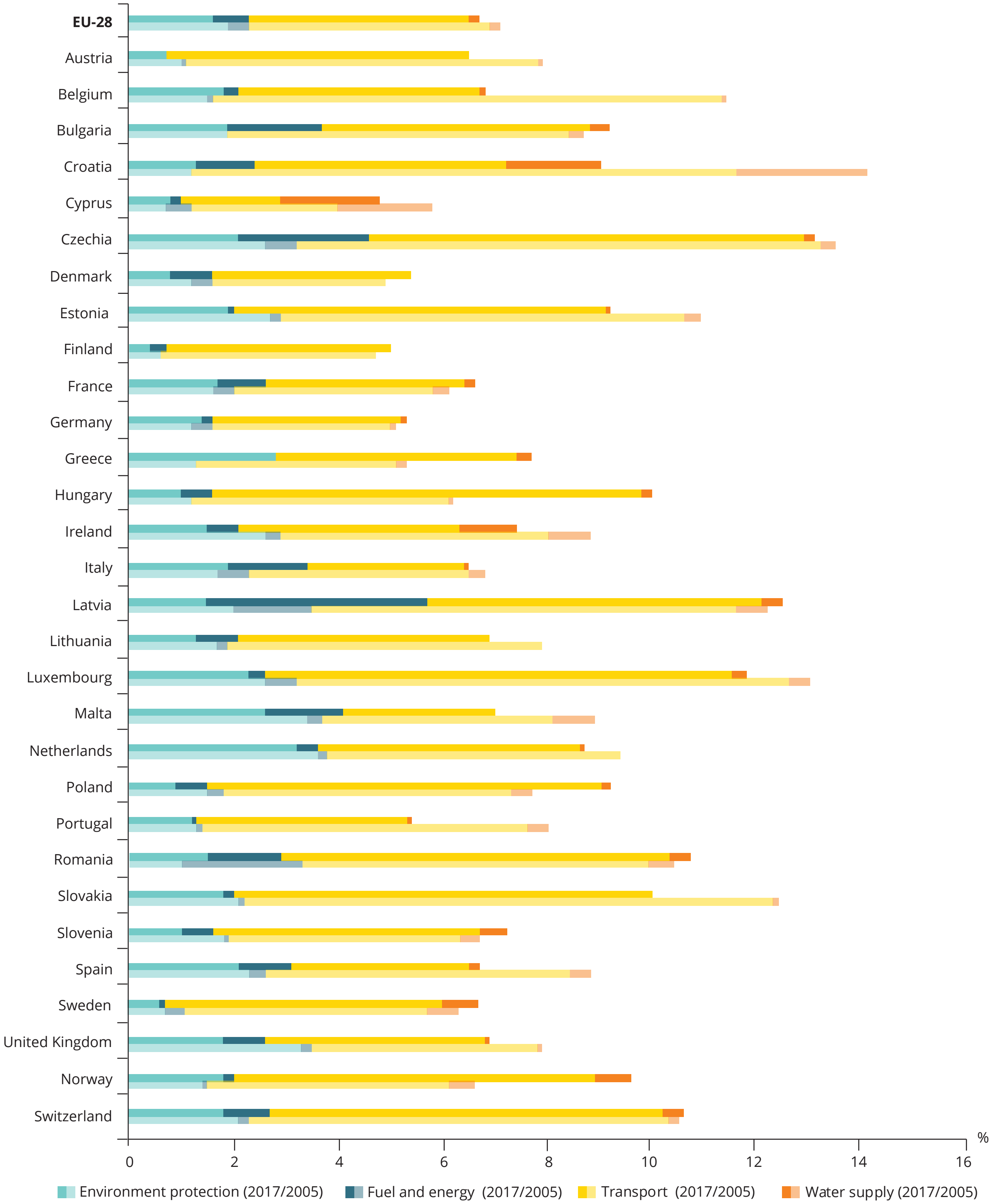
Public spending on the environment

Environmental protection expenditure in 2017 accounted for only about 1.6 % of total government expenditure, or about 0.8 % of the EU's GDP; this share has remained the same over time (Figure 4.4). This aggregate picture, however, hides a substantial degree of heterogeneity (Figure 4.5), ranging from a maximum for the Netherlands of more than 3 % and a minimum for Finland of less than 1 %.

By broadening the scope to other government spending areas closely related to the environment, such as fuel and energy, transport and water supply, the share of total government expenditure in the EU was roughly 7 % in 2017, but there were large differences between countries (Figure 4.6). Steep increases occurred in Greece, Hungary and Norway. By far the biggest part of this expenditure goes on transport. The largest decreases were reported for Croatia (more than 5 %) and Belgium (4.6 %).

Summing up, environmental considerations influence both sides of the public budget. On the one side, environmental taxes and emission trading schemes generate revenue; on the other, environmental expenditure protects nature and reduces pollution. The data show that revenues from and spending on the environment in the overall public budget is relatively small, pointing to limitations on how public spending can support the transition to sustainability in the coming decades.

Figure 4.6 **Government expenditure using a broader definition of environmental protection as a share of total government expenditure in the EU-28, Norway and Switzerland, 2005 and 2017**



Note: The broader definition of environmental protection includes COFOG function GF05 Environmental protection, GF0403 Fuel and energy, GF0405 Transport and GF0603 Water supply.

Source: Eurostat.

Box 4.1 The EU indicators for assessing fiscal sustainability

The S0 indicator is a composite indicator aiming to evaluate the extent to which there may be a risk of fiscal distress in the short term, stemming from the fiscal as well as the macro-financial and competitiveness aspects of the economy. A set of 25 variables, proven to perform well in the past in detecting fiscal distress, are the basis for constructing the indicator.

The medium-term sustainability indicator S1 shows the additional adjustment required in terms of improving the government's structural primary balance over 5 years to reach a 60 % public debt to GDP ratio by 2033, including finance for future additional expenditure arising from population ageing.

The long-term sustainability indicator S2 shows the upfront adjustment to the current primary balance, in structural terms, required to stabilise the debt to GDP ratio over the infinite horizon, including finance for any additional expenditure arising from an ageing population.

Source: EC, 2019e.

4.3 The future: fiscal sustainability and the green economy

The concept of fiscal sustainability is generally understood as the 'solvency' of the public sector' (EC, 2015) ([47]). It takes into account projected future tax revenues and public expenditure, as these data are essential for sound public finances, and it is highly relevant in the context of the EU Stability and Growth Pact ([48]). The rationale is to address 'fiscal sustainability challenges across different time horizons (short, medium and long term), and allows for the identification of the scale, nature and timing of fiscal sustainability risks' (EC, 2019e). The fiscal sustainability of EU Member States is assessed by referring to various indicators developed by the European Commission that distinguish different time horizons (EC, 2019e) (see Boxes 4.1 and 4.2 for a discussion of the relation between economic growth and fiscal sustainability).

The annual European Commission's *Fiscal sustainability report* provides a regular update on the fiscal sustainability challenges faced by Member States. Compared with the situation in 2009, when 'more than half of the Member States were deemed to be at high risk of fiscal stress in the short term' (EC, 2019e), public finances have improved. Only one country, Cyprus, has been found to be at risk of fiscal distress in the short term (EC, 2019e). However, the assessment of the fiscal sustainability of EU Member States is not as positive in the longer term, as '*in the medium-term*, high risks are identified in seven countries (Belgium, Spain, France, Italy, Hungary, Portugal and the United Kingdom). *In the long-term*, high risks are identified in six countries (Belgium, Spain, Italy, Luxembourg, Hungary and the United Kingdom)' (EC, 2019e; italics in original) ([49]). Fiscal sustainability analyses are also published by EU Member States, for example Germany ([50]), Sweden ([51]) and the United Kingdom ([52]), as well as by academic sources ([53]).

4.3.1 Environmental taxation and fiscal sustainability

Over time, achieving stricter EU environmental and climate policy targets will reduce the revenue-raising potential of energy taxes, as the consumption of energy products, such as transport fuels, will fall.

Furthermore, technological changes such as increases in the fuel efficiency of newly registered cars are expected to reduce energy tax revenues further. For

([47]) The literature provides a range of definitions of fiscal sustainability. In the context of this report, the Organisation for Economic Co-operation and Development definition is interesting, as it explicitly mentions the significance of environmental factors and socio-economic trends for assessing fiscal sustainability: 'Fiscal sustainability is the ability of a government to maintain public finances at a credible and serviceable position over the long term. Ensuring long-term fiscal sustainability requires that governments engage in continual strategic forecasting of future revenues and liabilities, environmental factors and socio-economic trends to adapt financial planning accordingly' (OECD, 2013).

([48]) The EU Stability and Growth Pact (SGP) is a set of rules designed to ensure that countries in the EU pursue public finances and coordinate their fiscal policies — for further information, see EC (2020b).

([49]) For a discussion of the framework and criteria used for the fiscal sustainability assessment, see EC (2019d).

([50]) In 2016, the German Federal Ministry of Finance (Bundesfinanzministerium) published the Fourth Report on the Sustainability of Public Finances, see BMF (2016).

([51]) The Swedish National Institute of Economic Research (Konjunkturinstitutet) publishes an annual report on the long-term sustainability of Sweden's public finance — see NIER (2019) for a summary of the 2019 report.

([52]) The Office for Budget Responsibility publishes fiscal sustainability reports annually, see OBR (2018).

([53]) See Andersen (2012), for a study linking the concept of fiscal sustainability to climate change, and Ekins and Speck (2014).

Box 4.2 Economic growth and fiscal sustainability

When studying potential future tax systems, an often-quoted rule in the economic and fiscal literature is that 'a tax base should reflect an economy's capacity to fund public expenditures, meaning that as the economy grows, the tax base should grow with it. Otherwise, it will be necessary to raise tax rates and, in doing so, worsen economic distortions' (Auerbach, 2010). This prescription is not necessarily applicable in any discussion of the effectiveness of environmental taxes, as their primary objective is to change behaviour and relative prices so that the tax base will be eroded over time. The underlying rationale for establishing this rule is almost certainly based on a taxation system that relies on *ad valorem* taxes rather than *ad quantum* taxes, which are predominant in the design of environmental taxes.

The basis of Auerbach's (2010) argument is the close and positive link between tax revenue and growth in gross domestic product (GDP). However, the demographic transition in the form of an ageing and shrinking population, which is projected for some European countries, is expected to reduce potential growth (Chapter 2) and tax revenues in the future. Furthermore, the consequences of an ageing society may include an increase in age-related public expenditure, implying that both sides of the public budget may be negatively affected based on the current fiscal system.

The dynamics between GDP and tax revenues may be a critical benchmark for an analysis of fiscal sustainability, as they allow the sensitivity of taxation aggregates to changes in economic activity to be estimated if tax rates are kept constant over time. When addressing questions linked to the fiscal implications of changes in economic growth rates from the revenue side of the budget, the answer may be found in 'tax buoyancy' — 'the measure for how tax revenues vary with changes in GDP' (Belinga et al., 2014).

Tax buoyancy describes the responsiveness of growth in tax revenue to changes in GDP — it takes account of the tax revenue to GDP ratio and whether it remains constant over time, considering changes in economic performance and no changes in the fiscal system, no tax rate increases or changes in the overall design of a country's tax system. A value exceeding 1 means, therefore, that GDP growth can improve fiscal performance, as a 1 % increase in GDP will increase the revenue side of the budget by more than that (Blanchard et al., 2010). Scholars from the International Monetary Fund estimated the tax buoyancy of 107 countries for the period 1980-2014 revealing variation between short- and long-term tax buoyancy for Organisation for Economic Co-operation and Development (OECD) countries. Such variation showed that not all European OECD countries had a value exceeding 1, which implied that 'tax revenue increases more than GDP, which could and potentially lead to reductions in the deficit ratio. A buoyancy of greater than unity over the long run is a desirable feature of a tax system if there is an increasing demand for public services and if a country would like to pursue financial stability' (Dudine and Tovar Jalles, 2017).

Source: EC, 2019e.

example, current EU legislation sets CO_2 emission targets for new cars of 130 g CO_2/km, which corresponds to fuel consumption of around 5.6 l/100 km of petrol or 4.9 l/100 km of diesel. A stricter target of 95 g CO_2/km will apply from 2021 onwards, corresponding to fuel consumption of around 4.1 l/100 km of petrol or 3.6 l/100 km of diesel.

The tighter CO_2 emission targets for the EU car and van fleets for 2025 and 2030 will realise increases in fuel efficiency of up to more than one third ([54]). The expected reductions in energy consumption and CO_2 emissions because of improvements in fuel efficiency may be offset by rebound effects ([55]). One of the policy tools for reducing potential revenue losses is to increase the tax rates levied on transport fuels in real terms.

In Norway the overall tax on petrol, made up of energy and CO_2 taxes, increases annually, at least in line with inflation, so that the real petrol tax rate is constant. However, Norway's petrol tax revenues declined by about 70 %, at 2010 prices, between 1995 and 2017, which is the result of several factors, including the shift towards electric vehicles ([56]). This issue is high on the national agenda, as reducing CO_2 emissions from transport is part of an overall policy to decarbonise the transport sector and the whole economy. It also deserves greater attention across Europe as it shifts

([54]) For further information see EC (2020c).

([55]) Increasing efficiencies can provide some gains in income — by decreasing the costs of using resources — that are then spent on more consumption, e.g. driving further in more fuel-efficient cars, so that not all of the expected gains in terms of reduced consumption will materialise. This fact is called the rebound effect, and is also known as the Jevons paradox (Jevons, 1865) if the rebound effect is greater than 100 %, i.e. outdoing the efficiency gains. For discussions of the rebound effect, see Sorrell (2007) and Greening et al. (2000).

([56]) The distances travelled by passenger cars are increasing in Europe and the growth rates vary between countries. Average annual growth at the EU level between 1995 and 2016 was 1 % but ranged from 2.5 % in Estonia to 0.4 % in the Netherlands and the United Kingdom (EC, 2018lh).

from oil-driven to electric vehicles, because current energy taxation schemes have much higher tax rates on transport fuels than on electricity (EEA, 2016).

A report published by the Organisation for Economic Co-operation and Development analysing various scenarios for decarbonising road transport in Slovenia came to the same conclusion, namely that tax revenue from diesel and petrol use in private cars is likely to decline substantially in the coming decades. This would put stress on government budgets, particularly in countries where fuel tax revenues represent a large share of total revenue (OECD/ITF, 2019) ([57]). The German Advisory Council on Global Change also foresees erosion of the tax take from fossil fuel and CO_2 taxation schemes in the long term, projecting a drop in fiscal revenues from a CO_2 tax and emission trading to zero as a result of the long-term decarbonisation of the German economy (WBGU, 2016).

Overall, it can be expected that tax bases will shrink as the EU system of environmental, energy and climate policy targets and objectives is enlarged, deepens and becomes more stringent ([58]) over the coming decades. As the tax base erodes, governments will need to identify new streams of revenue to compensate. In the area of carbon taxation, there is significant scope for broadening the tax base and increasing rates, and therefore in the short term this may help to bridge the gap in revenues. However, this will not be sufficient in the long term as carbon use decreases. 'The twin issues of carbon entanglement and long-term fiscal sustainability are only just beginning to be discussed in government finance ministries. Yet, as noted above, they are central to the success of the transition to low-emission, resilient economies' (OECD et al., 2018).

4.3.2 Technological transition, the collaborative economy and fiscal sustainability

As discussed in Chapter 3, new technologies will challenge 'traditional work arrangements and social protection systems … and may further exacerbate inequality' (OECD, 2018b). Safeguarding fiscal sustainability must take account of changes in employment patterns such as the rise of non-standard employment, the gig economy ([59]) and the emergence of the collaborative economy, especially the sharing economy and some forms of circular economy.

There is an observable trend towards increasing levels of atypical work in the EU, as permanent full-time employment as a share of total employment declined from 63 % in 2002 to 59 % in 2016, while the share of employees either employed through temporary contracts or in permanent part-time employment increased by 21-25 % over the same period (EC, 2018f).

Overall, the number of atypical/non-standard workers does not represent a significant share of the EU's workforce today ([60]); however, a faster increase in non-standard employment in the coming years can be expected as 'non-standard workers stand significantly higher risk of working on a job with high automation potential' ([61]) (EC, 2018f). The OECD (2018b) summarises the challenges for tax policy as 'increasing non-standard work may lead to increased ease of re-characterising labour as capital income, less revenue through social security contributions (SSCs), and reduced benefit entitlements, but potentially more job flexibility' ([62]). In addition, 'changes to the structure of labour markets, including an increasing number of non-standard 'gig' jobs, raise complexities for tax collection, and the equity and efficiency of the tax system' (OECD, 2018b).

The collaborative economy is probably one of the most fundamental developments posing challenges for the tax system, as it increasingly blurs the traditional boundaries in the legal and taxation systems, resulting in uncertainty over how existing classifications should be applied to businesses in the collaborative economy and the potential for similar activities to be taxed differently (EC, 2017c). The policy challenges are summarised in Box 4.3. As of 2016, 12 EU Member States are addressing this dichotomy by initiating or implementing policies and legislative acts ([63]) (EC, 2017c).

([57]) See also the discussion in the IEA *Global EV outlook* 2019 report and the options for the long-term stabilisation of fiscal revenue from transport (IEA, 2019a).
([58]) See EEA, (2019b) and ETC/WMGE (2019a).
([59]) The *gig economy* is a free market system based on flexible, temporary, or freelance jobs leading to increased flexibility in the labour market. The rise of the gig economy is closely connected to the increase use of online platforms. The gig economy is also known as the sharing economy, platform economy, collaborative economy or crowd work (see EP, 2016).
([60]) For a discussion of what is understood by atypical work, see the European Foundation for the Improvement of Living and Working Conditions' definition (Eurofound, 2020).
([61]) See also the discussion of the possible risks of non-standard work, as workers under these contract arrangements 'may be excluded from certain social protection rights or may receive wages at different levels from what would be justified by their productivity' (EC, 2019f).
([62]) For an analysis of how the world of work is changing by increasing the number of non-standard jobs and how these developments affect the tax systems in eight countries, see Milanez and Bratta (2019) and EP (2016, 2018).
([63]) See, for example, Bräutigam et al.'s (2019) discussion of the need to reform the tax system on the basis of a fiscal analysis of Airbnb in Germany.

Box 4.3 The challenges of the collaborative economy for policymaking

The collaborative economy raises the issue of when and how it should be taxed. On the one hand, taxation should not hamper such innovation at the outset. The collaborative platform allows more flexible working arrangements, increases resource efficiency and facilitates the circulation of information, hence creating new market places. It creates new job opportunities and may facilitate access to the labour market for low-skilled workers. On the other hand, if the collaborative economy is not taxed, tax bases will erode as their market presence grows, and traditional business models will suffer from a competitive disadvantage (as they will be taxed). Similar activities should be taxed in the same way, whether they take place in traditional sectors or in the collaborative economy sector. Moreover, the development of the sharing economy should not be a simple shift in the labour force from the traditional economy towards new forms of work with less social protection or poorer working conditions (EC, 2017d).

4.3.3 Future challenges for public budgets and the green economy transition

Looking ahead, this analysis of trends in the composition of government expenditure in EU countries provides some fundamental points for future consideration. First, traditional government functions, such as health and social protection, which already take up the lion's share of government expenditure in all countries, can be expected to further increase. Second, the transition to a low-carbon and resource efficient economy will require much larger investment from public authorities than the current expenditure on environmental protection.

Third, on the revenue side, the demographic and technological transitions will together likely alter tax revenues from employment substantially. Fourth, revenue-generation from environmental taxes will decrease as the EU meets its stricter future environmental and climate policy targets and objectives. Fifth, an ageing Europe will very likely increase the competition between social and environmental demands on public budgets. Finally, environmental taxation indexed to inflation can support green public investment in the short run but it cannot be expected to cover the full gap in the longer run ([64]); private finance will be needed to close the gap especially for infrastructure investment.

4.4 Finance for the green economy transition

Investment is crucial for transition processes and therefore it is critical to align the financial flows from public and private resources with the goals of the 2030 Agenda for Sustainable Development, the Paris Agreement, as well as with European environment and climate policies. This is also recognised in the European Green Deal in which sustainable finance is an important component as the investment needs are huge for achieving the ambition laid down in the European Green Deal (EC, 2019b). The significance of mobilising the public and private sector to finance the investment challenges is emphasised in the European Green Deal. The Sustainable Europe Investment Plan published by the EC in January 2020 is defined as the investment pillar of the European Green Deal and expected to play a key role as 'the Plan will mobilise at least EUR 1 trillion of sustainable investments over the next decade through the EU budget (EC, 2020a)'.

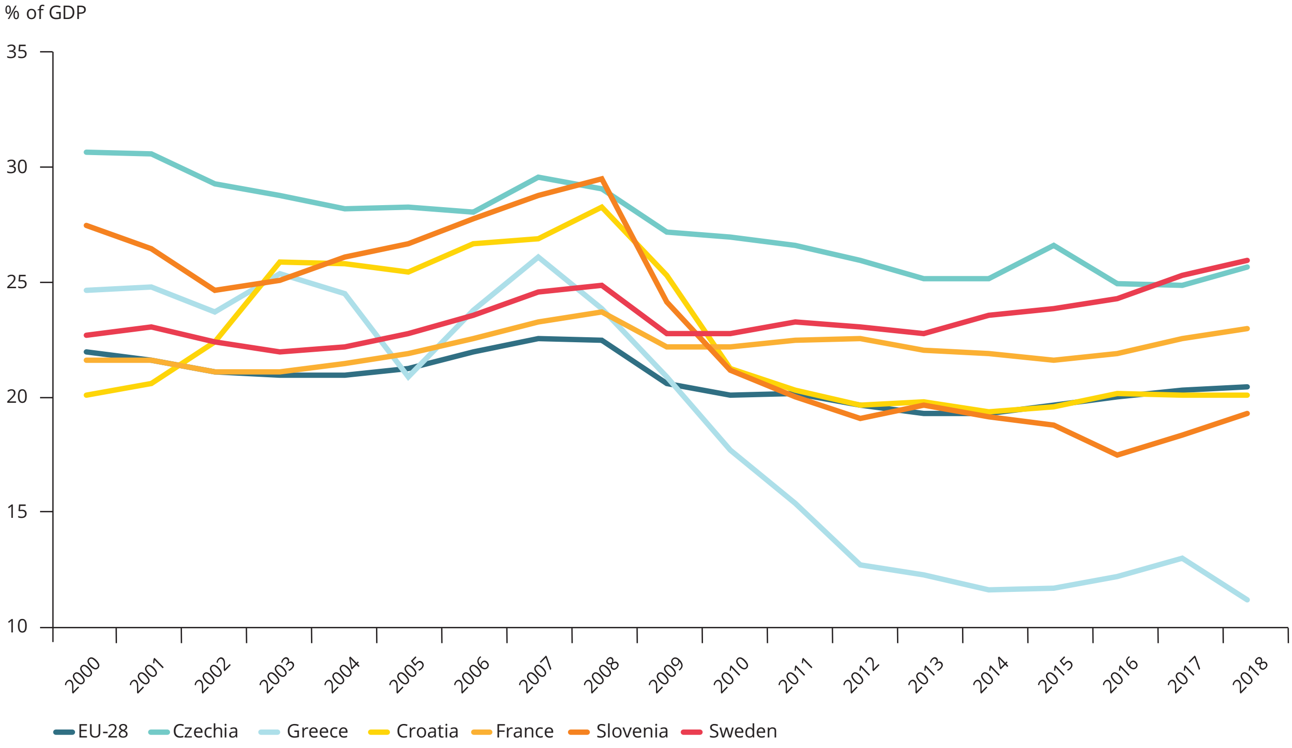
The current economic conditions, including low interest rates, broadly favour investment in the sustainability transition; however, current investment trends do not give cause for optimism (EIB, 2017; OECD, 2017b; OECD et al., 2017 and 2018; EBRD, 2018; EIB, 2018). The overall generally weak trend in investment in the EU countries partly explains this, especially in capital formation. For public investment, this is the result of fiscal consolidation and constraints in many EU countries, while, for private investment, weak demand and low economic growth have curtailed investment ambitions.

4.4.1 Investment — past trends

The EU remains affected by a general investment malaise. Investment in gross fixed capital formation increased rather steeply as a percentage of GDP in the years before the 2008 economic and financial crisis, then it collapsed in 2008/2009. Although investment

([64]) For a detailed study assessing what countries currently do with the revenues from carbon taxes, emissions trading systems and excise taxes on energy use, see Marten and van Dender (2019).

Figure 4.7 **Trends in investment (gross fixed capital formation as a percentage of GDP) in the EU-28, Croatia, Czechia, France, Greece, Slovenia and Sweden, 2000-2018**



Source: Eurostat.

has recovered since 2013, the levels remain lower than before the crisis with the exception of countries such as Sweden (Figure 4.7) ([65]).

One of the main reasons for this malaise is weak final demand by consumers, which hinders investment by businesses in increasing production capacity. Another is the persistent liquidity trap in many EU countries. After the initial stimulus from public support in the years after the 2008 financial crisis wore off, consumption demand as a proportion of GDP decreased and remains below pre-crisis levels in many EU countries.

In 2018, corporations contributed 61 % of total investment at the EU level, followed by households at 25 % and the public sector at 14 % (down from 18 % in 2009). The public sector share differed widely in 2018 across EU Member States, varying from 9 % in Ireland to 27 % in Greece and 30 % in Cyprus. The huge contribution of the public sector in Greece reflects the overall low level of investment, at 11 % of GDP compared with 21 % across the EU. Other countries with low total investment to GDP ratios compared with the EU average are Italy, Luxembourg, Portugal, the United Kingdom and Italy.

Public investment in the environment

Government investment in environmental protection shows significant differences among the EU Member States, Norway and Switzerland (Table 4.2). At the European level, public investment has fallen over the period 2005-2017 and that trend is reflected in most countries. Two countries, Greece and Norway, more than doubled their expenditure on environmental investment, while others cut public investment, most notably Croatia, Portugal and Spain. Overall, the trends reflect a structural weakness in the allocation of public investment in the environment, an aspect to bear in mind when considering future needs for and gaps in investment to meet environmental and climate policy objectives.

([65]) Net investment figures, i.e. gross fixed capital formation less consumption of fixed capital (depreciation), illustrate the same trend, namely that capital spending (investment activities) plummeted after the 2008/2009 economic and financial crisis and that net investment was negative in some EU Member States, such as Greece, Italy and Portugal in the 2010s. For details, see the Directorate-General for Economic and Financial Affairs' AMECO database (EC, 2020d).

Table 4.2 **Investment in the environment measured as gross fixed capital formation (GFCF; broad environment function) in the EU-28, Norway and Switzerland, 2005 and 2017**

	Share of GFCF (% of GDP)		Share of GFCF (% of total GFCF)		Share of GFCF (% of government GFCF)		Change (%) in GFCF between 2005 and 2017 (constant 2010 prices)
	2005	2017	2005	2017	2005	2017	
EU-28	1.1	0.9	5.2	4.4	35	32	-8
Belgium	0.7	0.6	3.1	2.7	32	29	8
Bulgaria	1.5	0.7	5.7	4.0	40	33	-31
Czechia	3.0	1.4	10.6	5.8	57	42	-37
Denmark	0.5	0.8	2.5	3.5	19	22	63
Germany	0.6	0.6	3.2	3.0	32	27	20
Estonia	1.5	1.7	4.7	7.1	33	32	43
Ireland	1.2	0.7	4.1	3.2	35	41	0
Greece	1.2	3.1	5.7	23.8	27	71	111
Spain	1.7	0.6	5.6	3.0	40	31	-59
France	1.2	0.9	5.3	3.8	29	26	-16
Croatia	3.1	0.7	12.3	3.6	55	27	-75
Italy	0.9	0.5	4.4	3.0	31	27	-45
Cyprus	0.7	0.4	3.2	1.7	20	13	-41
Latvia	0.9	1.2	2.9	5.5	27	26	57
Lithuania	1.4	1.1	6.1	5.8	40	35	5
Luxembourg	1.8	1.8	9.5	9.5	37	44	33
Hungary	1.7	1.8	7.0	8.1	40	40	26
Malta	1.2	0.5	5.4	2.5	26	23	-29
Netherlands	1.5	1.4	7.2	6.8	39	40	11
Austria	1.1	1.0	4.9	4.3	38	33	6
Poland	1.5	1.8	8.1	10.4	45	49	90
Portugal	1.9	0.6	8.4	3.7	48	33	-68
Romania	1.8	1.1	5.1	5.1	29	44	-19
Slovenia	1.0	1.3	3.7	6.8	26	41	53
Slovakia	1.9	1.5	6.8	7.0	54	47	23
Finland	0.9	1.1	3.9	4.8	25	26	28
Sweden	1.2	1.3	5.5	5.1	30	28	33
United Kingdom	1.2	1.0	7.1	5.7	40	37	-7
Norway	0.9	1.9	4.4	7.7	26	36	150
Switzerland	1.0	0.8	4.1	3.3	34	27	1

Note: Romania — data are for 2007 and not for 2005. The table is based on COFOG data from Eurostat: the change in investment in GFCF is based on a 'broad environment' classification and includes the COFOG function GF05 Environmental protection as well investment data for GF0403 Fuel and energy, GF0405 Transport and GF0603 Water supply.

Source: Eurostat.

4.4.2 *Green economy investments — future needs*

The United Nations estimates of the investment needed to meet the 2030 Sustainable Development Goals (SDGs) conclude that advanced economies' shares 'represent US$1.5 trillion per year while [for] emerging markets and developing economies (EMDEs) [they] represent US$4.5 trillion' (UNEP FI, 2018). An International Monetary Fund publication sums up the investment needed:

> For advanced economies, average additional spending for electricity, roads, and water and sanitation is positive, but below 1 percentage point of GDP. In contrast, additional spending for health and education is about -3 and -1.5 percentage points of GDP, respectively. These results reflect particular challenges facing advanced economies. Addressing gaps in infrastructure must be achieved within tight fiscal constraints, while in education and health care, advanced economies must improve outcomes while controlling relatively high levels of spending. (Gaspar et al., 2019, p. 11)

This suggests that European countries may be faced with at least a doubling of public investment to meet their SDG commitments. The roles of public versus private financial investment differs between individual SDGs. Public intervention is seen as critical for ending poverty (SDG 1) and hunger (SDG 2), improving health (SDG 3) and education (SDG 4), achieving gender equality (SDG 5), reducing inequality (SDG 10) and enhancing infrastructure (SDGs 6, 7, 9, 11). The private sector typically plays a limited role in these areas, in part because the returns on investment may be highly uncertain or may take a long time (Gaspar et al., 2019) ([66]).

Overall, the role of public investment in the form of fiscal and redistribution policy, including spending on infrastructure, education and health, is crucial for development ([67]). Obviously an increase in investment infrastructure that exceeds a business-as-usual scenario will also have implications for material consumption and will stimulate economic growth. The capital for the necessary investment is available, and the potential for innovation is vast. What is most needed is strong political leadership and credible, consistent policies (New Climate Economy, 2014).

When it comes to climate change mitigation, the need for investment is expected to increase over time and both public and private funds are expected to play a role in meeting demand. However, there is a need to scale up existing investment efforts, as current global and EU infrastructure spending is below the estimated amounts needed up to 2030 so that the energy, transport, water and telecommunications infrastructure can sustain growth, even without further action on climate change (OECD, 2017b).

The EU high-level expert group on sustainable finance (HLEG, 2017) underlines, for example, that the EU is not on track to deliver the EUR 11.2 trillion required to meet its broader 2030 energy policy targets. The biggest gaps relate to investment in energy efficiency in buildings (74 %) and transport (17 %), respectively. The Commission estimated that an additional annual investment of EUR 260 billion will be required for the achievement of the current 2030 climate and energy targets (EC, 2019b and 2019g). The additional annual investment is estimated to be about 1.5 % of GDP. It is striking to compare this figure to the findings that 'today around 2 % of GDP is invested annually in our energy system and related infrastructure (EC, 2018a)'. A thorough analysis of the investment needed for modernising and decarbonising the EU's economy between 2031 and 2050 concludes that investment would have to rise to 2.8 % (or around EUR 520–575 billion annually) in order to achieve a net-zero greenhouse gas economy (EC, 2018d). It means that additional annual investments of between EUR 175 and 290 billion during the period 2031-2050 are needed, i.e. a similar scale to that required during the next decade.

However, the European Commission also states that the level of ambition of these infrastructure investments 'are large from a macro-economic perspective, as gross fixed capital formation is currently close to 20 % of GDP in the EU. An increase in total investment of 1-2 percentage points of GDP, for example, would represent a considerable shift from consumption to capital investments' (EC, 2018d). These findings must be seen in relation to the trends in investment shown in Figure 4.7, as investment as a share of GDP increased by 1.6 percentage points between 1995 and 2007 but then declined by 3.3 percentage points over

([66]) The United Nations Environment Programme Finance Initiative (UNEP FI) report (2018) states that 'it is estimated only about 10 % of current infrastructure investments come from the private sector.'

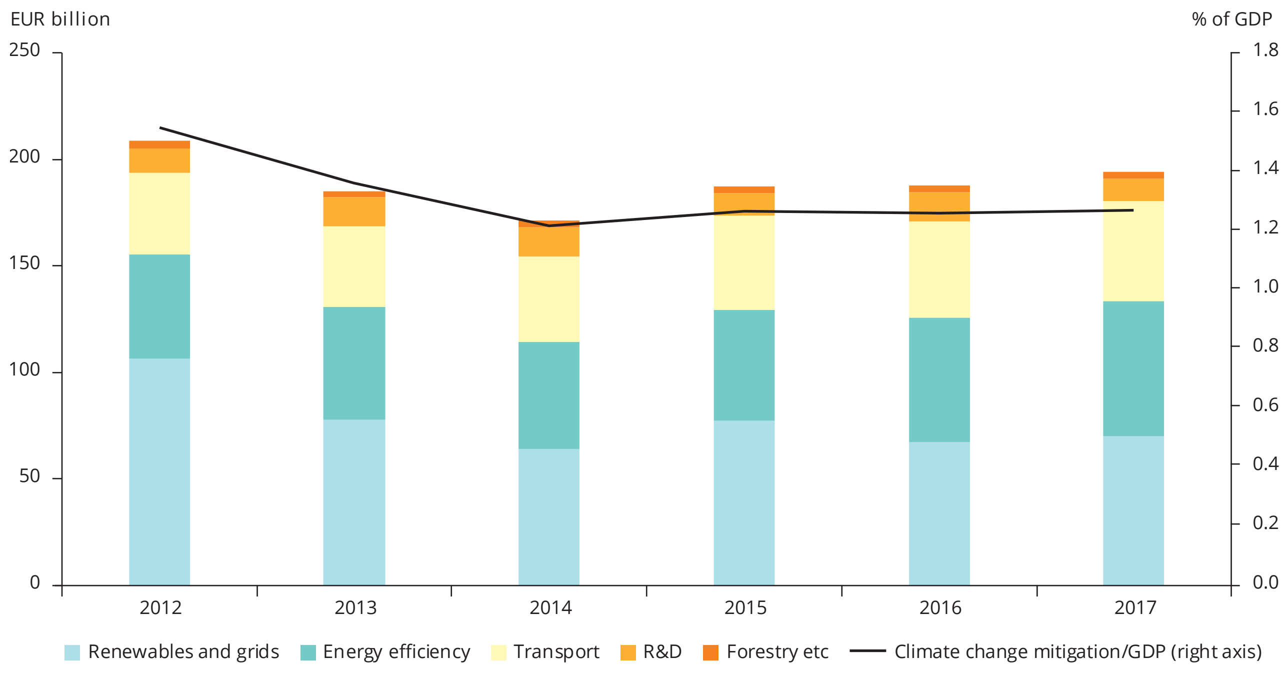
([67]) It is worthwhile highlighting that in April 2019 the Coalition of Finance Ministers for Climate Action was launched, recognising the challenges posed by climate change. Finance Ministries 'can also play a leading role in tackling climate change, incentivizing climate-informed public expenditure, and utilizing climate fiscal tools such as carbon taxes and emissions trading systems to cut emissions and prioritize low-carbon growth' (CAPE, 2020).

6 years because of the economic and financial crisis of 2008/2009 and other factors.

However, when looking at the actual trends in investment related only to climate change, as reported by the European Investment Bank (EIB, 2018), investment in climate change mitigation was around 1.6 % of EU GDP in 2012 but fell and more or less stagnated at about 1.3 % from 2014 onwards (Figure 4.8). As a share of gross fixed capital formation, it declined from 8.3 % in 2012 to 6.3 % in 2017. The European Investment Bank argues that 'investment in energy efficiency needs to be increased dramatically to meet EU targets for 2030 and beyond' and this investment is described as playing a 'pivotal role in the EU's endeavour to reach its long-run climate objectives' (EIB, 2018). The Sustainable Europe Investment Plan foresees that the EIB will be crucial in financing the transition to a carbon neutral, sustainable Europe as the EIB will become the EU climate bank. To achieve this objective, '[t]he EIB will gradually increase the share of its financing dedicated to climate action and environmental sustainability to reach 50% by 2025 and beyond' (EC, 2020a).

Regarding investment in the global energy system, experts have concluded that investment in the energy supply need be no higher than today but that additional investment is required in end-user sectors, i.e. in industry and households for more efficient appliances, building renovations, renewables and electrification (including electric vehicles and heat pumps) and not in electricity generation (OECD et al., 2018). This is of great significance, as it highlights the increasing role of the private sector in financing the sustainability transition. Climate finance data for European countries show that investment from the private sector already exceeds public investment. For example, in 2016 in France, households and private companies accounted for 64 % of total climate investment (Hainaut et al., 2018). Poland reported the same shares of climate investment expenditure in 2016 — public investment accounted for 36 %, corporations for 30 % and households for 34 % (WiseEuropa, 2019). The private sector share was somewhat higher in Germany for the same year, at 83 % of total investment, with the remaining 17 % coming from the public sector (Novikova et al., 2019). There was an overall increase of 16 per cent in climate investments in Germany between 2010 and 2016 where investment in energy efficiency measures increased by 18 % while investment in renewable energies declined by 6 % (Novikova et al., 2019) ([68]).

Figure 4.8 Trend in investment in climate change mitigation per sector in the EU-28, 2012-2017



Source: EIB (2018).

([68]) Recently published figures by CPI (2019) disclose that the average annual public climate expenditure in 2017/2018 represented 44 % of total commitments and private finance accounted for the majority of climate finance at around 56 %.

The International Energy Agency discussed the role of private-led energy investment and concluded that the private sector, companies and households initially finance about 90 % of energy investment:

> *Although stable over 2016-17, the share of private-led energy investment, in terms of ownership, declined in the past five years*. Despite the growing roles of renewables, where private entities own nearly three-quarters of investments, energy efficiency, which is dominated by private sources, and private-led grid investment, the share of investment from national oil companies and state-owned enterprise (SOE) thermal generators has risen by more. In terms of financing, public financial institutions underpin the largest thermal power investments in emerging economies; nearly all nuclear investments rely on state-backed finance. (IEA, 2018; p. 117, italics in original)

Although climate and energy will take the lion's share of transition investments, achieving the EU's other environmental protection objectives and targets will require further investment. For example, it is estimated that an additional EUR 54 billion and EUR 60 billion a year will be needed up to 2030 to meet air pollution and water quality objectives, respectively (FMST, 2019). It is instructive to compare these numbers with current public investment flows to see the scope of what is needed: in 2017, total public investment in the EU-28 for pollution abatement amounted to EUR 2.2 billion, for wastewater management EUR 7.4 billion and for water supply EUR 4.4 billion.

At the macroeconomic level, investment gaps exist elsewhere when considering Europe's desire for wealth creation and the need to maintain its competitiveness (EIB, 2016, 2018). For example, the European Investment Bank estimates annual gaps in investment in information and communication technology for broadband and digitalisation, in social and affordable housing, and in education and health; together these amount to EUR 81 billion or 0.6 % of GDP or 3 % of gross fixed capital formation (EIB, 2018). Again, increasingly strained public balance sheets limit the potential for public investment in these sectors while highlighting untapped potential for involving the private sector in triggering a green economy that is also a 'just transition'.

4.4.3 Private finance and the green economy transition

Development of private finance for the green economy

The increasing pressure on governments' fiscal sustainability suggests that only a limited fraction of the green funding needed may come from the public sector. This implies an increasing role for financial markets to enable private investors to pursue climate change goals as well as other environmental policy objectives and targets, such as the circular economy.

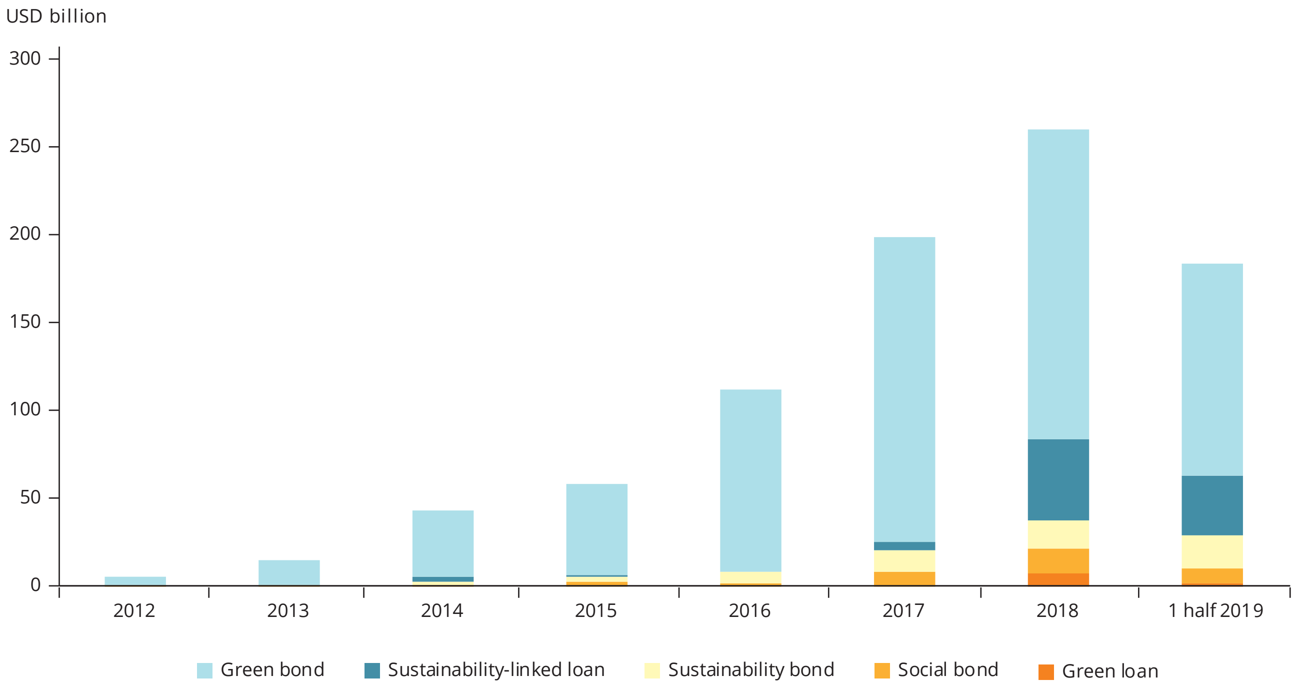
A growing number of institutional investors — pension funds, insurance companies, foundations and investment funds — are actively seeking financial products that support sustainability without compromising returns, liquidity or pricing. These investors are ever more willing to include socially and environmentally sustainable assets in their portfolios, and they are increasingly committed to adopting sustainability criteria in selecting their investments.

The increasing attention focused on green, sustainable or social financial instruments has increased the demand to develop a suitable framework for assessing which investments are really 'sustainable' and which are prone to environment-related risks. The issues are those of reliable criteria and reliable data, the latter being still rather scattered, as in the case of climate finance in the EU ([69]), for which a large number of European countries are unable to provide data on climate-related finance.

The *Roadmap for a sustainable financial system*, proposed by UN Environment and the World Bank (2017) exemplifies the complexities of the transition to including sustainable development principles in financial instruments, including issues related to data availability, the heterogeneity of the stakeholders and the differences between traditional and green investments in terms of returns, risks and relevant time horizons.

([69]) See, for example, *Assessing the state-of-play of climate finance tracking in Europe* (Trinomics, 2017), a report commissioned by the EEA.

Figure 4.9 Sustainable debt finance annual issuance, 2012-2019 (USD billion first half for 2019)



Source: BloombergNEF (2019).

The green bond market and future developments

The increasing issuance of green bonds is a clear example of how green investments have evolved in recent years. Green bonds are 'aimed at financing investments with an environmental benefit or a focus on reducing vulnerability to environmental change' (EEA, 2014).

Green bond issuances amounted to USD 177 billion in 2018 and, although no longer a niche product, they are still a tiny fraction of the more than USD 100 trillion global bond market (Bloomberg, 2019). A new phase started with the adoption of the United Nations' SDGs in 2015 as new bond markets emerged to finance projects aiming to address social issues. In 2018 social and sustainability bonds amounting to approximately USD 59 billion were issued.

Figure 4.9 reports the recent trend in sustainable debt finance. According to Bloomberg, 2019 was a record year in this respect and, assuming that issuance rates in the second half of 2019 were the same as in the first half of that year, an aggregate value of USD 380 billion for the whole of 2019 is expected. Green bonds dominate, and sustainability and social bonds are playing an increasing role. Despite these successes, 'the deployment of private capital for sustainable finance is still relatively limited' (UN Environment, 2019b). It could also be that the influence of social and sustainability bonds will grow as investors use the SDGs as benchmarks for measuring impact.

Sustainable finance in the EU political discourse

At the EU level, the sustainable finance initiative has been essential for 'developing an overarching and comprehensive EU roadmap on sustainable finance' (HLEG, 2018). This is because meeting EU environment and climate change objectives requires reorienting the European financial system by aligning economic, social and environmental goals. The underlying rationale is to improve the contribution of finance to sustainable and inclusive growth, in particular funding society's long-term need for innovation and infrastructure, and accelerating the shift to a low-carbon and resource-efficient economy. The second rationale is to strengthen financial stability and asset pricing, notably by improving the assessment and management of long-term material risks and intangible drivers of value creation — including those related to environmental, social and governance factors (HLEG, 2017).

Focusing on sustainable finance in general, the high-level expert group on sustainable finance identified the main features of a sustainable financial system (HLEG, 2017, Box 3), including its need to:

- consider the full value of financial assets, incorporating sustainability factors into valuations;
- be productive, serving its users' projects and needs;
- be resilient, withstanding and recovering from a wide range of shocks;
- demonstrate alignment between the sustainability preferences of its users and the outcomes of the decision-making process, ensuring accountability and transparency;
- take a long-term perspective and overcome the 'tragedy of the horizon' (see Carney, 2015).

Although the high-level expert group on sustainable finance concluded that a complete restructuring of the rules governing the financial system was not necessary, a comprehensive approach is required to align the financial system with sustainability strategies, and some regulations may have to be adapted to implement the required changes.

The European Commission's action plan on financing sustainable finance (EC, 2018b) sets out a comprehensive strategy to connect finance with sustainability in response to the recommendations of the high-level expert group on sustainable finance ([70]). The action plan aims, in particular, to reorient capital flows towards sustainable investment; manage financial risks stemming from climate change, resource depletion, environmental degradation and social issues; and foster transparency and long-term thinking in financial and economic activities.

The recent developments in the European legislative framework on sustainable finance testifies to the intention of including sustainability issues in financial market regulation. For example, legislative proposals aiming to implement the action plan on sustainable finance and support the completion of a capital markets union ([71]) have been made, including a regulation on disclosure relating to sustainable investment, sustainability risks and benchmarks (EC, 2020e).

A technical expert group on sustainable finance was set up to support the European Commission's work ([72]), and in June 2019 it published a technical report on an EU taxonomy for sustainable activities (TEG, 2019), which is seen as critical in directing attention to sustainability activities and finance across the economy. The EU taxonomy develops harmonised technical screening criteria and thereby determines whether an economic activity is deemed to be environmentally sustainable in at least one of the six environmental objectives ([73]) while avoiding significant harm to the other environmental objectives. The taxonomy will provide clear guidance for investment decisions as corporations are required to increase the disclosure of climate and environmental data. This will allow investors to direct their investments into environmentally sustainable activities, thereby supporting the transition of the European economy.

Sustainable finance: initiatives by financial institutions

Beyond political developments, financial institutions have taken many initiatives to tackle the challenges of environmental and climate risks, as well as looking at how these risks can be classified, disclosed, measured and possibly hedged. Mark Carney, at the time Governor of the Bank of England, in his speech 'Breaking the tragedy of the horizon — climate change and financial stability' (Carney, 2015) pointed to

([70]) For further information, see https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance_en

([71]) See https://ec.europa.eu/info/business-economy-euro/growth-and-investment/capital-markets-union_en.

([72]) For an over view of the group's work, see https://ec.europa.eu/info/publications/sustainable-finance-technical-expert-group_en#disclosures

([73]) The six environmental objectives are: climate change mitigation; climate change adaptation; sustainable and protection of water and marine resources; transition to a circular economy; pollution prevention and control; and protection and restoration of biodiversity and ecosystems.

three distinct risks that could affect financial stability — physical risk, liability risk and transition risk — stating that 'climate change becomes a defining issue for fiscal stability'.

By March 2019, the Climate Action in Financial Institutions Initiative (CAFII), launched in 2015, had engaged 44 financial institutions from all around the world: 22 bilateral, regional and national development banks, 12 multilateral development banks and subsidiaries, and 10 commercial financial institutions. CAFII acts as forum for knowledge creation and developing recommendations and its main aim is 'mainstreaming climate change considerations throughout financial institutions' operations, and in their investing and lending activities'. ' 'Mainstreaming' implies a shift from financing climate activities in incremental ways, to making climate change — both in terms of opportunities and risk — a core consideration and a 'lens' through which institutions deploy capital' (CAFII, 2020).

CAFII's action is in parallel with the Network of Central Banks and Supervisors for Greening the Financial System, created in 2017 by eight central banks and supervisors and now including 36 members and six observers. Its main purpose is 'to help strengthening the global response required to meet the goals of the Paris Agreement and to enhance the role of the financial system to manage risks and to mobilize capital for green and low-carbon investments in the broader context of environmentally sustainable development' (NGFS, 2019 ([74])).

In 2015, the Financial Stability Board Task Force on Climate-related Financial Disclosures was established and is today a central actor in the sustainable finance debate, as it supports companies to 'understand what financial markets want from disclosure in order to measure and respond to climate change risks, and encourage firms to align their disclosures with investors' needs'. The Task Force approach takes account of the challenges of physical, liability and transition risks and aims to 'develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders' (TCFD, 2020).

Overall, the increasing role of the private sector will be vital for achieving the critical mass of investments required for the low-carbon transition. The involvement of the private sector, however, may not always be taken for granted and could depend on three major factors (ETC/WMGE, 2019b): (1) the financial sector's attitude to allocating finance to low-carbon investments; (2) the economic attractiveness of these investments in comparison with other types of investments; and (3) the existence of motives beyond pure economic and financial returns, which may range from complex leadership strategies to participatory finance and ethical finance for sustainability ([75]).

4.4.4 Back to public resources: the future EU budget — financing energy/climate and the environment

The EU multiannual financial framework (MFF) establishes maximum annual amounts, or ceilings, that the EU may spend in different policy areas over a period of at least 5 years. In 2018, the European Commission presented a proposal for the new MFF for 2021-2027, amounting to EUR 1 279 billion, corresponding to EUR 1 134 billion at 2008 prices (EC, 2018i), which is now under negotiation. The figure is about 1.1 % of the EU's estimated gross national income.

The major areas of the proposed MFF 2021-2027 are: Single market, Innovation and Digital, including Horizon Europe for research and innovation, almost 15 % of the total MFF; Cohesion and Values, including Regional Development Fund and Social Fund, some 35 %; Natural Resources and Environment, including Agricultural and Maritime Policy, at nearly 30 %. These three areas together cover four-fifths of the proposed MFF.

The European Commission (EC, 2018i) proposed further strengthening of climate mitigation and adaptation in the MFF for 2021-2027. In particular, it suggested increasing the current targets for EU budget expenditure on climate objectives from 20 % to 25 %, including an increase in Horizon Europe's expenditure on climate-related research to 35 %. The commitment to 'mainstreaming climate change' to 25 % in the new MFF proposals would shift the total allocation to climate

([74]) See https://www.banque-france.fr/en/financial-stability/international-role/network-greening-financial-system.

([75]) Internal carbon pricing is a tool to increase the attractiveness of low-carbon investments. It helps to identify climate-related risks, as financial institutions can detect forward-looking carbon costs. The Task Force on Climate-related Financial Disclosures recommends using internal carbon pricing, but its use is still rather limited among financial institutions. For further details, see Navigant et al. (2019).

([76]) According to Directorate-General for Climate Action, 'the EU is broadly on track towards the 20 % target, but further efforts are needed. Based on the current trend, the climate-related spending under the 2014-2020 budget is projected to amount to EUR 200 billion or 18.8 % of the EU operational spending commitments' (EC, 2020f).

change from EUR 206 billion to EUR 320 billion, an additional EUR 114 billion ([76]).

The more environment-related 'new and reinforced priorities', which will receive significant additional budget compared with the previous MFF 2014-2020, are research and innovation (increase of 60 %) and the LIFE programme (increase of 70 %). A clearer demonstration is needed, however, ex ante and ex post, that these budget increases will actually go to climate-related investment/expenses and not just to conventional industrial and local development policies.

The EU has other instruments to support investment. For example, the European Investment Bank, which is committed to having no less than 25 % of total investment going to climate-related projects, has become the largest multilateral provider of climate finance worldwide. In 2018, the European Investment Bank invested EUR 16 billion in climate-related projects — and for renewable energy projects the figure was EUR 4.7 billion in 2017 ([77]).

Within the MFF 2021-2027 process, a reform of the EU's own resources has been initiated, starting from the proposals of the high-level group on own resources (Monti et al., 2016). The Proposal for a Council Decision on the system of Own Resources of the European Union (EC, 2018j), currently under negotiation, includes two new sources belonging to the class of market-based instruments for the environment ([78]).

The first of these sources is a contribution from the revenue generated by auctioning allowances under the EU Emissions Trading System (ETS). According to the European Commission (EC, 2018j), 'this would involve allocating a share of 20 per cent of certain revenues from the total of allowances available for auctioning to the EU budget.' The revenue from auctioned allowances dedicated to financing the Innovation Fund and the Modernisation Fund, as established under the revised EU ETS, will not be subject to the own resource contribution, whereas 'allowances available for auctioning that a Member State can allocate for free to the power sector should be counted towards the Own Resource contribution to ensure that the decision whether or not to make use of that option is based on economic grounds' (EC, 2018j).

The estimated amount of own resources coming to the EU budget from this measure is in the range of EUR 1.2-3.0 billion per year, depending on the market price of allowances and the annual volume auctioned, which in turn depends on the operation of the market stability reserve under the reformed EU ETS.

The second of the environment-related sources is a contribution arising from non-recycled plastic packaging waste. The measure is linked to the European strategy for plastics in a circular economy (EC, 2018k), and, according to the European Commission (EC, 2018j), 'the proposed Own Resource contribution would be directly proportional to the quantity of non-recycled plastic packaging waste generated in each Member State.' It is not a tax on plastics at the EU level, rather 'an incentive for the Member States to reduce these waste streams' in that 'the Own Resource contribution would be proportional to the quantity of non-recycled plastic packaging waste reported each year to Eurostat' (EC, 2018k). The potential revenue will be EUR 7 billion per year, based on a call rate of EUR 0.80 per kilogram of non-recycled plastics.

Together, these two market-based instruments are expected to provide 6 % of the total EUR 178 billion of own resources estimated to be available on average per year over the period 2021-2027. There are no provisions for these environment-related revenue streams to be earmarked for climate/environment investments and expenses.

4.5 A summary — fiscal competition, finance and the green economy transition

In a European macroeconomic policy environment pervaded by fiscal discipline and in the context of the public budget deficit criteria associated with the Stability and Growth Pact, fiscal sustainability may emerge as a long-term limitation on all public policies, with a clear priority necessarily given to social spending.

In this framework, financing the transition to a low-carbon, circular and green economy, as envisaged

([77]) In her speech to the European Parliament on 16 July 2019, the new President of the European Commission, Ursula von der Leyen, announced her agenda for turning the European Investment Bank into Europe's climate bank and wants to at least double its total finance dedicated to climate investment, which currently stands at 25 %, by 2025 (von der Leyen, 2019). This is now part of the Green Deal launched at the beginning of 2020.

([78]) The other innovative measure is a common consolidated corporate tax base (CCCTB) (EC, 2018m).

by the European Green Deal, the Paris Agreement and the United Nations' 2030 agenda for sustainable development and SDGs, is among the major challenges of our time. However, it cannot be seen as independent of other factors, which are crucial for its overall development, such as the design of the existing fiscal system. One of the future challenges is to revise the fiscal system in response to future challenges but this is not an easy task because of the existing fiscal system:

> Tax-base erosion presents another economic threat as the current system, based on 'bricks-and-mortar' and nation-states, struggles to keep pace with the globalised digital economy. Tax erosion could be a drag on public spending, including investment in, for example, programmes designed to reduce greenhouse gas emissions. Current tax systems may need re-evaluation as automation changes workplaces potentially reducing the number of jobs available (PwC, 2018b, p. 24).

There are good reasons to be cautious about the revenue-generating aspect of environmental taxation in the long run, with environmental and fiscal considerations supporting each other, in particular in the context of the tax-shifting programmes implemented in European countries in the 1990s and early 2000s (EEA, 2006, 2016). Meeting the EU's climate and energy objectives will erode the tax base of current energy taxation systems, especially with regard to taxes on transport fuels.

At the same time, the sustainability transition ([79]), as shaped by EU strategies and policies, requires a significant amount of public and private investment. The actual level of such investment in the major areas of the sustainability transition is, however, far lower than necessary. Public investment in the environment in EU countries is structurally low and has not increased in the last decade. Persistent fiscal unsustainability issues in many countries and the dual impacts of social spending and declining fiscal revenues caused by the ageing population limit future room for manoeuvre in all countries.

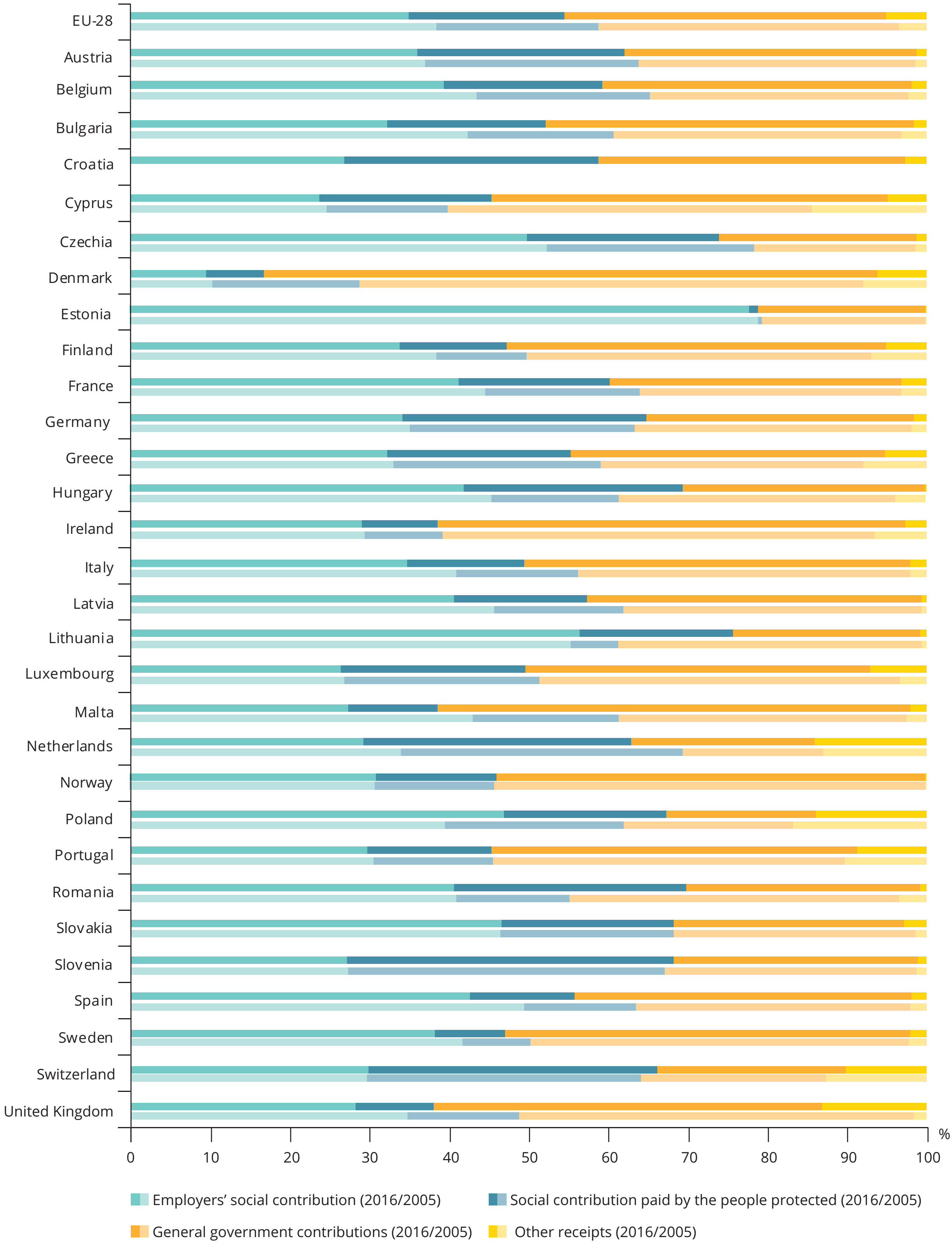
The role of the private sector will therefore be crucial in achieving the critical mass of investment required for the sustainability transition, both in general and specifically for innovation. The financial sector's attitudes to and the economic attractiveness of investing in the sustainability transition, in comparison with other types of investment, and the existence of innovative forms of 'social finance' (e.g. participatory finance, ethical finance) are among the key criteria for success.

The financial system is increasingly recognising and addressing climate-related risks. Various initiatives by financial supervisory bodies and central banks are responding to the need to embed climate risks in financial decisions. This changing perception in the financial system is reflected in an increasingly discriminatory attitude to borrowers' positive or negative contributions to the sustainability transition. This trend is emerging, for example, in terms of criteria for excluding certain activities when allocating financial investment and in the increase in major institutional and private investors taking a socially responsible approach to investment. The inclusion of such green and social conditions in portfolio allocation is growing rapidly and can be expected to become the new normal in future. It will therefore become an important lever for directing financial resources towards the sustainability transition.

This lively and ever-changing picture has found an institutional and regulatory framework in the EU's 2018 action plan for sustainable finance (EC, 2018b), which aims to reorient capital flows towards investment in sustainability, mainstreaming sustainability into risk management, and fostering transparency and long termism. The mainstreaming of climate change, now reinforced in the EU's MFF 2021-2027, can also contribute to redirecting private and public investment towards the transition.

([79]) For an overview of concepts and analytical tools relating to the sustainability transition, see EEA (2018), and for the practical implications of transitions research for policy and practice, see EEA (2019a).

Figure 4.10 **Changes in social protection receipts as a share of total receipts in the EU, Norway and Switzerland, 2005 and 2016**



Note: EU 2005 refers to the EU-27, as no data are available for Croatia for 2005.

Source: Eurostat.

5 Modelling the interactions between population ageing, technical change and fiscal sustainability

The peculiarity of the challenges addressed by this report is their systemic character and strong interdependencies, bringing into play feedback loops, delays and non-linear effects. In essence, prevailing policy approaches are no longer adequate for facing these interconnected challenges, because they are likely to address one issue, leading to suboptimal outcomes. New systemic thinking is required to identify, assess and prioritise policy interventions to deliver solutions to the parallel fiscal, socio-economic and sustainability transition challenges facing Europe.

It is also clear that assessing systemic issues and solutions calls for the use of integrated models. In this respect, the analysis presented in this chapter takes the approach of jointly modelling the impacts of multiple transitions and the potentially reinforcing or balancing effects of the ageing population, technological change, environmental policies and fiscal sustainability ([80]). The two models used for the analysis are: a quantitative Computable General Equilibrium (CGE) model to forecast the impacts of ageing population, technological change and environmental policies on fiscal sustainability and macroeconomic performance; and a qualitative systemic model (causal loop diagram, CLD) that analyses the simultaneous impact of social, economic and environmental variables on a system's performance.

Both modelling approaches employ a systemic approach but to different extents. The CGE estimates economy-wide impacts across a variety of economic sectors, as well as extending the analysis to the global economy (with dynamics across countries, specifically with inter-country flows of commodities and investments). The novelty of the approach is that while an ageing population, technological change and environmental policies have been widely investigated in the scientific literature in their own right, there are very few, if any, analytical studies that combine these three aspects to understand synergistic and non-synergistic linkages and feedback loops. The CLDs, based on systems thinking and system dynamics are bounded neither by data availability nor by formal methodological constraints. The result is a very comprehensive assessment of the main drivers of change in the system and of the impacts on them of macro-trends and selected policy interventions. There are two types of feedback loops: reinforcing (R) and balancing (B) ([81]).

5.1 The quantitative modelling approach

5.1.1 Description of the computable general equilibrium model framework

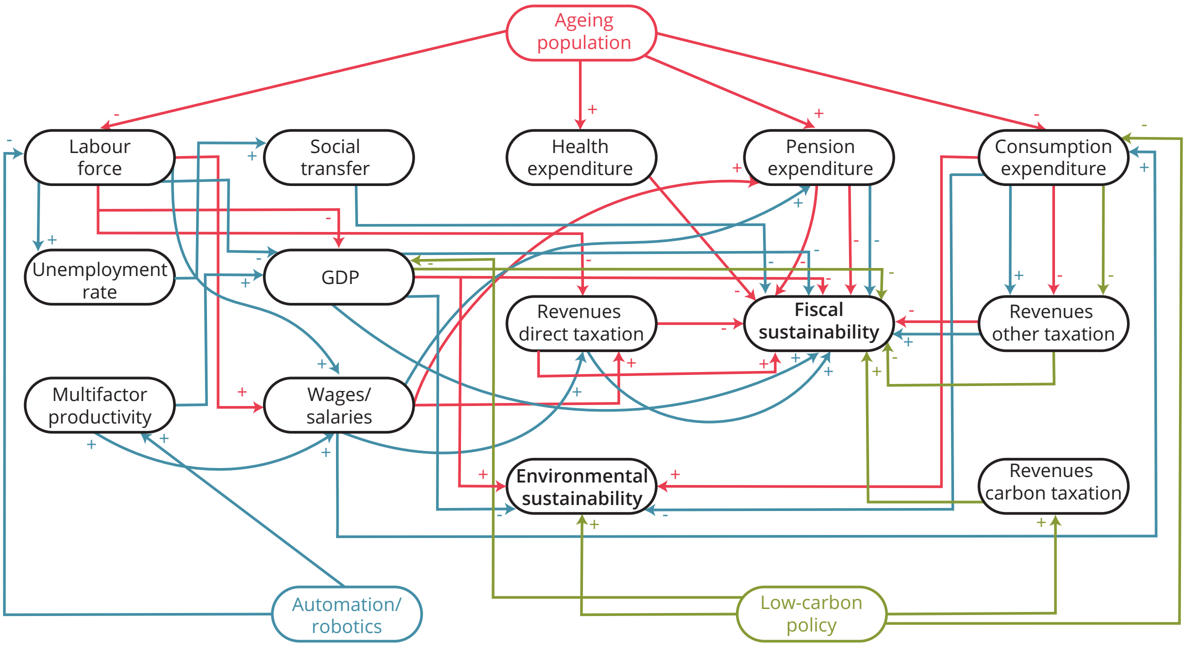
A general equilibrium approach models supply and demand behaviour across all markets in an economy (Lofgren and Diaz-Bonilla, 2010). Computable general equilibrium (CGE) models are a standard tool for empirical analysis and are widely used to analyse the aggregate welfare and distributional impacts of policies. The CGE model developed to carry out the analysis is called GDynEP-AG ([82]) and is enriched with a specific module for modelling changes in consumption patterns driven by various demographic trends ([83]).

The model evaluates linkages between these macro-trends through the lens of two EU key policy objectives: (1) achieving a deficit/GDP ratio threshold below 3 % under the EU Stability and Growth Pact; and (2) environmental sustainability objectives in the long-term, specifically decarbonisation by 2050.

Figure 5.1 describes the main interactions arising from integrating the ageing population and technological change into the context of environmental and fiscal

([80]) This chapter is an abridged version of the ETC/WMGE 2020 report that discusses the models and results in more detail.
([81]) See Annex 1 Box A1.2 for further information.
([82]) See Box 5.2.1 in Annex 5.2 of the ETC/WMGE report for a description of the model settings and full details of the modelling approach and the results in the report itself (ETC/WMGE, 2020). See also Costantini and Sforna (2020).
([83]) See Annex 1 Box A1.3 for further information.

Figure 5.1 Environmental and fiscal sustainability: effects of population ageing, technological change and environmental policies



Note: Red refers to impacts triggered by an ageing population, blue to the effects of technological progress and green to environmental/ climate policy measures.

Sources: Authors' own elaboration based on Golub (2013), Ianchovichina and Walmsley (2012), Peters (2016) and the GDynEP-AG model.

sustainability in the GDynEP-AG modelling framework. The figure distinguishes the three dynamics of ageing population (red), technological progress (blue) and environmental policies (green) and shows their impact on fiscal and environmental sustainability.

5.1.2 Modelling approach and results

Econometric models, like the CGE model used in this analysis, function by collecting historical data on a range of variables and using economic theory and statistical techniques to determine how changes in variables are correlated with changes in others and thus revealing the complex interactions between them and quantifying existing relationships (EEA, 2018 and EEA, 2020). This exercise therefore relies on actual data which is certainly a strength, but also a weakness: past relationships may not accurately capture current or future ones as 'futures are inherently uncertain (EEA, 2018)'; and a more sophisticated attempt to model pathways of causation would take a range of factors not captured by past data into account.

The base year in the model is 2015. Projections for macroeconomic variables, such as GDP and population, estimate long-term outcomes until 2050, dividing the time into eight steps of 5 years each. The model is then 'shocked' by changing policy or economic conditions, allowing observation of quantitative changes in the outputs, which provide an estimate of long-term outcomes, thereby revealing differences between the baseline and alternative scenarios.

The baseline case corresponds to a business-as-usual (BAU) scenario, which assumes that there will be no changes in demographic composition, technology, economics, policies or people's attitudes. Alternative scenarios are developed simulating an ageing population (LF15 and LF15C), and technological change, which results in an increase in productivity (LF15CR, LF15CRS and LF25CRS). Technical progress is simulated in two different ways in which investment in automation is transformed: the first acts on total factor productivity (TFP) (LF15CR), and the other influences multi-factor productivity homogeneously for various production factors. These are also tested at the sector level (LF15CRS), including the potential impact of massive automation on unemployment (LF25CRS).

Two additional scenarios (LF25CRSTXL and LF25CRSTXH) include analysis of the impacts of implementing a carbon tax in the EU from 2020 onwards, modelled on the basis of the carbon tax rates indicated by the World Bank (World Bank, 2017) ([84]).

These alternative scenarios for the effects of ageing, technological change and carbon taxes are sequenced as follows:

1. **LF15:** a change in the labour force in world regions according to data from the United Nations Department of Economic and Social Affairs (UNDESA) ([85]), corresponding to a 15 % reduction in the EU labour force in 2050 relative to 2015.

2. **LF15C:** equivalent to LF15 but with an additional change in the share of propensity to consume as a consequence of population ageing only in the EU.

3. **LF15CR:** ageing plus automation: the same as LF15C plus the effect of a technical change in production processes through an increase in TFP. It is assumed, in line with the Organisation for Economic Co-operation and Development (OECD, 2018c), that investment in automation will produce a 1 % annual increase in TFP.

4. **LF15CRS:** ageing plus automation differentiated across sectors: the same as LF15CR with the impacts on productivity of the automation process differentiated across sectors on the basis of their relative capital intensity. This scenario uses the share of capital intensity in each sector to allocate a 1 % annual increase in TFP among sectors to obtain a scenario fully comparable with LF15CR.

5. **LF25CRS:** ageing plus automation differentiated across sectors and unemployment: equal to LF15CRS in which the automation process acts as a biased technical change. A 10 % reduction in employment due to automation is assumed in addition to a reduction in the labour force due to ageing.

6. **LF25CRSTXL:** ageing plus automation, unemployment and environmental policy: this scenario starts from LF25CRS but adds a carbon tax lower bound (World Bank, 2017).

7. **LF25CRSTXH:** ageing plus automation, unemployment and a more stringent environmental policy: this scenario starts from LF25CRS and adds a carbon tax upper bound (World Bank, 2017).

Table 5.1 reports the results for all scenarios across six variables: total GDP, GDP per capita, CO_2 emissions, total tax revenues, total government expenditure and the EU Stability and Growth Pact target of keeping the deficit/GDP ratio below 3 %.

The focus of quantitative analysis is to provide policymakers with concrete results by calculating the quantitative effects of changes in variables and thereby being able to reveal how policy instruments can influence transition pathways and the achievement of policy targets. For example, the modelling results (Table 5.1) demonstrate that a carbon tax can contribute to environmental sustainability by reducing greenhouse gas emissions and can contribute to fiscal sustainability by countering the negative impacts of ageing and technological change on tax revenues. At the same time, careful consideration of the carbon tax rate is essential to minimise possible negative impacts on GDP.

The key results from this integrated quantitative modelling approach ([86]) are:

- Population ageing can reduce GDP because of a reduction in the labour force. The introduction of automation, on the other hand, can increase productivity and contribute to an increase in GDP, bringing it close to that of the BAU scenario. Nevertheless, if technological change also leads to a reduction in the labour force, GDP decreases below its level in the BAU scenario by 2050.

- Scenarios with a lower labour force register lower fiscal revenues because of a reduction in revenues from direct taxation. Ageing affects revenues from indirect taxation because of changes in the structure of consumption.

- When automation is included, however, the total revenue increases, especially when automation results in a rise in productivity. Conversely, if automation entails an additional reduction in the labour force, there is a sharp decrease in total revenue.

- An ageing population could mean that from 2035 the EU will not be able to meet the deficit/GDP ratio target of below 3 %. Technological change, however, generally improves fiscal sustainability and implies a lower deficit/GDP ratio.

([84]) The carbon tax modelled in the analysis is based on the results of the extensive review of the High-Level Commission on Carbon Prices (CPLC, 2017), led by Joseph Stiglitz and Nicholas Stern, and the extrapolation done by the World Bank (2017). Further information on the tax rates can be found in ETC/WMGE (2020).

([85]) As for the BAU scenario, the population is calibrated on the basis of data from UNDESA's medium scenario (UNDESA, 2017). UNDESA data and population projections are used to allow consistent calibration of the model for all regions at the global level.

([86]) For a detailed discussion of the results, see ETC/WMGE (2020).

Table 5.1 Trends in macroeconomic variables, CO_2 emissions and the public budget for six scenarios

Scenario		2015	2020	2030	2040	2050
BAU	GDP (EUR million)	14 808 018	16 274 803	19 818 745	24 163 062	27 482 057
	GDP per person (constant 2015 EUR)	29 179	31 852	38 670	47 408	54 662
	CO_2 emissions (2015 = 100)	100	98	92	87	84
	Total tax revenues (EUR million)	6 182 644	6 845 631	8 247 565	9 685 353	10 416 398
	Total govt expenditure (EUR million)	6 505 150	7 199 500	8 653 511	10 171 871	10 959 151
	Deficit/GDP (%)	-2.18	-2.17	-2.05	-2.01	-1.97
LF15	GDP (EUR million)	14 808 018	16 274 062	19 817 664	23 661 103	25 865 680
	GDP per person (constant 2015 EUR)	29 179	31 904	38 940	47 991	55 187
	CO_2 emissions (2015 = 100)	100	98	92	86	80
	Total tax revenues (EUR million)	6 182 644	6 845 804	8 214 209	9 573 013	10 103 930
	Total govt expenditure (EUR million)	6 505 150	7 201 959	8 673 747	10 154 175	10 762 205
	Deficit/GDP (%)	-2.18	-2.2	-2.36	-2.55	-2.69
LF15C	GDP (EUR million)	14 808 018	16 179 566	19 440 836	22 828 993	24 467 651
	GDP per person (constant 2015 EUR)	29 179	31 718	38 200	46 303	52 204
	CO_2 emissions (2015 = 100)	100	97	92	86	81
	Total tax revenues (EUR million)	6 182 644	6 804 170	8 030 446	9 143 840	9 506 389
	Total govt expenditure (EUR million)	6 505 150	7 181 153	8 571 732	9 851 572	10 281 263
	Deficit/GDP (%)	-2.18	-2.33	-2.78	-3.1	-3.17
LF15CR	GDP (EUR million)	14 808 018	16 179 566	19 688 818	24 027 904	27 488 911
	GDP per person (constant 2015 EUR)	29 179	31 718	38 687	48 735	58 650
	CO_2 emissions (2015 = 100)	100	97	93	90	89
	Total tax revenues (EUR million)	6 182 644	6 824 845	8 192 232	9 663 904	10 542 314
	Total govt expenditure (EUR million)	6 505 150	7 181 153	8 643 302	10 175 589	11 066 956
	Deficit/GDP (%)	-2.18	-2.2	-2.29	-2.13	-1.91
LF15CRS	GDP (EUR million)	14 808 018	16 179 566	20 087 351	24 521 060	27 819 901
	GDP per person (constant 2015 EUR)	29 179	31 718	39 470	49 735	59 356
	CO_2 emissions (2015 = 100)	100	97	94	90	88
	Total tax revenues (EUR million)	6 182 644	6 824 845	8 335 156	9 810 325	10 618 812
	Total govt expenditure (EUR million)	6 505 150	7 181 153	8 744 252	10 272 917	11 095 233
	Deficit/GDP (%)	-2.18	-2.2	-2.04	-1.89	-1.71
LF25CRS	GDP (EUR million)	14 808 018	16 179 566	18 935 502	22 547 519	25 480 657
	GDP per person (constant 2015 EUR)	29 179	31 718	37 207	45 732	54 365
	CO_2 emissions (2015 = 100)	100	97	90	85	83
	Total tax revenues (EUR million)	6 182 644	6 822 778	8 029 273	9 191 739	9 786 424
	Total govt expenditure (EUR million)	6 505 150	7 178 118	8 587 571	9 863 539	10 536 135
	Deficit/GDP (%)	-2.18	-2.2	-2.95	-2.98	-2.94
LF25CRSTXL	GDP (EUR million)	14 808 018	16 111 137	18 567 892	21 727 868	24 173 855
	GDP per person (constant 2015 EUR)	29 179	31 584	36 484	44 070	51 577
	CO_2 emissions (2015 = 100)	100	85	67	55	47
	Total tax revenues (EUR million)	6 182 644	6 808 445	7 916 331	9 047 964	9 562 641
	Total govt expenditure (EUR million)	6 505 150	7 159 985	8 505 080	9 685 501	10 265 160
	Deficit/GDP (%)	-2.18	-2.18	-3.17	-2.93	-2.91

Table 5.1 Trends in macroeconomic variables, CO_2 emissions and the public budget for six scenarios (cont.)

Scenario		2015	2020	2030	2040	2050
LF25CRSTXH	GDP (EUR million)	14 808 018	16 041 227	18 241 876	21 067 775	23 190 375
	GDP per person (constant 2015 EUR)	29 179	31 447	35 844	42 731	49 479
	CO_2 emissions (2015 = 100)	100	78	56	43	36
	Total tax revenues (EUR million)	6 182 644	6 790 299	7 864 104	8 923 677	9 413 777
	Total govt expenditure (EUR million)	6 505 150	7 141 641	8 430 711	9 538 925	10 055 003
	Deficit/GDP (%)	-2.18	-2.19	-3.11	-2.92	-2.77

Source: ETC/WMGE (2020).

- The introduction of a carbon tax improves fiscal sustainability. Across all scenarios the level of the deficit is always lower and fiscal discipline targets always reached.

- Lower CO_2 emissions compared with the BAU scenario result from economic contraction caused by reductions in the labour force. Introducing automation increases the level of emissions. The introduction of mitigation policies delivers a more pronounced reduction in CO_2 emissions. Higher carbon tax scenarios allow the EU to get closer to its 2050 climate policy objective.

5.2 The qualitative modelling framework: causal loop diagram

5.2.1 The integration of ageing population, technological change and fiscal sustainability

The main advantage of causal loop diagrams (CLDs) is to provide a more comprehensive assessment of the main drivers of change in the system and their interactions, and how they can be influenced by policies and other interventions. Their main disadvantage is lack of quantification of these relationships. Figure 5.2 illustrates the multiple interlinkages between population ageing, technological change and fiscal sustainability. Creating CLDs and analysing feedback loops allows us to identify dominance in the system. In other words, some feedback loops are stronger than others and therefore steer the system in a specific direction ([87]). For ageing, technological change and fiscal sustainability, the following main dynamics emerge:

- Population ageing primarily strengthens reinforcing (R) loops. This highlights that action needs to be taken, otherwise growing costs and declining public revenues will create a vicious cycle in which resources will not be available to modernise the economy. In other words, population ageing creates considerable challenges for fiscal sustainability.

- Technological change has both pros and cons. On the downside, adopting information and communications technology (ICT) and robotisation may result in technological unemployment, exacerbating the issues emerging from population ageing such as extra public costs, including welfare spending. This could also lead to reduced consumption and public revenues, and possibly create a vicious cycle, raising challenges for fiscal sustainability. On the upside, ICT and robotisation also carry the potential to increase economic productivity, leading to higher gross domestic product (GDP) and hence possibly creating new jobs and thereby generating higher tax revenues. In other words, if economic growth offsets the negative impacts of technological unemployment and consumption, technology could increase fiscal sustainability and mitigate the impact of population ageing.

- Fiscal sustainability is also affected by public and private investment in, for example, energy efficiency technologies. Here it can be seen that population ageing could either reduce the uptake of new technologies or stimulate it, especially in the context of smart services. The same goes for ICT, which may introduce new appliances and services that require additional electricity and hence increase energy consumption above a baseline scenario.

([87]) See Annex 1, Sections A1.2 and A1.3 for more information on this modelling approach and a discussion of the underlying key concepts.

Furthermore, the increased use of mobile phones and smartphones has increased electricity use, but may also modernise and replace existing processes, thereby reducing energy needs. A transition to a green economy, if implemented effectively through, for example, increasing energy efficiency, may reduce the potential role of environmental taxation in supporting fiscal sustainability.

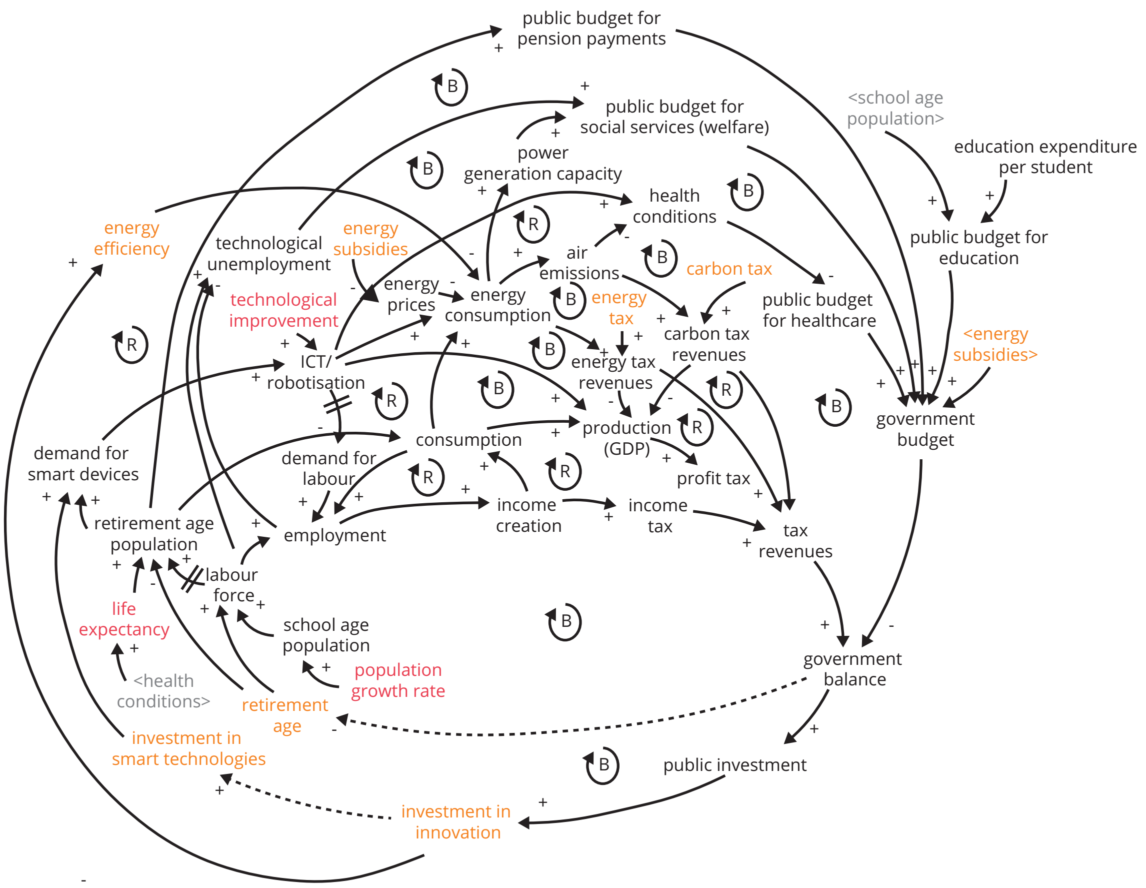
Specific interventions to counter some of the undesirable outcomes of population ageing, technological change and fiscal sustainability include increasing the retirement age, which would reduce stress on the fiscal balance, but this would have only a temporary effect. Investment in innovation and technology would allow a reduction in costs and boost productivity, but it might also lead to technological unemployment and reduced public revenues from environmental taxation. Removing market distortions, such as harmful energy subsidies, would improve the fiscal balance and raise energy prices, stimulate energy efficiency and reduce health costs. Overall, it is critical to assess the likely outcomes of interventions across the dimensions of sustainable development and for various economic stakeholders, in the short, medium and longer term, to anticipate potential side effects and improve policy effectiveness.

5.2.2 *Performance monitoring and evaluation*

The feedback loops also provide useful guidance for selecting indicators for performance monitoring and evaluation. In practice, there are three types of indicators: (1) those directly affected by policy interventions; (2) those that form critical feedback loops; and (3) those that belong to several feedback loops, also known as crucial nodes in the system.

The first group of indicators supports the analysis of policy effectiveness and shows whether the interventions implemented are leading to intended or expected outcomes. The second group is critical, because changes in trends indicate that policy impacts

Figure 5.2 **The integrated causal loop diagram: ageing population, technological transition and fiscal sustainability**



Source: ETC/WMGE (2020).

are not only direct but also indirect and induced and that they can propagate through the dominating feedback loops. The third group of indicators act as precursors of systemic change and can help to determine whether side effects will emerge or whether the implemented policy will have lasting desired effects.

Monitoring and evaluation of integrated systems also has to be carried out at different levels considering, first, the shocks introduced to the system through policy interventions, second, system responses within sectors or thematic areas, and, finally, whole system responses across sectors, economic stakeholders, the dimensions of sustainable development and time.

In conclusion, indicators have to be assessed in relation to the feedback loops to which they belong. This is because the system-wide impact of an increase in a given indicator is determined by whether it is embedded in a reinforcing loop, and hence growth will propagate through the system, or in a balancing loop, through which there will be stronger pressure to counter change and reach equilibrium. It is therefore only by using indicators and feedback loops simultaneously, as shown by CLDs, that system performance can be assessed with confidence. This is especially the case for complex systems, in which multiple trends and policy packages affect performance and there is a high degree of connection across sectors and hence indicators.

5.3 Main conclusions

Overall, this study indicates that mixed modelling methods and multidisciplinary knowledge can inform the formulation of effective policy packages across a range of parallel, systemic and societal challenges.

The results obtained are far from perfect, in particular in 'today's world characterised by increasing volatility, uncertainty, complexity and ambiguity' (EEA, 2020). Nevertheless, it does show how the synergies emerge from using two systemic methods. The CGE model provides much needed quantification of the outcomes of macro-trends and policies, although they are impaired by a strong rigidity in modelling assumptions. This is crucial to prioritise efforts and deliver value for money. The CLDs, despite being qualitative, create a shared understanding of the dynamics of the system and can serve both as a blueprint for model and scenario formulation, as well as for the interpretation of results. Specifically, being more comprehensive than a CGE model, CLDs allow the determination of how the results of a model may change when considering the potential addition of factors and dynamics that could not be quantified.

This study is a small initial step ([88]), but one that could stimulate further work on developing complex, systems models to inform decision-making around the multiple transitions confronting Europe in the coming decades.

([88]) See ETC/WMGE (2020) for further information on the advantages of linking inputs from system dynamics analysis into a dynamic computable general equilibrium model.

6 Summary and reflections from a systemic perspective

6.1 A wealth of interactions: how do demographic and technological change and fiscal sustainability influence the environment?

The key idea behind this report is that, to achieve the sustainability transition, its environmental components must be integrated into a systemic framework of major socio-technical and economic changes: population ageing and pervasive technological change as macro-drivers, and fiscal and finance instruments as possible constraints to the transition itself. To drive the sustainability transition, environmental policies have to work in the face of these major driving forces.

The interaction between fiscal sustainability and the ageing population mostly focuses on the expenditure and revenue sides of the public budget (OECD, 2017c; Yoshino et al., 2019). However, an ageing population also leads to changes in production and consumption systems, which have implications for long-term environmental and climate policy objectives. This aspect will require much more attention in public policy in the coming decades.

Investment in infrastructure and spending on research and development are key factors for the sustainability transition. Although many technological changes are said to be environmentally friendly, the actual environmental consequences are more difficult to predict because other concurrent factors may lead to opposite effects. Technological progress can also lead to disruptive changes in the economic system that have major fiscal implications that are relevant for public investment in the sustainability transition. The multiple pressures on public resources mean that private finance will be needed to meet the required investment.

There are doubts over whether environmental tax revenue can be sustained as a relatively high share of total tax revenue in the coming decades as environmental tax bases are eroded as the EU gets closer to meeting its objectives. On the expenditure side, the environment is also a recipient of public funds, demands for which are expected to rise in the coming years to support the transition to a low-carbon, resource-efficient and circular economy.

Fiscal discipline and the need to balance public budgets will create fiscal competition between various public policy domains against a backdrop of low economic growth for European economies in the future. At the same time, lower economic growth rates may be beneficial for the environment, as this will decrease consumption of resources, environmental pollution and potential loss of environmental habitats and biodiversity. In contrast, low economic growth may hinder investment in infrastructure for the sustainability transition. In addition, social security systems are highly dependent on economic growth (Petschow et al., 2018). There is a need to study the complex links between fiscal sustainability, 'which is invariably predicated upon future growth primarily to manage demographic changes' (Bailey, 2015), and the environmental critique of economic growth:

> Synthesising notions of fiscal and environmental sustainability into welfare state analysis breeds a new paradox for welfarism. If we are to reduce levels of (taxable) economic activity as post-growth theorists suggest, we *ceteris paribus* threaten the public sector funding base of welfare states and impede the state's traditional mechanisms of 'crisis management'. Simultaneously, the welfare state is required more so than ever in what could be a tumultuous transitional period, not only in terms of protecting society's poorest and most vulnerable but also in terms of facilitating decarbonisation attempts and providing efficient modes of insuring against a confluence of socio-economic and environmental risks. We, thus, have a scenario where it is problematic for welfare states to be financed by (or to justify) environmentally unsustainable growth, whilst welfare states themselves must be regarded as crucial transitional mechanisms. Current levels of welfare expenditure may be considered fiscally unsustainable but ironically, it may be that welfare state atrophy should be considered environmentally unsustainable. (Bailey, 2015, p. 795)

This argument for dealing with 'sustainability in a more sustainable way' is highly relevant for policymaking. As Europe will change because of digitisation, emerging new technologies, stricter environmental and climate policies and demographic trends, the fiscal and social security systems have to be reformed so that these challenges can be properly addressed. It is evident that the existing labour and environmental taxation schemes have not kept up with these developments.

6.2 (Re)directing fiscal policies in response to a wealth of interactions

The cornerstones of the taxation system are no longer the same as those that the welfare state was built on in the last century. Taxation must be radically reformed if the State is to be able to continue to provide the preconditions for inclusive and sustainable well-being (Mokka et al., 2017). Proposals for revising and/or adapting existing fiscal schemes are now being discussed.

Options for new taxation schemes are manifold. One of the most prominent in the environmental and climate policy field is the more widespread implementation of carbon pricing schemes, as spelled out by the European Commission:

> Environmental taxation, carbon pricing systems and revised subsidy structures should play an important role in steering this transition. Taxation is amongst the most efficient tools for environmental policy. Therefore, taxes and carbon pricing should be employed to account for negative environmental impacts and focus on increasing energy efficiency, reducing greenhouse gas emissions and enhancing the circular economy. (EC, 2018a, p. 18)

The carbon border adjustment mechanisms as proposed by the European Commission in the European Green Deal could also generate additional budget revenues and simultaneously reduce the risks of carbon leakage and thus to provide a level playing field for EU industry.

Other environmental taxation schemes can also be considered. For example, resource taxes directly increase the price of natural resources (minerals, aggregates, water). Higher prices are essential to increase resource efficiency, promote recycling and foster transition to a circular economy.

However, as discussed several times throughout this report, when environmental taxes are effective, they reduce the tax base. Therefore, alternative taxation schemes need to be considered to ensure fiscal sustainability. Distance-based and congestion charges in the transport sector are examples of innovative fiscal schemes, which can be set to reflect the pollution costs and congestion implications of different types of vehicles, supporting the transition to zero-emission mobility. They can also compensate for declining revenues from the current energy and vehicle taxation schemes as internal combustion engine vehicles are phased out. The International Energy Agency discusses different options distinguishing between near-term options and long-term solutions ([89]). It is noteworthy to emphasise that:

> The long-term stabilisation of fiscal revenue from transport is important to ensure continued availability of funding for the development and maintenance of transport infrastructure, among other goals. But it cannot only be based on the adjustments listed as near-term options. This is due to the growing impact of such adjustments to the taxation structure and to distortions that they risk imposing on the fiscal framework applied to the transport sector. [...] A long-term solution to the challenges posed by the transition towards zero-emissions vehicles is therefore very likely to require the development of structural reforms in tax schemes. Given the nature of taxes applied to the transport sector, these reforms will need to consider the combination of taxes applied to distances driven, vehicles and fuels (IEA, 2019a, p. 193).

The political process of revising transport fuel and vehicle taxation schemes should start soon, as clarified by Adam and Stroud (2019), '... before the revenue disappears and expectations of low-tax motoring become ingrained. It should lay out how it [government] plans to tax low-emissions driving in the long term whilst incentivising the take-up of lower-emissions cars in the short term.'

When it comes to some of the challenges engendered by technological change, various fiscal instruments are under scrutiny, ranging from robot taxation schemes to digital taxes, as well as financial transaction taxes, the so-called Tobin tax.

- A **robot tax** is promoted by entrepreneurs, academics including Bill Gates and Robert J. Shiller, a Nobel Prize winner in 2013, and was also discussed by the European Parliament in 2017. However, this type of a tax is heavily criticised as a potential obstacle to further innovation and for hampering the adoption of robots in industry. The latter point is rather interesting to follow up, as

([89]) See also Raccuja (2017) and OECD/ITF (2019).

South Korea introduced a robot tax in 2018, but at the same time it is the country with the highest robot density in manufacturing ([90])

- **Digital taxation (digital service tax):** this type of tax is attracting a lot of attention in the international tax policy debate ([91]). The basis for applying a digital taxation scheme is to amend the existing taxation framework, i.e. following corporate taxation rules, as it is not capable of dealing with businesses operating in the digital economy because of the obvious mismatch between profits being taxed in one country and value being created in another. Digital taxation schemes are either already implemented or have been proposed in several European countries (e.g. Austria, France, Italy, Spain and the United Kingdom ([92])), but other countries (Denmark, Ireland and Sweden) are opposing this form of taxation (Euractiv, 2019a) ([93]). High-level discussions at the Organisation for Economic Co-operation and Development (OECD) are ongoing, aiming for a 'more universal' approach ([94]). This aims to reform corporate income tax rules but such a reform is seen as a long-term solution. In the short term, the policy approach is to implement a digital service tax that should be withdrawn if the international corporate tax rules are reformed ([95]). The digital taxation schemes now under discussion are designed in such a way that revenue arising from digital activities is subject to tax in the country or countries where the services are used. The projected revenue generated from such a tax appears rather limited but critically depends on the design of the tax in terms of scope and tax rate. For example, a German study estimates a revenue potential of EUR 3-4 billion, which is approximately 0.1 % of the total tax revenue in the 28 Member States of the EU (EU-28) (IHK, 2018). The European Commission calculates that the revenue would amount to EUR 5 billion per annum (quoted in IHK, 2018).

- **Financial transaction tax (FTT):** the European Commission put forward a proposal for taxing the financial sector at the European level in 2011. The underlying rational of an FTT is to address financial market instability and to generate revenue for the public budget. An FTT scheme levies a tax on the transaction of financial instruments, such as stocks, shares and bonds. Since that initial proposal, discussion of the pros and cons of an FTT have been high on the political and tax agenda, but different views and approaches are taken among the EU Member States. The European Commission presented another proposal for an FTT in 2013. The proposal has been revised and, in its latest iteration (December 2019), the German Finance Minister submitted a revised proposal for a Council Directive regarding the introduction of a common financial transaction tax to EU Member States under what is known as the enhanced cooperation procedure ([96]). Early estimates of likely revenue have been considerably reduced: in 2011, the European Commission expected to generate approximately EUR 57 billion per annum through the FTT; in 2013, the estimate was EUR 30-35 billion for participating countries, and the latest estimate in a 2019 draft directive amounts to EUR 3.5 billion (Euractiv, 2019b).

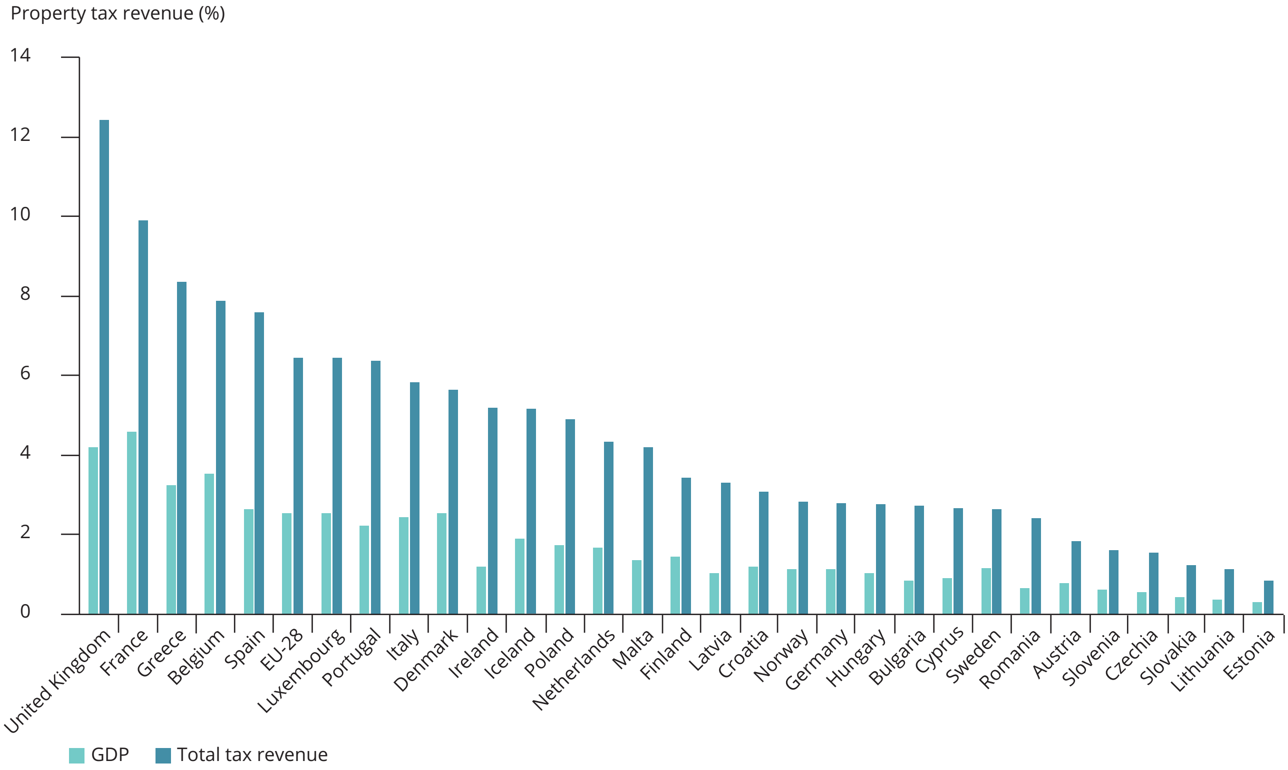
It is estimated that the projected revenue from these new instruments would be quite small in comparison with the total tax take, including social security contributions, at the EU level, which amounted to about EUR 6 200 billion in 2018. Other options that are high up the political agenda include funding pensions from consumption and wealth taxes to give a broader tax base and incentives to substitute capital for labour and to have a smaller impact on the economy's competitiveness. However, the equity considerations of reforms need to be addressed by appropriate expenditure policy measures (EBRD, 2018).

It is not surprising that equity considerations play a key role in the current political debate because of the increasing inequality across society (Picketty, 2013). This is also significant in the context of extending/implementing broad carbon pricing policies because of their possible regressive effects whereby poorer people are unduly impacted.

The potential of consumption taxes, such as value added tax (VAT), as budget sources for financing old-age expenditure could be considered in countries with low VAT or sales tax rates. However, European countries today rely heavily on VAT revenues as making

([90]) For lists of the pros and cons of robot taxation, see Merler (2017), Oberson (2017), Shiller (2017), Atkinson (2019) and Porter (2019).
([91]) For a detailed discussion on the merits of this type of tax, see Schön (2019).
([92]) For an overview of the proposed or implemented digital service taxes in Europe, see Tax Foundation (2020).
([93]) The European Commission published the digital tax package on the taxation of the digital economy in March 2018 (EC, 2018m).
([94]) See the OECD discussion and developments (OECD, 2018d, 2019d, 2019e).
([95]) It is important to highlight in this discussion that in 2018 the Commission's proposed own resources legislative package for 2021-2017 included the common consolidated corporate tax base. It is envisaged that this instrument will generate EUR 11 billion per year from 2023 onwards by applying a 3 % rate to the share of taxable profits of each EU Member State (EC, 2018n).
([96]) For an overview of the different types of financial transaction taxes and which countries introduced them globally, see BNY Mellon (2018).

Figure 6.1 Property tax revenues as shares of gross domestic product (GDP) and of total tax revenues in the EU-28, Iceland and Norway, 2018



Sources: Eurostat and Directorate-General for Taxation and Customs Union.

a significant contribution to the public budget, and an OECD study (Rouzet et al., 2019) concluded '... that many other countries, particularly in Europe, have already exploited this avenue and may have reached the point — estimated at between 21 and 27 % for standard VAT — where further increasing value-added tax rates would actually decrease total tax receipts due to disincentives and tax avoidance effects'.

Finally, a frequently raised alternative is property taxation and in particular recurrent taxes on immovable property, sometimes known as land value taxation ([97]). There are large differences in the design and scope of property taxation in Europe as shown in Figure 6.1.

The revenues are comparable to environmental tax revenues, at least in some EU Member States. At the EU level property taxes as a share of gross domestic product (GDP) amounted to 2.5 % and the environmental tax as a share of GDP was 2.4 % in 2018. The European Commission's summary is therefore revealing:

> Recurrent taxes on real-estate property have attracted increasing attention from policymakers because in many countries where they are low they offer a potential source for increasing revenue, while at the same time they are considered to be the least detrimental to economic growth given the immobility of the tax base. (EC, 2019d, p. 46)

([97]) See the report by Transport for London (TfL, 2017), in which the concept of land value taxation is discussed: 'Since public transport generates significant positive externalities, it is not efficient for fare payers to cover all capital expenditure. In the past, general taxation has funded the gap (including business rates and government grants). But as the funding requirement grows, without alternative funding sources, there is no obvious way of paying for major network upgrades and extensions, other than increasing the burden on general taxation. Land value capture (LVC) is one such alternative funding source.'

Probably the most controversial option discussed is a wealth tax ([98]). Nevertheless, it is clear that we need a mix of fiscal policy measures for dealing with the long-term policy pressures and challenges. Fiscal policy measures are necessary for the sustainability transition but not sufficient, as they must be linked to non-fiscal policy measures such as setting emission standards for vehicles and increasing the pension age.

6.3 In conclusion

Major transformative forces are at work in Europe reshaping society, the technological system and public policy models. The sustainability transition resides in this transformative environment. Reciprocal synergies and barriers may emerge and have been discussed throughout this report. The picture is complex and includes multiple possible interactions and feedback loops.

Overall, however, when the sustainability transition is considered in the multiple-transition setting, environment and climate actions definitely move from the realm of sectoral policies to take a central position in macro-level economic, financial, fiscal and social policies. This may, inter-alia, enable Europe to achieve the 'just' sustainability transition in coming decades that addresses social, economic and environmental objectives in a balanced and fair way across society.

([98]) For a definition and a discussion of the pros and cons of wealth taxes, see the World Bank report by Bogetic et al. (2015).

Abbreviations

AI	Artificial intelligence
BAU	Business-as-usual (scenario)
CGE	Computable general equilibrium (model)
CIS	Community Innovation Survey
COFOG	Classification of the Functions of Government
COICOP	Classification of individual consumption by purpose
CLD	Causal loop diagram (model)
EEA	European Environment Agency
ETS	Emissions Trading System
EU	European Union
EU-28	The 28 Member States of the EU
EU-SILC	EU Statistics on income and living conditions (database)
GDP	Gross domestic product
ICT	Information and communications technology
IT	Information technology
MFF	Multiannual financial framework
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
SDG	Sustainable Development Goal
TFP	Total factor productivity
VAT	Value added tax

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Annex 1

A1.1 Data sources and methodologies for calculating greenhouse gas footprints and allocating them to the COICOP two-digit categories

Key data sources

The analysis is based on a combination of official Eurostat data with input-output data from Exiobase 3.4 (Tukker et al., 2013; Wood et al., 2015) ([99]). Eurostat data report information on private household consumption expenditure (level and composition by consumption purpose: COICOP two-digit classification — Classification of Individual Consumption According to Purpose) and other household characteristics broken down by the age of the reference person based on the Household Budget Survey at 5-yearly intervals. Eurostat also publishes official population projections (2015 edition) broken down by age, which were employed to calculate what-if scenarios. Moreover, we used European Union Statistics on Income and Living Conditions (EU-SILC ([100])) microdata to allocate household consumption expenditure and greenhouse gas footprints to people belonging to the same age group. Data from Exiobase 3.4 were used to estimate sector- and country-specific greenhouse gas footprints in terms of worldwide emissions related to domestic final demand for products and services. The reference year for the calculation is 2011, as this is the last year for which the full set of Exiobase data are available.

An important limitation of using consumption surveys to evaluate the consequences, including the environmental consequences, of changing consumption patterns is that consumption surveys do not account for the fact that many products and services are used by consumers with no contextual expenditure. The typically relates to public services that are guaranteed to citizens or residents of a country at usually a low cost and are financed by general taxation. In these cases, consumers' direct expenditure will either be zero or a limited share of the total cost, while the rest will be paid indirectly through taxes.

To shift from a household-based footprint to a person-based footprint by age, we need to retrieve information on the age structure of the components of households, broken down by the age of the reference person in the household (Akkerman, 2005). Household composition by members' age is calculated using microdata from the EU-SILC database. The composition is calculated separately for households whose reference person belongs to the various age groups (< 30; 30-44; 45-59; 60+). This country-specific estimated matrix of household age composition is then used to attribute a greenhouse gas footprint to individual members and the corresponding age group. The results are then applied to the various Eurostat population scenarios and their age-cohort composition.

Methodology for calculating greenhouse gas footprints

Estimating the average greenhouse gas footprint for each COICOP two-digit category is a two-step procedure. First, environmentally extended input-output tables from Exiobase 3.4 are used to calculate the greenhouse gas footprint of final demand by detailed product category (200 products based on the statistical classification of products by activity (CPA) 2002 classification) for each EU country. For this purpose, we consider the total requirements of the three most important greenhouse gases — CO_2, methane (CH_4) and nitrous oxide (N_2O) — measured as CO_2-equivalent global warming potential. Total greenhouse gas requirements consider all emissions, occurring domestically or abroad, arising from producing goods and services that are needed to satisfy domestic final consumption. The estimate of total greenhouse gas requirements is based on the world input-output table ([101]) for the year 2011, which considers all bilateral transactions in monetary terms across 200 product categories and 48 world countries/regions.

([99]) https://www.exiobase.eu/index.php/data-download/exiobase3mon
([100]) https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions
([101]) http://www.wiod.org/home

More specifically, the vector of greenhouse gas footprint per monetary unit of final consumption is calculated as the matrix product between the column vector of direct greenhouse gas emissions per monetary unit of gross output, by country and product, and the world matrix of total requirements, that is, the Leontief matrix (Wiedmann et al., 2009, 2010).

Second, we need to allocate product-/country-specific greenhouse gas footprint estimates to more aggregated consumption purpose categories to match the COICOP 1999 classification used in consumption surveys. Although Eurostat provides a table matching up corresponding categories in the CPA 2002 and COICOP 1999 classifications (Eurostat, 2020d), further adjustments are needed, as expenditure in consumption surveys considers the price of goods and services inclusive of trade and transport margins (purchaser price), while such margins are not included in product-specific final consumption expenditure in the Exiobase 3.4 input-output data. As transport- and trade-related activities represent a relevant component of the overall greenhouse gas footprint, their corresponding environmental pressures need to be allocated to the various COICOP categories to compute the overall footprint correctly. For further details of the allocation table employed in the current report, see ETC/WMGE (2018).

A1.2 A qualitative systemic approach — the system dynamics framework

Pioneered by Jay W. Forrester in the late 1950s, system dynamics is an integrated quantitative modelling approach used to understand (complex) real-world issues and guide decision-making over time to achieve sustainable long-term solutions.

System dynamics is a flexible methodology that allows the integration of social, economic and environmental indicators in a single framework of analysis. System dynamics models are based on the assumption that structure drives behaviour and use causal relationships to link variables. Models can be customised to analyse the socio-economic implications of various actions across social, economic and environmental sectors and actors, including households, the private sector and the government, within and across countries. In fact, system dynamics models can be top down or bottom up, general or partial equilibrium.

The pillars of system dynamics models are feedback, delays and non-linearity, which are identified by creating causal maps or causal loop diagrams (CLDs), which are based on systems thinking (Box A1.1) and, like system dynamics, are qualitative.

Box A1.1 What is systems thinking?

Systems thinking is an approach that allows better understanding and forecasting of the outcomes of decisions across sectors and economic actors and over time and in space (Probst and Bassi, 2014). It emphasises that the system is made of several connected parts, rather than focusing on its individual parts.

With systems thinking being an approach, there are several methodologies and tools to support its implementation and hence the identification of the underlying functioning mechanisms of a system and their quantification and evolution over time. In general terms, identifying the components of a system and their relationships, established, for example, through the use of causal loop diagrams (CLDs), represents (1) the **soft** side of systems theory. Attempts to quantify these links and forecast how their strength might change over time by using, for example, system dynamics models represents (2) the **hard** side of the field.

Regarding point (1), CLDs allow us to create a shared understanding of how the system works and hence identify effective entry points for (human) intervention, such as public policies. When this is done using a participatory approach, it helps to bring people together, creating the required building blocks for the co-creation of a shared and effective theory of change.

Regarding point (2), system dynamics models allow us to quantify policy outcomes across social, economic and environmental indicators (UNEP, 2014), providing insights into the relative strength of various drivers of change (scenario analysis) and supporting the identification and prioritisation of policy interventions (policy analysis). These models can be bottom up or top down (UNEP, 2011; Probst and Bassi, 2014).

In the context of this research, the role of systems thinking is to assess the extent to which the main drivers of change considered — population ageing, technological change and fiscal sustainability — can shape future trends, affect the effectiveness of existing policies and require future intervention. This in turn allows us to identify a system's safe operating space and limits, anticipating the emergence of side effects across social, economic and environmental indicators.

CLDs (Box A1.2) have several purposes:

(1) they bring the ideas, knowledge and opinions of those participating in the process together;

(2) they highlight the boundaries of the analysis; and

(3) they allow all stakeholders to gain a basic to advanced knowledge of the systemic properties of the issues analysed.

Having a shared understanding is crucial for solving problems that touch upon several sectors, or areas of influence, that are normally found in complex systems (Sterman, 2000; Rouwette and Franco, 2014). Delays and non-linearity are captured by creating a quantitative model, which includes stocks and flows.

System dynamics models, as opposed to computable general equilibrium (CGE) and energy systems models, do not aim to optimise the behaviour of a system. Rather than developing policies that optimise a certain aspect, system dynamics models support the development of integrated policies that contribute to the long-term stability of a system through what-if scenarios. Thus, instead of providing a policy for optimising energy supply, system dynamics helps formulate a set of policy measures that may improve

Box A1.2 Causal loop diagram

A causal loop diagram (CLD) is a map of the system analysed or, better, a way to explore and represent the connections between key indicators in a sector or system under analysis (Probst and Bassi, 2014). According to Sterman (2000), 'a causal diagram consists of variables connected by arrows denoting the causal influences among the variables. The important feedback loops are also identified in the diagram. Variables are related by causal links, shown by arrows. Link polarities describe the structure of the system. They do not describe the behaviour of the variables. That is, they describe what would happen if there were a change. They do not describe what actually happens. Rather, it tells you what would happen if the variable were to change.'

CLDs include variables and arrows (called causal links), with the latter linking variables together with a sign (either + or -) on each link, indicating a positive or negative causal relation. A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction (Table A1.1). A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction. Circular causal relations between variables form causal, or feedback, loops. There are two types of feedback loops: reinforcing (R) and balancing (B). The former happen when an intervention in the system triggers other changes that amplify the effect of that intervention, thus reinforcing it. The latter tend towards achieving a goal or equilibrium, balancing the forces in the system (Forrester, 1961).

By highlighting the drivers and impacts of the issue to be addressed and by mapping the causal relationships between the key indicators, CLDs support the identification of policy outcomes using a systemic approach (Probst and Bassi, 2014) and can in fact be used to create storylines corresponding to the implementation of policy interventions, by highlighting direct, indirect and induced policy outcomes across social, economic and environmental indicators.

Table A1.1 Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	–
↓	↑	–

CLDs use a systems approach and are highly compatible with and complementary to other methods. Like every other method, CLDs also have some shortcomings. First, the effectiveness of a CLD is directly related to the quality of the work and the knowledge that goes into developing the diagram. Multi-stakeholder perspectives should be incorporated and cross-sectoral knowledge is essential to correctly identify the causes of the problem and design effective interventions. Second, the boundaries of the system and the relationships between the key variables have to be correctly identified. Errors in creating the diagram may lead to biased assessments of policy outcomes, overstating or underestimating some of the impacts across sectors and actors. Third, the estimation of the strength of causal relations, even if these are correctly identified, cannot be guaranteed, as the causal diagram is a qualitative tool.

several indicators at once, providing, for example, an affordable energy supply while generating employment and reducing emissions to the air. As a result, system dynamics models inform both policy formulation and assessment, as well as monitoring and evaluation.

A1.3 Computable general equilibrium modelling framework

A general equilibrium approach models supply and demand behaviour across all markets in an economy (Lofgren and Diaz-Bonilla, 2010). CGE models are a standard tool for empirical analysis, and are widely used to analyse the aggregate welfare and distributional impacts of policies affecting many markets or containing menus of different tax, subsidy, quota or transfer instruments.

CGE models optimise utility for economic actors, and the three conditions of market clearance, zero profit and income balance are used to simultaneously solve the setting of prices and allocation of goods and factors that support general equilibrium. CGE models are first solved in a base year by deriving parameters consistent with historical data and optimisation assumptions. The model is then 'shocked' by changing policy or economic conditions. Economic modellers observe the quantitative change in the outputs, which provide an estimate of long-term outcomes.

CGE models are in general top down, meaning that variables such as energy consumption are determined by parameterised equations, rather than by considering individual technologies.

These models estimate all direct and indirect impacts and follow these impacts through time, allowing them to distinguish between first-, second- and third-order effects. On this basis, the World Bank argues that general equilibrium analysis is the most appropriate way to estimate the macroeconomic impacts of subsidies and their reform (World Bank, 2010). In general, the advantage of a general equilibrium approach is that it considers indicators of a full set of impacts across an economy — not only household incomes but also macroeconomic effects, such as inflation — and estimates how specific economic sectors will be affected.

The main limitation of CGE models is the assumption about optimisation and how closely it mirrors reality. There are two additional limitations concerning employment and productivity. Regarding the former, CGE models normally work under the assumption of full employment, with salaries and wages changing depending on the performance of the economy.

Box A1.3 The GDynEP-AG model

The model developed to support the analysis in this report is GDynEP-AG, a recursive dynamic computable general equilibrium (CGE) model, which is a specific version of the GTAP/GDynEP model. GDynEP-AG is the result of merging the GdynE (the energy version of the dynamic Gdyn), developed by Golub (2013) and Ianchovichina and Walmsley (2012) and improved by Markandya et al. (2015), with the new GTAP-Power (Peters, 2016), which introduces a detailed representation of the renewable electricity sector to GTAP.

GDynEP-AG is based on the last version of the GTAP-Database (GTAP-Database 9.1), which takes 2011 as the starting point for historical data.

This version of the model distinguishes between the energy-generating technologies and introduces, for the first time, supply from renewable energy sources, as well as an analysis of the transmission and distribution sector. The new data, updated to 2011, include coal, gas, oil, hydro, wind, solar, nuclear and other power sources as electricity-generating technologies, while gas, oil, hydro and solar generating technologies are further divided between base and peak load.

The GDynEP-AG model version developed here is aggregated into 19 regions (EU, United States, Russia, Rest of Europe, Rest of OECD East, Rest of OECD West, Brazil, China, India, Asian energy exporters, Continental Asia, Rest of South Asia, South East Asia, African energy exporters, Western Africa, East and South Africa, American energy exporters, South America, and Central America and Caribbean) and 22 sectors (agriculture; food, beverages and tobacco; textiles; wood; pulp and paper; chemical and petrochemical; non-metallic minerals; basic metals-1 (iron and steel); basic metals-2 (non-ferrous metals); machinery equipment; transport equipment; other manufacturing industries; transport; water transport; air transport; and services), while energy commodities have been disaggregated into coal, oil, gas, oil products, electricity from fossil fuel and nuclear sources, and electricity from renewable sources).

The scenario setting is based on a time horizon up to 2050, divided into intervals of 5 years.

This is an important limitation for policies that may lead to job losses or create employment. As far as productivity is concerned, CGE models generally do not incorporate social and human capital as a key factor of production. As a result, with a few exceptions, for example the World Bank's Maquette for Millennium Development Goals Simulations (MAMS) development model, changes in health and education do not affect economic productivity and production.

One of the key aspects of CGE models is that they are suitable for investigating the economic impacts of policies by taking into account interactions between various agents and markets. Accordingly, applications of CGE models include examining policies in the fields of international trade, public finance (tax reforms), agriculture, transport, change in world prices, welfare, economic growth and income distribution, changes in public expenditure, energy and environmental policies, especially following the introduction of carbon taxation (Menezes et al., 2006). Given the main subject of this report, the focus here is on CGE models applied to the issues of environment, technology, an ageing population and taxation.

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