CHAPTER 1

MEGATRENDS AND SUSTAINABILITY

KEY FIGURES

100 %
increase in greenhouse gas emissions since 1980

2x
more Europeans aged 80+ by 2100

45 %
of global wealth owned by the richest 1 %

0
countries in the world meet basic needs for its citizens at a globally sustainable level of resource use

84 %
of Horizon 2020 investments relate to at least one SDG

What can we learn?

- **R&I activities, and R&I policy, take place in a context where global and long-term forces are influencing our needs**, including climate change, an ageing population, and growing inequalities.
- **Climate change** is the most serious among these trends.
- **R&I is key for addressing SDGs, going beyond GDP**.
- **More than 80% of investments under Horizon 2020** can be directly related to **addressing specific SDGs**.

What does it mean for policy?

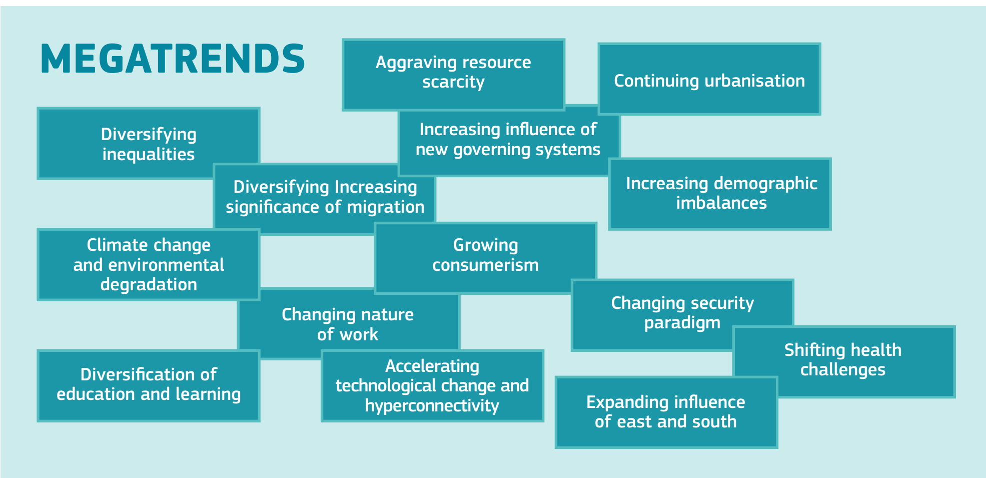
- **SDGs require transformative change**. EU R&I policy can set a direction to generate knowledge and solutions for this transformation.
- **Transformative R&I policy** can also be a key enabler of the European process for SDG policy coordination.
- **Transformative innovation and systemic transitions** involve several new policy challenges, such as horizontal policy coordination, the diffusion of radical innovations and providing directionality.

1. Megatrends, the long-term driving forces shaping our future

R&I activities, and R&I policy, take place in a context whereby global and long-term forces are influencing our needs. These forces, or *megatrends*[1], are shaping our world and will drastically influence our future (Figure 1-1). While the COVID-19 pandemic has been disrupting our society in recent months, the EU has been facing global forces in the longer term that are influencing our needs, including climate change, loss of biodiversity, an ageing population, and growing inequalities. It is crucial that we understand what these forces mean for R&I: how they affect R&I, but also how R&I can contribute to addressing the challenges they entail, by providing solutions for them, by enabling a better understanding of them, and by making our society more resilient in the long term (Ricci et al., 2017).

The COVID-19 crisis is unprecedented and the world is struggling to contain the pandemic. It has disrupted our lives, economy and society and stopped almost all economies worldwide from fully functioning. **While R&I is at the core of the response to the pandemic itself** in the areas of virology, vaccine development, treatments and diagnostics, **it will be also crucial in the economic recovery from the crisis**, not only to spur economic activity, but also to accelerate the transitions that our planet and society need - a new economy for health and well-being in a broad sense (physical, mental, skills, social, environmental and economic aspects).

Figure 1-1 Megatrends in the EC Megatrends Hub



Source: European Commission

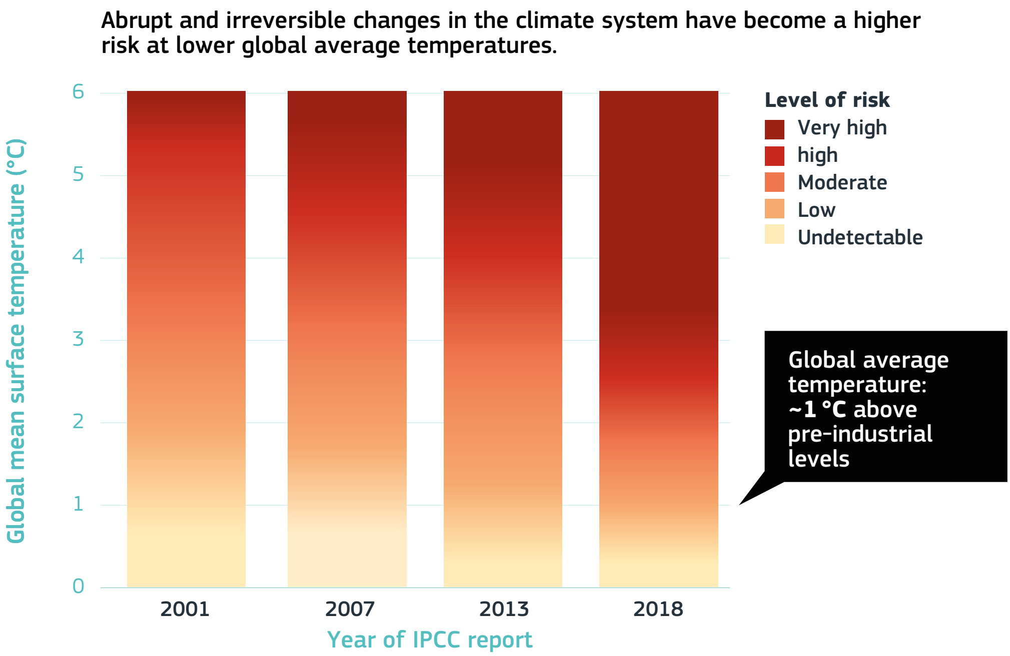
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-1.xlsx

1 See the EC Megatrends Hub or OECD (2016).

Climate change poses an existential threat

Among these megatrends, climate change poses an existential threat and requires enhanced ambition and greater climate action by the EU and at the global level[2]. The scientific case for climate action has become increasingly overwhelming and shows that a business-as-usual scenario, with continued pollution and greenhouse gas emissions[3], largely driven by economic and population growth, will lead to a further increase in global warming, ocean acidification, desertification and changing climate patterns (Figure 1-2). This has immediate implications for food security, rising sea levels and stronger storms affecting coastal areas, health issues, migration, and growing economic damage. At the same time, the Earth's biodiversity and resilience show persistent declining trends. These trends are significantly driven by resource extraction and processing which account globally for half of total greenhouse gas and 90% of biodiversity loss due to land use (United Nations, 2019a). Hence, collective action is required to steer the Earth system, i.e. biosphere, climate, and societies, to stabilise it in a habitable state. This can include **'decarbonisation of the global economy, enhancement of biosphere carbon sinks, behavioural changes, technological innovations, new governance arrangements, and transformed social values'** (Steffen et al., 2018).

Figure 1-2 Too close for comfort



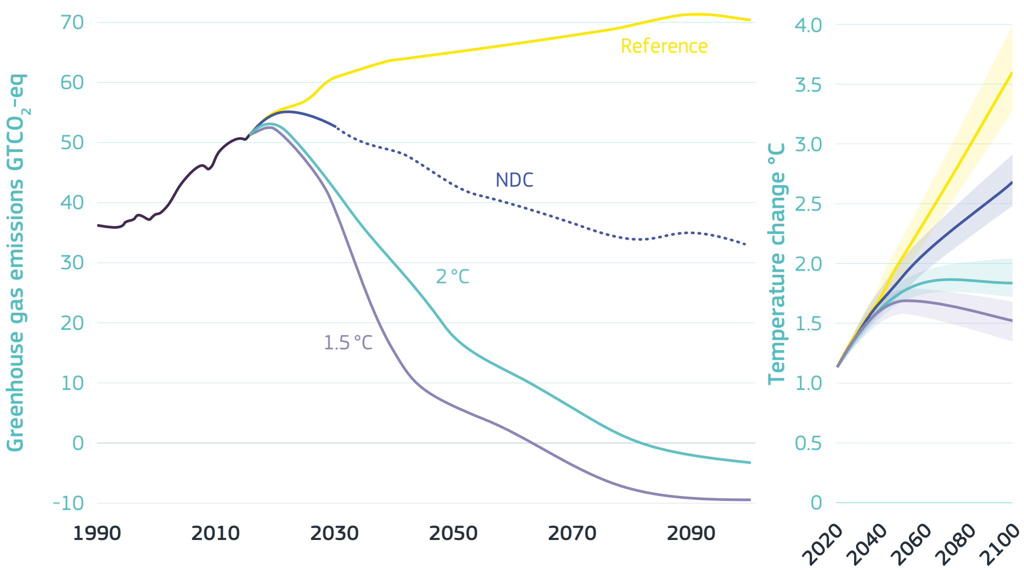
Science, research and innovation performance of the EU 2020

Source: Lenton et al. (2019)
Note: IPCC refers to Intergovernmental Panel on Climate Change
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-2.xlsx

2 https://www.consilium.europa.eu/media/41123/17-18-euco-final-conclusions-en.pdf
3 Greenhouse gas emissions have increased by 100% since 1980, raising the average global temperature by at least 0.7 degrees Celsius (IPBES, 2019).

In this context, the 2015 UNFCCC[4] Paris Agreement set the goal of keeping a global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5 degrees Celsius. The IPCC special report Global Warming of 1.5 °C (IPCC, 2018) states that 'climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 °C and increase further with 2 °C. [...] Pathways limiting global warming to 1.5 °C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (high confidence)' (Figure 1-3).

Figure 1-3 Global GHG emissions and global average temperature change (with median probability)



Source: GECO 2018 (POLES-JRC 2018; MAGICC online)

Note: The NDC[5] scenario assumes that the global average rate of decarbonisation implied by the NDCs in 2020-2030 is maintained over 2030-2050.

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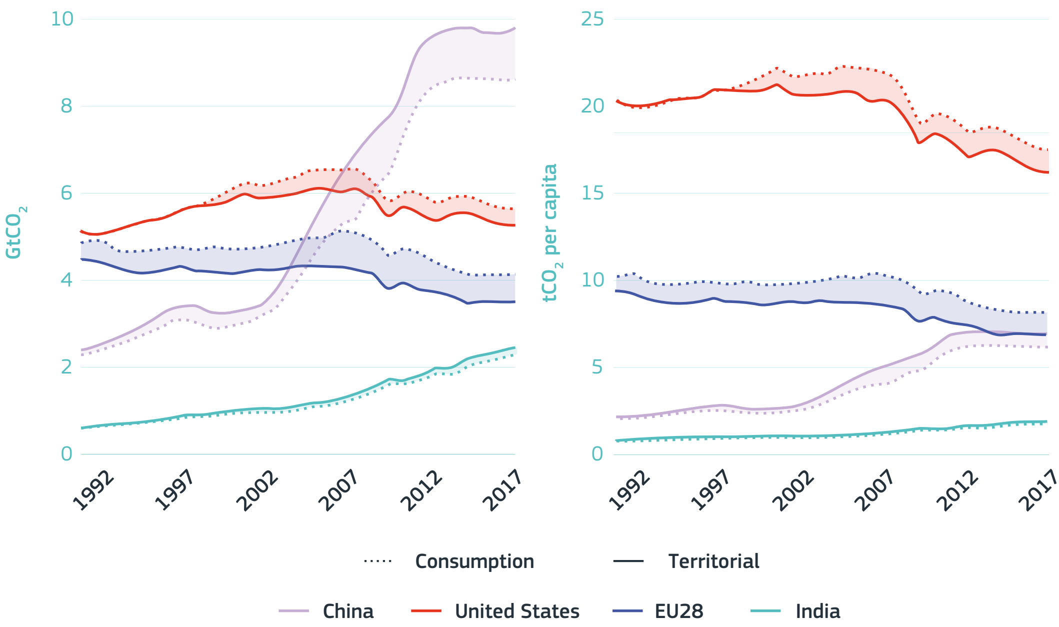
Current trends for emissions and energy consumption are not on track to meet either the 2 °C or the 1.5 °C targets. Reaching these targets implies that the global energy system and energy consumption patterns would have to undergo a profound and immediate transformation to sustain unprecedented levels of global annual decarbonisation rates. Global greenhouse gas emissions would need to be cut by half by 2050 compared to 1990 and drop to zero around 2080 in order to keep temperature change under 2 °C. The 1.5 °C

4 United Nations Framework Convention on Climate Change.

5 Nationally Determined Contributions.

target means an even faster reduction of emissions (European Commission, 2018). In the global context, carbon is embodied in trade flows, such that the carbon footprint from territorial emissions can differ significantly. Current net flows of embodied carbon are from developing countries to developed countries, such as the EU or the United States. These flows can offset the efforts made in terms of reducing emissions. As a result, while territorial EU emissions per capita are on a par with China (Figure 1-4), consumption-based emissions per capita are significantly higher in the EU (United Nations, 2019b).

Figure 1-4 CO_2 **allocated to the point of emissions and consumption**



Science, research and innovation performance of the EU 2020

Source: United Nations (2019b). Emissions Gas Report

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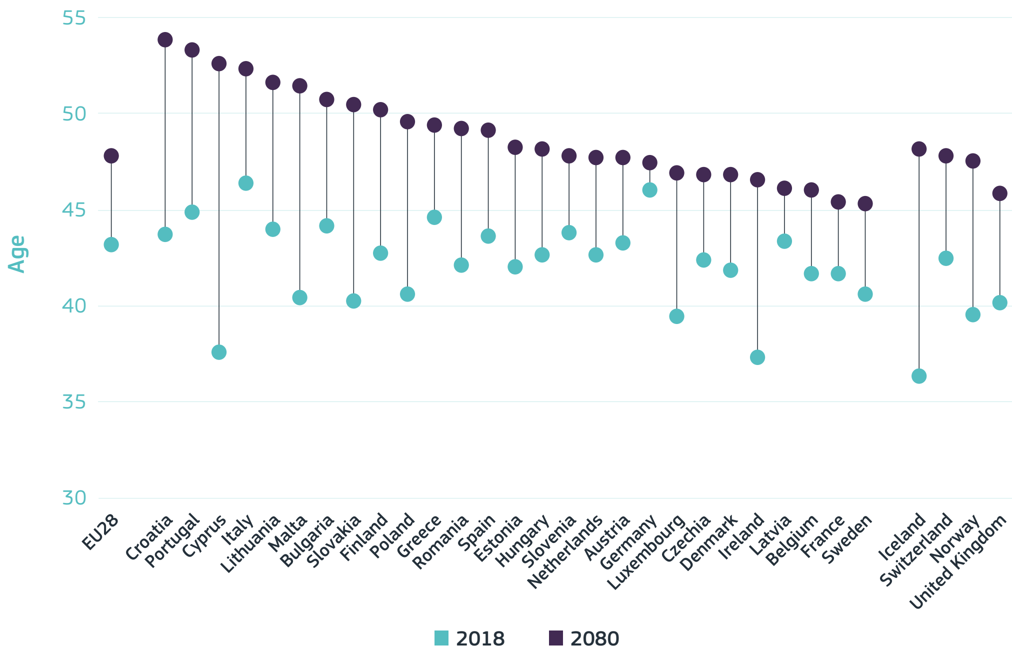
R&I will be key to achieving the climate goals. It can enable non-polluting and affordable sources of energy. Developing low-carbon technologies and solutions for decarbonisation are needed to achieve a 2 °C scenario and mitigate the consequences of climate change. According to the GECO 2018 report, 'in particular, technologies like biomass combustion with carbon capture and sequestration (BECCS) would allow CO_2 removals through using biomass energy (BE) – assumed to be carbon neutral – combined with CCS. The availability of this technology at affordable costs could be key in limiting temperature change to below 2 °C or even further.' R&I can provide solutions for and a better understanding of the challenges related to climate change and the ongoing degradation of the natural environment, including loss of biodiversity.

EU population is ageing

Another trend that directly relates to R&I is the EU's ageing population. In 2018, 20% of the EU population was aged 65 years or over. By 2100, the share of people aged 80 years or more is expected to more than double, reaching 14.9% of the entire population[6]. The median age of the EU28 population is projected to increase by 4.7 years, from 43.1 years in 2018 to 47.8 years in 2080[7] (Figure 1-5). The EU's old-age-dependency ratio[8] is projected to nearly double – from 30.8% in 2018 to 58% by 2100. The total age-dependency ratio is projected to increase from 54.2% in 2018 to 83.5% by 2100[9]. This is the result of consistently low birth rates and high life expectancy that are reshaping the EU age pyramid (Figure 1-6). One consequence of increased longevity is that people will have to work more years before they retire (Eurostat, 2019). Despite that, the number of people of working age is projected to shrink in the EU, while the share of retired people is expected to increase. An ageing population is not a phenomenon specific to the EU as the entire planet is ageing. However, one continent stands apart: Africa, in particular sub-Saharan Africa, presents very young demographics and will be the demographic engine of the world in the 21st century (EPRS, 2020).

Figure 1-5 Median age, 2018 and 2080[(1)]



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: demo_pjanind and proj_18ndbi)

Note: [(1)]Values for 2018 are a baseline projection.

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6 Based on Eurostat: Population projections at national level (EUROPOP2018).

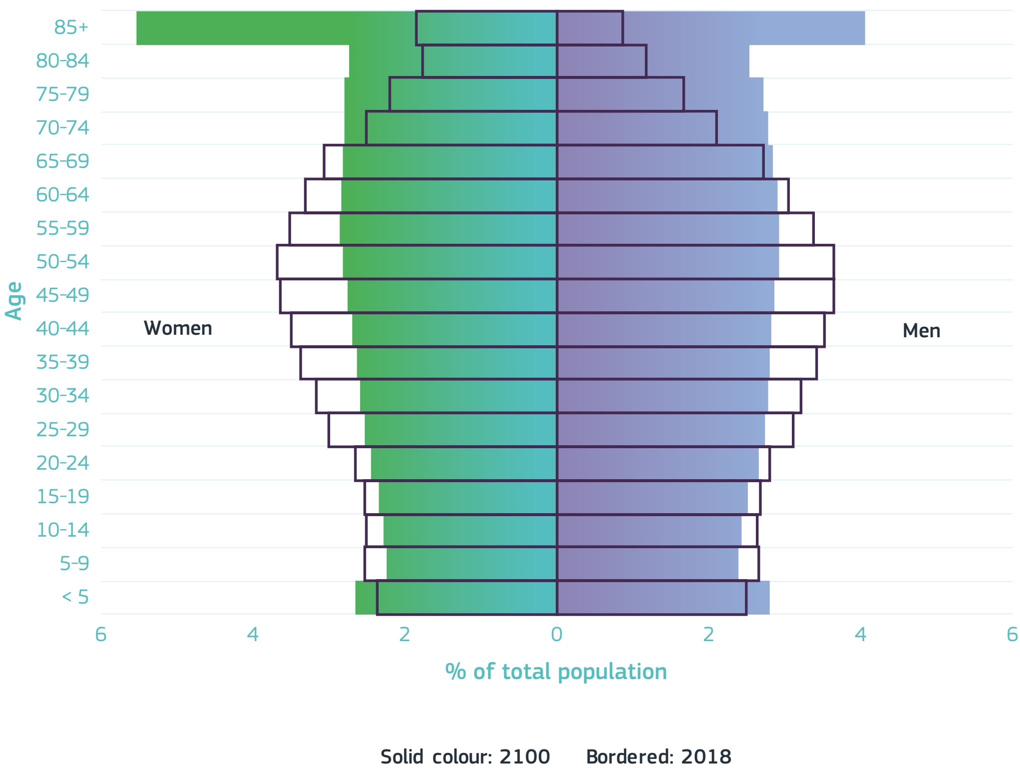
7 Based on Eurostat: Population projections at national level (EUROPOP2018).

8 Ratio between the population aged 65+ and those aged 15-64.

9 Based on Eurostat: Population projections at national level (EUROPOP2018). See also European Commission's Competence Centre on Foresight – Megatrends Hub.

This trend has several consequences for R&I. First, it means that R&I will be increasingly expected to address the need for ageing-related innovations, as ageing will involve changes in lifestyle and a growing demand for specific products and services. There will be a greater need for R&I to address ageing-related illnesses, support active ageing and foster technologies such as robotics and neurosciences which can provide support to the elderly[10]. Second, productivity will need to increase to compensate for the declining share of the population in working age, together with inflows of high-skilled migrants, especially in the case of an ageing R&I workforce.

Figure 1-6 EU age pyramid, 2018[(1)] and 2100[(2)] (as % of total population)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: demo_pjangroup and proj_18np)

Notes: [(1)]Provisional. [(2)]Projections (EUROPOP2018).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-6.xlsx

10 See OECD (2016).

Inequalities[10] are growing, in particular in the context of digitalisation and technological acceleration

There are concerns that new technologies may exacerbate social and geographical inequalities through job and wage polarisation, income disparities, regional disparities, and 'winner takes most' markets and industries. Intense discussion on the growing divergences and inequalities between groups of people are also increasingly focused on geographical imbalances, as described by the 'geography of discontent' or economic imbalances with emerging analyses on the lack of productivity diffusion between leading and laggard firms.

BOX 1-1 Geography of discontent

The term geography of discontent refers to a set of local economic conditions that characterise declining and lagging-behind areas (Rodríguez-Pose, 2018; McCann, 2019). It has been shown that unfavourable local conditions such as, for example, regional unemployment (linked to industrial decline) and their perception have repercussions regarding trust towards the political institutions or can drive anti-system and populist voting in Europe (Dijkstra et al., 2018).

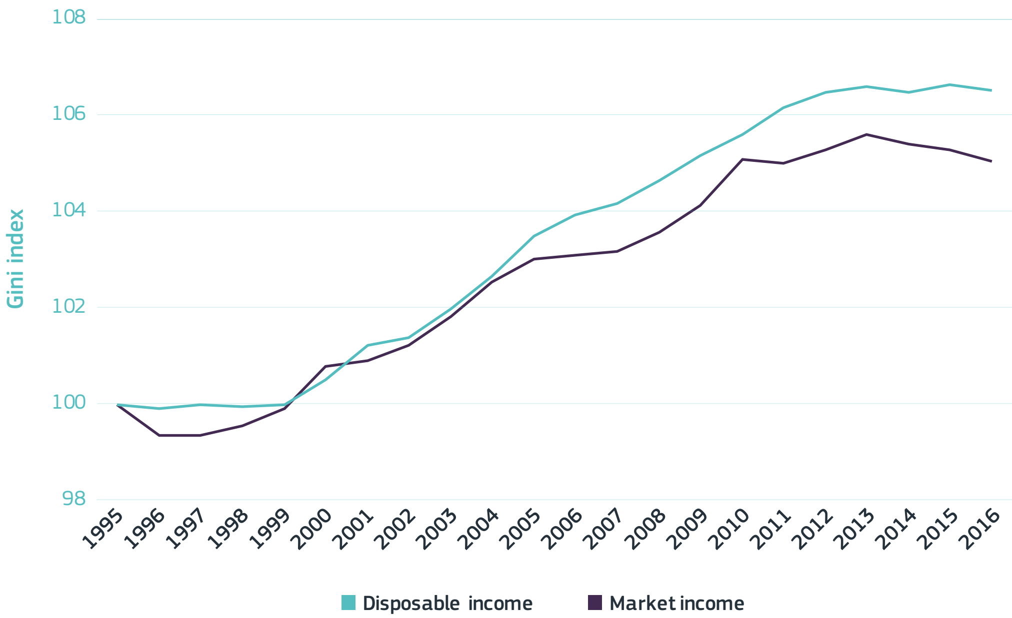
Increased inequality as well as underperforming productivity and growth dynamics are becoming the main challenges for Europe's social political agenda. Overall, compared to other countries, Europe is a more equal place to live. This situation is largely driven by Europe's distribution of incomes and resources. Nevertheless, the commonly used Gini coefficient as a measure of inequality of income shows that EU income inequality has increased during the last two decades (Figure 1-7)[12]. Greater inequalities challenge the balance between distributional tensions and preferences for equity, in particular within countries and for population groups of a certain age or place of residence (OECD, 2019a; World Bank, 2019). Gender inequalities also remain in Europe, with an average EU gender pay gap of 16 % and extremely slow progress over time (European Commission, 2019a and 2019b).

These evolutions challenge the view that high competitiveness and strong investments in R&I automatically lead to more equality, driven by higher growth and more jobs. There is growing awareness that competitiveness and inclusiveness must go hand in hand. Recent evidence suggests that overly high levels of inequality are not economically, socially or politically sustainable (Iammarino et al., 2018; IMF, 2019; OECD, 2019b). If there is no diffusion of innovation, there is a risk that the benefits of innovation will be limited to skilled individuals, areas or companies with strong R&I assets. Evidence focusing on top income inequality and its interplay with innovation shows that technological change is associated with a higher share of income for the entrepreneur, at the expense of workers' compesation hence increasing the top inequalities (Aghion et al., 2016).

11 Recent figures suggest that the 45 % of global wealth is owned by the richest 1 % (Credit Suisse Research Institute, 2019).

12 The Gini Index for market income (before taxes and social transfers) in the EU rose from 46 in 1995 to 48.4 in 2016, being larger than Japan (42 in 2015) and Korea (34 in 2016) but lower than the United States (50.8 in 2016).

Figure 1-7 EU[1] - Gini index of inequality – market income and disposable income (1995 = 100), 1995-2016



Science, research and innovation performance of the EU 2020

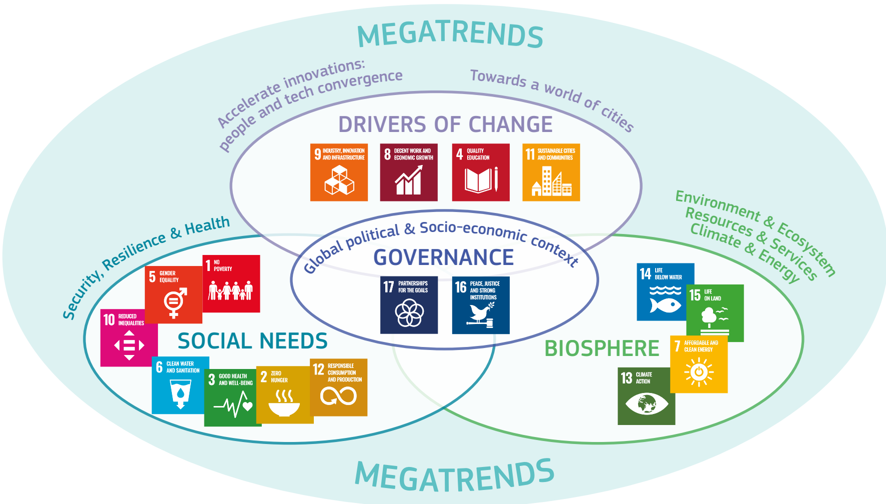
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat
Note: [1]EU is the weighted average of the values for the 27 EU Member States.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-7.xlsx

The rapid changes in global value chain configurations enabled by the application of new technologies have important implications for the new models of work organisation and workplace management. So far, most of the debate has focused on the phenomena of **skill-biased technological change**, whereby greater automation and digitalisation could enable the displacement of low-skilled jobs while increasing the demand for high-skilled jobs (software and data experts, engineering, etc.). These shifts in production technology that favour skilled labour over unskilled labour have provoked discussions on the effects of technological change on labour market and wage inequalities (Acemoglu and Autor, 2011; Okazawa 2013). **Routine-biased technological change** represents a more recent approach predicting that automation and digitalisation will lead to a decline in jobs that are rich in the routine component while increasing jobs that entail fewer routine tasks. This adjusted approach captures well the latest changes in the employment distribution with a declining share of middle-skilled occupations relative to high- and low-wage occupations, defined as 'job polarisation' (Sebastian and Biagi, 2018). In this context, skills will largely determine Europe's competitiveness and capacity to drive innovation. Chapter 5.2 'Investment in education, human capital and skills' elaborates on the skills required in future labour markets, while Chapter 4.1 'Innovation, the future of work and inequality' explains in more detail the impacts on labour markets.

2. An aspiration towards sustainability

These trends mean that our climate and environment, economy and society are experiencing profound changes that will fundamentally alter our current way of life. This is happening against a backdrop of rapid technological change that is redefining our economies and societies. Taken together, these challenges imply the need for three deep transitions along the axes of ecology, economy and society, going beyond the traditional focus on GDP growth. In this context, the EU and its Member States have signed up to the **UN 2030 Agenda for Sustainable Development**[13] **that specifies 17 Sustainable Development Goals** with 169 targets to guide the transition towards sustainable development (Figure 1-8). The SDGs represent an integrated concept that reconciles economic with social and environmental challenges.

Figure 1-8 Megatrends and Sustainable Development Goals



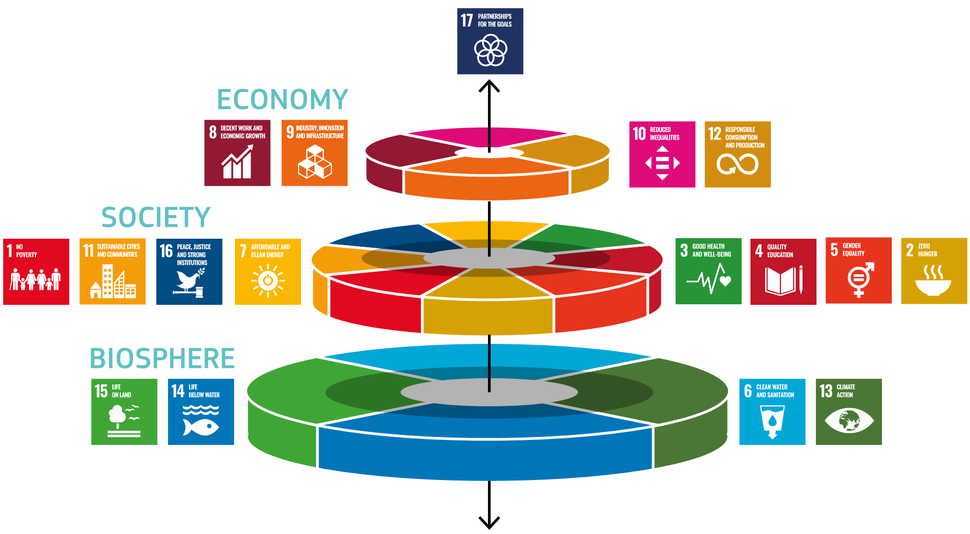
Source: BOHEMIA project (European Commission, 2018)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-8.xlsx

13 https://sustainabledevelopment.un.org/post2015/transformingourworld

Economic, social, and environmental sustainability are not separate. They are interdependent and build upon one another. A prosperous and efficient economy thrives within a healthy, inclusive and resilient society, and both depend on a healthy biosphere. Thus, restoring and growing the stock of life and prosperity supporting ecosystems is a key dimension of economic sustainability. The shift from a sectoral to a holistic perspective is visualised in the 'wedding cake' model of sustainability (Figure 1-9), developed by the Stockholm Resilience Centre. This vision implies that the economy serves society so that it evolves within the safe operating space of the planet. These interconnections also imply that there are trade-offs and synergies between the SDGs. While the SDG framework shows many synergies, those related to higher incomes, better access to energy, more economic growth, and industrial and infrastructure investments tend to increase the overall extraction and consumption of natural resource, making it harder to achieve targets on their efficient use, the better management of chemicals and waste, climate mitigation and the protection of terrestrial ecosystems and biodiversity (EEA, 2020). The key challenge lies in making the right policy choices to leverage the synergies and minimise the potential trade-offs among the SDGs.

Figure 1-9 **Sustainable Development Goals**



Source: Stockholm Resilience Centre

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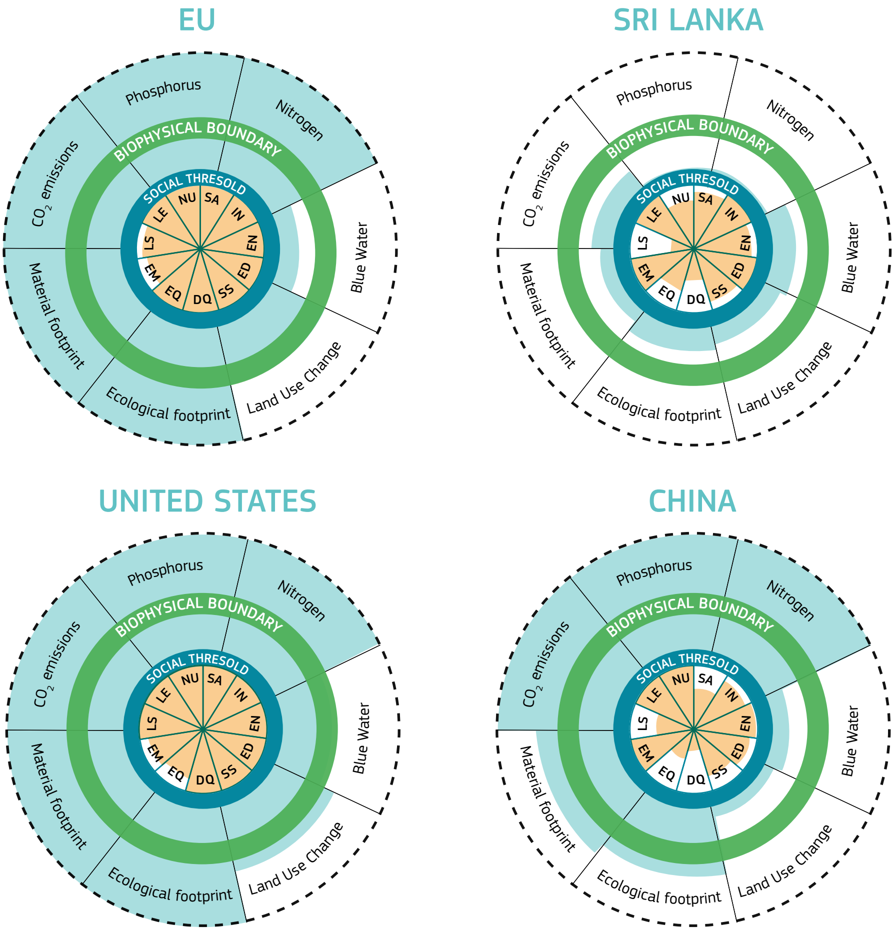
Sustainability implies that we should thrive in a safe and just space between planetary boundaries and social boundaries[14] (Raworth, 2017). On the one hand, an environmental ceiling of planetary boundaries should not be crossed as this would mean unacceptable environmental degradation and potential tipping points in Earth systems. On the other hand, many dimensions of human deprivation lie below social foundations. Moving into the space between these two boundaries is an aspiration that requires 'far greater equity in the use of natural resources, and far greater efficiency in transforming those resources to meet human needs' (Raworth, 2012).

Currently, no country in the world seems to meet basic needs for its citizens at a globally sustainable level of resource use. O'Neil et al. (2018) aim to quantify the transgression of biophysical boundaries and achievement of social thresholds for over 150 countries (Figure 1-10). They show that 'physical needs such as nutrition, sanitation, access to electricity and the elimination of extreme poverty could likely be met for all people without transgressing planetary boundaries. However, the universal achievement of more qualitative goals (for example, high life satisfaction) would require a level of resource use that is 2-6 times the sustainable level, based on current relationships.' Europe achieves the social thresholds for almost every indicator, but it does so by transgressing the safe levels for almost all biophysical boundaries. The only one that Europe does not exceed is water use. At the other extreme, countries like Sri Lanka stand within the safe boundary for every single environmental indicator but only achieve an acceptable level for three of the social indicators. The situation in the United States is similar to the EU, with most social thresholds achieved and biophysical boundaries transgressed. In comparison, China presents more shortfalls regarding the social dimensions but less overshoot on the biophysical aspects.

14 Planetary boundaries' is a concept which refers to a series of sustainability limits beyond which lie tipping points for many earth systems that could result in the planet becoming inhospitable for humanity. In her book 'Doughnut Economics', Kate Raworth joined the idea of planetary boundaries with that of a social foundation to provide the 'safe operating space' for humanity.

Figure 1-10 Doughnut representation of biophysical boundaries and social thresholds

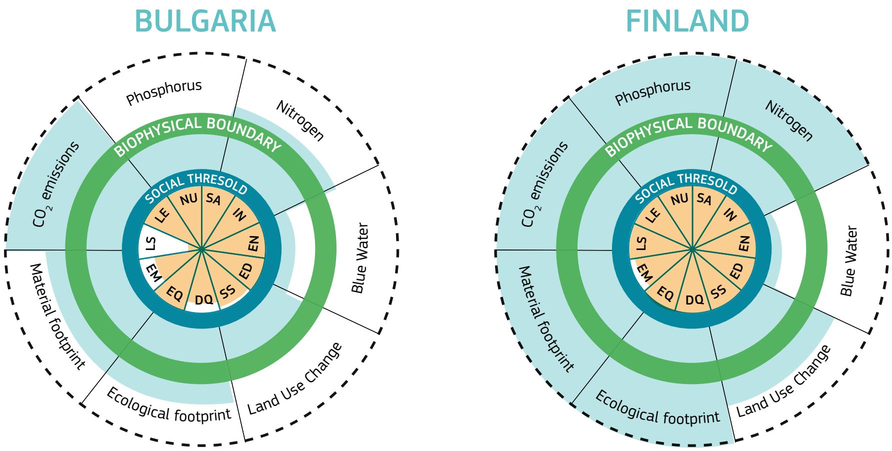


LS – LIFE SATISFACTION
LE – HEALTHY LIFE EXPECT.
NU – NUTRITION
SA – SANITATION
IN – INCOME
EN – ACCESS TO ENERGY
ED – EDUCATION
SS – SOCIAL SUPPORT
DQ – DEMOCRATIC QUALITY
EQ – EQUALITY
EM – EMPLOYMENT

Source: https://goodlife.leeds.ac.uk/
Note: Orange wedges show social performance relative to a threshold associated with meeting basic needs (blue circle); light blue wedges show resource use relative to a biophysical boundary associated with sustainability (green circle). Wedges with a dashed edge extend beyond the chart area. Ideally, a country would have orange wedges that reach the social threshold and light blue wedges within the biophysical boundary. This graphic is based on Kate Raworth's work on Doughnut Economics. Here, EU refers to EU+UK.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-10.xlsx

There are also disparities between Member States in terms of social and biophysical achievements. Bulgaria presents the lowest average level of transgression of biophysical boundaries[15] and Finland the highest (Figure 1-11). All EU countries transgress at least five out of the seven biophysical boundaries, with Spain, Portugal and Greece transgressing all of them. There is more dispersion in terms of social achievements, with the lowest thresholds achieved in Latvia (4 out of 11), Lithuania and Portugal (5), while the Netherlands and Austria achieve all social thresholds.

Figure 1-11 **Extreme biophysical scores in the EU**



LS – LIFE SATISFACTION
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Source: https://goodlife.leeds.ac.uk/

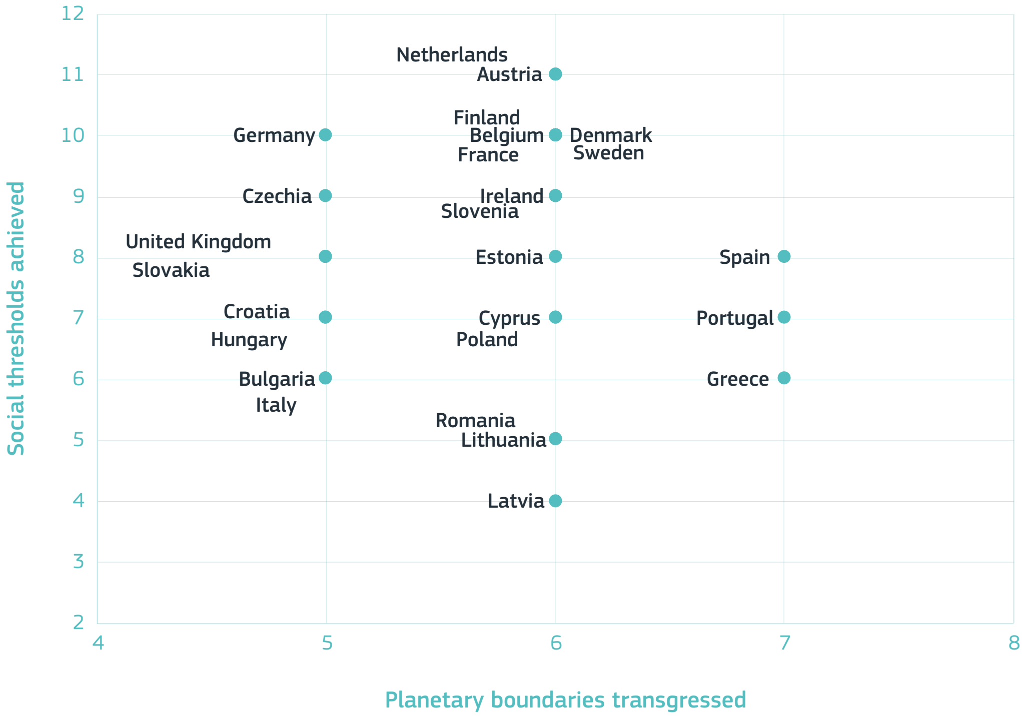
Note: Orange wedges show social performance relative to a threshold associated with meeting basic needs (blue circle); light blue wedges show resource use relative to a biophysical boundary associated with sustainability (green circle). Wedges with a dashed edge extend beyond the chart area. Ideally, a country would have orange wedges that reach the social threshold and light blue wedges within the biophysical boundary. This graphic is based on Kate Raworth's work on Doughnut Economics.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-11.xlsx

15 Based on the average score of the dimensions.

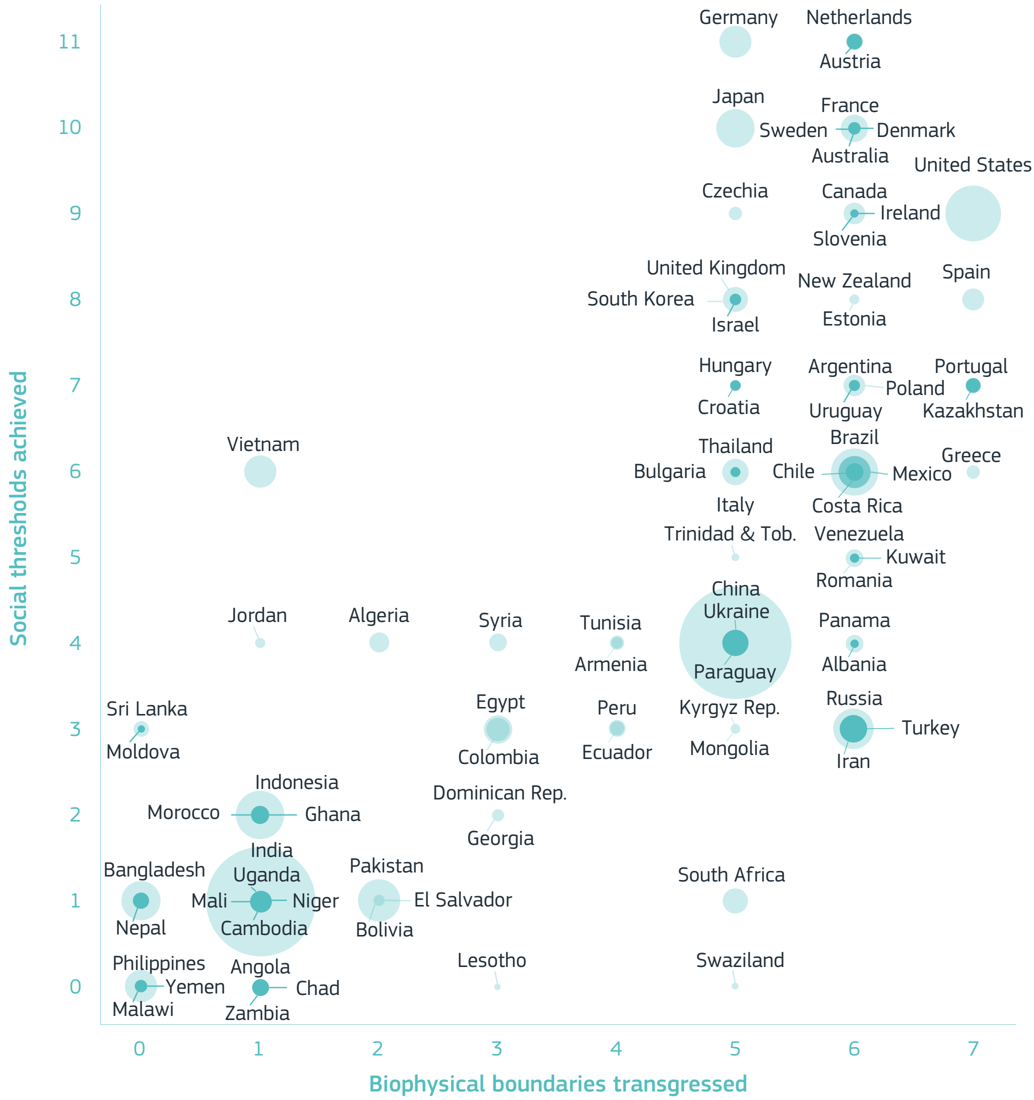
These results suggest that countries that do well on the social indicators are using resources at an unsustainable level. This shows the challenge of achieving social thresholds while not exceeding the biophysical boundaries (Figure 1-12), using resources at a level that is high enough to meet people's basic needs (the social foundation) but not higher than the ecological ceiling (as determined by the planetary boundaries), as conceptualised by Raworth (2017). O'Neil et al. (2018) present an overview of countries at the global level that illustrates the relationship between these two dimensions (Figure 1-13).

Figure 1-12 Biophysical boundaries and social thresholds in the EU28



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on https://goodlife.leeds.ac.uk/
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-12.xlsx

Figure 1-13 Biophysical boundaries and social thresholds – global perspective



Source: O'Neil et al. (2018)

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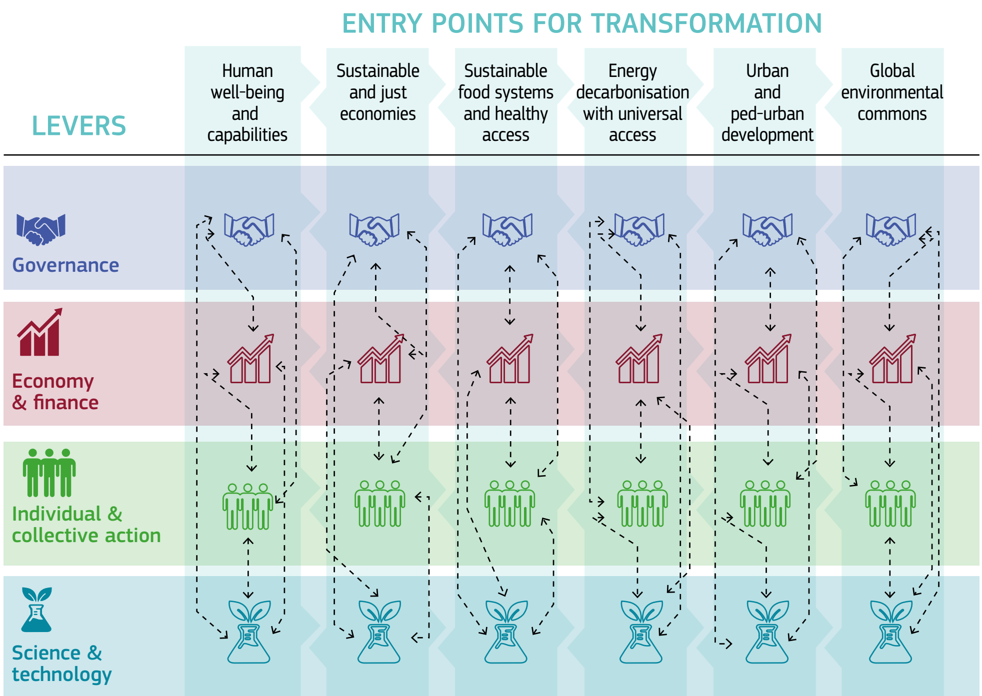
3. R&I can accelerate the transition to a sustainable Europe

The interconnection between social, economic and environmental issues call for systemic change in which R&I plays a key role. EPSC (2019) highlights the need for policy action directed at 'capturing the multiple dimensions of sustainability [...] to overcome the often siloed approach pursued by most actors at all levels of government', referring to the inextricable links of the safe and just space for humanity between social shortfall and ecological overshoot. In this context, cross-cutting policies such as R&I will play a key role in achieving sustainable development. They have the unique capacity to set directionality without being prescriptive, and to create synergies across policies to increase overall impact. Science and technology are key levers for the transformation required to address SDGs (United Nations, 2019b). However, R&I will need to interact with other levers, such as governance, economy and finance, and individual and collective action, in order to bring about the transformations required to address the SDGs (United Nations, 2019b) (Figure 1-14).

Figure 1-14 **Entry points for transformation**



Source: United Nations (2019c), Global Sustainable Development Report

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R&I is a cornerstone for a robust European project in a global context that can accelerate the transition to sustainability, while improving our well-being and ensuring longer-term prosperity. First, R&I is needed to produce novel solutions in areas like health, digital technologies, industrial transformation, resilient societies, natural resources, energy, mobility, environment, food, low-carbon economy and security. R&I solutions also enable both economic and environmental efficiency to be improved while developing new sustainable ways to satisfy human needs. Second, R&I helps to build the necessary knowledge and understanding of the phenomena to be addressed. Third, R&I, in particular frontier research, can strengthen society's resilience by building a reservoir of knowledge over the long term (Ricci, 2017). Hence, R&I can become a compass helping the EU to navigate the complexities of the 'Anthropocene' and to co-create a common route. R&I can also be the engine room for answers and solutions in the transformation towards sustainability, contributing to solving challenges at the global level. Figure 1-15 presents some of our main findings on how R&I contributes to sustainability.

Figure 1-15 Sustainability across the report

▸ **Consumers are increasingly putting pressure on companies to become more environmentally friendly**, with millennials leading this push for change in organisations. ▸ **Indicator**: › Percentage of respondents who said that it is 'extremely' or 'very' important that companies implement programmes to improve the environment, with each generation.	Continue reading in Chapter 2 - Changing innovation dynamics in the age of digital transformation
▸ **Productivity growth and sustainability can reinforce each other**. Productivity can help overcome the trade-off between environmental policy and long-term growth. ▸ **Indicators**: › Sectors most affected by the transition to sustainability in the energy sector (million jobs) › Growth of the environmental sector in the EU.	Continue reading in Chapter 3.1 - Productivity puzzle and innovation diffusion
▸ Despite some progress, a pronounced **gender gap remains in the creation of innovative startups**. ▸ **Indicators**: › Evolution of the share of innovative startups with at least one female founder, 2000-2016 › Share of innovative startups founded between 2000 and 2017 with at least one female founder by country › Number of unicorns with at least one female founder, by year of first venture capital round raised, 2013 - May 2019 ▸ A **'tech with a purpose' approach** would leverage R&I to create the solutions that match the urgency of the environmental and social challenges of our time.	Continue reading in Chapter 3.3 - Business dynamics and its contribution to structural change and productivity growth

▸ It is important for **adult learning systems to be inclusive and aligned with skill needs in order to reach out to workers at most risk of job loss or displacement**. ▸ **Indicators**: › Participation rate in adult training › Highest and lowest shares of job-related adult learners ▸ The emergence of digital technologies does not help to close **the gender gap** as observed by lower participation of women in ICT-related fields and platform work. ▸ **Indicators**: › Share ICT specialists by sex › Share of platform learners by age and sex › Female-founded startups across different sectors – share of companies with at least one female founder (%)	Continue reading in Chapter 4.1 - Innovation, the future of work and inequality
▸ **The increasing level of knowledge complexity[16] suggests that even the metropolitan areas and well-connected regions concentrate top scientific publications in the fields of societal challenges**. ▸ **Indicator**: › Relative specialisation of top regions by societal challenges	Continue reading in Chapter 4.2 - Regional R&I in Europe
▸ **The United States leads in climate-related R&D spending, China has recently quadrupled its spending, slightly overtaking the EU**. ▸ **Indicator**: › Investment in climate R&I ▸ **Member States are slowly steering their national budgets towards societal and environmental challenges**. ▸ **Indicator**: › Evolution of government budget allocations to R&D in the EU	Continue reading in Chapter 5.1 - Investment in R&D
▸ **Gender imbalances among graduates are larger compared to the number of enrolled students where women represent 54%**. ▸ **Indicator**: › Share of tertiary graduates by sex ▸ **Women are a minority in the top academic grade and their position in recent years has improved only slightly**. ▸ **Indicator**: › Share of females as head of institutions in the higher education sector ▸ Although females represent roughly half of EU graduates at doctoral level, **women represent only about a third of all EU researchers and only one fifth of researchers in the business sector**. ▸ **Indicator**: › Total researchers	Continue reading in Chapter 5.2 – Investment in education, human capital and skills

▸ **Science is key in addressing societal challenges**. The EU leads high-quality scientific publications in the **food/bioeconomy and climate/environment** sectors. ▸ **Indicators**: › Regional collaboration matrix for SDG core and citing papers › Share of scientific publications by societal challenge › Shares (%) of top 10 % scientific publications by societal challenges, 2006 and 2016 › EU specialisation by societal challenge compared to its major competitors, 2005-2009 and 2014-2018 › EU specialisation compared to the US › Global performance of EU universities against UN SDGs in the Times Higher Education University Impact Rankings 2019	Continue reading in Chapter 6.1 - Scientific performance
▸ The EU is **leading technological progress in the fields of energy, climate and environment and food and bioeconomy**. ▸ **The total number of patent applications related to the societal challenges increased over time in all fields**. ▸ **Indicators**: › Total number of PCT patent applications by societal challenge, 2000-2016 › Share of PCT patent applications by societal challenges, 2016 vs. 2006 › EU27 Specialisation Index by societal grand challenge (vs. rest of the world) › EU27 Specialisation Index(1) by societal grand challenge (vs. United States and China), three-year average period	Continue reading in Chapter 6.3 - Innovation output and knowledge valorisation
▸ **AI is a potential game changer for productivity and sustainability**, provided the right complementary skills, infrastructure and management culture are in place. **R&I solutions are needed to mitigate the environmental footprint of AI**. ▸ **Indicators**: › How AI and digital technologies can contribute to cutting global emissions across sectors (estimates) ▸ **The lack of gender diversity in AI research persists although over time progress is being made, notably in European countries**. ▸ **Indicators**: › Percentage of AI and non-AI papers with at least one female author by country, 2018	Continue reading in Chapter 7 - R&I enabling artificial intelligence

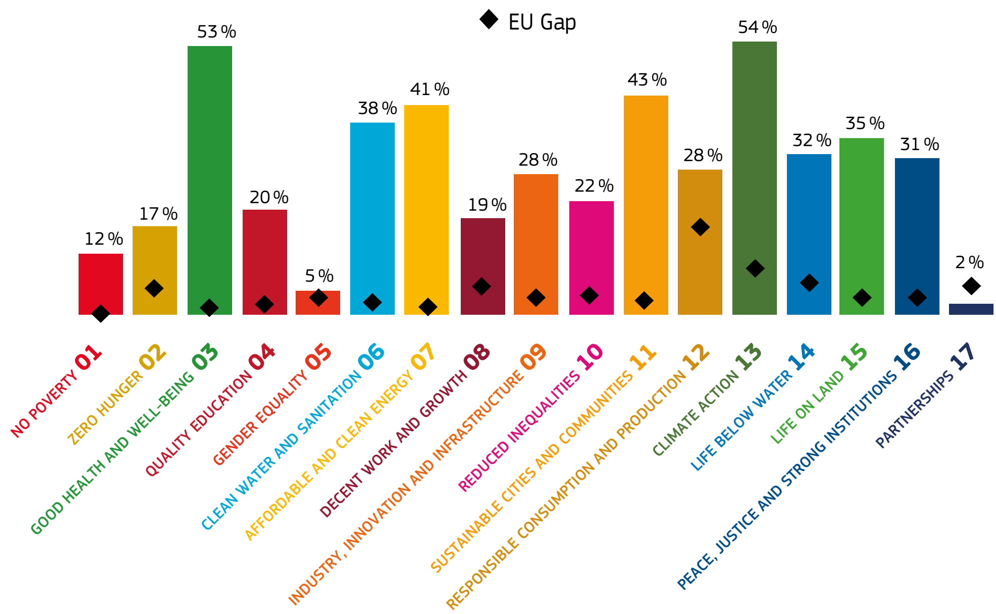
Science, research and innovation performance of the EU 2020

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-15.xlsx

16 Refers to assets for innovation activities of the knowledge economy. See Chapter 2 Changing innovation dynamics in the age of digital transformation or earlier publications, such as Westlund, 2006.

R&I projects under Horizon 2020 illustrate how R&I can foster the Sustainable Development Agenda (see Box 1-2). Potentially, 84% of current Horizon 2020 investments relate to at least one of the SDGs. All three pillars of the programme appear to contribute to the SDGs to a similar degree ('top-down' and 'bottom-up' investment) which could indicate an underlying systemic move towards an 'SDG-inspired' R&I. The largest share of investment relates to climate action and good health and well-being (54% and 53% of the current Horizon 2020 investment, respectively) (Figure 1-16). Conversely, the focus of EU R&I investment on responsible production and consumption is low compared to the current EU performance gap in this area (28% of current Horizon 2020 investment). The EU performance gap is based on the latest EU distance to target reported by the UN Sustainable Development Report 2019 (Sachs et al. (2019)).

Figure 1-16 Share of Horizon 2020 investment and the EU distance to target, by SDG[(1)]



Source: European Commission (2020). Monitoring Flash: Sustainable Development Goals

Note: [(1)]The report uses a methodology based on the keyword search to relate projects funded with SDGs. For each of the SDGs, a list of keywords was assembled based on the compilation and cross-checking of keywords used for similar endeavours (i.e. Mapping Austrian Research Contributions to the Sustainable Development Goals, Aurora Universities Network SDG analysis and Australian Guide for Getting Started with the SDGs in Universities).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-16.xlsx

BOX 1-2 Examples of R&I projects providing solutions that contribute to SDGs (funded by the EU R&I Framework Programme)

Never-ending battery

EU funding helped an Estonian company produce an energy-storage device called an ultracapacitor which is 100 times more powerful than an ordinary battery and can withstand 1 million recharge cycles. Skeleton's ultracapacitors are based on graphene, a two-dimensional form of carbon with remarkable properties. The company raised EUR 13 million to build a manufacturing facility in Germany capable of producing millions of new ultracapacitors a year.

More about the SKLCarbonP2 project.

Making old buildings energy efficient

Old buildings consume a lot of energy. Finding a solution to decarbonise Europe's building stock is a vital part of the fight against climate change. The EU-funded BERTIM project has developed a new industrial solution that cuts the energy consumption of renovated buildings by half, and the time spent on the building site by 30 %.

More about the BERTIM project.

On the way to zero-emission flights

Commercial aircraft are a major source of emissions. The EU-funded MAHEPA project is developing and testing hybrid electric propulsion using light aircraft and is studying whether or not the system can be scaled up to power commercial aircraft. The project is developing modular components for hybrid airplanes scheduled to fly in 2020.

More about the MAHEPA project.

Greener water transport with an electric ferry

Europe has around 900 ferries for cargo, cars and passengers, which account for 35 % of the world fleet. For more energy-efficient vessels that emit less carbon dioxide in the future, an EU-funded project will demonstrate a fully electric ferry. It will have a 40-km range, a speed of 25 km/h, and capacity for some 30 cars and 200 people. The prototype ferry will connect the island of Aeroe (DK) to the mainland.

More about the E-ferry project.

Using CO_2 as a raw material to make plastics

The technology allows for the conversion of steel-sector emissions into carbon to produce polyols, a widely used plastics component. Global demand for polyols is around 4 million tonnes per annum. Producing even 10% from exhaust emissions and waste gas would save up to 150 000 tonnes of fossil raw materials annually and, at the same time, an equivalent amount of CO_2 emissions. The technology has numerous applications which can lead the way to a more sustainable chemical sector.

More about the Carbon4PUR project.

Reactor optimisation by membrane-enhanced operation

The technology enables the same chemical (aldehydes) to be produced from the same feedstock but in a much more efficient process: the reduction of side-product formation (and as a consequence cutting CO_2 emissions by 90%), omitting distillation leading to energy savings of up to 5.3 GWh (78% less than compared to the state of the art), and an 8% reduction in feed products to produce aldehydes, plus a substantial cost reduction (OPEX).

More about the ROMEO project.

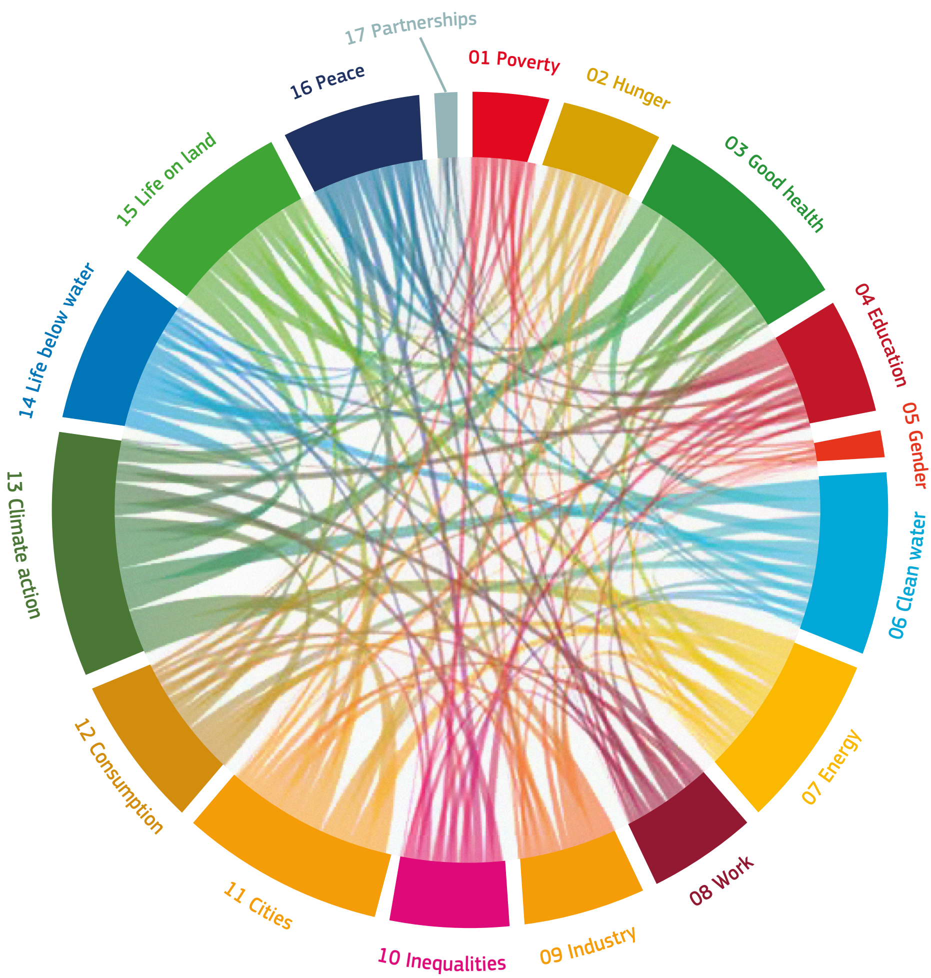
A secure platform for the flexible management of shared process resources

Resource efficiency offers major economic opportunities for the European process industry, both in terms of cost savings as well as opportunities to offer greener products and services. Industrial symbiosis is the use by one company or sector of by-products, including energy, water, logistics and materials, from another. The development of a secure platform allows for the flexible management of shared process resources with intelligent decision-support tools. It provides plant operations and production managers with the robust and reliable information that they need in real time to effectively and confidently share resources (plant, energy, water, residues and recycled materials) with other companies in an optimum symbiotic ecosystem. There is the potential for a 10% reduction in industry's GHG emissions, while industry has less needs for fresh water across Europe: up to 40%. In future, there will be a need to move from industrial symbiosis towards industrial urban symbiosis (with a much higher potential for reducing energy, water or material needs).

More about the SHAREBOX project.

R&I projects also illustrate significant interconnections between SDGs. Given the systemic nature of sustainable development, the current investment is highly interconnected – on average Horizon 2020 project potentially relates to three different SDGs (Figure 1-17). Some observed interlinkages, such as climate, energy and water, are expected, while others, such as climate action and good health, are more surprising. This also shows the high levels of trade-offs and synergies between SDGs and their targets. R&I can help to overcome these trade-offs, although there is also a risk of their exacerbation[17].

Figure 1-17 Overview of the interlinks between SDGs based on Horizon 2020 projects



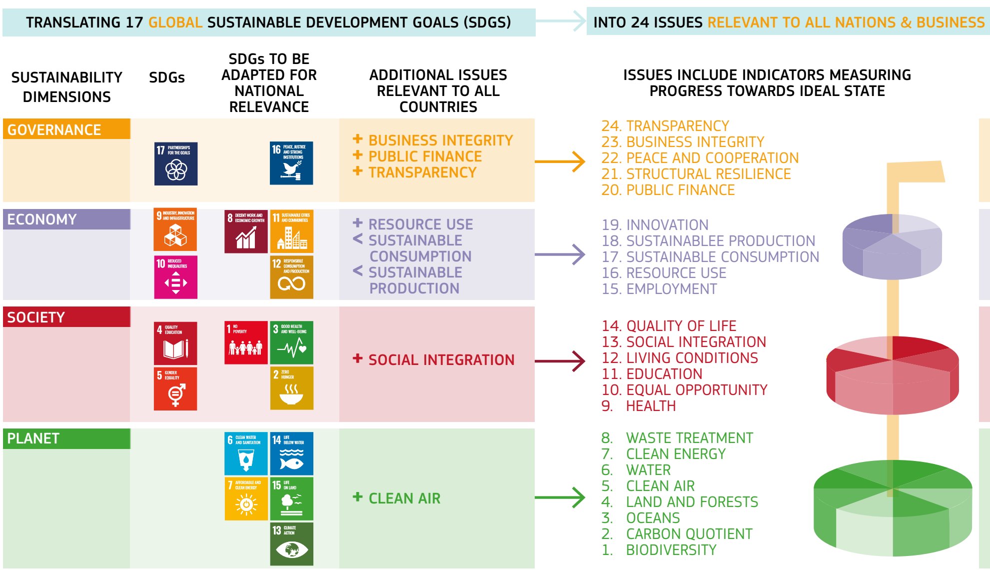
Source: European Commission (2020), Monitoring Flash: Sustainable Development Goals
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-17.xlsx

17 For example, as shown by Vinuesa et al. (2020) AI can act as an enabler for 79 % of all targets, although the progress of 35 % of them may be inhibited by AI, at least to some extent. This requires policies that help direct the vast potential of I towards the greatest benefit for individuals and the environment, as well as towards achieving the SDGs.

4. Conclusion: a transformative innovation policy

The EU is fully committed to sustainable development and endorses its holistic and integrated approach, mainstreaming the SDGs into EU policies and initiatives, with sustainable development as an essential guiding principle for all of its policies. This calls for policy coherence for sustainable development across different dimensions: social, environmental and economic, in relation to our people, planet and prosperity. Hence, it requires an integrated multidimensional policymaking approach, which is directional and evidence-based (Figure 1-18). The sustainability transformation is also an unprecedented governance challenge at all levels from local to global. This results from the combined effect of the urgency, the scale of the necessary transformations, and the complexity and interdependence of issues in a context of fragility and unpredictability. Well-conceived and coherent policies should stimulate the three sustainability dimensions – environmental, social and economic – to reinforce each other. In order to achieve this, **EU R&I policy should be guided by principles such as co-creation, diffusion, uptake, transformation and the directionality of research and innovation** (Box 1-3).

Figure 1-18 Example of translation of 17 SDGs into four dimensions



Source: Muff et al. (2018)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-18.xlsx

BOX 1-3 The theoretical background behind principles for transformative R&I policy

Co-creation: European strengths lie in the robust culture of using the community approach for collective action. The founding principle of European cooperation through the EU was to facilitate and cultivate the building of trust, understanding and sharing as a method of achieving common goals (Monnet, 1996) in a community open to ideas, innovation and peace. The efforts of the last 60 years have cultivated a robust culture of doing things together resulting in stronger pan-European collaborations necessary to address the most pressing continental issues at hand. These efforts have also recognised the fact that no EU Member State is big enough to tackle issues such as energy transitions and the fight against climate change alone. These issues profoundly challenge almost all aspects of our society. So right effort should be met with the right action. A co-creation approach that is horizontal, inclusive, with a sense of a common European purpose, would respond directly to the challenges and crises of our time.

Diffusion: a functioning European innovation system requires the right links among actors and the knowledge flows between them to be nurtured and progressively created. Chaminade and Edquist (2010) describe how the innovation systems theory was a reaction to the inadequacies of the neoclassical 'market failure' approach to justify public intervention to support innovation processes. They postulate that interventions by the public sector should be done in those cases in which the system does not function well, i.e. where system actors are not communicating well. If we observe the whole of the EU as a big potential innovation system, comprising universities, entrepreneurs, citizens, governments and the environment, there is a case to ensure that knowledge flows freely and that at a systemic level there is no unfair concentration to hamper economic and social progress.

Uptake: a modern European R&I innovation strategy should create system conditions that are favourable for market uptake and societal benefit of research and innovation. The challenges of designing effective innovation policies, including their industrial dimensions, imply understanding the dynamics and roles of technological development. Tassey (2007, 2014) introduces new elements relevant to the transition from basic science to commercial products - generic technology platforms, infratechnologies (e.g. measuring methods and standards) and proprietary technologies. His model opens up the space for exploring interdependencies in both markets and innovation systems over time, and at the level of a critical commercialisation path for the industrialisation of emerging innovations. Hence, it is not enough to promote research results and individual pieces of innovation – there is also a need to ensure a systemic approach that extends to all the technology elements needed for successful uptake to happen.

Transformation: R&I will have a major role in supporting a profound transformation of our value chains, which is needed to achieve the SDGs. The incentives for systemic changes in industries, especially legacy industries (e.g. agro-food, energy, legacy IT, transport, construction), and in customer behaviour are often too low in the short term. These changes can also involve high risks in the medium term so long-term benefits for sustainability are difficult to capture. However, innovation, especially digital innovation, is causing wide-ranging industrial transformations (McFee and Brynjolfsson, 2017). One of the roles of public policy interventions through R&I will be to facilitate these reconfigurations of value chains. Even if innovations often come from small and medium-sized enterprises (SMEs), most of such organisations may not have the required resources and organisational skills to compete in globally disrupted and changing value chains. In the past, this was addressed in certain sectors by ensuring rich access to venture and other capital (Janeway, 2018), but legacy sectors, which are also being disrupted and transformed, call for the deployment of a full range of innovation policy interventions (Bonvillian and Singer, 2017).

Directionality: an SDGs framework for the implementation of EU R&I policy calls for direction and an effective framework for coordination, alignment and synchronisation. This framework calls for steering of R&I to address specific issues but it does not prescribe the way how they should be addressed. Research into policy design for investment in R&I indicates that there can be different methods for priority setting in the research agenda, involving the science push or demand pull for innovation (Nemet, 2009; Stewart, 1995; Mazzucato, 2017). Different approaches have been explored to explain and systemise how R&I contributes to technological change. Because technological transitions in societies take distinct (Geels and Schot, 2007; Svensson and Nikoleris, 2018) and converging (Bainbridge and Roco, 2016; Roco and Bainbridge, 2013) integral pathways it is necessary to be able to direct the evolution of the R&I portfolios. Such directionality should be based on sound evidence gathered for example from foresight analysis (Schaper-Rinkel, 2013). In this context, an agile, responsive and socially accountable R&I policy that provides directionality must integrate a **horizontal approach that encompasses the coordination of policy instruments, an alignment of policy objectives and the synchronisation of investments**.

EU R&I policy can set the direction (see Box 1-4) to generate knowledge and solutions for the transformation towards sustainability, while improving our well-being and ensuring long-term prosperity and enhancing Europe's competitiveness as a global sustainability leader. It should promote systemic approaches beyond disciplines, sectors and policy areas. When challenges cross several policies, such as the food system, the strength of R&I is evidence-based orchestration. Transformative R&I policy can be a key enabler of the European process for SDG policy coordination. This is only possible with synergies between the environmental, social, and economic dimension of sustainable development by following a comprehensive, systemic, and ambitious approach at the EU level. A new transformative R&I policy will also need to engage with other actors in society to deploy new solutions on a massive scale, in particular the radical innovations required for such a transformation[18].

BOX 1-4 Transformative innovation and socio-technical transitions to address grand challenges

Frank Geels, University of Manchester

Transformative innovation and systemic transitions are gaining increasing attention in the context of three policy problems. First, addressing the climate change problem will require radical innovation and low-carbon transitions in many systems. Second, addressing other grand societal challenges (like ageing, obesity, energy security, urban quality of life, inequality) and the SDGs will require transformative innovations in healthcare, agro-food, and urban systems. Third, low-carbon and sustainability transitions offer attractive growth prospects.

Transformative innovation and systemic transitions involve several new policy challenges:

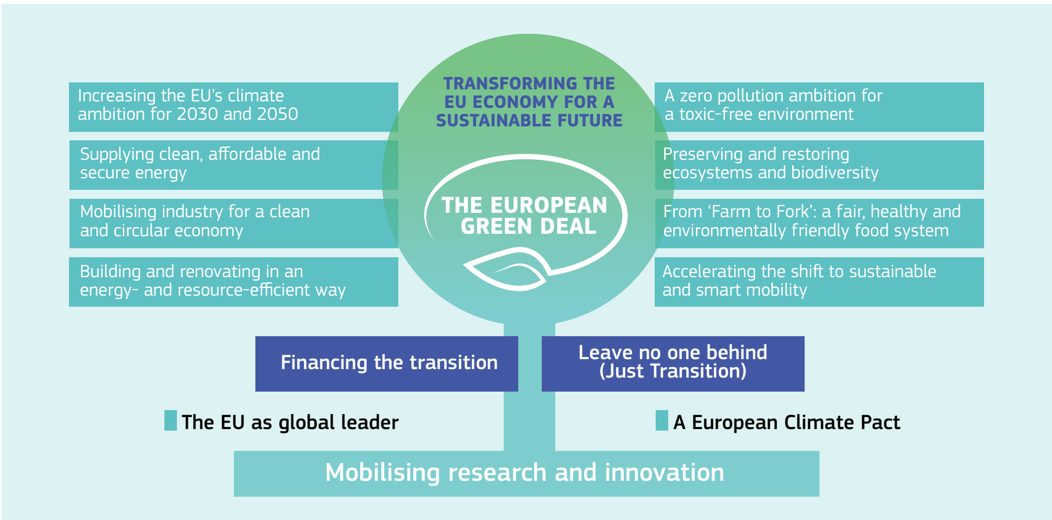
1. Horizontal policy coordination
2. Transform social, business model and infrastructural innovation, not just technologies
3. Wider set of actors and coalitions (startups, cities, communities, citizens, NGOs)
4. Visions and missions (drive and directionality)
5. Diffusion of radical innovations into markets and society

Continue reading in Chapter 9 - Transformative innovation and socio-technical transitions to address grand challenges

18 The Joint Research Centre is making an important contribution to the operationalisation of transformative innovation with the recently launched Territorial Reviews of Industrial Transition (https://s3platform.jrc.ec.europa.eu/industrial-transition).

R&I will play a crucial role in driving the transition to a climate-neutral Europe and green economy. The European Green Deal Communication confirms that: 'New technologies, sustainable solutions and disruptive innovation are critical to achieve the objectives of the European Green Deal' (Figure 1-19). To deliver on the Green Deal, Horizon Europe will continue to create new knowledge and solutions to attain the SDGs and will provide even more directionality through its mission-oriented approach (e.g. on climate change, healthy oceans, climate-neutral and smart cities, and soil health and food) and European partnerships. In addition, it has set a 35% spending target for climate. It is also important to acknowledge that the vast majority of current Horizon 2020 programme investment is expected to foster the Sustainable Development Agenda.

Figure 1-19 European Green Deal



Source: DG Research and Innovation, adapted from the Communication on The European Green Deal[19]

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-19.xlsx

19 COM(2019) 640 final.

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