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IMPACT ASSESSMENT REPORT

Part 4

Accompanying the document

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Securing our future
Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society

{COM(2024) 63 final} - {SEC(2024) 64 final} - {SWD(2024) 64 final}

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1 THE INTERNATIONAL DIMENSION

The consequences of the triple planetary crisis of climate change, biodiversity loss and pollution pose an existential threat, particularly to the most vulnerable. All regions and citizens are directly affected by climate change, for example through job losses in climate-affected sectors such as agriculture, fisheries, and tourism. Unequal exposure and vulnerability to climate and environmental impacts of different regions and socio-economic groups worsens pre-existing inequalities and vulnerabilities. Yet, the impacts of climate change are not neutral, as for instance older people, persons with disabilities, displaced persons, or socially marginalised have different or less adaptive capabilities. The planet is warming at a higher speed than expected and all countries are affected by the impacts of climate change. Russia's war of aggression against Ukraine has caused human suffering and massive environmental damage, increased risks to nuclear safety in Ukraine and precipitated an energy and food crisis with global impacts.

As a consequence of the international commitments under the Paris Agreement, and to address the above-mentioned problems, a technological revolution is taking place, with massive investments in renewable energies in developed countries and in China, and in decarbonisation in most of the industrialised economies. With more ambitious environmental and climate policies in developed countries, the markets and investments are evolving, which requires an adaptation of production processes across value chains, thereby creating new gaps between frontrunners and the others and possible new dependencies. This is mobilising governments in different regions of the world, looking for reference models, expertise, and finance for developing greener production processes, diversifying their supply chains, and maintaining their access to markets, while reducing pollution and providing better access to energy in their territory.

At the same time, investments in fossil fuel energy continue at a high pace, and the EU REPowerEU plan and Fit-for-55 policies aim at smoothening the transition between fossil fuels and low-carbon energy sources, to become climate-neutral in 2050. By agreeing and delivering on the ambitious social and economic transformation, the EU and its Member States aim to inspire global climate action and demonstrate that moving towards climate neutrality is not only imperative, but also feasible and desirable. Supporting this global transformation, the EU and its Member States stand ready to engage with all Parties of the Paris Agreement to ensure the timely delivery of robust and ambitious long-term low greenhouse emission development strategies in line with the objectives of the Paris Agreement.

1.1 Climate and energy diplomacy raison d'être

In this context, the climate and energy diplomacy of the EU aims inter alia at engaging with partners worldwide to implement the Paris Agreement, to limit the global temperature increase to 1.5°C compared to pre-industrial levels, to support the most vulnerable, such as Least Developed Countries and Small Island Developing States in adapting to climate change effects, and to increase international climate finance for mitigation and adaptation. EU action also aims at supporting just transitions towards climate neutral and resilient economies and societies, by encouraging the deployment of renewable energies and increasing energy

efficiency with a view to phasing out fossil fuels. EU cooperation should encourage partners to embrace the opportunities of the green transition, including a safe and affordable access to green energy.

Climate diplomacy is also deployed to support energy security and the green transition in the Western Balkans and the Eastern Neighbourhood and will promote the green reconstruction of Ukraine. It further operates both at multilateral level, in all relevant international fora such as the UN, G20 and G7, OECD or regional organisations, and in bilateral contexts.

Bilateral climate diplomacy has been expanding in the recent years, as an external pillar of the European Green Deal. Climate diplomacy instruments support the multilateral climate negotiations as well as regulatory convergence by deepening mutual understanding about the EU and other countries' climate policies and objectives. They also allow for a strengthening of international cooperation.

While some third countries express concerns about the impact of elements of the European Green Deal measures, for example on their trade relations with the EU, other countries have also showed interest in better understanding the EU climate and energy policies, and learn from the EU's experience in developing a well-functioning carbon market, in modelling, in adaptation strategies, etc. Bilateral climate diplomacy thus allows to project and explain all the policy aspects of the European Green Deal, to create opportunities for cooperation and investments, for developing joint approaches and solutions, and for technical assistance, amongst other types of cooperation. Climate diplomacy instruments facilitate mutual understanding, keeping the channels open for exchanges, including of knowledge and trade. Climate diplomacy allows to avoid creating, or to overcome, new barriers emerging from different policy approaches.

Other international EU actions, such as on biodiversity loss, natural resource management and circular economy, are complementary of climate diplomacy, strictly speaking, as key parts of a holistic approach towards the achievement of the 2030 Agenda and the SDGs. The EU diplomacy in all relevant international fora, including the G7, G20, UNEA, WTO etc, advances an agenda in line with and in support of the implementation of the goals and targets of the Kunming Montreal Global Biodiversity Framework to halt and reverse biodiversity loss, and to promote the uptake of the circular economy and more in general the sustainable use and management of natural resources. An example is the key role played by the EU in the context of the UN Environment Assembly to achieve ambitious language on circular economy, suistainable consumption and production, nature-based solutions, and sustainable management of mineral resources in the Resolutions 4/1, 4/19, 5/5, 5/11 or 5/12.

Bilateral engagement between countries and regions in general will further expand with the uptake of the green transition in more countries, as mutual understanding, learning from each other and developing joint approaches are key for success and for leaving no-one behind. There is also demand from stakeholders, including businesses, for clear policy orientations and legal certainty. The EU is part of this active global diplomatic efforts (see e.g., Council Conclusions on Climate and Energy Diplomacy of 9 March 2023) and is willing to step up its engagement in areas such as cooperation on Emissions Trading Systems, energy transition, modelling, and adaptation. The Commission and Member States are active in different contexts, and ways of cooperating together to achieve common operational objectives should be further explored.

1.2 Climate diplomacy instruments

The European Commission is engaging in a broad range of High-Level Dialogues on topics related to climate and energy, amongst others, with third countries, such as Canada, Australia, Japan, New Zealand, China, India, Indonesia, Colombia, or Mexico. This allows for exchanging on respective climate policies and identifying areas for further cooperation. New High Level Climate Dialogues are being launched with Chile and Brazil.

The Green Alliances with Japan and Norway, as well as the Green Partnerships with Morocco and the Republic of Korea are recently designed instruments that allow the EU to strengthen cooperation with like-minded countries that either committed to climate neutrality by mid-century or are putting in place ambitious climate policies by 2030. Such alliances and partnerships provide for a reinforced platform of policy dialogue on reforms linked to the green transition, ad-hoc technical, financial assistance, and investments. They encompass climate but also energy and environmental policies in a whole-of-government approach, where all concerned ministries must participate. Green Alliances and partnerships put climate on the political agenda of the respective countries and provide a clear direction of travel.

The G7-led Just Energy Transition Partnerships (JETPs) with South Africa, Indonesia, Viet Nam, and Senegal are another powerful instrument to prompt sectoral reforms guided by climate ambition. Under shared responsibility between the G7 members, JETPs provide a platform by which partner countries can work with climate finance donor support, private sector investors, multilateral development banks (MDBs) and relevant actors to achieve a just energy transition. The EU Commission and EEAS are co-leading together with the UK on the JETP with Viet Nam.

The integration of the EU climate acquis into the European Economic Area and the EU accession negotiations are also two channels for extending the EU climate legislation to the neighbouring partner countries, including via the Energy Community.

Plurilateral initiatives have achieved significant success in advancing with the commitments set out under the Paris Agreement and the Convention on Biological Diversity. The EU has worked with partner countries to put forward the Global Methane Pledge, which now has over 150 participants and a dedicated secretariat. Likewise, the EU committed to put forward a pledge on Renewable Energy and Energy Efficiency at the upcoming COP 28 in the United Arab Emirates.

The EU is leading the international support for climate change action and works together both on a multilateral and bilateral level with global partners. The EU, its Member States, and its financial institutions, collectively known as Team Europe, is the leading contributor of development assistance and the world's biggest contributor of climate finance, with over EUR 23 billion public finance committed in 2021.

1.3 Engagement of the EU in multilateral fora

The European Commission and the High Representative will continue to work with Member States to mobilise all diplomatic channels – including within the United Nations, the G7, G20, the OECD and other international fora to achieve the ambitions set out in the Paris Agreement. The EU has been able to act as a bridge builder between different Parties and continues to ensure that the principles embodied in the Paris Agreement can be entrusted.

The United Nations Framework Convention on Climate Change (UNFCCC) process has achieved a lot in the recent decades. The Paris Agreement and Katowice rulebook provide a robust framework for climate action. The process is a unique framework within which we should continue to enhance international cooperation, catalyse increased Party and non-Party stakeholder ambition, transparency, and action, while providing a space to exchange experiences in transitioning to low greenhouse gas emission and climate resilient economies and societies.

The ambition cycle built upon the Global Stocktake under the Paris Agreement and the regular submission of NDCs and adaptation communications, as well as information on finance flows and the enhanced transparency framework will be the central feature in driving enhanced climate action and support to achieve the long-term goals of the Paris Agreement. The following work strands are playing a key role in engaging all Parties to the Paris Agreement in achieving the agreed upon objectives:

On Mitigation, the European Union is strongly advocating for an ambitious Mitigation Work Programme within the UNFCCC, focusing on delivering concrete solutions to close the ambition and implementation gap in this critical decade towards 2030 and incentivizing high ambitions.

On Loss and Damage at COP27 in Sharm el-Sheikh, the European Union played a leading, constructive role by presenting a bridge-building proposal and showing openness to what resulted in the establishment of the new funding arrangements, including a fund for assisting developing countries that are particularly vulnerable to the adverse effects of climate change, in responding to loss and damage. Following that decision, the European Union engages constructively in the Transitional Committee work to deliver on all elements of its mandate in line with our consistent commitment to scale up and strengthen support for the sources, funds, processes, and initiatives under and outside the climate regime that are at the core of funding arrangements for loss and damage.

On Adaptation, a steady progress has been made towards the Global Goal on Adaptation (GGA) by implementing the two-year Work Programme launched at COP26, the global commitment to double adaptation finance, the adoption of the 2021 EU Adaptation Strategy, and the continued adoption and revision of EU Member States' National Adaptation Plans and Strategies ([1]). At COP27, and in the follow up intersessional Conference 58 in Bonn, Parties agreed on the possible structural elements of a GGA Framework for consideration and adoption at COP28. The Global Stocktake should enable Parties to analyse past efforts to increase resilience and implement adaptation actions while, at the same time, looking forward with increased ambition at all stages of the adaptation policy cycle (risk assessments, planning, monitoring and evaluation).

The FAC Council Conclusions on Climate and Energy Diplomacy approved in March 2023 were another strong political signal and set the course, together with the Environment Council Conclusions, for the EU to support the achievement of an ambitious outcome of COP28.

([1]) See https://climate-adapt.eea.europa.eu/en/countries-regions/countries.

1.4 Climate change and international security

Current climate extremes, rising temperatures and sea levels, desertification, water scarcity, threats to biodiversity, environmental pollution and contamination are threatening the health and well-being of humanity, and can create greater displacement, migratory movements, pandemics, social unrest, instability, and conflicts. Europe's armed forces are also confronted with the changing and challenging operational conditions due to climate change. These new threats have already prompted allies and partners to update their policies too.

The EU sets out four priorities on Climate Change and Security, namely strengthening planning, decision-making and implementation; operationalising the response to climate and security challenges; enhancing the climate adaptation and mitigation measures of Member States' civilian and military operations and infrastructure; and reinforcing international partnerships. This is done through around thirty actions, including: establishing a data and analysis hub on climate and environment security within the EU Satellite Centre; deploying environmental advisors in the EU Common Security and Defence Policy (CSDP) missions and operations; setting up training platforms at national and EU level such as an EU Climate, Security and Defence Training Platform; developing thorough analysis and studies of related policies and actions, especially in vulnerable geographical areas such as the Sahel or the Arctic.

1.5 Climate change and trade

1.5.1 Trade policy

As the world aims to achieve the goals of the Paris Agreement, trade policy has a role to play in supporting an ecological and green transition not only within the EU but globally. This includes, for instance, accelerating investment in clean energy or the promotion of value chains that are circular, responsible, and sustainable. It also means creating opportunities for sustainable products and services to be traded more extensively.

As the EU continues to be a front runner with the Green Deal and its associated policy implementation, it places significant importance in supporting partner countries in building the necessary mechanisms, capacity and systems via technical exchanges, financial support, and diplomatic efforts.

Trade policy can serve as a platform to engage with trading partners on climate and environmental action, multilaterally e.g., in the World Trade Organization or bilaterally through our Free Trade Agreements. Commitments to sustainability have been continuously strengthened in EU trade agreements, in particular with regard to enhancing climate action through the recent Communication on Trade and Sustainable Development chapters in free trade agreements ([2]). The Commission has also stepped-up efforts to implement and enforce the sustainable development commitments of EU trade agreements. On climate change more specifically, the EU’s most recent agreements all include a binding commitment of the Parties to ratify and effectively implement the Paris Agreement. For countries with which the EU has or is negotiating free trade agreements, climate policy dialogues are also pursued within the

([2]) COM(2022) 409 final

Trade and Sustainable Development sub-committees, complemented by institutional advisory and monitoring mechanisms. Joint Committees under the EU Strategic Partnership Agreements also provide a forum to review the respective climate, energy, and environmental policies. In addition to or in the absence of such existing frameworks, bilateral summits and other official visits create opportunities to exchange on climate policy issues.

Plurilaterally as well as multilaterally, the EU is involved in the trade and climate nexus. Within the WTO, the EU is working towards making the body a more relevant forum to tackle climate change. In the plurilateral context in the WTO, the EU is involved in discussion on environmental sustainability, ending plastics pollution and fossil fuel subsidy reform. Outside the WTO, the EU together with Ecuador, Kenya and New Zealand forged the Coalition of Trade Ministers on Climate ([3]). The Coalition will provide political steer and guidance to boost inclusive cooperation on climate, trade, and sustainable development.

In trade related discussions in other plurilateral fora, the High Representative and the Commission have been additionally intensifying work and international outreach on ending environmentally harmful fossil fuel subsidies along a clear timeline, with the aim of setting milestones for their phase-out, including through the G7 and the G20, and in the context of the fossil fuel subsidies reform dialogue in the OECD. The EU also supports the modernisation of the OECD arrangements on officially supported export credits([4]). Furhermore, the EU is an active participant in the OECD's Joint Working Party on Trade and Environment that provides analytical work on the trade and environment nexus, including climate change.

1.5.2 Emissions accounting

Discussing the linkages between climate policy and trade also links to the differences between and complexities of accounting for production based vs. consumption-based emissions. Combining and comparing different types of emission accounting methods considering trade is valuable to consider the role of exporting industries and related value chains and their respective emissions ([5]). The most common emission accounting method is production-based accounting (PBA). PBA accounts for territorial, production-based emissions and is used for official accounting and reporting (including the EU and international targets, e.g., under the UNFCCC). This is mainly due to sovereignty (the emissions for which a country can be held responsible) and measurement issues (allocating part of another country's emissions to a third country is technically complex).

Besides that, there are two ways of taking trade into account when estimating emission shares. Consumption-based accounting (CBA) assigns emissions where the final product is consumed, considering emissions along the entire value chain. It might penalise countries that are active in reducing emissions in sectors involved in international trade. This is because a country would see a part of its mitigation effort allocated to its export partners, while it would

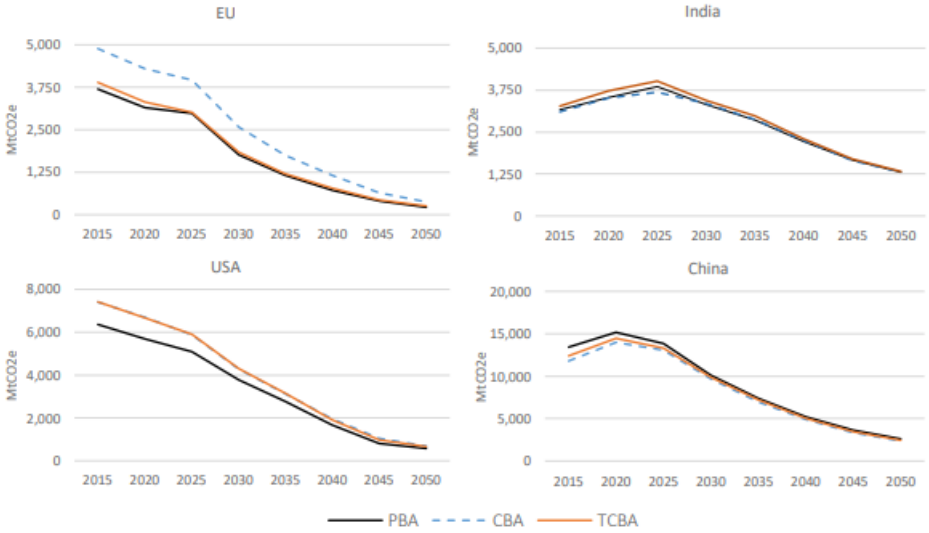
([3]) See https://www.tradeministersonclimate.org/.

([4]) See the Council Decisions of July 2023 in support of modernised export credits (10117/23 and 10121/23).

([5]) See, for example, Jakob et al., 2021, Sharing responsibility for trade-related emissions based on economic benefits, *Global Environmental Change* 66: 102207, https://doi.org/10.1016/j.gloenvcha.2020.102207.

be penalised for a lack of similar effort from its import partners. To correct for this effect, technology adjusted consumption-based accounting (TCBA) accounts for differences in technology of export sectors to adjust the CBA metric. Under TCBA, export-related emissions are subtracted based on the average carbon intensity for the relevant sector on the world market, rather than the domestic average, under the assumption that a similar good would have been produced at the average emissions intensity on the world market for that sector ([6]). This metric thus assigns lower emissions to a country than under CBA when its exports are cleaner than the world average, after accounting for sectoral differences in the composition of exports. The EU has reduced both its production-based and consumption-based emissions over the last decades ([7]). Including the TCBA method shows a strong reduction of the gap between EU GHG emissions comparing the PBA and CBA method. Figure 1 shows the GHG emission trajectories for the EU, the US, India, and China under the three methods for emission accounting (projections post-2020 are based on the JRC GECO 2022 1.5 scenario).

Figure 1: GHG emissions under different GHG emission accounting methods



Source: JRC-GEM-E3 model

Overall, assessing the interlinkages between climate policies and trade balances depends on various parameter and approximations, making long term outlooks on trade balances challenging. However, it is clear that with a transformation towards net-zero, fossil fuel-based sectors and products will naturally see a decline in demand, whereas sectors and products already in line with net-zero targets are expected to experience higher demand.

Lastly, EU's net-zero technology industry can contribute to global emission reductions outside EU when products and technologies are exported or when manufacturing in EU

([6]) Kander, A., Jiborn, M., Moran, D.D., Wiedmann T.O. (2015), National greenhouse-gas accounting for effective climate policy on international trade. *Nature Climate Change* 5: 431–435. https://doi.org/10.1038/nclimate2555.

([7]) See, for example, the estimates of CO_2 emissions embodied in international trade by the OECD, see https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm .

replaces more polluting manufacturing outside EU. Such contribution to global emission reduction would be additional to the scenarios analysed in this impact assessment and further points at the significance of building on the capacity of the EU in raw materials and industrial clean manufacturing.

1.6 Global competition for raw materials

Demand for non-energy raw materials, such as metals and minerals, increases rapidly with climate ambition ([8]). Unlike fossil-powered technologies, the key technologies to decarbonise the power generation, industry, and transport sectors (namely wind, solar PV, batteries, and hydrogen) require large quantities of metals and minerals ([9]).

In view of the 2050 climate neutrality, the demand for renewable energy generation and decarbonised transport in the EU is expected to increase, and so too the demand of raw materials. Substituting materials and increasing material efficiency and circularity can mitigate the projected rise in demand to a certain extent, but these steps are not expected to reverse the trend (see Annex 6).

Markets are reacting to the current and forecasted increases in demand for critical materials, with significant increases in supply forecast. The market size of key energy transition minerals doubled over the past five years, reaching USD 320 billion in 2022. The IEA says supply of minerals critical to the energy transition could move close to levels needed to support climate pledges by 2030 after investment in critical minerals production jumped 30% last year to $41 billion, having gained 20% in 2021. Exploration spending also rose by 20% in 2022, driven by record growth in lithium exploration. For lithium, the IEA forecasts supply by 2030 will reach 420,000 metric tons - only a touch short of demand estimated at 443,000 to meet government pledges ([10]).

As large uncertainty exists in future amounts of both the demand and supply of metals and materials for decarbonisation, this is reflected in the uncertain outlook for prices of these materials. Large short-term swings have been witnessed in the past due to unbalanced supply and demand market factors, e.g., lithium prices were at record highs at the start of 2023, but by April 2023 had approximately halved ([11]). Likewise, silicon prices spiked four-fold in mid-2021, but by mid-2022 had returned to pre-spike prices ([12]).

A net-zero economy in the EU will need a secure supply chain able to meet increased product and material demand. Certain products and intermediate material – such as cement and steel – do not represent a supply concern since their manufacturing relies on raw materials that are relatively abundant on earth and whose manufacturing chain is geographically spread across world regions, including the EU. Other products and intermediate materials requiring raw

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([8]) World Bank (2017). The Growing Role of Minerals and Metals for a Low Carbon Future.

([9]) JRC (2020). Critical Raw Materials for Strategic Technologies and Sectors in the EU.

([10]) IEA (2023). Critical Minerals Market Review 2023.

([11]) BNEF (2023a). Battery Metals Monthly: Lithium Price Recovery Begins.

([12]) BNEF (2023b). Transition Metals Outlook 2023.

materials that are not available or manufactured in the EU in large quantities (critical raw materials or CRM) are at high supply risk. Supply risk factors can be country-level concentration of global production of primary raw materials and sourcing to the EU, governance of supplier countries ([13]) (including environmental aspects), contribution to recycling, substitution, EU import reliance and trade restrictions in third countries.

The EU currently relies almost exclusively on imports for many CRM. In fact, for 31 out of 82 individual materials or groups assessed, the import reliance is 100% at the extraction or processing stage, and above 80% for another 6 materials ([14]).

More importantly, within these imports, suppliers are highly concentrated ([15]), and the main suppliers are in many cases exposed to significant environmental, social and governance risks ([16]). In three cases, namely light REE, heavy REE and magnesium, the supply share of one country, China, is above 90%. This concentration expands along the value chain, with the processing stage being even more concentrated than the extraction stage for some materials, such as lithium. China controls 69% of the global capacity for refined lithium, 60% for refined cobalt, 79% for refined manganese ([17]). In addition to the concentration of supply in single countries, some actors have expanded their dominance of the global value chain by taking control of economic activities and assets in third countries, such as China controlling cobalt mines in Congo ([18]). As witnessed during the COVID-19 crisis and the energy crisis following Russian's military aggression against Ukraine, the consequences of excessive dependence on single suppliers can jeopardise the functioning on the single market and harm the EU's competitiveness.

([13]) Worldwide Governance Indicators (WGI): http://info.worldbank.org/governance/wgi/. Accessed on 18-04-2023.

([14]) European Commission (2020). Study on the EU's list of Critical Raw Materials – Final Report.

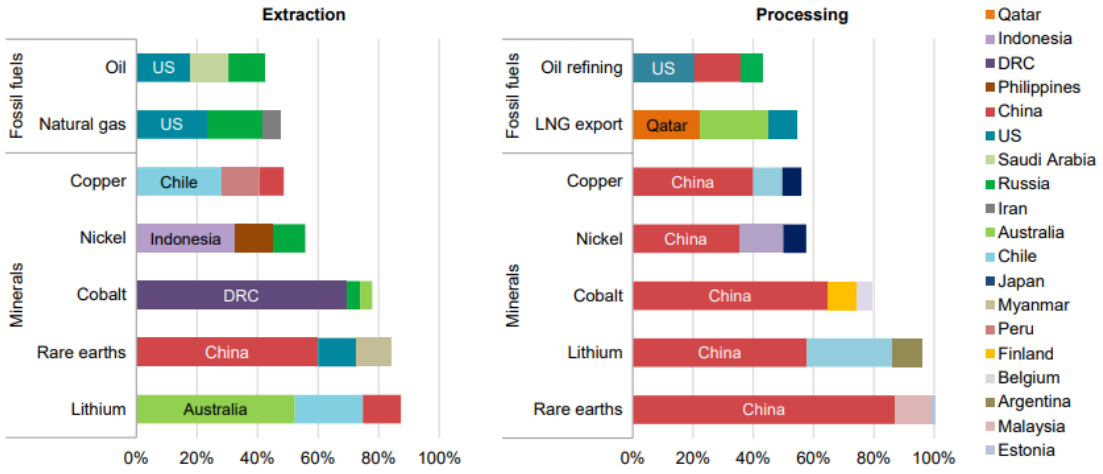
([15]) The share of the biggest supplier to the EU is 99% for the group of light rare earth elements (China), 98% for the group of heavy rare earth elements (China), 98% for borates (Turkey), 93% for magnesium (China), 85% for niobium (Brazil), 78% for lithium (Chile) and 68% for Cobalt (DR Congo), source: Study on the EU's list of Critical Raw Materials (2020): Final Report, European Commission 2020.

([16]) See IEA (2021) report on Clean Energy Minerals, page 126-131.

([17]) JRC (2023). Supply chains and materials demand forecast in strategic technologies and sectors in the EU. A foresight study.

([18]) Luc Leruth and Adnan Mazarei (2022). "Who controls the world's minerals needed for green energy?" https://www.piie.com/blogs/realtime-economic-issues-watch/who-controls-worlds-minerals-needed-green-energy. Accessed on 10-10-2023.

Figure 2: Major countries in extraction and processing of selected minerals and fossil fuels



Notes: LNG= liquefied natural gas. The values for copper processing are for refining operations. Data from: IEA (2020a), USGS (2021), World Bureau of Metal Statistics (2020), Adamas Intelligence (2020).

Source: Leruth and Mazarei (2022) ([19]).

EU reliance on CRM imports is also due to a lack of efficient use of domestic resources, both primary and secondary. The EU is currently a minor player in terms of extraction and processing of primary CRMs. Despite being highly recyclable, the share of recycled CRM is very low: this is because usually CRMs are used in low concentration as part of alloys, which make the recovery process complex, and, until recently, their limited demand did not justify investment in recycling infrastructure. Consequently, the share of CRM secondary production is minimal, and significant CRM resources leave Europe in the form of wastes and scrap.

The EU strategy to overcome the challenges related to the supply of critical raw material is described in the Critical Raw Material Act ([20]), which aims to strengthen the different stages of the European critical raw materials value chain and diversifying the EU's imports of critical raw materials to reduce strategic dependencies by developing win-win partnerships on sustainable raw materials value chains with resource rich countries and negotiate trade agreements to facilitate trade and investment in CRM in third countries ([21]). For more details, see section 2.1. Circular economy measures, including product policies, can also help optmise the supply of critical raw materials, as they can lower primary CRM consumption and demand, and provide additional co-benefit in reducing biodiversity and pollution impacts stemming from CRM extraction and processing.

([19]) Luc Leruth and Adnan Mazarei (2022). "Who controls the world's minerals needed for green energy?" https://www.piie.com/blogs/realtime-economic-issues-watch/who-controls-worlds-minerals-needed-green-energy. Accessed on 10-10-2023.

([20]) COM(2023) 165 final

([21]) COM(2020) 474 final

2 AN INDUSTRIAL STRATEGY

Industry is one of the backbones of EU economy, and reducing its emissions is a key step toward the 2050 climate neutrality.

Decarbonisation of the industry is complex. While it includes the production of some commodities like metals and cement, the remainder of the sector's output is extremely heterogenous, producing very different materials and end products. It covers a highly diverse set of input-output relationships that are highly integrated with the energy sector and the overall economy. Decarbonising industry also enables to reduce the embodied emissions in the products and equipment used in transport sector and the built environment. Given the heterogeneity of the industrial sector, it stands to reason that a wide variety of decarbonisation levers will be required, there is no silver bullet for complete industrial decarbonisation and more ad-hoc solutions that consider the specific characteristics of the sub-sectors needs to be implemented. An increasing number of technological solutions that result from net-zero technology compatible investments and innovation could provide mainstream solutions in many industrial sub-sectors by 2040, such as new manufacturing technologies, innovation in processes, use of alternative materials or sources and cleaner supply chain.

The climate transition represents a great opportunity for creating jobs and growth. The net-zero technology manufacturing industries, and its related ecosystem, are expected to undergo rapid growth in the coming decades. Innovative business models, such as circular practices and sharing economy, together with more responsible and sustainable consumer choices will steer industry toward more resource-efficient and less climate-intensive value chains.

Today, the EU is already a global leader in certain clean sectors and is well positioned to maintain its central role in the coming years. Embracing the industrial transition and encouraging the development of domestic green and circular industry will provide a competitive advantage to the EU. It will decrease resource dependency and spur innovation, making the EU stronger at global level. However, especially the US and China are investing heavily to compete on industrial decarbonisation solutions.

In response, between January and March 2023, the Commission tabled a number of proposals to strengthen the growth and innovative strategy from the European Green Deal. The Green Deal Industrial plan, adopted by the Commission on 1 February 2023 provides the overarching principles of this reinforced industrial strategy to make Europe the home of clean tech and industrial innovation. Additionally, provisions relevant for the EU industrial strategy are also included in the provisional agreement on the proposal for a revision of the Renewable Energy Directive (RED) proposed as part of the Fit-For-55 package as well as the revision proposed as part of the REPowerEU package, and for the revision of the F-gases regulations.

2.1 The Green Deal Industrial Plan

The **Green Deal Industrial plan** contains four pillars. The first one is to improve the regulatory environment to focus investment on strategic sectors and projects as well as accelerate permitting. The second pillar aims at speeding up investment and financing for clean tech production in Europe. To that end, the temporarily adapted state aid rules (Temporary Crisis and Transition Framework) and in the medium term an EU Sovereignty Fund (now announced on June 19, 2023, under the name the Strategic Technologies for Europe Platform or STEP) allow for financing with short term flexibility. The third pillar is skills with the establishment of Net-Zero Industry Academies to roll out re-skilling

programmes and facilitated access to EU labour markets for third country nationals. The fourth pillar is trade with the aim to maximise existing trade agreements, combat unfair trade practices and an emphasis on clean tech and net-zero industrial partnerships.

The Net Zero Industry and Critical Raw Materials Acts published together on March 16, 2023, were proposals announced under the first pillar on Regulatory Environment of the Green Deal Industrial Plan.

The **Net Zero Industry Act** proposal offers a predictable legal framework for net-zero industries in the EU. It focusses on 'net zero technologies' that will make significant contribution to decarbonisation and defines a list of 'Strategic Net Zero technologies' (solar photovoltaic and solar thermal; hydrogen electrolysers and fuel cells; sustainable biogas/biomethane technologies; battery/storage technologies; heat pumps and geothermal energy technologies; grid technologies; onshore wind and offshore renewable, CO2 capture and storage) which can receive particular support and are subject to a target to provide at least 40% of the EU's annual deployment needs for strategic net-zero technologies by 2030. The Act also sets an EU objective to reach an annual 50Mt of CO2 injection capacity in strategic storage sites in the EU by 2030, to be funded based on proportional contributions from EU oil and gas producers.

The main pillars of the Act are the setting of enabling conditions by improving the conditions for investment in net-zero technologies by enhancing information, reducing the administrative burden to set up projects and simplifying permit-granting processes. In addition, the Act proposes to give priority to Net-Zero Strategic Projects. Besides the CO2 capture target, it also aims to diversify the supply for net-zero technologies and requires public authorities to consider sustainability and resilience criteria for net-zero technologies in public procurement or auctions.

It also enhances skills with new measures to ensure there is a skilled workforce supporting the production of net-zero technologies in the EU, including setting up Net-Zero Industry Academies, with the support and oversight by the Net-Zero Europe Platform. It also has specific measures to foster innovation by making it possible for Member States to set up regulatory sandboxes to test innovative net-zero technologies under flexible regulatory conditions. Finally, it sets up a Net-Zero Europe Platform to assist the Commission and Member States to coordinate action and exchange information, including around Net-Zero Industrial Partnerships. The Net-Zero Europe Platform will support investment by identifying financial needs, bottlenecks, and best practices for projects across the EU. It will also foster contacts across Europe's net-zero sectors, making particular use of existing industrial alliances.

Most of the net-zero technologies needed for the green transition use a number of critical raw materials in their manufacturing processes that are sources outside the EU. Ensuring adequate future supply of critical raw materials is necessary to achieve the 2050 climate neutrality target.

The Commission regularly publishes the list of critical raw materials for the EU, the last one dating from 2020 ([22]), and recently forecasted future critical raw material trends ([23]). These are factual tools to define challenges and identify opportunities to support EU policy development for critical raw materials in different domains (trade, research and innovation, industry, and sustainability).

The Critical Raw Material Act ([24]) illustrates the EU strategy to develop win-win partnerships on sustainable raw materials value chains with resource rich countries and negotiate trade agreements to facilitate trade and investment in CRM in third countries ([25]). These partnerships aim to contribute to the diversification of the EU's raw materials supply chain and enhance the sustainability of CRM production.

The **Critical Raw Materials Act** sets clear benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030:

- At least 10% of the EU's annual consumption for extraction,
- At least 40% of the EU's annual consumption for processing,
- At least 15% of the EU's annual consumption for recycling,
- Not more than 65% of the Union's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.

In the same approach as with the Net-Zero industry act, it proposes to give priority to selected Strategic projects with support for access to finance and shorter permitting timeframes. Member States will also have to develop national programmes for exploring geological resources. It also aims to ensure that the EU can mitigate supply risks with the monitoring of critical raw materials supply chains and coordination of strategic raw materials stock among Member States. It emphasises the need for investing in research, innovation, and skills with the establishment of a large-scale skills partnership on critical raw materials and a Raw Materials Academy. Finally, it also has several measures to protect the environment and improve the circularity and sustainability of critical raw materials, in the EU and abroad. Member States will need to adopt and implement national measures to improve the collection of critical raw materials rich waste and ensure its recycling into secondary critical raw materials. Special provisions on permanent magnets ensure that products that contain them meet circularity requirements and provide information on the recyclability and recycled content.

The Regulation was accompanied by a Communication which actions by the Commission to improve international engagement to diversify the EU import of critical raw materials and to further develop strategic partnerships. It also lists a number of actions by the Commission to

([22]) COM(2020) 474 final

([23]) JRC (2023). Supply chains and materials demand forecast in strategic technologies and sectors in the EU. A foresight study.

([24]) COM(2023) 165 final

([25]) COM(2020) 474 final

improve the circularity of critical raw material, including a number of revisions of waste legislations.

The Critical Raw Materials Act helps the EU to move from a linear to a circular economic model of production and consumption. At its core, the **circular economy** seeks to reduce waste to a minimum, converting into valuable resources. Instead of take-make-dispose, it involves prolonging lifetime of products, reusing, repairing, refurbishing as well as sharing and leasing. Ecodesing is key to exploit the benefits of the circular economy at maximum. If this is no longer possible and a product reaches its end of life, recycling allows maintaining its materials within the economy. The circular economy will thereby create business opportunities and jobs while requiring fewer virgin materials and less energy. This can reduce greenhouse gas emissions, mitigate risks associated with the supply of materials, and protect the environment.

2.2 Energy measures supporting industry

Energy efficiency contributed significantly to decarbonisation of industry in the last years, encouraged both by the Energy Efficiency Directive ([26]) and other pieces of EU legislation and by technological progresses in industrial processes. The remaining potential for energy efficiency is still large ([27]), and the amended Energy Efficiency Directive ([28]), formally agreed on 24 July 2023, significantly raises the EU's ambition and places a strong emphasis on energy efficiency: the EU countries will be required to achieve an average annual energy savings rate of 1.49% from 2024 to 2030, up from the current requirement of 0.8%, driving energy savings in different sectors, including industry.

In 2021, electrification only accounted for 33% of final energy use in industry, while direct combustion of fossil fuels covers the remaining use ([29]). Fossils fuels are burned to provide industrial heat to many and varied applications ranging from low temperature heat in food preparation to high temperature heat in blast furnaces. Electrifying low and mid-temperature industrial heat with decarbonised electricity can lower industrial emissions today with currently available technologies. Low temperature heat may be provided by heat pumps, while heat for specific applications can rely on innovative, low-carbon technologies, such as electric arc furnaces, infrared heating, and induction heating. A 3-stage analysis of the technological potential for industry electrification in 11 industrial sectors in the EU (accounting for 92% of Europe's industry CO2 emissions) shows that 78% of the energy demand is electrifiable with technologies that are already established, while 99% electrification can be achieved with the addition of technologies currently under development. ([30]), ([31]).

([26]) Directive (EU) 2023/1791

([27]) U.S. DOE Advanced Manufacturing Office. Improving steam system performance: a sourcebook for industry, 2nd ed. Washington, D.C., 2012

([28]) COM/2022/142 final

([29]) Eurostat Energy Balances 2023

([30]) Madeddu et al. (2022). The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat). *Environ. Res. Lett.* 15 124004. DOI 10.1088/1748-9326/abbd02

Fuels switching to renewable hydrogen and other decarbonised fuels (both e-fuels or biofuels) are also an option to decarbonise industrial applications where electrification and energy efficiency methods cannot be applied ([32]). Fuel switching from fossil fuels to renewable hydrogen or e-fuels can provide high-temperature heat with substantially lower emissions. The actual impact on emissions should also take into account considerations external to the industrial processes: the use of biomass should be sustainable and balanced with respect to the carbon sink needs and biodiversity constraints; the actual carbon intensity of e-fuels depends on the origin of the carbon ([33]).

The provisional agreement on the proposal for a revision of the Renewable Energy Directive (RED) proposed as part of the Fit-For-55 package as well as the revision proposed as part of the REPowerEU package, reached in the seventh trilogue on March 2023, includes the following relevant provisions supporting electrification and fuel switching in the EU industry:

- An EU indicative target of an increase of at least 1.6 percentage points in the share of renewable sources in the amount of energy sources used for final energy and non-energy purposes in the industry sector. as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030. ([34])
- A binding national target of at least 42% on the contribution of renewable fuels of non-biological origin used for final energy and non-energy purposes in the hydrogen used for final energy and non-energy purposes in industry by 2030, and of at least 60% by 2035. ([35])
- An EU regulatory framework determining when renewable fuels of non-biological origin can count towards the abovementioned targets.

([31]) Beyond Zero Emissions (2022). *Zero Carbon Industry Plan. Electrifying Industry*.

([32]) BNEF (2021). Hot Spots for Renewable Heat. Decarbonizing Low- to Medium-Temperature Industrial Heat Across the G-20.

([33]) Commission Delegated Regulation (EU) 2023/1184

([34]) Member States may count waste heat and cold towards the average annual increases referred to in the first subparagraph, up to a limit of 0.4 percentage points, provided the waste heat and cold is supplied from efficient district heating and cooling, excluding networks which supply heat to one building only or where all thermal energy is solely consumed on-site and where the thermal energy is not sold. If they decide to do so, the average annual increase shall increase by half of the waste heat and cold percentage points used.

([35]) For the calculation of that percentage, the following rules shall apply: 10794/23 LZ/st 101 ANNEX TREE.2.B EN (a) For the calculation of the denominator, the energy content of hydrogen for final energy and non-energy purposes shall be taken into account, excluding: (i) hydrogen used as intermediate products for the production of conventional transport fuels and biofuels; (ii) hydrogen that is produced by decarbonizing industrial residual gases and is used to replace the specific gases from which it is produced. (iii) hydrogen produced as a by-product or derived from by-products in industrial installations; (b) For the calculation of the numerator, the energy content of the renewable fuels of non-biological origin consumed in the industry sector for final energy and non-energy purposes shall be taken into account, excluding renewable fuels of non-biological origin used as intermediate products for the production of conventional transport fuels and biofuels. (c) For the calculation of the numerator and the denominator, the values regarding the energy content of fuels set out in Annex III shall be used.

Emissions from **ozone depleting substances (ODS)** result in depletion of the ozone layer and have thus adverse impacts on our health, the biosphere, as well as having large economic implications. These gases have internationally been regulated under the Montreal Protocol on substances that deplete the ozone layer. This has been successful in rapidly reducing on a global scale the production, use and associated emissions of ODS. These gases are also often strong greenhouse gases. EU Regulation (EC) 1005/2009 (ODS Regulation) ([36]) regulates the use of ODS in the EU and has phased out production and consumption of ODS in the EU. A recent revision of the ODS Regulation has further increased its ambition by targeting ODS banks in the EU, by requiring ODS to be recovered from old insulation foams when buildings are renovated or demolished. This aims to prevent the equivalent of 180 million tonnes of CO2 or 32,000 tonnes of ozone depleting potential (ODP) emissions by 2050.

Fluorinated greenhouse gases (F-gases) typically replaced ODS when these were prohibited. There has been globally a rapid increase of F-gas use and emissions. The F-gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). These gases, while not being ODS, are covered by the Paris Agreement because they are highly potent greenhouse gases. They have numerous applications in everyday life, for example in refrigeration, air conditioning, insulation, fire protection and as aerosol propellants. At EU level, F-gases currently account for 2.5 % of total GHG emissions.

In the EU, the emissions of these gases have only started to reduce since the introduction of the F-gas Regulation ([37]). Since then, also internationally additional action was taken, with the inclusion of notably HFCs (the largest group of F-gases) into the Montreal Protocol as a controlled substance in 2019 with the aim of stopping global growth and achieving significant emission reductions by 2050.

More recently the EU's F-gas Regulation was updated and significantly strengthened in a provisional agreement with the co-legislators ([38]). It will reduce between 2015 and 2050 the amount of HFC coming onto the EU market, expressed in CO2-eq., by 95% by 2030 and by going to zero by 2050. This will bring an important contribution to the Fit for 55 goals and making Europe climate neutral by 2050.

2.3 Circular economy and sustainable products

Several trends are deeply transforming industry independently of the decarbonisation process. The fourth industrial revolution, with automation and innovative solutions like robotics and 3D printing are changing the way the end products are fabricated ([39]), progressively shifting from mass production to mass customisation ([40]). Technological improvements are improving

([36]) Regulation (EC) No 1005/2009

([37]) Regulation (EU) No 517/2014

([38]) https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4781

([39]) Huang RA. Multi-scale life cycle framework for the net impact assessment of additive manufacturing in the United States. Northwestern University, 2016.

([40]) Pine, B. Joseph (1993). Mass Customization – The New Frontier in Business Competition. Harvard Business School Press. p. 13. ISBN 978-0-87584-372-8.

the material and resource efficiency of certain industrial processes: minimising material scrap at each step can reduce emissions associated with the process.

Following a circular economy approach, many industrial products can also be designed to improve their material efficiency, and in certain cases, to employ less-carbon intensive materials (material substitution). Currently, manufacturing and construction firms frequently choose to use more material to save labour, reduce legal or financial risks, simplify supply chains, or simply to conform with customary practices. This is particularly evident for cement and steel, where concrete mass in buildings could be reduced by up to 40% by using high strength concrete only where needed ([41]) and metal in common products like cars and structural beams, could be reduced by 30% ([42]).

Certain end products in the building sector can maintain the same structural properties while manufactured with less-carbon intensive material: concrete and steel can be substituted by timber-based products ([43]), while cement can be partially replaced by supplementary cementitious materials up to a 40% content ([44]).

Demand-side intervention, materialising through the principle of sufficiency, are also important levers of the decarbonisation of industry ([45]). Sufficiency, defined as collective and individuals' practices to minimise demand while delivering human wellbeing for all within planetary boundaries ([46]), ([47]), ([48]), influences directly on the request for end products and influence industrial activity ([49]). The economy shifts from mass production to mass customized services and sharing practices ([50]), where flexible, shared and integrate products

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([41]) Fischedick M, Roy J, Abdel-Aziz A, Acquaye A, Allwood J, Ceron J-P, et al. Industry. Climate change 2014: mitigation of climate change (fifth assessment report), Cambridge, U.K.: IPCC; 2014. p. 739−810.

([42]) Allwood J.M., Cullen J.M., *Sustainable materials without the hot air*, Cambridge, England: UIT Cambridge Ltd., 2015.

([43]) Heeren N., et al. 'Environmental impact of buildings—what matters?,' *Environ. Sci. Technol.*, 49:9832, 2015.

([44]) Scrivener K.L., et al. *Eco-efficient cements: potential economically viable solutions for a low-CO2 cement-based materials industry. Paris, France: UN Environment Program*, 2017.

([45]) IEA, *Net Zero by 2050. A roadmap for the Global Energy Sector*, 2023.

([46]) The concept of planetary boundaries defines a safe operating space for societies, by proposing boundaries for anthropogenic perturbation of nine critical Earth-system processes: climate change, ocean acidification, stratospheric ozone, global phosphorus and nitrogen cycles, atmospheric aerosol loading, freshwater use, land use change, biodiversity loss, and chemical pollution. Crossing such boundaries can lead to catastrophic impacts for societies.

([47]) Raworth. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist*, 2017.

([48]) Rockström J. et al., 'Planetary boundaries: Exploring the safe operating space for humanity.' *Ecol. Soc.* 14, 32, 2009.

([49]) It is assumed that the decrease in end-user demand of certain products will impact proportionally net trade, resulting in identical changes in domestic production and industrial activity.

([50]) David, M. "Sharing: post-scarcity beyond capitalism?". *Cambridge Journal of Regions, Economy, and Society*. 10 (2): 311–325, 2017. doi:10.1093/cjres/rsx003.

are produced locally with low unit cost and marketed as personalised custom services ([51]). Reusing, repairing, renewing, and recycling existing products extends product's lifetime on the market. This results in more service provided for the same energy input and avoided emissions from product replacement, leading to lower industrial emissions and dematerialisation of the economy. Studies shows that smart strategies and reduced material consumption could shrink global GHG emissions by 39% and cut virgin resource use by 28%. ([52])

The Commission has highlighted the relevance of a circular economy in its Long-Term Strategic Vision on GHG Emissions Reduction as well as in the 2030 Climate Target Plan. To speed up the transition towards a circular economy, the Commission presented the new Circular Economy Action Plan in March 2020. Since then, several packages of measures have followed. The proposals target the design of products, empower consumers, encourage a sustainable consumption, and focus on resource-intensive sectors, such as electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, and more.

In March 2022, the Commission proposed the new Ecodesign for Sustainable Products Regulation (ESPR) ([53]), which addresses product design and sets new requirements to make products more durable, reliable, reusable, upgradable, reparable, easier to maintain, refurbish and recycle, and energy and resource efficient. The proposal extends the existing Ecodesign framework ([54]) and is the cornerstone of the Commission's approach to more environmentally sustainable and circular products.

Future policies will build on these and other measures to help the EU achieving its 2050 climate neutrality target.

2.4 Industrial carbon management strategy

Complete decarbonisation of the industrial sector will also imply reductions in both energy and non-energy GHG emissions, where CO2, and more general, carbon is part of the material processing or is used as feedstock for the final product. Industrial emission can be significantly reduced by adaptations in industrial processes and material compositions. Combining these emission reducing initiatives with circularity and carbon capture, including Carbon Capture and Utilisation (where CO2 is used in materials), industries can mitigate most of its emissions.

Renewable hydrogen and other decarbonised fuels will become the chemical feedstock to replace conventional, high-emitting reactions in several industrial processes. For instance, in the steel sector, hydrogen can directly reduce the iron that is later transformed into steel, and large number of chemical processes can use hydrogen to substitute fossil input. In the cement sector, CO2 is mainly released during the calcination process for clinker manufacturing for

([51]) Coletti, P., *Mass Customization. An Exploration of European Characteristics*, 2011.

([52]) Circle Economy, *The Circularity Gap Report*, 2021.

([53]) COM/2022/142 final

([54]) C/2022/2026

clinker manufacturing, which can be mitigated via low-carbon energy input, like hydrogen, and material substitution in cement and further innovation in chemically binding CO2 to materials.

Biomass may also be used many industrial processes and materials, both as source of carbon but also of a range of other chemicals and molecules. However, limits exist on the quantity of biomass that may be sustainably produced, given competition with food, agriculture and biodiversity needs ([55]).

CO2 coming from industrial emissions can also be captured to supply carbon atoms where industry needs them ([56]), coupling different sectors. The CO2 captured can be combined with hydrogen to generate e-fuels but can also be stored in long-life products, such as plastics or minerals. For instance, renewable methanol (derived from H2 and carbon neutral CO2) can also be an excellent precursor for many end products used in the chemical sector. The annual global demand for chemicals and derived materials is estimated to rise to 1,000 million tonnes of carbon (Mt C) by 2050 ([57]). When such products are recycled at the end of life, the same carbon can be re-captured and re-used, leading to a more circular use of the carbon and pave the way for negative industrial emissions.

Carbon capture technologies that can be used to produce e-fuels, or store carbon in products and materials are at prototype or demonstration stage today. With the proposed EU objective to reach an annual 50Mt of CO2 injection capacity in strategic storage sites by 2030 based on funding obligations to EU oil and gas producers, the Commission has put a first step towards a comprehensive EU strategy to create a Net-zero industrial carbon management market by 2030. This market is projected to become capable to capture, transport, store or use several hundred million tonnes of CO2 from fossil sources that cannot be avoided, from biogenic and from atmospheric origin by 2050 that are necessary to reach climate neutrality. The EU growing trend is in line with global projections, with the IEA showing around 6 GtCO2 of carbon captured worldwide in 2050 ([58]).

2.5 Aligning investments with climate neutrality

The EU's sustainable finance policies complement and enable sectoral policies outlined above by supporting companies and the financial sector in the alignment of private investments with the objectives of the European Green Deal. The EU has made considerable progress in implementing its sustainable finance agenda over the last five years. Milestones include the adoption of the Taxonomy Regulation ([59]) and its various delegated acts covering six environmental objectives, including climate change mitigation and adaptation; the Sustainable

([55]) IPCC, *Special report: global warming of 1.5 °C*, 2019.

([56]) IEA. "World Energy Outlook". 2022.

([57]) Kahler et al. *Turning off the Tap for Fossil Carbon: Future Prospects for a Global Chemical and Derived Material Sector Based on Renewable Carbon*, 2021.

([58]) IEA (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach, *IEA*, Paris https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach, License: CC BY 4.0

([59]) Regulation (EU) 2020/852 amending Regulation (EU) 2019/2088.

Finance Disclosure Regulation (SFDR) ([60]); EU climate benchmarks in the Benchmark Regulation ([61]); the European Green Bond Standard ([62]); and the Corporate Sustainability Reporting Directive (CSRD) ([63]). The mandatory European Sustainability Reporting Standards ([64]) under the CSRD will enable companies to communicate sustainability information in a standardised way to a variety of lenders, investors, and other stakeholders. This includes the disclosure of transition plans for climate change mitigation, comprising implementing actions and related plans, to ensure that the business model and strategy are compatible with the transition to a sustainable economy and with the limiting of global warming to 1,5 °C in line with the Paris Agreement and the objective of achieving climate neutrality by 2050 as established in the Climate Law (Regulation (EU) 2021/1119), and, where relevant, the exposure of the undertaking to coal-, oil- and gas-related activities. A 2023 Commission Recommendation ([65]) illustrates how the sustainable finance framework encompasses transition finance and explains how companies, investors and financial intermediaries can voluntarily use the current sustainable finance framework to finance their transition to a climate neutral and sustainable economy, while enhancing their competitiveness.

In particular, **green bond markets** have soared in recent years. Cumulative issuances of bonds aligned with the International Capital Market Association's (ICMA) Green Bond Principles, ([66]) for instance, will very likely pass the EUR 1 trillion mark in 2023 (see Figure 3).

([60]) Regulation (EU) 2019/2088

([61]) Regulation (EU) 2019/2089

([62]) COM/2021/391 final

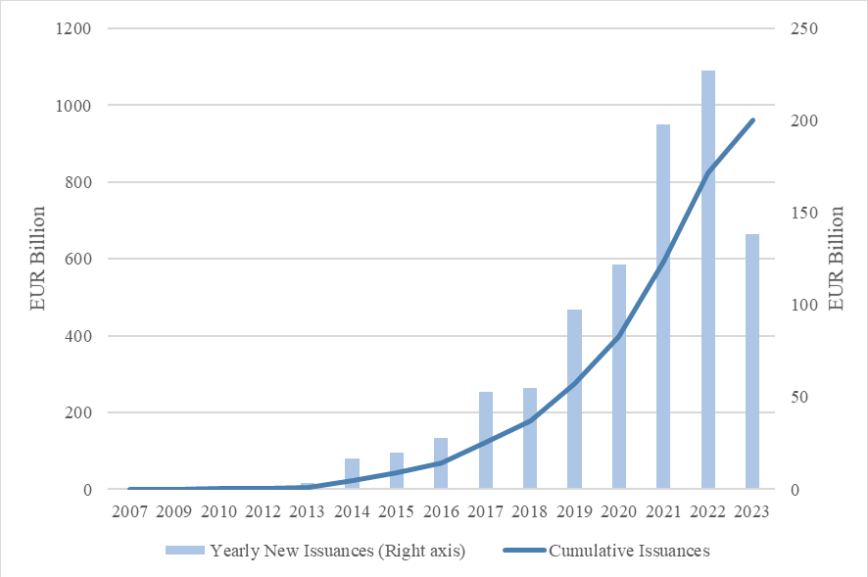
([63]) Directive (EU) 2022/2464

([64]) C/2023/5303 final

([65]) Commission Recommendation on facilitating finance for the transition to a sustainable economy (C(2023) 3844).

([66]) See https://www.icmagroup.org/sustainable-finance/the-principles-guidelines-and-handbooks/green-bond-principles-gbp/.

Figure 3: Issuance of green bonds in the EU

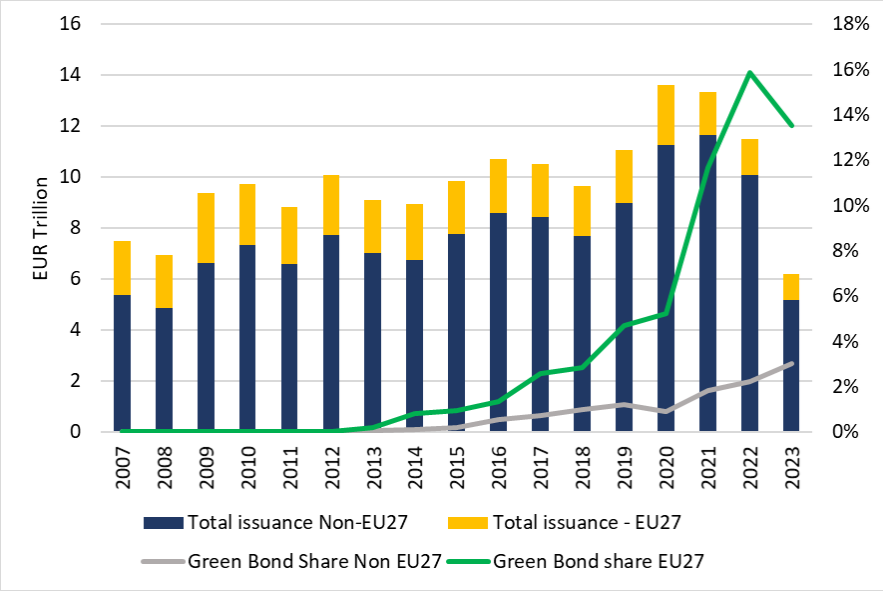


Note: Aligned with the ICMA's green principles, data as of 30 June 2023.

Source: Dealogic DCM and JRC calculations.

This increase in absolute green bond issuances is reflected in **green bonds' share of the corresponding bond market**. For EU and non-EU issuers, the share in the EU27 remained lower than 1% until 2013, but has significantly increased since then, and even more markedly from 2016, on the back of strong growth of the green segment. In 2022, green bonds accounted for 16% of newly issued bonds in the EU27, and only 2% of overall issuance in non-EU markets, confirming Europe's leading role in the sustainable debt capital market (see Figure 4).

Figure 4: Green bond share in total new issuance for EU and non-EU



Note: Data as of 30 June 2023.

Source: Dealogic DCM and JRC calculations.

Sustainability-linked bonds emerged in 2019 as a new financial instrument, complementing green bonds in green debt markets. These instruments have garnered a lot of interest from both issuers and investors given the ease of setting them up and their ability to incentivise the transition with contractual sustainability targets, which differentiates them from green bonds. However, their uptake is still limited compared to green bonds, having peaked in 2021 at EUR 51.8 billion, given the more recent development of this new type of assets.

It should be noted however that the "green-ness" of green bonds and sustainability-linked bonds remains cause for concern due to the risk of greenwashing in spite of the emergence of standards and principles that require third-party certification and adequate reporting. Political agreement was reached in early 2023 on the voluntary **EU Green Bond Standard**, which will rely on the EU Taxonomy and independent reviewers to provide guarantees with a high degree of confidence that financing raised compliant with this standard is genuinely 'green' ([67]).

2.6 Research, development, and innovation

2.6.1 Role of research and innovation

Science is at the core of EU policymaking. Policies developed with an insufficient scientific basis are less likely to solve the underlying issue and more likely to give rise to unintended consequences. Research and innovation (R&I) is a key engine through which to foster Europe's sustainable productivity growth, competitiveness, inclusiveness and fairness – it is a key enabler of the green transition.

([67]) See https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/european-green-bond-standard_en.

The urgency of the climate crisis requires an unprecedented mobilisation of R&I across all sectors to achieve transformative change in our society and economy. R&I is fundamental in many domains, notably in net-zero technologies, circular economy and sustainable bioeconomy including sustainable agriculture land-use and forestry, zero-emissions mobility, building techniques, and the adaptation to climate change to improve our preparedness for and response to climate-related extreme events.

The strategic orientations for the EU climate research and innovation investments are outlined in the Horizon Europe Strategic Plan 2025-2027 Analysis ([68]), as well as the climate R&I priorities crystalised from the process of developing the Horizon Europe Strategic Plan 2025-2027.

2.6.2 Research, development, and innovation for the Green Transition

R&I is critical to achieving the clean energy transition and meeting the objective of climate neutrality by 2050. This section first reviews the identified needs in terms of R&I to achieve the green transition of Europe.

The European Commission regularly collects and assesses evidence on the development and uptake of low-carbon industrial technologies. This includes industry's focus on R&D investment, Member States' engagement in relevant R&I, and local action to support industrial transformation ([69]).

2.6.2.1 Climate science

Advancements in climate science whilst creating a solid knowledge base remain essential to catalyse the transition towards a climate-neutral and climate-resilient society. The challenges outlined in the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) will need to be addressed with research that furthers our understanding of the changing climate and its implications. This will contribute to closing knowledge gaps, developing crucial tools to support decisionmakers in the design and implementation of effective mitigation and adaptation solutions at various time and spatial scales, whilst taking into account complementarities and trade-offs with other policy objectives.

2.6.2.2 Space data

Space data and services play a crucial role in enabling the achievement of climate neutrality targets. Integration of space technology with climate change mitigation efforts is indispensable for reducing greenhouse gas emissions and combating climate change. EU

([68]) See https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-strategic-plan-2025-2027-analysis-now-public-2023-05-25_en.

([69]) Relevant monitoring tools include the EU Industrial R&D Investment Scoreboard, the Strategic Energy Technology Information System (SETIS), the Science, research and innovation performance of the EU (SRIP) reports, the Horizon Europe Results Platform, the Innovation Radar, the Global Industrial Research & Innovation Analyses (GLORIA) project, etc. They continuously improve their monitoring and assessment work including on breakthrough industrial technologies and innovation ecosystems, in collaboration with the European Innovation Council (EIC).

Space data and services are essential assets to supporting the implementation of the Green Deal.

Copernicus (Earth observation), Galileo and European Geostationary Navigation Overlay Service (EGNOS) (satellite navigation) supply the information companies need to monitor environmental indicators, to reduce their environmental impact, to become more sustainable and to drive their green transformation.

EU space data and services can contribute to the achievement of climate target and can be used for: Monitoring and Measurement of various parameters, including greenhouse gas concentrations, land use change, deforestation and ocean temperatures; Understanding Climate Patterns including analysing atmospheric circulation, ocean currents, and weather systems; Early Warning Systems for extreme weather events and natural disasters related to climate change, such as hurricanes, droughts, floods, landslides, wildfires, or storm surges; Carbon Accounting and Reporting by measuring and quantifying emissions from different sources, including deforestation, industrial activities, and transportation; Climate Modelling; International Cooperation; Climate Education and Awareness; Monitoring Deforestation and Land Use Change to enable targeted action to protect forests; Agriculture and Livestock Management to improve agricultural practices and livestock management, leading to reduced emissions from these sectors, Supporting Renewable Energy by helping identify suitable locations for renewable energy projects; Improving Transportation Efficiency by aiding the monitoring and optimizing transportation routes; Methane Detection; Forest Fire Detection and Management; and Environmental Policy and Decision-Making by providing valuable information to develop and implement effective environmental policies.

2.6.2.3 Technological approaches

The green transition relies on a range of innovations and technological solutions that together drive the path towards climate neutrality in a complementary manner. This section does not outline an exhaustive list of technologies that will enable the green transition. Rather it provides a selection of key technological solutions that are often at different stages of maturity and technological readiness level and that can decarbonise different sectors and parts of the economy.

Clean energy generation

Research and innovation will be crucial to support the transition of the energy system with the aim to reduce the overall energy demand, whilst ensuring that the supply of energy is independent, diversified, climate-neutral, and resilient to the impacts of climate change.

The reinforcement of the competitiveness of the European value chain relies on the development of clean, sustainable, and “circular by design” energy technologies. Diverse R&I activities on key clean energy technologies such as solar energy, wind energy, sustainable biomethane and advanced biofuels, hydropower, geothermal energy, heat pumps, ocean energy and synthetic renewable fuels are needed to achieve and eventually maintain the autonomy and competitiveness of the EU energy supply. At the same time, it needs to be ensured that ecosystems are not harmed in the process, and that the zero-pollution ambition of the European Green Deal is supported, whilst bringing social benefits for all.

Further, research and innovation activities are needed to advance the modernisation of the energy networks, grids, markets, and services, as well as to support energy system integration

and to accelerate electrification. Integrating demand response, lowering the cost of energy storage solutions at various timescales, while minimising the use of critical raw materials and ensuring their reuse and recycling, are key elements of the energy system.

Moreover, the output from research and innovation can accelerate the deployment of Carbon Capture, Utilisation and Storage (CCUS) in electricity generation, industry applications, and negative emissions technologies.

Electrification

Reducing emissions from industrial sectors will require coordinated action throughout value chains to boost and accelerate innovation and deployment of all mitigation options, including integration of renewable electricity. R & I still remains crucial for even 'mature' low-emission energy technologies such as heat pumps, as well as new technologies to electrify high temperature processes.

Buildings are responsible for around 40% of EU energy demand and are pivotal to the success of the energy transition and achievement of a climate neutral economy. Research and innovation is needed to achieve the full electrification of building systems with the integration of grid-compatible and flexible solutions that involve demand side management, energy storage, and electric vehicle charging.

Energy storage

R&I activities will allow for the development of lower cost and more sustainably produced battery technologies and other long-term storage technologies, not only in transport applications (road, maritime and aviation), but also in stationary storage applications, where new solutions, such as flow batteries, can play a key role in the development of resilient energy grids. Supporting local sustainable battery production capacity (including equipment and skills development) will be an important driver, but R&I will also need to focus on the replacement, reuse, recycling and end-of-life management of batteries and raw materials recovery.

Renewable hydrogen

Decarbonising the production of hydrogen used as an industrial feedstock, and for new uses as an energy carrier requires R&I for the scaling up of hydrogen production and the production of synfuels, and to develop large-scale hydrogen storage systems.
Whilst the technologies used to integrate green hydrogen into a carbon-free energy system are already available, innovation is needed for the scale-up, demonstration, and deployment of hydrogen-based systems in order to take advantage of European technological leadership.

Biotechnology and biomanufacturing

The advances in life sciences and information technology are leading to deeper understanding of functioning of living organisms and providing tools to influence biological processes. Increasingly biotechnology and biomanufacturing are becoming important EU assets to advance strategic autonomy and competitiveness and to enable timely solutions to urgent crises, including climate change or pandemics. However, despite the first-class research in biotechnology, the EU could enhance the efforts for deployment and commercialisation of

biotechnology solutions. An initiative is being prepared on EU Biotechnology and Biomanufacturing.

2.6.2.4 Sustainable transportation

Transport is the only sector where greenhouse gas emissions are still above their 1990 levels (18% higher in 2021 relative to 1990). The transport sector (including international aviation and maritime) is responsible for 27% of GHG emissions in the EU (of which over 76.2% came from road transportation in 2021). Energy use of oil and petroleum products accounted for 90.7% of the final energy consumption ([70]) in transport. Intensified R&I activities are needed, across all transport modes and in line with societal needs and preferences, for the EU to reach its policy goals towards net-zero greenhouse gas emissions by 2050, and to significantly reduce air pollutants towards the zero-pollution ambition.

As regards road transport, research and innovation actions must focus on contributing to the shift to zero-emission mobility by targeting cost- and energy-efficient zero-tailpipe-emission vehicles and their integration of these vehicles in the mobility system.

Road transport has the potential to be largely electrified as it provides high potential for absorbing renewable electricity at times when it is abundant and feed it back into a grid when there is scarcity. With the projected increase of electric vehicles already by 2030 it is necessary to ensure that they can contribute to optimising electricity grid in a cost-effective way by offering flexibility services such as energy storage capacity and demand response thanks to smart charging and bidirectional charging which are expected to become mainstream in the coming years. Moreover, private recharging infrastructure in buildings or depots for specific purpose vehicle fleets where electric vehicles typically park for extended periods of time are highly relevant to energy system integration and could contribute the most to optimising the electricity grid through the flexibility services thus reducing the need for additional investments to expand the grid due to increased electrification. In the rail sector, regenerative braking and energy buffers offer a large untapped potential for enhanced energy efficiency.

The European aviation sector aims to reach climate neutrality by 2050. This objective relies on the development of sustainable aviation fuels, and hydrogen-powered zero-emission aircraft and infrastructure. R&I actions on aviation need to develop integrated aircraft technologies for deep decarbonisation transformation and to reduce all negative non-CO2 impacts and emissions. Likewise, research and innovation is required to further advance net zero-emission solutions on new fuels, engines and ship designs in the shipping sector.

2.6.2.5 Circular industry

A functioning circular economy is one of the key objectives of the European Green Deal. Research and innovation is critical to achieving a circular economy by fostering new safe

([70]) Final energy consumption excludes international aviation and maritime. The energy consumption in air transport and maritime are dominated by oil products.

ways of designing, producing, repurposing, reusing, repairing, and recycling. R & I is needed to reinforce our resilience and strategic dependency by decoupling economic growth from resource use.

There is much scope for improvement for design of circularity in terms of circularity technologies applicable to different value chains with special attention to disassembly, remanufacturing/upgrading, recycling, and 'Zero-X' – zero defects, zero breakdowns, zero waste.

It will be important to develop and test different circularity technologies in the context of the entire value chain and life cycle, with a view to facilitating deployment, further developing value chains for circularity.

Research will be needed to enable energy-intensive industries to embrace the circular economy as a key pillar in the design of their value chains. This will be fundamental to ensuring the efficient use of resources (material, energy, and water) by these resource-intensive industries. Particularly important in this context is the development of innovative upcycling of secondary raw material and of resource-efficient industrial processes.

Achieving circularity of both raw materials and advanced materials is a key challenge for the future. The establishment of new materials flows, as well as the advancement of the recovery, re- and up-cycling of materials from waste relies on R&I.

2.6.2.6 Sustainable circular bioeconomy

In "A Clean Planet for All: Long-term Strategy, 2018" Bioeconomy is one of the seven strategic building blocks towards a net zero GHG economy. Bioeconomy sectors mentioned in this IA (i.a. food and non-food bio-based value chains from agriculture, LULUCF, bioenergy) were included under Reaping the full benefits of Bioeconomy and creating essential carbon sinks for: sequester and store C in agricultural land, forestry and wetlands; substitute C-intensive materials; create new business opportunities; developing climate-friendly farming and forestry systems; unlocking the potential of aquatic resources; and substitute fossil fuels in power generation.

Innovation in the sustainable bioeconomy lays the foundations for the transition away from a fossil-based economy. Sustainable bio-based innovation is an important segment of the overall bioeconomy and takes into account sustainability in all its dimensions. Research and innovation need to contribute to scaling up the potential of bioeconomy to substitute GHG intensive products and materials, as well as to improving the circularity aspects of bio-based systems, with a particular focus on biowaste, waste management and valorisation, considering the whole life cycle of bio-based products and technologies. Moreover, the cross-cutting aspect of zero pollution in the sector has to be further implemented.

The EU agriculture sector is the only major agriculture system in the world that has reduced its GHG emissions (by 20 % since 1994). The development of sustainable agriculture and food systems is one of the main priority areas of action for the EU. Key research areas for agriculture include mitigation and adaption to climate change, enabling more sustainable farming practices, and fostering sustainable livestock systems.

Further R & I is needed in the forestry sectors in order to meet the expectations of the European Green Deal. Specifically, there is a need to foster multifunctional forests for future

generations through sustainable management approaches, technologies, innovative wood and non-wood products, prevention and management of forest disturbances, urban forestry, management of genetic resources, deployment of inclusive and fair value chains, and improved governance. Overall, a better understanding of consumption of these resources is needed to help shifting to more sustainable consumption patterns ([71]).

2.6.2.7 Socio-economic & behavioural R&I

Research and innovation must go hand in hand with social innovation, inclusiveness, and promotion of solutions that allow the integration of aspects going beyond functionality, whilst achieving efficiency, sufficiency, and sustainability. The important role of social sciences and humanities must be realised to advance behavioural change and social acceptance, trust, and uptake of solutions.

The necessary innovations to address key societal challenges, notably climate change, call for interdisciplinary approaches to research and innovation that combine knowledge from the social sciences and the humanities, including the arts and science, technology, engineering, and mathematics, while at the same time maintaining the human-centric focus.

Research is needed to evaluate the societal impact of climate change and the measures required to achieve climate neutrality and to prepare for adverse impacts and risks linked to climate change.

2.6.3 Advancing the European RDI system

2.6.3.1 Role of RDI

In 2019, the European Green Deal Communication emphasised the key enabling role of R&I in steering the EU towards climate neutrality by 2050 and pointed out the need for the R & I agenda to take a systemic approach to achieving the ambitious targets. Innovation is needed to develop and adopt cutting-edge clean technologies, transformative climate policies and novel practices tailored for a climate-neutral society. Achieving the goals of the Paris Agreement requires rapid and profound changes across all countries, sectors, and aspects of how the society operates and calls for mobilising R&I at the scale and speed that are commensure with this challenge. Innovative net-zero solutions must not only be developed and deployed faster, but also have to be climate-proof. The problems at stake today are complex and interconnected, thus requiring solutions from multiple perspectives, disciplines, and sectors, maximising the co-benefits, and attenuating the trade-offs. Beyond delivering technological innovation, R & I policies are increasingly expected to provide novel instruments and to act as a lever for catalysing transformational change towards sustainable development, empowering individuals, and communities to meet societal needs and build sustainable, inclusive and resilient societies. All this will require sustained and more effective investments in research

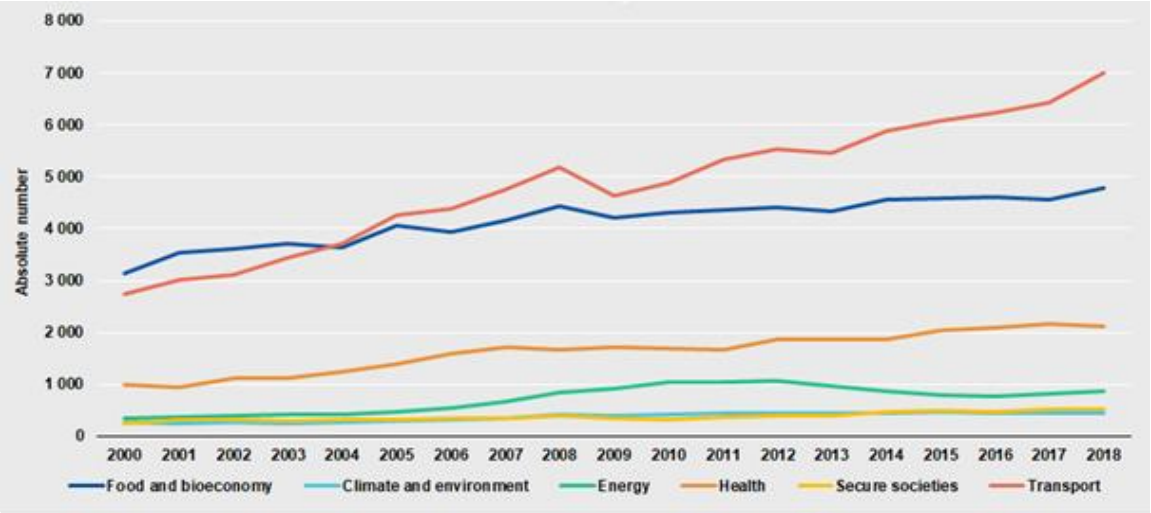
([71]) European Commission, Directorate-General for Research and Innovation, *European bioeconomy policy – Stocktaking and future developments – Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/997651.

and innovation, from public and private sources alike, if the EU is to succeed in decarbonising at sufficient speed to fall in line with what the science says is necessary.

2.6.3.2 Where the EU is today

The EU has remained stable over time in terms of number of patent applications filed related to the societal grand challenge (SGC) "Climate and Environment" (Figure 5). The EU is still the top worldwide patent applicant in the field of "Climate and Environment" (23 %), but its share has declined (see Figure 6), underscoring the importance of stepping up the investments to secure Europe's leadership in technologies needed for the transition.

Figure 5: Number of patent applications filed under the PCT in the EU by SGC



Note: Covers PCT patents at the international phase designating the European Patent Office. Fractional counting method used; inventor's country of residence and priority date used.

Source: Own analysis based on Science-Metrix using the European Patent Office's patent statistics database ([72]).

European countries ([73]) are also among the leaders of the green transition**.** From 2016 to 2021, Europe produced 30 % of all green inventions worldwide. Japan was second, with 21 %, followed by the United States (19 %) and China (13 %). The European lead is especially strong for domains such as green transport (41 %), biofuels (37 %) and wind energy (58 %). The production of solar energy technology or batteries is more evenly distributed among the largest and most innovative countries ([74]).

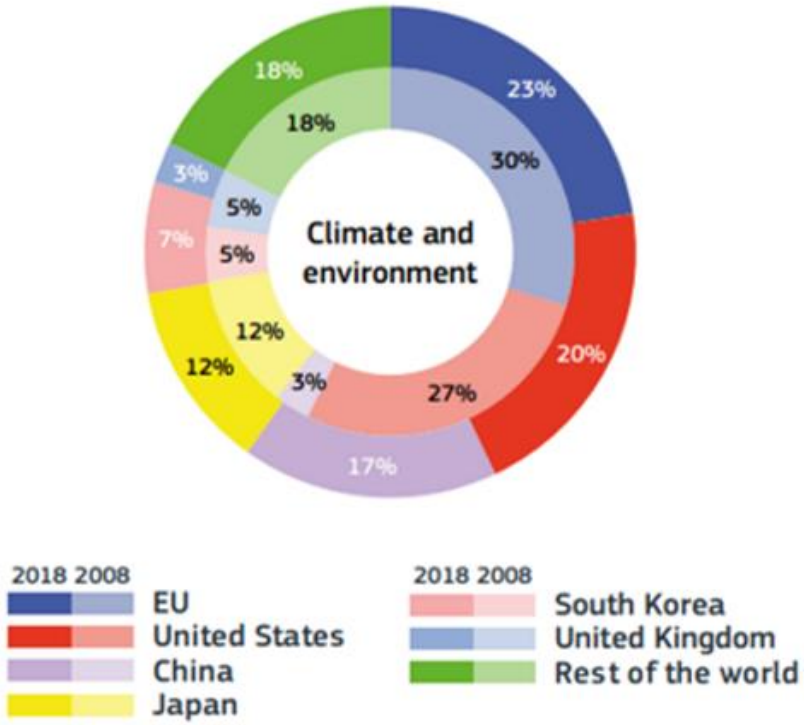
Europe has maintained a stable position in the green transition since 2004. In addition, although a slowdown can be observed during the 2007–2008 financial crisis, the rate of output of innovation has been relatively stable since 2014.

([72]) European Commission, Directorate-General for Research and Innovation (2022). Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([73]) Understood as the group comprising the EU-27, the United Kingdom, and the European Free Trade Association countries.

([74]) See https://www.paballand.com/asg/esir/fow/green-transition.html.

Figure 6: Global patent applications for SGC "Climate and Environment"



Note: Filed under the PCT. 2008 (interior ring) and 2018 (exterior ring).
Source: Own analysis based on Science-Metrix using the European Patent Office's patent statistics database ([75]).

The EU has put in place a number of instruments and funding programmes that aim to deliver research and innovation results, with a particular focus on the green transition:

- The **EU Framework Programmes for R&I** Horizon 2020 (2014-2020) and Horizon Europe (2021-2027) ([76]), with the latter having a budget of EUR 95.5 billion, of which 35% are allocated to tackling climate change. Horizon Europe plays an important role in mobilising research and innovation in the most strategic areas for transitioning to climate neutrality and resilience, notably through its comprehensive portfolio of EU partnerships ([77]) and missions ([78]).

([75]) European Commission, Directorate-General for Research and Innovation (2022). Science, research and innovation performance of the EU 2022 – Building a sustainable future in uncertain times, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/78826.

([76]) See https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en.

([77]) See https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/european-partnerships-horizon-europe_en

([78]) See https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe_en

- The **European Institute of Innovation and Technology's** (EIT) **Knowledge and Innovation Communities** (KICs), that comprises public-private partnerships on different societal challenges, including on climate ([79]) and energy ([80]).
- The **Innovation Fund ([81])** under the Emissions Trading System (ETS), which is the EU fund for climate policy, and aims to bring to the market solutions to decarbonise European industry and support its transition to climate neutrality.
- The **European Regional Development Fund ([82])** (ERDF) and **Cohesion Fund ([83])** (CF) support Member States in advancing the transition to climate neutrality and other EU priorities. The funds will deliver at least EUR 78 billion in investment in climate action in 2021-2027 (30% of the total ERDF and 37% of the total Cohesion Fund budget allocation).
- The **LIFE Programme ([84])** is the EU's funding instrument for the environment and climate action.
- R&I is a key dimension of the **National Energy and Climate Plans ([85])** (NECPs). The inclusion of specific and measurable R&I objectives in the NECPs will help integrating national strategies and priorities at EU level in a 2030-2050 perspective.
- The EU is participating in international fora on innovation related to decarbonisation, in particular as a member of the **Clean Energy Ministerial ([86])** and of the **Mission Innovation ([87]).**
- Furthermore, the EU supports the work of the **IPCC ([88])** which makes a major contribution to the advancement of climate science, which underpins evidence-based climate policies and global climate diplomacy. The support is channelled, inter alia, through the EU Framework Programmes for R&I ([89]).

([79]) See Climate-KIC | The EU's main climate innovation initiative, https://www.climate-kic.org/.

([80]) See KIC InnoEnergy: a new approach to education, https://eit.europa.eu/news-events/news/kic-innoenergy-new-approach-education.

([81]) See 'What is the Innovation Fund?', https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en.

([82]) See https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-regional-development-fund-erdf_en.

([83]) See https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/cohesion-fund-cf_en.

([84]) See https://cinea.ec.europa.eu/programmes/life_en.

([85]) See https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans_en.

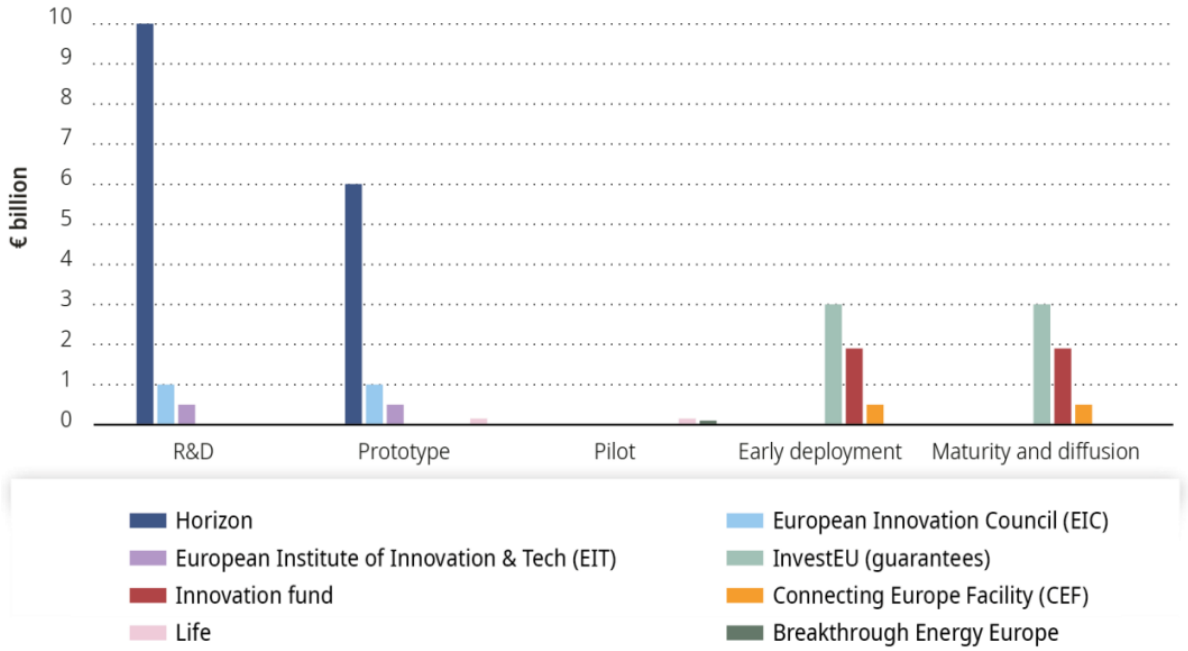
([86]) See https://www.cleanenergyministerial.org/.

([87]) See Mission Innovation – Catalysing Clean Energy Solutions for All (mission-innovation.net).

([88]) IPCC — Intergovernmental Panel on Climate Change, https://www.ipcc.ch/.

([89]) Factsheet EU research & innovation – Top funder of leading climate science, https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/5417b4fd-c9fa-11ed-a05c-01aa75ed71a1.

Figure 7: Available public funding by stage of the RD & D process



Note: Annualised estimates for the period 2021 – 2027, except from the Innovation fund which is annualized for the period 2020-2030 and the Breakthrough Energy Europe which spans over the 2018-2023 period, in 2022 EUR values.

Source: European Scientific Advisory Board on Climate Change (2024) ([90])

2.6.3.3 Future R&I for EU decarbonisation & industrial growth

Even if the EU is positioned as a leader in terms of the green transition, continued investment into R & I progress and uptake are still critical for implementing the European Green Deal ([91]), and translating the leadership into environmental, economic, and social benefits.

To deliver on the green and digital transitions, systemic change should be fostered across our entire economy and all sectors, covering both production and consumption side, and with a focus on energy (as key enabler for electrification and decarbonisation of other sectors), energy-intensive industry, (large-scale) infrastructure, transport, food, agriculture and land-use, construction and buildings. Some innovations are market-ready, such as solar power, but many need to be improved and scaled up, while others still need to be invented to reach climate neutrality. In order to enable such systemic changes, unprecedented mobilisation of R&I is needed, with technological innovation complemented by social, governance and economic innovation, as well as behavioural research on accelerating the transition towards climate neutrality. Given the potential of demand-side mitigation ([92]), research is needed to

([90]) European Scientific Advisory Board on Climate Change (2024): Towards EU climate neutrality: progress, policy gaps and opportunities

([91]) European Commission, Directorate-General for Research and Innovation (2022), *Science, research and innovation performance of the EU 2022 (SRIP)*, Publications Office of the European Union, Luxembourg, https://data.europa.eu/doi/10.2777/38888.

([92]) IPCC AR6 estimates that demand side mitigation could deliver 40–70% of emissions reductions by 2050.

better understand how lifestyle choices can contribute to climate objectives. Finally, in the context of this impact assessment, a defining element of the scenarios proposed is the ability to deploy novel technologies with important implications for choices on how to accelerate and scale up R&I to support the more ambitious options.

According to the Analysis for the Horizon Europe Strategic Plan 2025-2027 ([93]), the following priorities for EU R&I were identified for delivering on the European Green Deal, many of relevance for addressing the climate change challenge:

- protect and restore natural capital;
- decarbonise the economy;
- accelerate the transition to chemicals and materials that are safe and sustainable ([94]);
- achieve a circular economy and the zero pollution ambition;
- modernise our infrastructures, buildings, and transport, and make them more resilient;
- protect the health and well-being of citizens and communities (including rural ones);
- design sustainable and resilient agriculture, forestry, fisheries and aquaculture, and food and water systems; and transform our ways of producing and consuming ([95]).

In the context of the transition to climate neutrality, it is also important for Europe to pursue reciprocal openness and a level playing field through strategic international R & I cooperation with like-minded partners.

2.7 SMEs

The transition implies challenges and opportunities for SMEs. At the stakeholder event organised by the Directorate General on Climate Action on June 9th, one SME mentioned that the reduction of activity in some sectors (for example in the supply chain for fossil fuel engines in the automobile sector ([96])) will be compensated by new opportunities (in growing activities (for example, demand for heat pumps in the residential sector).

([93]) See https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/horizon-europe-strategic-plan-2025-2027-analysis-now-public-2023-05-25_en.

([94]) European Commission, Directorate-General for Research and Innovation (2022), *Strategic research and innovation plan for safe and sustainable chemicals and materials*, Publications Office of the European Union, Luxembourg, DOI: 10.2777/876851.

([95]) European Commission (2019), The European Green Deal, COM(2019) 640 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN.

([96]) Less than 0.07% of SMEs in the EU are in the manufacturing of motor vehicles, trailers and semi-trailers; less than 0.06% are in the manufacturing of other transport equipment (Eurostat Structural Business Statistics). Around 3.4% are in the wholesale and retail trade and repair of motor vehicles and motorcycles. Other sectors involved in the supply chain of the automobile sector may be not impacted by the transition (e.g., textile manufacturing), negatively impacted (e.g., the manufacturing of compounds used in fossil fuel engines) or positively impacted (e.g., the manufacturing of batteries).

Specific measures and programmes exist to support SMEs in the transition (see SME test in Annex 4). In 2014-2020, the European programme for small and medium-sized enterprises (COSME) contributed to the climate mainstreaming objectives. The detail of measures and initiatives conducted under the programme are presented in the COSME 2020 Monitoring Report ([97]). To give a few examples, the Equity Facility for Growth (EFG) and the Enterprise Europe Network (EEN) paid attention to the challenges implied by the decarbonisation. The EEN helped SMEs to improve their energy and resource efficiency and reduce their emissions. The COSME Equity Facility for Growth (EFG) invested EUR 6.7 million in a Venture Capital (VC) fund dedicated to clean technologies. In the time period 2014-2020, the EFG facilitated more than EUR 62 million of investments in SMEs in the 'Energy and Environment' sector. The COSME programme is an experience to learn from for developing other comparable programmes in the next decades.

Aware of the impact that climate change may be for SMEs, the European Investment Bank (EIB) Group also pays attention to develop financing tools that are particularly adequate ([98]). It works with financial intermediaries that offer products targeting small and medium firms and micro-enterprises. Some of the instruments offered by the EIB Group typically helps more established small businesses while others focus on enterprises in earlier stages of growth.

The recent SME Relief Package ([99]) is expected to support SMEs in the transition to a low-carbon economy. Rules to ensure small businesses are paid in due time help them invest and innovate in sustainability and hire more employees ([100]).

In addition, depending on the regions and the sector in which SMEs operate, they may benefit from measures and programmes aimed at supporting specific regions and sectors throughout the transition (see Annex 9).

3 AN INCLUSIVE AGENDA

3.1 Just transition and social policy

The European Green Deal sets out the strategy for the Union to become the first climate-neutral continent and to transform the Union into a sustainable, fairer, and more prosperous society. It stresses that no person and no place should be left behind. Addressing from the outset the socio-economic impacts of the energy and climate transition and protecting households, exposed industries and workers throughout the process is a prerequisite for a fair and inclusive transition. It is clear by now that the impacts of the green transition on

([97]) Report from the Commission to the European Parliament and the council. COSME 2014-2020. Programme for the Competitiveness of Enterprises and SMEs. 2020 Monitoring Report.

([98]) Small and medium enterprises. Overview 2022. European Investment Bank Group.

([99]) COM(2023) 535 final

([100]) Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., Lozar, B. Annual Report on European SMEs 2022/2023, Publications Office of the European Union, Luxemburg, 2023, doi:10.2760/028705, JRC134336.

businesses and employment will vary by sector, occupation, region, and country ([101]). Restructuring and adjustment in the companies, sectors, and industrial ecosystems most affected by the transition will require the development of new business models while upskilling, reskilling or labour reallocations both across sectors and regions will be needed.

The transition will bring numerous benefits (job creation, healthier environment, cheaper and cleaner energy, better living comfort). Yet, ensuring a fair and inclusive transition will require to pay due attention to transforming sectors (automotive, agriculture, forestry, waste), the quality of jobs being created, the impact on various skills segments and the gender gap. Increased climate ambitions combined with important labour shortages, calls for timely investments in education and (re)skilling. Additional and targeted measures to address the distributional impacts of the transition, including social challenges such as energy and transport poverty aspects, are also required. Wide stakeholder involvement based on close cooperation with social partners and civil society is essential for ensuring a just and inclusive transition towards a climate neutral economy, especially in regions and sectors most affected.

3.1.1 How to accompany the transition?

To accompany the transition to a climate neutral economy, the EU has put in place a comprehensive enabling framework. Council Recommendation 2022/C243/04 adopted in 2022 provides Member States with comprehensive guidance on measures to address the employment and social aspects of climate policies. The objective of these measures should be to provide active support to quality employment, ensure access to quality education, training, and life-long learning, provide fair tax benefit systems and social protection, and ensure access to essential services. In 2023 and 2024, Member States are required to update their 2030 national energy climate plans (NECPs,) which are the central strategic planning tool under the Governance Regulation. In the Commission Notice 2022/C495/02, the Commission stressed the importance of considering fair transition aspects when designing policies and measures to advance towards climate neutrality.

3.1.2 Energy and transport poverty aspects

Energy poverty is exacerbated by the fact that the EU's population is projected to continue ageing and shrinking in the coming decades. This demographic change can have a significant impact on energy poverty as older people are particularly affected by it (lower incomes, live in poorly insulated homes and are more susceptible to health problems associated with cold homes). Climate change affects the poor at a disproportionately higher rate as they frequently suffer from poor health conditions and work outside more often ([102]).

In 2021, the European Commission launched the Energy Poverty Advisory Hub (EPAH), the leading EU initiative aiming to eradicate energy poverty and accelerate the just energy transition of European local governments. In April 2022, the Commission Energy Poverty and Vulnerable Consumers Coordination Group was established. It provides EU countries with a

([101]) SWD(2020) 176 final

([102]) Meyer-Ohlendorf, Nils; Spasova, Deyana; Graichen, Jakob; Gores, Sabine (2023): Designing the EU 2040 climate target. Ecologic Institute, Berlin.

space to exchange best practices and increase coordination of policy measures to support vulnerable and energy-poor households. A new Social Climate Fund (SCF) ([103])will support vulnerable households, transport users and micro-enterprises affected by the introduction of emissions trading for fuels used in road transport and buildings. The aim is to help these groups reduce their reliance on costly fossil fuels by making buildings more efficient, decarbonising heating and cooling of buildings (including integrating energy from renewable sources) and increasing access to sustainable transport. In addition, the SCF can also support vulnerable groups through national measures via targeted and temporary direct income support.

3.1.3 Employment and skills related aspects

3.1.3.1 Better understanding of jobs and skills required

As the transition will have substantial effects on labour demand and skills in some specific regions, sectors, and occupations, it is essential to better understand and monitor where shortages are expected and who will be adversely affected. To better anticipate these changes, there is a need to develop up-to-date labour market and skills intelligence and foresight. More granular data (e.g., at regional, occupational, and gender levels), more precise definitions of green jobs and skills, as well indicators are required. Cooperation between public authorities at all levels and with social partners, civil society organizations, educational organisations and enterprises is important for improving the evidence base for a fair and inclusive transition. Several Commission initiatives have been laying the ground for further work in this area such as the recent GreenComp reference framework for sustainability competences ([104]), the European Skills, Competences, and Occupations (ESCO) taxonomy on skills for the green transition ([105]) and the CEDEFOP Green Observatory which tries to map skills needed in the EU job market.

3.1.3.2 Targeted upskilling and reskilling

To mitigate unemployment in declining sectors and address increasing labour shortages in key sectors for the green transition, it is essential to re- and upskill the workforce in impacted sectors and to ensure that educational programmes are labour market relevant. Today, 70-80% of people see the green transition as an opportunity but around 50% of people are not sure whether they have the rights skills ([106]). Several EU Level initiatives seek to address the growing demand for "green" skills. The European Skills Agenda is the current five-year plan to help individuals and businesses develop more and better skills and thereby spur the green and digital transition. Actions within the EU Skills Agenda, such as the Pact for Skills, demonstrate the facilitating role that the EU can play in connecting Member States, education and training providers, industry, and social partners to effectively identify skills and learning

([103]) Regulation (EU) 2023/955 of the European Parliament and of the Council of 10 May 2023 establishing a Social Climate Fund and amending Regulation (EU) 2021/1060.

([104]) See https://joint-research-centre.ec.europa.eu/greencomp-european-sustainability-competence-framework_en.

([105]) See https://ec.europa.eu/newsroom/empl/items/741088/en.

([106]) Eurobarometer on fairness, inequality and intergenerational mobility.

pathways. The recent EU's Skill Partnership for the automotive ecosystem is a good example of a tailored approach to bridge the gaps and facilitate road transport electrification ([107]). Skills are also at the centre of the Green Deal Industrial Plan with initiatives such as the skill academies for clean technology sectors, initiatives aimed at ensuring there is a skilled workforce supporting the production of net-zero technologies in the EU.

But equipping the workforce with the right set of skills is just one side of the coin. It needs to be complemented with measures supporting access to quality employment, in particular through public employment services, tailored job search assistance and other active labour market policy measures. The European Social Fund Plus, the EU's main instrument for investing in people, is becoming an increasingly more important tool in the current context. Within this framework, Member States have programmed around 6 billion € for the period 2021-2027 including in the area of skills development, green entrepreneurship, job search assistance, active labour market policies and social inclusion of people impacted by the transition. In addition, other funds such as the Recovery and Resilience Facility, Invest EU and the Just Transition Fund can support up- and reskilling. ([108])

Finally, as the climate and energy transition affects women differently than men ([109]), specific attention can be paid to the gender aspects in programmes and plans designed to facilitate and support the transition, for example in the NECPs ([110]).

3.1.4 Strategic cooperation and communication

Effective multilevel governance at the EU, national and regional levels is key for the kind of long-term systemic change that is needed to reconfigure production and consumption systems in impacted sectors ([111]). From the outset, fair and inclusive transition objectives should be integrated into policymaking at all levels through an effective whole-of-society approach. Regional and local authorities need to play an active role in the development, implementation and monitoring of fair transition policies. Indeed, local authorities are the closest to citizens and implement 70% of all EU legislation, 90% of climate adaptation policies, and 65% of the Sustainable Development Goals ([112]). Active involvement of social partners, civil society, educational and training institutions, and those affected at different stages is essential for raising awareness and providing reliable information to the public, facilitating learning and

([107]) Tamba, M., Krause, J., Weitzel, M., Ioan, R., Duboz, L., Grosso, M., Vandyck, T. Economy-wide impacts of road transport electrification in the EU, Technological Forecasting & Social Change, 182 (2022) 121803.

([108]) An overview of all funds which can contribute to upskilling and reskilling is available on the following webpage: https://ec.europa.eu/social/main.jsp?catId=1530&langId=en.

([109]) See EIGE (2023). Gender Equality Index 2023. Towards a green transition in transport and energy, Publications Office of the European Union

([110]) COM(2023) 796 final

([111]) Eurofound and EEA (2023), The transition to a climate-neutral economy: Exploring the socioeconomic impacts, Publications Office of the European Union, Luxembourg.

([112]) Resolution of the European Committee of the Regions - The Green Deal in partnership with local and regional authorities (2020/C 79/01).

ensuring support across regions and economic sectors for the systemic changes to come. This requires investments in capacity development. To give an example of relevant initiative, the European works councils (EWCs) is a European representation of employees (over 17 million) at company level. They facilitate the information, consultation, and participation of employees with a focus on transnational issues. At the EU level, several tools exist. For example, the Council recommendation on social dialogue can help ensure that the new jobs for the green transition are quality jobs with good working conditions. It can support (re)skilling, job transitions and EU competitiveness. In the Communication on Enhancing the European Administrative Space (ComPAct) ([113]), the Commission sets out actions to reinforce the capacity of public administrations across Member States to manage the green transition, by up- and reskilling civil servants, mainstreaming the green transition into the policymaking cycle, and greening their own organisation and operations."

3.1.5 Examples of fair and inclusive transitions

Promoting the exchanges of best practices while considering country specificities can help ensure successful transition across countries and regions.

Financial incentives for home renovation play a key role to support energy-poor and vulnerable households to achieve energy savings.

Germany's transition away from coal for electricity generation entails significant structural change and economic and social challenges, with over 19,650 direct and 35,734 indirect jobs impacted in coal mining ([114]). In particular, the transition to clean energy is affecting three coal mining areas: the Lausitzer Revier, the Rheinische Revier, and the Mitteldeutsche Revier. Measures to address this challenge were designed. For example, the "adjustment allowance" ("Anpassungsgeld") provides financial support to workers facing job losses. Under this scheme, former mining workers above the age of 50 and meeting certain conditions can receive a bridge aid for a maximum of five years until entitlement to benefits from the miners' pension insurance. Furthermore, the federal government has pledged to support the affected states ("Länder") with up to EUR 14 billion in financial transfers for regional investments until 2038 at the latest. The federal government will fund additional measures with up to EUR 26 billion, such as rail and road infrastructure, research institutions ([115]). The Just Transition Fund was also utilized to help the most affected regions.

One example of a successful transition in the energy sector is the offshore wind evolution of the city of Esbjerg in Denmark. Esbjerg underwent a fundamental transformation from servicing the oil and gas sectors over the past three decades to becoming one of Europe's leading hubs for offshore wind. Reskilling and upskilling pathways were designed to absorb

([113]) COM(2023) 667 final

([114]) SWD(2020)504 final

([115]) SWD(2020)504 final

workers from the oil and gas industry to the offshore wind sector, which helped avoid high unemployment and economic stagnation of the region ([116]).

Poland is developing 120 Sectoral Skills Centres (SSCs) which will cover industries related to the green transition, i.e., in areas of renewable energy, environmental protection, environmental engineering and waste management. Practical trainings will target young people and people with disabilities, adults and teachers for vocational education and training ([117]).

Another successful example is the "*Contrat de Transition Écologique*" (CTE) initiated in France as a partnership programme between the State and local communities to help develop local projects that diversify the local economy, for sustainability and environmentally responsible development. Each contract lasts three to four years. The process started in 2018, experimenting with 18 territories and later expanding to 107 territories. This initiative shows how cooperation between the State, local authorities and local socioeconomic actors can support ecological action undertaken at national level and transpose it to the local level ([118]).

3.2 Regional policy and local action

Regional authorities play a crucial role in the climate transition because they are at the forefront of implementing climate change mitigation and adaptation measures. Each of them faces unique opportunities and challenges as they decarbonise their economies (see Annex 8) by 2040. To support regions with the implementation of locally tailored ambitious climate policies and measures, the EU has put in place a comprehensive and flexible enabling framework. This framework is supplemented by the initiatives and strategies developed by national and regional authorities. However, neither regional, nor national or EU authorities can act alone. It is vital that different levels of government coordinate their climate efforts, both within and across borders.

3.2.1 Available EU funding, objectives, and strategies

A significant share of the EU's multiannual financial framework (MFF) for 2021-2027 and NextGenerationEU (€2.018 trillion in current prices) will directly support climate action in less developed regions. At least 30% of these two sources combined will be spent on fighting climate change ([119]). A significant share of these amounts should be spent by the end of 2029. The next, post-2027, long-term budget of the EU will be adopted under the next Commission mandate.

([116]) Implementation of just transition and economic diversification strategies. A compilation of best practices from different countries. United Nations Climate Change. Katowice Committee on Impacts. 2023.

([117]) Vocational education and training and the green transition - Publications Office of the EU (europa.eu). DOI: 10.2767/183713

([118]) Just transition interventions: report by the Katowice Committee of Impacts (created in 2018 in the framework of the UNFCCC with a mandate for monitoring response measures).

([119]) EU budget today. Midterm review of the MFF 2021-2027. https://commission.europa.eu/strategy-and-policy/eu-budget/motion/today_en.

Several spending programmes under the EU's 2021-2027 budget have climate spending targets of at least 30%. These include the European Regional Development Fund (ERDF) (30%), Horizon Europe (35%), the Cohesion Fund (37%), the Connecting Europe Facility (60%), and LIFE (61%). 100 % of the resources of the Just Transition Fund (JTF) contribute to climate objectives. The resources from the JTF's own envelope are additional to the investments needed to achieve the EU's overall 30% climate expenditure target ([120]). Several of these funds strongly support less developed regions or, in the case of the JTF, target the regions most affected by the climate transition.

The Governance of the Energy Union and Climate Action Regulation ([121]) facilitates the involvement of all governance levels including regional actors in addressing energy and climate policies by creating a permanent Multilevel Climate and Energy Dialogue in Member States. Such a permanent and regular dialogue on climate and energy among all levels of governance and relevant stakeholders has delivered various benefits: continuous political support, ownership, feedback loops, shared responsibility as well as a better implementation of the necessary actions.

The EU has developed strategies and measures to tackle climate change in regional clusters. For instance, the macro-regional strategies (MRS) address common challenges such as climate change in defined geographical areas, allowing the impacted regions to benefit from strengthened cooperation ([122]). The MRS involve 19 EU and 10 non-EU countries. They will contribute to increasing economic, social, and territorial cohesion. The MRS are:

- the EU strategy for the Baltic Sea Region (EUSBSR, 2009);
- the EU strategy for the Danube Region (EUSDR, 2011);
- the EU strategy for the Adriatic and Ionian Region (EUSAIR, 2014); and
- the EU strategy for the Alpine Region (EUSALP, 2016).

3.2.2 The EU's cohesion policy

The EU's cohesion policy aims to promote and support the overall harmonious development of all EU Member States and regions, making it a vital element of the enabling framework. The policy is implemented by Member States' national and regional bodies in partnership with the European Commission. It contributes to the goals of the Commission priorities, including the European Green Deal (EGD) and more specifically the transition to climate neutrality. Cohesion policy has been allocated a major share of the EU budget – currently €378 billion for 2021–27 ([123]). Figure 8 indicates that most of the cohesion funds are targeted at less developed regions, which are regions with a GDP per capita under 75% of the EU average.

The cohesion policy is delivered through specific funds:

([120]) Official Journal of the European Union. L231/1. 30.6.2021.

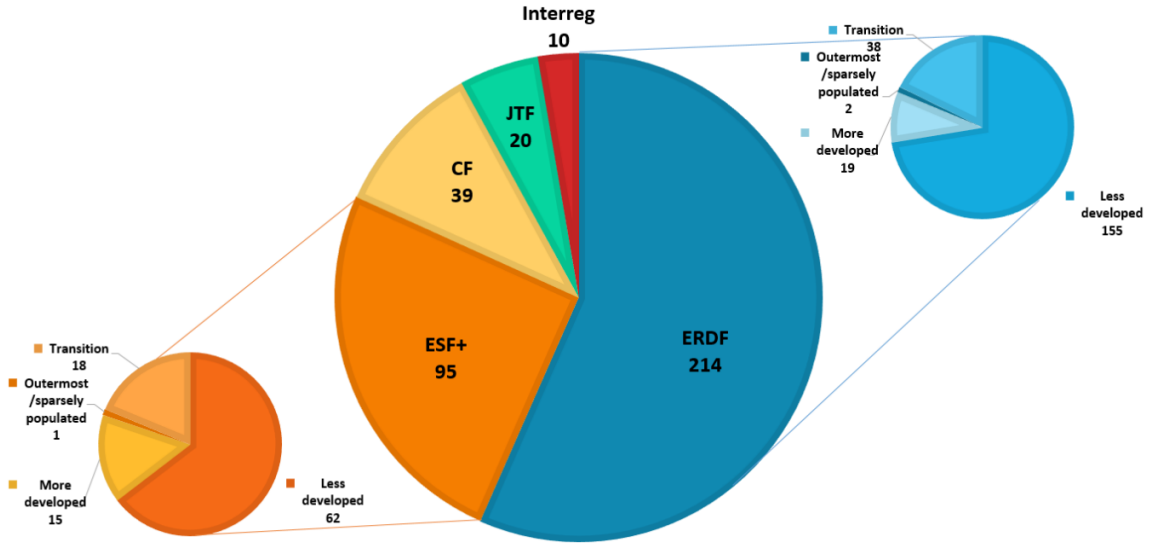
([121]) See Governance of the Energy Union and Climate Action (europa.eu).

([122]) Inforegio - Macro-Regional Strategies. https://ec.europa.eu/regional_policy/policy/cooperation/macro-regional-strategies_en

([123]) Inforegio – EU cohesion Policy: 2021-2027 programmes expected to create 1.3 million jobs in the EU.

- The European Regional Development Fund **(**ERDF), which invests in the social and economic development of all EU regions and cities;
- The Cohesion Fund (CF), which invests in environment and transport in EU countries with gross national income (GNI) per capita below 90% of the EU-27 average;
- The European Social Fund Plus (ESF+), which supports jobs and, more generally, a fair and socially inclusive society in EU countries (see the section "Just transition & social policy" in Annex 9 of this impact assessment);
- The Just Transition Fund (JTF), which supports regions most affected by the transition towards climate neutrality. It is one of the three pillars of the Just Transition Mechanism (see below);
- Interreg funds, which support territorial cooperation across EU borders as well as with certain neighbouring third countries.

Figure 8: Investment by fund and category of regions

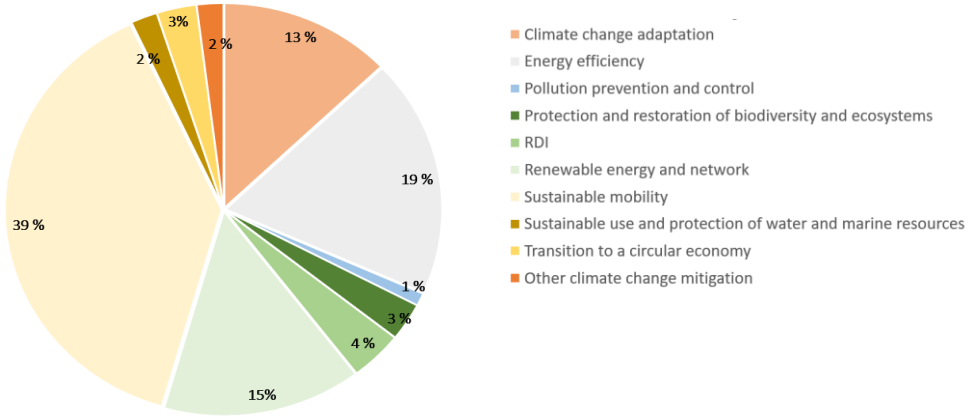


Note: billion EUR. ERDF: European Regional and Development Fund; ESF+: European Social Fund Plus; CF: Cohesion Fund; JTF: Just Transition Fund.

Source: European Commission.

With over EUR 118 billion in EU funded climate investments in the 2021-2027 programming period, cohesion policy is providing a significant contribution to the European Green Deal (EGD). The adopted 2021-2027 ERDF and CF programmes allocate respectively 33% and 56% of their funds to climate action, which exceeds the minimum regulatory commitments of 30% for ERDF and 37% for the Cohesion Fund. The major areas to receive support are energy efficiency; sustainable urban mobility; renewable energy and networks; and climate change adaptation (see Figure 9). In addition, 100% of the JTF's funds benefit climate action. ESF+ will contribute to the creation of green jobs. Combined, these climate relevant investments will enable regions to significantly boost the implementation of the EU's climate and environmental policies that aim to improve the life and prospects of people throughout the EU.

Figure 9: ERDF/CF climate expenditure by climate-relevant policy area



Source: European Commission.

The cohesion policy's enforcement mechanisms help to ensure climate action stays on track. For example, cohesion policy has introduced a climate adjustment mechanism that can introduce remediation measures when there's insufficient progress. Further, during the 2025 midterm review, the adopted programmes will be reviewed. This review will provide an opportunity to take account of the country-specific recommendations (CSRs), including those concerning climate policy, and of the progress made by Member States in implementing National Energy and Climate Plans (NECPs).

3.2.2.1 Just Transition Mechanism

In addition, the newly created Just Transition Mechanism (JTM) ([124]) provides targeted support to the regions most affected by the climate transition, for example those that must cease fossil-fuel related activities, transform and restructure carbon-intensive industries and/or diversify their economy, maintain social cohesion, invest in future-proof job opportunities, retrain the affected workers and youth to prepare them for future jobs.

The JTM consists of three pillars:

- JTF ([125]), which contributes to alleviating the socio-economic impacts of the transition to a climate-neutral economy and to support the economic diversification and reconversion of the territories concerned. The actions supported by the JTF should directly contribute to alleviating the impact of the transition by financing the diversification and modernisation of the local economy and by mitigating the negative repercussions on employment.
- A dedicated InvestEU 'Just Transition' scheme to support economically viable investments by private and public sector entities in a wider range of projects. The

([124]) See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en

([125]) Just Transition Fund: https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/just-transition-fund_en

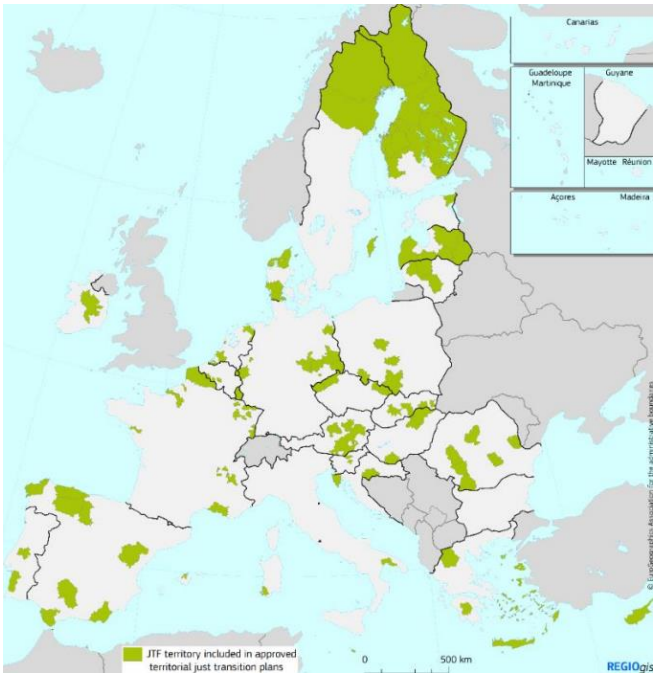
investments should foster economic growth and ultimately economic attractiveness of the Just Transition territories.

- The Public Sector Loan Facility for additional investments to be leveraged by the European Investment Bank (EIB). This helps public sector entities in the most affected regions to meet their development needs in the transition towards a climate-neutral economy.

3.2.2.2 Territorial Just Transition Plans (TJTPs)

The territorial just transition plans provide a novel model for the territorialisation of the climate action, by defining the territories which might receive financing from the JTM. These plans set out the challenges in each territory, as well as the development needs and objectives to be met by 2030. The territories eligible for support by the JTF are published on the Just Transition Platform website with the links to the plans ([126]).

Figure 10: Overview of territories in approved territorial just transition plans (Sept. 2023)



Source: European Commission.

Box: An example of support by the JTF: the decarbonisation of the Swedish industry

The JTF is helping the Swedish industry transition to climate neutrality ([127]), while maintaining competitiveness and sustaining economic and employment levels in the

([126]) Inforegio - Just Transition Fund. https://ec.europa.eu/regional_policy/funding/just-transition-fund/just-transition-platform_en

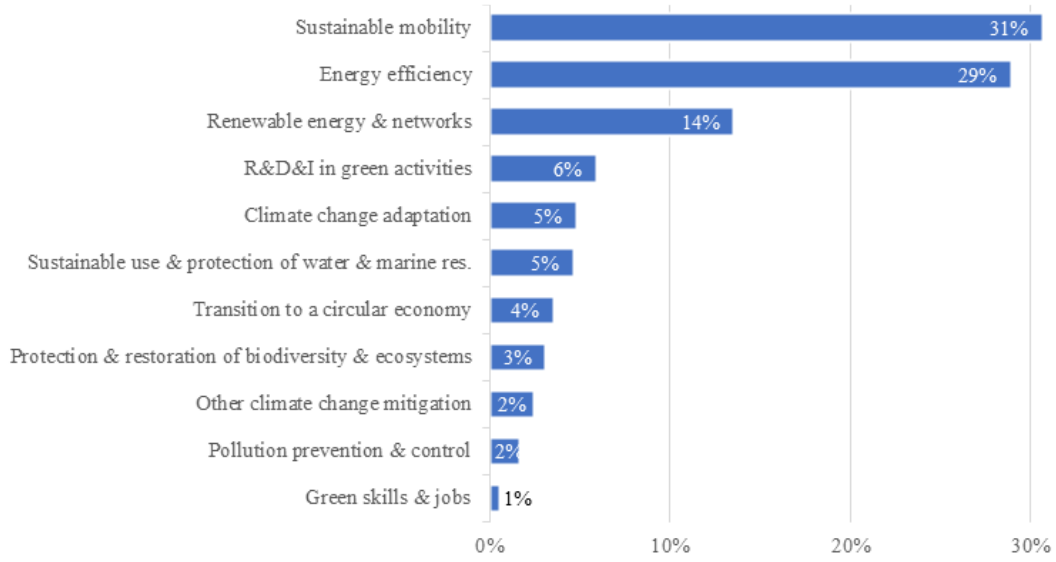
([127]) EU Cohesion policy: €155.7 million climate transition Sweden. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_5316

Norrbotten, Västerbotten and Gotland regions. As industrial emissions account for 32% of Sweden's total greenhouse gas emissions, the transformation of the steel, mineral and metals industry is expected to have important socio-economic impacts. The JTF will help alleviate these impacts by investing EUR 155.7 million in research and innovation and in the retraining and reskilling of workers.

3.2.3 The Recovery and Resilience Facility

The Recovery and Resilience Facility (RRF) will help achieve the EU's targets to reduce net greenhouse gas emissions by at least 55% by 2030 and to reach climate neutrality by 2050. The RRF Regulation provides that the reforms and investments included in each of the recovery and resilience plans must reach targets for climate and digital expenditure. The measures supported by the RRF are contributing to meet the EU's climate ambition by promoting sustainable mobility, increasing energy efficiency, and promoting a higher deployment of renewable energy sources (Figure 11). They will also ensure progress towards climate adaption and other environmental objectives such as reducing air pollution, promoting the circular economy, or restoring and protecting biodiversity.

Figure 11: Breakdown of expenditure supporting the green transition, by policy area



Note: This chart shows a breakdown of the estimated contribution to the policy pillar according to a list of policy areas established by the European Commission. The percentage relates to the overall share of the plan tagged under this policy pillar.

Source: Recovery and Resilience Scoreboard.

The reforms and investments that support climate objectives in Member States' RRPs have exceeded the target of 37% of total allocation set in the RRF Regulation. Total estimated climate expenditure in the adopted plans amounts to EUR 204 billion, which represents about

40% of the total plans' allocation as calculated according to the climate tracking methodology ([128]).

3.2.4 Other EU initiatives

There are several other EU funds, policies, and initiatives that support Member States and their regions with implementing climate policies (see below a non-exhaustive list of such initiatives). Not all these initiatives directly or exclusively target specific EU regions. However, they will all have an impact on climate action in specific regions.

3.2.4.1 Funding

The Modernisation Fund ([129]) is a programme from the European Union to support 10 Member States to meet the 2030 energy targets by helping to modernise energy systems and improve energy efficiency.
The Innovation Fund ([130]) is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies. The Innovation Fund's total funding depends on the carbon price, and it may amount to about €40 billion for 2020-2030 (assuming a carbon price of €75/tCO2). In practice, the Innovation Fund allowances from the EU ETS are being auctioned based on the agreed schedule and the revenues perceived are used to provide support to innovative projects afterwards.
Connecting Europe Facility (CEF) is a key EU funding instrument to deliver the European Green Deal and an important enabler towards the Union's decarbonisation objectives for 2030 and 2050 ([131]). It supports the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy, and digital services.
The InvestEU Programme ([132]) supports sustainable investment, innovation, and job creation in Europe. With the EU budget guarantee provided to International and National promotional banks, the InvestEU programme aims to trigger more than €372 billion in private investments to high EU policy priority areas. Its Advisory Hub will provide advisory support services to regional authorities.

([128]) The RRPs had to specify and justify to what extent each measure contributes fully (100%), partly (40%) or has no impact (0%) to climate objectives, using Annex VI to the RRF Regulation. Combining the coefficients with the cost estimates of each measure allows calculating to what degree the plans contribute to the climate target. Please note that the contribution to the green transition pillar is higher than the contribution to climate objectives as defined in Annex VI of the RRF Regulation, since methodologies differ. The differences arise mainly because all covered measures are considered to contribute with 100% of their estimated cost to the pillar, while some contribute only with 40% of their estimated cost to the climate objectives as defined in Annex VI of the Regulation. In addition, the green transition pillar also includes coefficients for environmental objectives that are wider than climate objectives as per Annex VI of the RRF Regulation.

([129]) See https://modernisationfund.eu/.

([130]) See https://cinea.ec.europa.eu/programmes/innovation-fund_en.

([131]) See https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en.

([132]) See https://investeu.europa.eu/investeu-programme_en.

The EIB ([133]) offers targeted support for projects in less-developed regions, including for green transition projects.

3.2.4.2 Fostering collaboration between regional authorities

Horizon Europe Mission on Cities ([134]) involves local authorities, citizens, businesses, investors as well as regional and national authorities to deliver 100 climate-neutral and smart cities by 2030 and to ensure that these cities act as experimentation and innovation hubs to enable all European cities to follow suit by 2050.
The EU Covenant of Mayors for Climate & Energy ([135]) is an initiative supported by the European Commission that brings together thousands of local governments that want to secure a better future for their citizens. Local governments voluntarily commit to implementing EU climate and energy objectives and the European Green Deal on the ground. The initiative is a first-of-its-kind bottom-up approach to energy and climate action. There are almost 11.000 cities committed to become climate neutral by 2050.
Regions4Climate ([136]) is developing innovative tools and collaborative practices to support European regions and communities in developing and implementing their own resilience plans that not only explicitly address social, environmental, and economic innovations but also inherently consider social equity and social justice concerns associated with resilience building.
The European Climate Pact ([137]) is a movement of people united around a common cause, each taking steps in their own worlds to build a more sustainable Europe. Launched by the European Commission, the Pact is part of the European Green Deal and is helping the EU to meet its goal to become climate-neutral by 2050.

3.2.4.3 Regional State Aid

The European Commission's regional state-aid ([138]) policy supports economic development and employment. The regional aid guidelines set out the rules under which Member States can grant state aid to companies to support investments in new production facilities in the less advantaged regions of Europe or to extend or modernise existing facilities.

3.2.4.4 Technical assistance

The Commission offers technical assistance to Member States and their regions, including through the following measures.

([133]) See https://www.eib.org/en/projects/regions/index.htm.

([134]) See Climate-neutral and smart cities, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en.

([135]) See https://eu-mayors.ec.europa.eu/en/home.

([136]) See Regions4Climate - Building resilient communities, https://regions4climate.eu/.

([137]) See https://climate-pact.europa.eu/index_en.

([138]) See Regional Aid, https://competition-policy.ec.europa.eu/state-aid/legislation/modernisation/regional-aid_en.

The C4T Community of Practice ([139]) is a community-based platform that aims to support EU Member States and regions to make a better use of EU funds for sustainability transitions. C4T engages national, regional, and local cohesion and sustainability transitions practitioners in sharing experience and good practices, creating partnerships and jointly identifying solutions. C4T also provides technical assistance to facilitate the development and/or implementation of sustainability transitions. C4T brings together beneficiaries involved in the implementation of transition measures with support from cohesion policy under Policy Objective 2 'A greener, low-carbon transition towards a net zero carbon economy and resilient Europe'.

EU Technical Support Instrument ([140]) is the EU programme that provides tailor-made technical expertise to EU Member States to design and implement reforms. The support is demand driven and does not require co-financing from Member States.

The policy support facility ([141]) gives Member States and countries associated to Horizon Europe practical support to design, implement and evaluate reforms that enhance the quality of their research and innovation investments, policies, and systems.

The Climate Adaptation Platform for the Alps (CAPA) ([142]) supports decision-makers in Alpine countries, regions, and municipalities in adapting to climate change by giving them access to knowledge resources and information that have been selected by experts based on relevance and usefulness criteria. It offers knowledge products for a broad spectrum of administrative and socio-economic sectors (agriculture, energy, health, water management, spatial planning, etc.). It puts strong emphasis on cross-sectorial aspects of adaptation.

3.2.5 Example of a region that has received support: the Ruhr region

The Ruhr region in North Rhine-Westphalia has traditionally been one of Europe's industrial powerhouses, based on the extraction of coal ([143]). Spanning roughly 2,700 $km^2$the Ruhr Valley lies in the state of North-Rhine Westphalia, made up of 53 cities that came to depend on coal mining when it reached an industrial scale in the 1800s. At their height in the 1950s, the mines employed about 600,000 workers, entwining the region's identity with coal. According to Reitzenstein et al. (2021), Galgoczi (2014), Sheldon et al. (2018), in the Ruhr region in 1957, 70% of the population was employed in coal, iron and steel industries (half in coal mining).

([139]) See Inforegio - Cohesion for Transitions (C4T), https://ec.europa.eu/regional_policy/policy/communities-and-networks/cohesion-4-transition_en.

([140]) See https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/technical-support-instrument/technical-support-instrument-tsi_en.

([141]) See https://ec.europa.eu/research-and-innovation/en/statistics/policy-support-facility.

([142]) See https://climate-adapt.eea.europa.eu/en/metadata/portals/climate-adaptation-platform-for-the-alps-capa#:~:text=The%20platform%20provides%20resources%20about,analytical%20studies%20and%20policy%20reviews).

([143]) See https://economy-finance.ec.europa.eu/system/files/2022-12/dp176_en_green%20transition%20labour.pdf.

Cohesion policy supported many projects in the framework of a long-term strategy aimed at transforming the region, including the restoration of the river system, the construction of a bicycle network, the creation of landscape parks, and the conversion of former steel sites and railroads into lakes and green neighbourhoods. This is embedded in nearly three decades of EU funding to support the structural change of this old industrial region into a modern, green metropolis. This involved structural policies to support the specialization of the region, the development of new universities, infrastructures, in particular in renewable energy, and cultural activities. Several policies contributed to the successful transition in the Ruhr region. These include a consistent engagement of different levels of governments; a strong participation of social partners; targeted public sector investments; institutional cooperation; and effective labour market policies.

Coal mining has now completely disappeared but despite the loss in coal jobs, the overall number of jobs stayed constant. The support provided to the Ruhr region turned it into an exemplary territory for green infrastructures and an attractive area for companies.

In the 2021-2027 period, the Ruhr region is also one of the German territories benefitting from the JTF. The fund will help the region with investments in skills, green innovation, and environmental restoration. This contributes to cushioning the socio-economic impacts of Germany's coal phase-out.

3.3 Lifestyle and individual action

3.3.1 Sustainable lifestyle choices

Individual action is one of the key factors to efficiently mitigate climate change and protect the environment. Household consumption has been associated with up to 72% of global greenhouse gas emissions ([144]), thus changes in individual and household lifestyles have an enormous potential to reduce GHG emissions.

Making more climate-friendly choices on an individual level requires a willingness to adopt new behaviours, but policy makers need to facilitate more climate-friendly lifestyle choices by removing barriers and creating incentives to set up proper framework conditions for new lifestyles ([145]). Examples for an improvement of proper framework conditions for new lifestyles are increasing their availability (e.g., through improved access to public transport), incentivizing their use (e.g. reducing taxes on repair work to increase the longevity of products) or informing individuals about the environmental impact of their choices (e.g., reliable and trustworthy eco-friendly or energy efficiency labels, protection against false green claims, and reliable data on door-to-door transport emissions ([146])).

Some examples for individual action in a non-exhaustive list are:

([144]) Hertwich, E.G., Peters, G.P., 2009. Carbon footprint of nations: A global, trade-linked analysis. Environ. Sci. Technol. 43 (16), 6414–6420.

([145]) Frederiks, E. R., Stenner, K., Hobman, E. V. 'Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour', *Renewable and Sustainable Energy Reviews*, 41, 1385-1394, 2015.

([146]) COM(2023) 441

- Sustainable lifestyle choices: individuals can make choices in their daily lives to reduce their carbon footprint such as reducing waste, consuming more sustainable and sufficient. This includes buying locally and environmentally friendly products and opting for long-lasting products, reducing single-use products, and opting for the reuse of products. Furthermore, citizens can choose a more sufficient lifestyle by buying less and repairing more as part of advanced circular economy practices.

- Sustainable transportation: walking, cycling, or using public transport instead of using a car can significantly reduce carbon emissions. Citizens can also advocate for 'mobility as a service' such as car- and bike-sharing options that aim to share transport modes between individuals and aim for a higher use intensity. An increasing concern on climate change and a shift in the social norm among citizens may incentivize citizens to use less flights in favour of more sustainable transport alternatives, like rail.

- Energy and housing transition: individuals may participate in the transition to renewable energy sources at the individual level through supporting community-based renewable energy projects, the installation of solar panels on their homes, or adopting energy efficiency measures in homes and businesses. This may also include a shift towards reduced floor area and a preference for renovation over new construction.

Results from the public consultation show that large parts of EU citizens are in general willing to adopt new lifestyles and to adopt a variety of individual actions to reduce their own carbon footprint (82%). The highest support was expressed for individual action towards a more circular economy such as repairing or reusing goods (88%) ([147]) and reducing wasteful consumption through the use of long-lasting appliances, clothing and other products (89%). High support was also expressed for a dietary change towards more climate-friendly diets (85%) and for the use of climate-friendly labels (82%) and the acceptance of renewable energy infrastructure in one's municipality (80%).

However, it appears these changes in lifestyles and consumption patterns need support from policy makers ([148]), for example through a change in the choice architecture, incentives, available mobility alternatives, or urban planning ([149]). EU citizens indicated in the public consultation that number of policies would help them adopting a more climate-friendly lifestyle ([150]). Citizens indicated as most helpful, if prices of goods and services would reflect their climate impact to a better degree (Avg. = 4.43), the facilitation of personal investments in climate friendly solutions (Avg. = 4.27) and ensuring that the most vulnerable in society have access to climate-friendly products and services (Avg. = 4.19). On general, all types of

([147]) Participants in the Public Consultation questionnaire were asked which of the listed personal actions they would be willing to take to fight climate change. Percentages indicate EU citizens willingness to take these actions.

([148]) Scientific Advice Mechanism (SAM), 'Towards Sustainable Food Consumption', *Group of Chief Scientific Advisors Scientific Opinion*, No.14, 2023.

([149]) IPCC AR6 WG III, Summary for Policy Makers.

([150]) EU citizens indicated on a scale from 1 (not helpful) to 5 (very helpful) how much the following proposals would help them to reduce their personal climate footprint. Numbers in brackets show the mean value. The closer a mean value to 5 the more helpful it is assessed on average.

support to increase information, raising awareness and facilitating the access to climate-friendly solutions was rated positively (Avg. = 3.77 to 4.04).

3.3.2 Sustainable food consumption

A particularly relevant field for changing lifestyles is food consumption. With regard to demand-sided mitigation potentials associated with individual choices, behaviour and lifestyle changes, the IPCC has identified nutrition as the area with the biggest potential to reduce emissions ([151]). Also, throughout the EU, food has both emerged as the consumption area of individuals with the highest environmental and climate impact ([152]), as well as a field that shows a notably high agreement for willingness to change throughout EU citizens. As an example, a high share of EU citizens indicated their inclination in the public consultation to eat food with a lower climate impact, such as plant-based, local, or sustainably produced food (85%). When looking more closely on food consumption habits of EU citizens, animal-based products (i.e., meat, dairy products, and eggs) stick out since they make up only about one quarter of the total amount of food consumed while contributing to more than 60% of the climate change impacts from food ([153]). This is due to the lower efficiency from an input/output perspective of animal-based products compared to other food products ([154]).

A voluntary change in food diets in societies is not uncommon. Food diets can change in a comparably short time and recent history underlines the potential for widespread changes, including on more diverse and healthier diets ([155]). Moreover low-meat diets increase in EU countries as some recent examples show. The number of products being labelled as vegetarian, or vegan has increased significantly ([156]) and with-it meat-alternatives in supermarkets. Meat consumption per capita in Germany declined in 5 years until 2022 by 13% for beef and cattle and by 20% for pork and is now at the lowest total consumption level since 1989. ([157]) One of the main reasons is that meat alternatives become increasingly available and plant-based diets increasingly popular among the population. On EU level, a

([151]) IPCC AR6 WG III, Summary for Policy Makers Figure SPM.6

([152]) Five areas of consumption have been assessed: food, mobility, housing, household goods and appliances. Food makes up 48% of the consumption footprint on environmental impacts and 38% of the consumption footprint on climate change for an average EU citizen in 2021. See Sanyé Mengual E, Sala S, 'Consumption Footprint and Domestic Footprint: Assessing the environmental impacts of EU consumption and production. Life cycle assessment to support the European Green Deal', *Publications Office of the European Union*, 2023.

([153]) European Commission, Joint Research Centre, Sanyé Mengual, E., Sala, S., Consumption footprint and domestic footprint – Assessing the environmental impacts of EU consumption and production – Life cycle assessment to support the European Green Deal, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2760/218540

([154]) Capone, R., et al., 'Food System Sustainability and Food Security: Connecting the Dots.', *Journal of Food Security*, 2, 1, 13-22, 2014.

([155]) Vermeulen, S.J., et al., 'Changing diets and the transformation of the global food system', *Ann. N.Y. Acad. Sci.*, 1478, 3-17, 2020.

([156]) FReSH insights report, 'Consumption behavior and trends: understanding the shift required towards healthy, sustainable, and enjoyable diets', *Geneva: World Business Council for Sustainable Development*, 2018.

([157]) BLE (2023), Press Release: Fleischverzehr 2022 auf Tiefstand.

slight general trend of dietary change is also visible. In the last five years before 2023, per capita consumption of meat declined by nearly 2% and consumption of fresh dairy products by 6%, a trend that is generally expected to continue in the future. This is in line with results from the public consultation.

Furthermore, the European Commission projects a shift from red meat to white meat ([158]), which is associated with lower GHG emissions. The current changes in dietary preferences result from health considerations and consumer concerns about climate, animal welfare and environment. The increasing availability of protein alternatives also play a role in dietary changes. Importantly these meat alternatives can be vegetables, fish as well as artificial meat. However, to obtain a sustainable and healthy diet simply replacing meat with fish comes with its own concerns. Overexploitation is already impacting fish stocks, and more importantly Europeans consumption of fish should with regard to healthy diets not drastically increase. ([159])

4 HEALTHY NATURE AND SUSTAINABLE CIRCULAR BIOECONOMY

Managing the land more sustainably is not only important for the achievement of climate targets but is also essential to ensure that the land sector can continue to provide food, biomass, freshwater and ecosystem services for generations to come, in the context of increasing global warming.

4.1 Current policy framework on carbon removals and agriculture GHGs

Management of land and biological resources within ecologic boundaries is one of the dimensions of bioeconomy policies. There are challenges to be addressed, such as the increased pressure on land for climate mitigation and adaptation and nature protection while supplying an increasing demand of biomass for food, materials (e.g., bioplastics, long-lasting wood products) and bioenergy. To ensure environmental integrity, there is a need to understand the status and resilience of terrestrial and marine ecosystems, including their services and related socio-economic costs and benefits.

The current policy framework addresses the climate change mitigation potential of sustainable land management practices through national targets. These targets are characterised by a separation between the agriculture sector and the Land Use, Land Use Change and Forestry (LULUCF) sector. The agriculture sector, which corresponds to non-CO2 emissions mainly related to the raising of livestock, the use of fertilisers and the management of manure, is not governed by a specific sectoral target; its emissions are instead included in the national emission targets under the Effort Sharing Regulation together with other sectors. Recently, with the Fit-for-55 revision, Effort Sharing targets underwent a significant increase in ambition: emissions in these sectors will have to be cut by 40% (up from -29%) by 2030 as

([158]) European Commission, DG Agriculture and Rural Development, 'EU agricultural outlook for markets, income and environment, 2022-2032', Brussels, 2022.

([159]) Willet et al., 'Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems', Lancet, 2019.

compared to 2005 emission levels. The LULUCF sector mainly corresponds to CO2 fluxes (i.e., emissions and removals) between soils, biomass and the atmosphere; with the LULUCF Regulation, the EU has recently agreed on a new target to achieve 310 MtCO2 of net removals in 2030, and this target is distributed across Member States through binding national targets.

National targets can trickle down to the individual land managers through public-based or market-based incentives to take climate action. The Common Agricultural Policy (2023-2027 period), which includes several climate-related obligations and incentives, represents an important budget envelope that Member States can use to support farmers in adopting more sustainable land management practices and to help to achieve those national climate targets. Every EU Member State describes in a national CAP Strategic Plan how it intends to design CAP requirements and interventions to contribute (among others) to the objective of climate mitigation and adaptation. Under the enhanced conditionality, by 2025, land management practices minimising or avoiding carbon release will be applied on agricultural wetlands and peatlands in all EU countries. Member States are planning to support carbon removals and protection, and reduced methane and nitrous oxide from better use, management, and application of fertilisers on 35% of the EU's utilized agricultural area with practices beyond conditionality. Eco-schemes, agro-environment climate commitments and investments are broadly used to support practices such as agroforestry, afforestation, soil cover and reduced tillage, grassland protection, and management of peatland. Investments in improved manure storage and management, low emission slurry spreading, and anaerobic digesters have been planned to address livestock-related emissions, with some Member States planning other practices such as outdoor grazing, improvement of feeding plans and feed additives. Over 600 000 ha are planned to be supported for afforestation, agroforestry, restoration, and creation of landscape features. A specific article in the CAP Strategic Plan Regulation requires Member States to assess whether their CAP Strategic Plan should be amended according to recent agreements on more ambitious EU climate targets for the LULUCF and the Effort Sharing sectors.

The upcoming proposal for a legislative framework for sustainable food systems (FSFS) is one of the flagship initiatives of the Farm to Fork Strategy ([160]). It aims to accelerate and make the transition to sustainable food systems easier while mainstreaming sustainability in all food-related policies and strengthening the resilience of food systems. As a result of a more sustainable food system emissions in the agriculture sector as well as in food processing industry should decline. One important input to the proposal is the independent expert report ([161]), which highlights the need to decrease the environmental impacts from food production, reduce food waste and loss, and stimulate dietary changes towards healthier and less resource-intensive diets through a combination of various policy measures.

([160]) COM(2020) 381 final

([161]) European Commission, Directorate-General for Research and Innovation, Group of Chief Scientific Advisors, Towards a sustainable food system – Moving from food as a commodity to food as more of a common good – Independent expert report, Publications Office, 2020, https://data.europa.eu/doi/10.2777/282386.

Carbon farming is a business model whereby land managers are rewarded for providing carbon sequestration. To enable this approach, the Commission has proposed an EU-wide voluntary framework for the certification of carbon removals, as a tool to reliably monitor, report, and verify (MRV) high-quality carbon removals that deliver unambiguous climate benefits and have the potential to also deliver on biodiversity and restoration of ecosystem services. The proposed framework can create innovative business opportunities for land managers, but only if the resulting carbon removals are credible and trustworthy, so that they can attract private and public financial support. Carbon farming will provide farmers, foresters, and other land managers with an additional source of income in exchange for storing carbon in the soil, trees, shrubs, wetlands, and peatlands. The proposal requires that carbon farming does not harm other environmental objectives and encourages the delivery of environmental co-benefits, such as on biodiversity and the provision of ecosystem services. Once the Regulation enters into force, the EU-level quality criteria and verification rules will be further operationalised through technical certification methodologies adopted by the Commission, in the forms of Delegated Acts, tailored to the different types of carbon removal activities. To this end, the Commission has established an Expert Group on Carbon Removals, which will assist the Commission to map out best practices on certification methodologies for carbon removals, ensuring full and close involvement of civil society.

4.2 Reducing GHG emissions from the land sector

4.2.1 Agricultural emissions

GHGs emitted from agricultural activities include non-CO2 emissions such as methane (CH4) and nitrous oxide (N2O). Most of these non-CO2 emissions come from the livestock digestion process, the management of manure, and the use of fertilisers. Over the last decade, the agricultural sector has not reduced its absolute GHG emissions, although increasing production efficiencies have led to reduced GHG emissions per unit produced. Practices to reduce methane emissions from enteric fermentation should focus on breeding to reduce methane intensity and improve animal health and fertility, optimising feed management and use of pastures/grazing, and using appropriate feed additives. The best way to reduce fertiliser emissions is to optimise the fertilisation process, mainly through a precise selection of the fertiliser dose in space and time (precision agriculture); other options include management practices beneficial for the nutrient cycle and soil, such as using legume crops or pastures in rotation instead of nitrogen fertiliser, catch and cover crops or practicing minimum tillage for cropping. Techniques to decrease manure-related emissions are cooling slurry, slurry acidification, covering manure and slurry stores, anaerobic digestion with biogas recovery for renewable energy, improvements in the housing of livestock.

4.2.2 Halt and reverse the loss of soil carbon

Besides creating non-CO2 emissions, agricultural activities may cause a loss of carbon from soils due to the use of land as cropland and grassland. Overall, EU soils are losing carbon. In 2019, Member States reported net emissions of 108 MtCO2 from organic soil and net removals of 44 MtCO2 from mineral soil. The IPCC ([162]) cites afforestation, enhanced

([162]) IPCC AR6 WG III Full Report, 2022, Mitigation of Climate Change

sequestration in cropland and grasslands, use of biochar, peatland and costal wetland restoration and agroforestry as mitigation options with a positive impact on soil carbon storage. These nature-based removals can provide important co-benefits such as better resilience to climate change (in particular, droughts and floods) improved soil quality, increased crop yields, improved biodiversity and reduced N_2O and CH_4 emissions, when implemented properly ([163]). However, the solutions can also lead to increased competition for land and negative impacts on food production (with consequent risks for food security) and on biodiversity, as well as increase N_2O and CH_4 emissions and the risk of subsequent loss of sequestered carbon due to climate change and future disturbances ([164]).

4.2.3 Increase forest carbon sinks

The capacity of EU forests to sequester carbon has been rapidly declining: EU forests only absorbed 256 MtCO2 in 2020, down from 320 MtCO2 in 2016 and 357 MtCO2 in 2013. The decline in the forest sink can be attributed to an increase in wood demand, an increasing share of forests reaching harvest maturity, and an increase in natural disturbances ([165]). To reverse this trend, it is important to consider mitigation options in the LULUCF sector such as improved forest management, afforestation, rewetting, and emission reduction on agricultural land, while ensuring that any new forest is composed of mixes of species that can be resilient in the face of climate change.

4.3 Preserve and restore biodiverse ecosystems

Climate change and biodiversity loss are two of the most pressing issues of the Anthropocene. The rapid decline of biodiversity and changes in climate are interdependent: they share underlying direct and indirect drivers, they interact and are mutually reinforcing. Furthermore, both can have cascading and complex effects that impact people's quality of life and compromise societal goals.

Climate change is one of the five main drivers of global biodiversity loss, with change of land and sea use, direct exploitation, pollution, and invasive alien species ([166]). At the same time, biodiversity is an essential ally to fight climate change. Healthy ecosystems deliver services that are key for climate mitigation and adaptation (protection against floods, droughts, urban heat and desertification, water retention, air, and water purification). However, it should be noted that climate change is not the only factor threatening ecosystems. For instance, certain forestry practices may be beneficial to store carbon but can exacerbate the risks of extreme weather events, such as forest fires or plagues ([167]). More biodiverse forests are more resilient,

([163]) European Environment Agency, Briefing no. 14/2022, Soil carbon, 2022. doi: 10.2800/822511

([164]) IPCC, 2022, IPCC 6 Assessment Report, WG3, Chapter 12

([165]) SWD(2021) 609 final

([166]) IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Version 1). Zenodo. https://doi.org/10.5281/zenodo.6417333

([167]) Robbie S.H. Johnson, Younes Alila (2023). Nonstationary stochastic paired watershed approach: Investigating forest harvesting effects on floods in two large, nested, and snow-dominated watersheds in British Columbia, Canada, Journal of Hydrology, Volume 625, Part A, 129970, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2023.129970.

multifunctional, productive, deliver more ecosystem services and even capture more carbon ([168]) ([169]).

Nature-based solutions are actions to protect, conserve, restore, sustainably use, and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience, and biodiversity benefits ([170]). In that sense, nature-based solutions not only help to mitigate climate change but also can directly provide additional benefits to biodiversity and people ([171]). Examples of concrete nature-based solutions are conserving forests and ecosystems, and ecosystem restoration, reforestation, and afforestation. The IPCC highlights that nature-based solutions have greater likelihood of being successful than other mitigation measures on agriculture, forestry and land-use, whose rapid deployment is essential to reach the 1.5°C target ([172]).Biodiversity-friendly climate strategies, far from leading to additional costs, are often a more economical approach than mitigation that does not take environmental protection into account ([173]), thanks to the synergies generated and the socio-economic costs avoided from degraded ecosystems ([174]).

The EU has launched several initiatives to preserve and restore biodiverse ecosystems. The EU Biodiversity Strategy for 2030 ([175]) is a part of the European Green Deal and focuses on halting biodiversity loss, protect areas at land and at sea, restoring degraded ecosystems, and introduce measures to enable the necessary transformative changes as well as to tackle the global biodiversity challenge. The EU Forest Strategy for 2030 ([176]) builds on the EU biodiversity strategy for 2030 and sets a vision and concrete actions to improve the quantity and quality of EU forests and strengthen their protection, restoration, and resilience. It aims to restore and enlarge the EU's forests to combat climate change but also to reverse biodiversity loss and ensure resilient and multifunctional forest ecosystems. The strategy is designed to

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([168]) Lewis, S.L., Wheeler, Ch.E.; Mitchard, E.T.A. and Kock, A. (2019). "Restoring natural forests is the best way to remove atmospheric carbon, in *Nature*, 68, 25-28, https://doi.org/10.1038/d41586-019-01026-8.

([169]) Pukkala, T. (2016). Which type of forest management provides most ecosystem services? Forest Ecosystems *3*, 1-16.

([170]) UNEA (2022). Nature-based solutions for supporting sustainable development. UNEP/EA.5/Res.5. Available at: https://wedocs.unep.org/20.500.11822/39864.

([171]) Seddon, N. et al. (2020). 'Global recognition of the importance of nature-based solutions to the impacts of climate change', Global Sustainability, 3, p. e15. Available at: https://doi.org/10.1017/sus.2020.8.

([172]) IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: https://www.ipcc.ch/report/ar6/wg3/.

([173]) Strassburg, B.B.N. et al. (2018). 'Strategic approaches to restoring ecosystems can triple conservation gains and halve costs', Nature Ecology & Evolution, 3(1), pp. 62–70. Available at: https://doi.org/10.1038/s41559-018-0743-8.

([174]) Pörtner, H.-O. et al. (2023) 'Overcoming the coupled climate and biodiversity crises and their societal impacts', Science, 380(6642), p. eabl4881. Available at: https://doi.org/10.1126/science.abl4881

([175]) COM(2020) 380 final

([176]) COM(2021) 572 final

address various challenges and opportunities related to forests, including environmental, economic, and social aspects. Part of the strategy therefore is to promote the sustainable forest bioeconomy for long-lived wood products, ensure the sustainable use of wood-based resources for bioenergy and the re- and afforestation of biodiverse forests.

The proposal for a Directive on Soil Monitoring and Resilience ([177]) is also part of the EU Biodiversity Strategy for 2030 and was proposed to ensure a level playing field and a high level of environmental and health protection. More specifically, the proposed Soil Monitoring Law aims to address key soil threats in the EU, such as erosion, floods and landslides, loss of soil organic matter, salinisation, contamination, compaction, sealing, as well as loss of soil biodiversity.

4.4 Investment needs for biodiversity and a sustainable and circular bioeconomy

The Bioeconomyy Strategy Progress Report 2022 ([178]) which was delivered in response to the updated EU bioeconomy strategy ([179]) emphasizes that EUR 2.7 billion of private investment has been unlocked to bio-based industries, which helped to develop new technologies for sustainable and circular bio-based value chains. However, pressure on ecosystems is increasing and more action is needed. Most importantly, future bioeconomy needs to develop solutions on how to better manage land and biomass demands ([180]) and make consumption patterns more sustainable.

Annual financing need for biodiversity protection and restoration reaches up to EUR 48 billion per year to 2030, with a foreseen gap of around EUR 19 billion, with implications beyond 2030. As part of this, nature restoration investments of EUR 8-15 billion per year, need to be maintained up to 2050 ([181]). These investments are also necessary to increase the carbon removal capacity and the resilience of ecosystems.

4.4.1 Towards biodiversity credits and payment for ecosystem services (PES)

The Kunming-Montreal Global Biodiversity Framework (GBF) commits parties to increase financial resources for biodiversity ([182]) for example through stimulating innovative schemes

([177]) COM(2023) 416 final

([178]) European Commission, Directorate-General for Research and Innovation, European bioeconomy policy – Stocktaking and future developments – Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/997651.

([179]) COM/2018/673 final

([180]) See for instance JRC, 'Biomass production, supply, uses and flows in the European Union', *JRC Science for policy report*, 2023.

([181]) European Commission, Directorate-General for Environment, Nesbit, M., Whiteoak, K., Underwood, E. et al., Biodiversity financing and tracking – Final report, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2779/950856.

([182]) GBF Target 19 'Financial resources increased to $ 200 billion per year, including $ 30 billion through international finance'; https://www.cbd.int/gbf/targets/19/.

such as payment for ecosystem services (PES), green bonds, biodiversity offsets and credits, and benefit-sharing mechanisms, with environmental and social safeguards.

Payment for ecosystem services (PES) ([183]) represent a policy instrument and describe incentives provided to landowners, farmers, or communities in exchange for managing their land or natural resources in ways that benefit the natural ecosystems and its respective services. Ecosystem services are the various benefits that humans receive from natural ecosystems, including clean water, air purification, soil fertility, pollination, and climate regulation. PES has received wide attention among scientists, governments, and institutions, and have been implemented at local, national, and international levels ([184]). PES programmes around the globe have already generated annual payments over US$36 billion by 2018 ([185]) financing services such as providing water quality and quantity, biodiversity and habitat conversation, pollination services, but as well climate change mitigation through forests and other ecosystems. In a PES scheme dedicated to climate mitigation, owners of land that hosts ecosystems such forests, grasslands, and wetlands but also agroecosystems would receive a premium for carbon sequestration and long-term carbon storage. The payments are either user-financed (direct beneficiaries of ecosystem services), government-financed, or compliance-based (parties facing regulatory obligations paying to satisfy their mitigation requirements such as the EU ETS).

Biodiversity credits is a more specific policy instrument designed specifically for biodiversity. The credits are tradeable units of biodiversity, which can be bought by companies to measure milestones towards becoming nature positive. They can be self-standing or complement voluntary carbon credits. Biodiversity credits represent improvements in biodiversity, while biodiversity offsets are measurable conservation outcomes designed to compensate for adverse impacts of projects. The credits may become an emerging instrument to mobilize financial resources toward nature-positive outcomes and are generating interest among many governments, financial entities, and stakeholders at both global and European level. While biodiversity credits are certainly not a panacea to close the biodiversity finance, they can provide a sizable contribution.

Work is ongoing internationally to define and develop instruments for resource mobilisation in favour of biodiversity. In this context, biodiversity credits and related tools could help to address the concerns raised by countries with high forest cover and low levels of deforestation, such as Gabon and Guiana, which are calling for more international funding earmarked for the conservation and protection of tropical forests. It is important to offer

([183]) Sattler, Claudia, and Bettina Matzdorf. "PES in a nutshell: From definitions and origins to PES in practice—Approaches, design process and innovative aspects." Ecosystem services 6 (2013): 2-11.

([184]) China has implemented large-scale PES programs, particularly for watershed protection, reducing erosion and reforestation. Mexico has established PES programs to protect forests and watersheds. The UN's Reducing Emissions from Deforestation and Forest Degradation (REDD+) program involves payments for conserving forests and reducing carbon emissions. The United States pay alndowners and farmers for watershed, biodiversity protection and the control of soil erosion.

([185]) Salzman, J., Bennett, G., Carroll, N., Goldstein, A. and Jenkins, M. 'The global status and trends of Payments for Ecosystem Services', *Nature Sustainability*, 1(3), pp.136-144, 2018.

incentives to these countries to avoid deforestation and preserve their forests. At the same time biodiversity credits, self-standing or part of voluntary carbon removals credits, must be reliable, measurable and guarantee high-quality (including additionality, long-term duration and sustainability), avoiding greenwashing. At this stage, there are several voluntary schemes internationally, but without common methodologies and supervision. The Commission is reflecting on how to address this issue and exploit the potential of biodiversity credits.

There are however other market-based instruments to support biodiversity: taxation (based, for instance, on the "polluter pays principle") and subsidies ([186]). The advances in cost-benefit analysis methodologies, which increasingly include environment-related impacts and a long-term perspective, represent an opportunity for further biodiversity and climate friendly investments, such as nature-based solutions. The European Investment Bank (EIB) provides good examples about how these methodologies and approaches are already implemented ([187]).

([186]) Romain Pirard, 2012, Market-based instruments for biodiversity and ecosystem services: A lexicon, Environmental Science & Policy, Volumes 19–20, Pages 59-68, ISSN 1462-9011, https://doi.org/10.1016/j.envsci.2012.02.001.

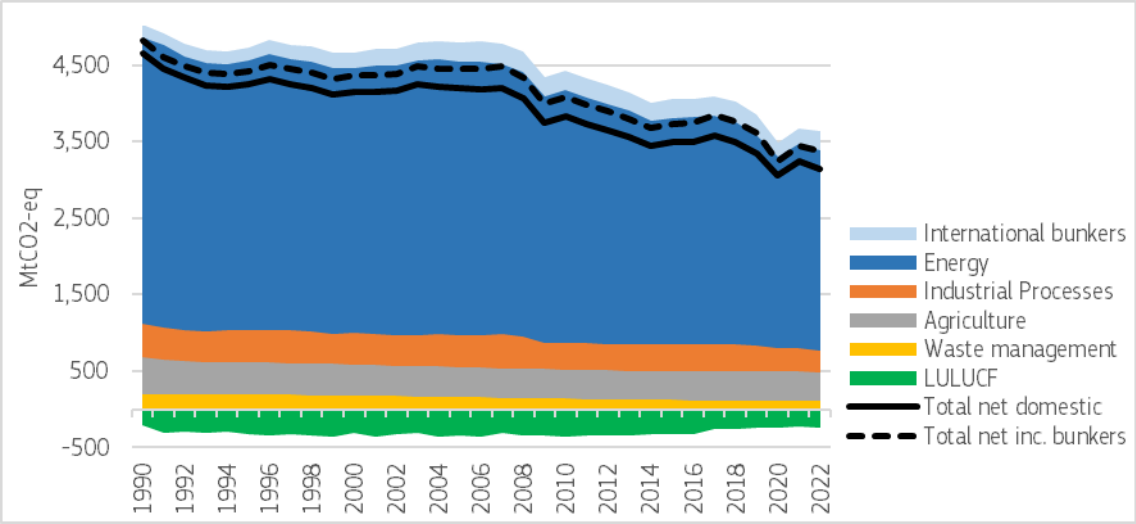
([187]) The EIB partnered with the NBI Global Resource Centre of IISD and provided funding for project preparation activities and will probably provide financing for implementation. The EIB used these results to understand the value of NBS compared to grey infrastructure, particularly regarding environmental impacts, such as reduced erosion, carbon storage, and improved habitat quality/biodiversity.

ANNEX 10: State of play of GHG emissions and the energy system

1 TOTAL GHG EMISSIONS IN THE EU

After the 2021 strong rebound in greenhouse gas (GHG) emissions following the unprecedented fall in 2020 due to the COVID-19 pandemic, EU emissions in 2022 are expected to be back in line with its 30-years descending trend. According to provisional data, total EU domestic GHG emissions (i.e., excluding LULUCF and international aviation) decreased by 2.4% in 2022 compared to 2021, whilst EU GDP grew by 3.5% in the same year. This translates into a reduction in GHG emissions of 30.4% compared to the 1990 base year (or 29% when international aviation is included). Over the same period, there is an approximated increase in reported GHG net removals from land use, land use change, and forestry (LULUCF) of 14 million tonnes of CO2 equivalent compared to 2021([188]). As a result, net GHG emissions for 2022 (i.e., including LULUCF) are expected to be 32.5% below the 1990 level (or 31.1% when international aviation is included).

Figure 12: Historical EU GHG emissions



Source: EEA GHG data viewer (extracted 20/6/2023).

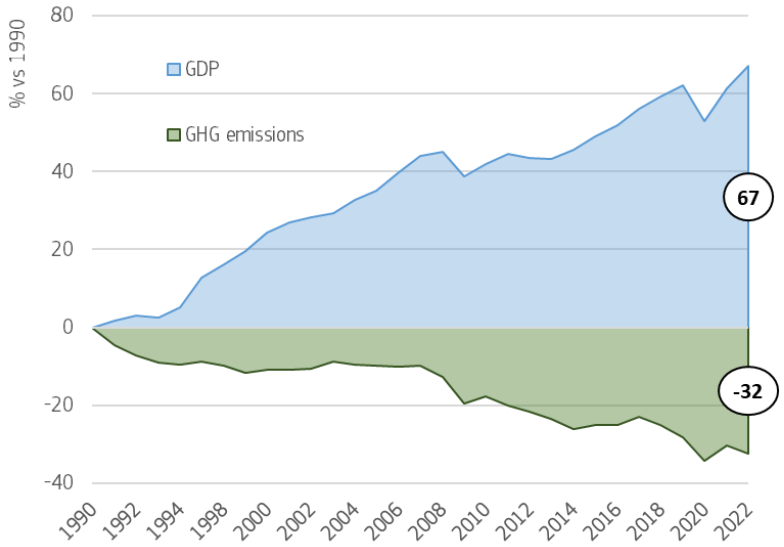
Emission reductions in the last three decades (1990-2021) were significant in the energy industry (e.g., electricity and heat production, -42%), in the manufacturing industry (e.g., iron and steel production, -48%) and in the industrial processes and product use industries (e.g., chemical industry, -65%; metal industry, -44%). Conversely, emissions in the transport sector have increased, especially in road transportation (+16%) although they have been slightly decreasing since 2010. While the agriculture sector has reduced emissions over 1990-2010 (by 22%), emissions since have stabilized or even very slightly increased. Finally, natural CO_2

[188] Approximated 2022 data could suggest a break to the declining trend in the LULUCF sink observed in recent years. However, the assessment takes into consideration the large uncertainty of these data and as it will possibly be subject to revisions.

sink role of land use, land use change, and forestry sector (LULUCF) has declined at a worrying speed in the last decade, getting back to close to the 1990 level.

Policies promoting more efficient energy use, a growing deployment of renewable energy supply and the use of less carbon intensive fossil fuels have played a key role in driving the decarbonisation process so far. This has allowed continued decoupling of emissions and economic growth, with the GHG emission intensity of GDP falling to 229 gCO2-eq/EUR in 2022, less than half the 1990 level.

Figure 13: GHG emissions and GDP development in the EU (1990 = 100)



Source: 2023 GHG EEA inventory data, AMECO and WB ([189]).

2 EMISSIONS UNDER THE EMISSION TRADING SYSTEM

By 2022, the EU ETS had helped drive down emissions from power and industry installations by 37.3% compared to 2005 levels.

Overall EU ETS emissions in 2022 decreased by 0.2% compared to the previous year. ([190]) This reflects a slight decrease in emissions from power and industry installations and a continued rebound in emissions from aviation after the COVID-19 pandemic. Looking to before COVID-19, however, emissions have remained on the decline. In 2022, emissions were around 8% lower than in 2019.

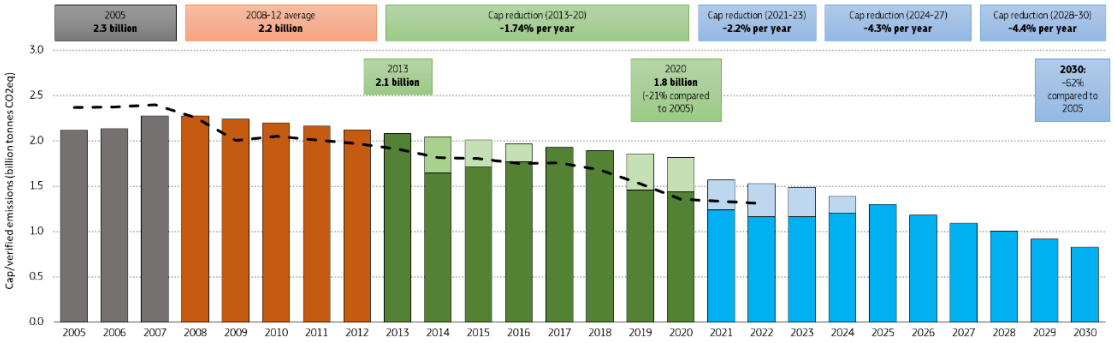
Emissions from the energy sector and manufacturing decreased slightly by 1.8% compared to 2021, partially as result of the energy crisis and its impacts. EU verified emissions from

([189]) 2022 GHG data from approximated GHG EEA inventory estimates. 1995-2022 GDP from AMECO (6-DOMESTIC PRODUCT – 6.1 GROSS DOMESTIC PRODUCT – GDP, at constant prices (OVGD)) and 1990-1994 derived from WB (NY.GDP.MKTP.KD | GDP constant 2015 US$) with growth rate applied to AMECO 1995.

([190]) Based on data from the EU Registry as of 30 June 2023.

aircraft operators increased significantly, by 75% compared to 2021, reflecting a continued rebound of air traffic.

Figure 14: Historical evolution of ETS emissions



Note: Verified ETS emissions 2005-2022, Member States projections with existing measures 2021-2030, ETS cap phases 2, 3 and 4, and accumulated surplus of ETS allowances 2008-2021; including UK (Northern Ireland), Norway and Iceland; NB: adjusted for cap phase 4. ([191]) Legend: bars (cap), light shade bars in 2014-16 (allowances backloaded in phase 3), light shade bars since 2019 (feeds of allowances to the Market Stability Reserve), dash line (verified emissions).

Source: Climate Action Progress Report 2023.

3 EMISSIONS UNDER THE EFFORT SHARING LEGISLATION

The Effort Sharing legislation covers emissions from domestic transport (excluding CO2 emissions from aviation), buildings, agriculture, small industry, and waste which account for around 60% of total domestic EU emissions. The Effort Sharing legislation sets binding national targets to reduce emissions in these sectors compared to 2005 levels, under the Effort Sharing Decision (ESD) ([192]) for the period 2013-2020 and under the Effort Sharing Regulation (ESR) ([193]) for the period 2021 to 2030.

In the period 2013 to 2020 all Member States met their effort sharing obligations under the ESD in every year. The EU overachieved its 2020 emission reductions target by more than six percentage points. EU-27 emissions covered by the ESD were 16.3% lower in 2020 than they were in 2005. Compared to 2013, the EU-27 emissions were 7.2% lower in 2020. 2020 was the last year covered by the ESD. Member States could not carry-over (bank) AEAs for use in future years under the ESR.

Based on approximated data, emissions from the effort sharing sectors in 2022 were 3% lower than in 2021. It followed the rebound of emissions in 2021, after the pandemic. The reduction

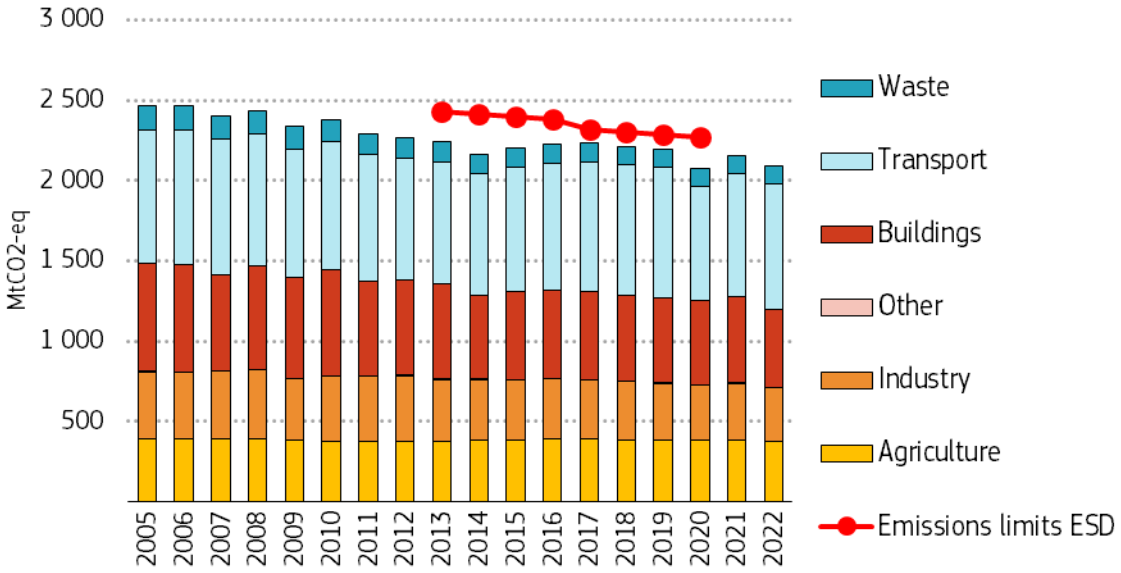
([191]) Emissions cap in the EU ETS (considering the 2023 revision of the ETS Directive, i.e. rebasing in 2024 and 2026, inclusion of the maritime transport sector in 2024, and the linear reduction factor of 4.3% in 2024-27 and of 4.4% from 2028), compared with verified emissions. Aviation is not included. Due to scope changes, 2005-7 figures are not directly comparable to the latest.

([192]) Decision No 406/2009/EC of 23 April 2009

([193]) Regulation (EU) 2018/842 of 30 May 2018, as amended by Regulation (EU) 2023/857 of 19 April 2023

in emissions resulted in particular from the buildings sector which showed an emission decrease of more than 9% compared to 2021. Small industry showed the second largest emission reduction with a decrease of almost 6% compared to 2021. The transport sector is the largest sector under the ESR, accounting for over one third of total effort sharing emissions, and the only one that saw its emissions increase, by over 2% from 2021 to 2022.

Figure 15: Historical evolution of GHG from ESR sectors



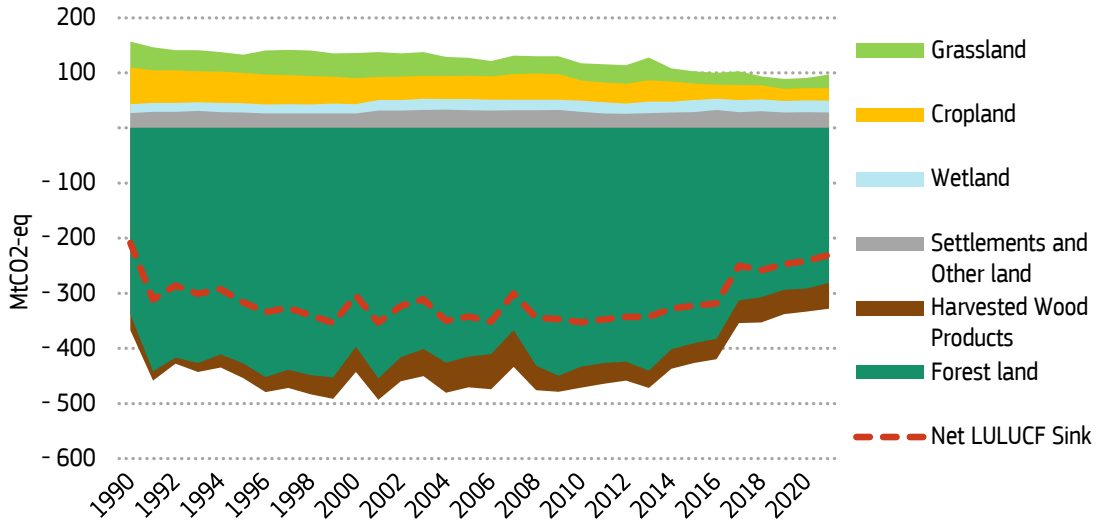
Note: From GHG inventory data (2005-2021) and approximated GHG inventory data (2022) as reported by Member States under Regulation (EU) 2018/1999, compiled and checked by the EEA. The ESD AEAs are expressed in GWP AR4, all other numbers are in GWP AR5. Figures include EU-27 only.

Source: EEA.

4 EMISSIONS UNDER THE LULUCF REGULATION

On EU level, the LULUCF sector absorbs more greenhouse gases than it emits, making it a net carbon sink and thereby contributing to achieving the commitment. Nevertheless, carbon removals have significantly decreased in recent years, and the land sink function declined at a worrying speed in the last decade. The decreasing trend is mainly due to a decrease in removals by an increase in harvest rates and to a limited extent, caused by reduced carbon sequestration in ageing forests across certain areas. The increasing frequency of natural disturbances such as windstorms, forest fires, and droughts introduces inter-annual variations and impacts long-term trends (see Figure 16).

Figure 16: Historical evolution of GHG from LULUCF



Note: Gridded line shows the net LULUCF net removals.

Source: UNFCCC 2023.

5 RENEWABLES DEPLOYMENT UNDER THE RENEWABLE ENERGY DIRECTIVE

The Renewable Energy Directive is the legal framework for the development of clean energy across all sectors of the EU economy, supporting cooperation between EU countries towards this goal. The Renewable Energy Directive (2009/28/EC) was adopted in 2009 and set an EU target of 20% renewables by 2020 and national binding targets.

Since that, the share of renewable energy sources in EU energy consumption has increased from 12.5% in 2010 to 21.8% in 2021.

Given the need to speed up the EU's clean energy transition, the Directive EU/2018/2001 was revised and entered into force in 2018. It sets an overall European renewable energy target of 32% by 2030 and includes rules to ensure the uptake of renewables in the transport sector and in heating and cooling. The directive sets common principles and rules for renewable energy support schemes, sustainability criteria for biomass and the right to produce and consume renewable energy and to establish renewable energy communities. It also establishes rules to remove barriers, stimulate investments and drive cost reductions in renewable energy technologies and empowers citizens and businesses to participate in the clean energy transformation.

In July 2021, the Commission proposed another revision of the directive, raising the 2030 target to 40% (up from 32%), as part of the 'Fit for 55' package.

Less than a year later, following Russia's military aggression against Ukraine and the need to accelerate the EU's independence from fossil fuels, the Commission proposed to further increase the target to 45% by 2030.

On 30 March 2023, a provisional agreement was reached for a binding target of at least 42.5% by 2030, but aiming for 45%. Building on the 2009 and 2018 directives, the current proposal introduces stronger measures to ensure that all possibilities for the further development and uptake of renewables are fully utilized. This will be key to achieving the EU's objective of

climate neutrality by 2050. To support renewables uptake in transport and heating and cooling, the proposal seeks to convert into EU law some of the concepts outlined in the energy system integration and hydrogen strategies, published in 2020. These concepts aim at creating an energy-efficient, circular, and renewable energy system that facilitates renewables-based electrification and promotes the use of renewable and low-carbon fuels, including hydrogen, in sectors like transport where electrification is not yet a feasible option.

This new legislation is likely to be formally adopted in October (vote in EP schedule on 12 September, and adoption at the Council on 9 October).

6 ENERGY EFFICIENCY DIRECTIVE

First adopted in 2012, the Energy Efficiency Directive (EED, Directive 2012/27/EU) ([194]), setting rules and obligations for achieving the EU's ambitious energy efficiency targets, was updated in 2018 and 2023 to reflect the increased targets and to adapt the measures to deliver them.

The 2012 EED quantified the 20% energy efficiency target by 2020 and established a set of binding measures to help the EU reach it.

In 2018, the 'Clean energy for all Europeans package' ([195]) introduced the revised EED (Directive 2018/2002) ([196]) to update the policy framework to the 2030, having already in mind the 2050 decarbonistion objective. The central feature was the establishment of a prominent energy efficiency target for 2030, set at a minimum of 32.5% improvement compared to the 2007 projections for the same timeframe, which translated into indicative targets of 1,128 Mtoe of primary energy and 846 Mtoe for final energy consumption for the whole EU by 2030 ([197]).

In 2021, primary energy consumption in the EU reached 1,309 Mtoe, a 5.9% increase compared with 2020, but still below the 2019 level (1,354 Mtoe). Data ([198]) show that the EU had a distance to reach the 2030 target of 16.0% in 2021 (Figure 17).

([194]) https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027

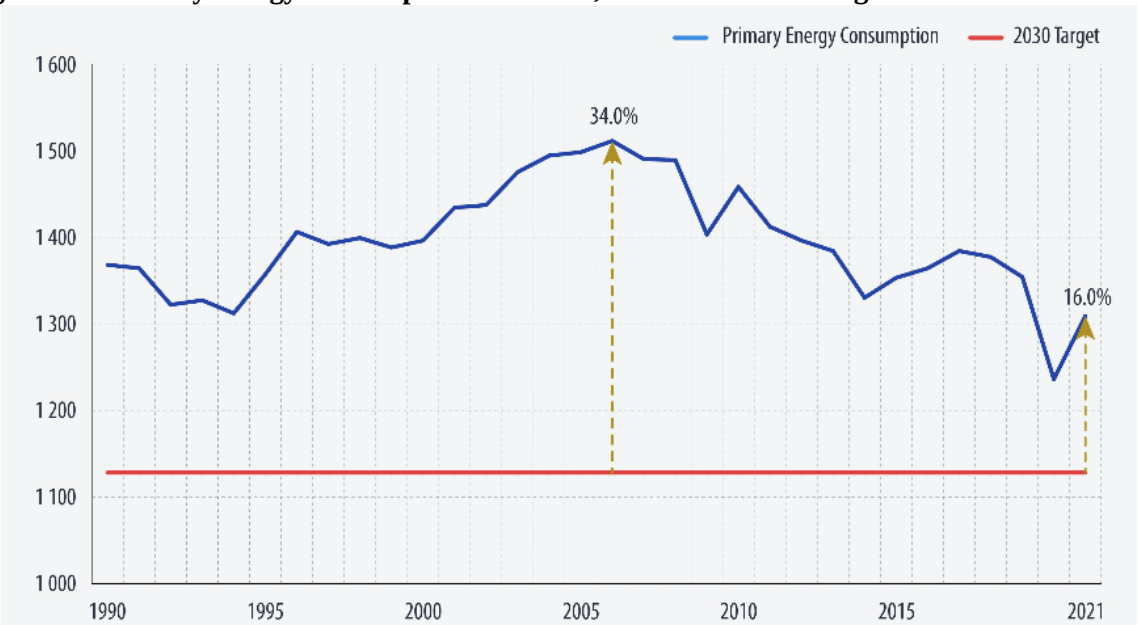
([195]) https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

([196]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0210.01.ENG

([197]) Both targets refer to the post BrexitEU27. The initial EU28 targets were talking of 1,273 Mtoe of primary energy and 956 Mtoe of final energy consumption.

([198]) https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20221219-4

Figure 17: Primary energy consumption in the EU, distance to 2030 target

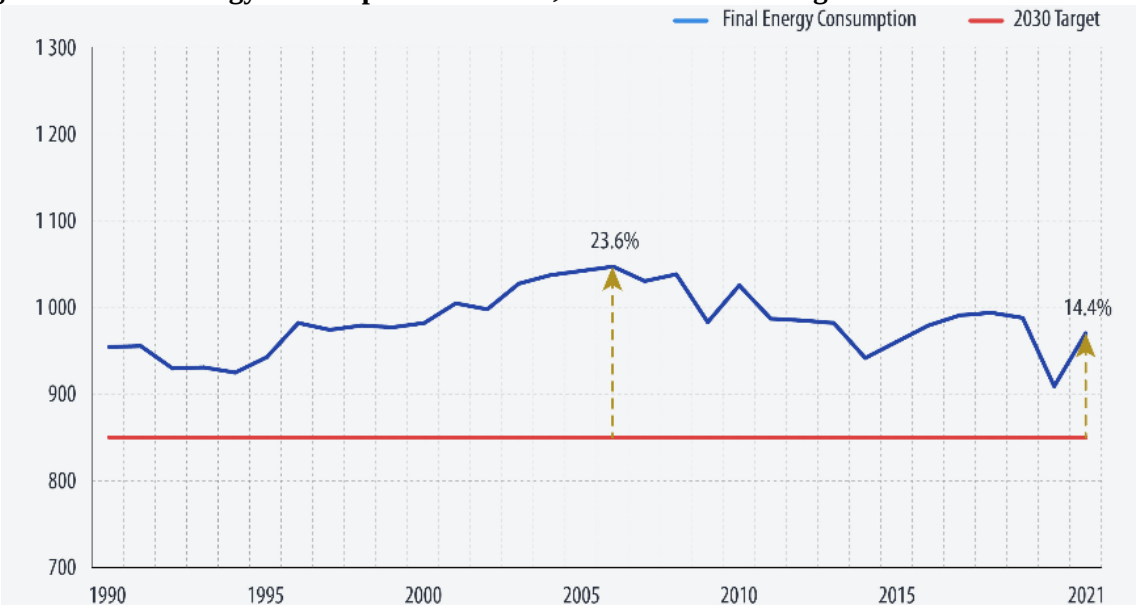


Unit: Mtoe

Source: Eurostat.

Final energy consumption reached 968 Mtoe in 2021, a 6.8% increase compared with 2020 and a 1.8% decrease compared with 2019. In 2021, final energy consumption was 14.4% away from the 2030 target (Figure 18).

Figure 18: Final energy consumption in the EU, distance to 2030 target



Unit: Mtoe

Source: Eurostat.

To achieve the 2030 climate target, as set by the 2030 Climate Target Plan, and contribute to ensuring energy security within the EU, the EED recast formally agreed on 24 July 2023 ([199]) significantly raises the EU's ambition, by making it binding for EU countries to collectively achieve an additional 11.7% reduction of final energy consumption by 2030, compared to the 2020 reference scenario projections ([200]). This translates into an idicative target of 992.5 Mtoe of primary energy and a binding target of 763 Mtoe for final energy consumption for the whole EU by 2030. Furthermore, the EED reacst establishes 'energy efficiency first' as a fundamental principle of EU energy policy, recognising its vital role in practical policy applications and investment decision-making beyond the energy sector.

([199]) https://energy.ec.europa.eu/news/european-green-deal-energy-efficiency-directive-adopted-helping-make-eu-fit-55-2023-07-25_en

([200]) https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-targets_en

Annex 11: The climate policy framework considered for the analysis

The list of EU policies considered is presented in the tables below, organised by sector. This list of EU policies is an updated version of the list of policies presented in Annex I of the EU Reference Scenario 2020 report ([201]). Some of the most recent policies mentioned in the list have been proposed by the European Commission but have not been formally adopted (negotiations are underway).

1 ENERGY EFFICIENCY POLICIES

Energy Efficiency		
1	Ecodesign Framework Directive	Directive 2009/125/EC
	Stand-by Regulation	Commission Regulation (EC) No 1275/2008 as amended by Commission Regulation (EU) No 801/2013
	Office/street lighting Regulation	Commission Regulation (EC) No 347/2010
	Lighting Products in the domestic and Tertiary Sectors Regulations	Commission Regulation (EU) 2019/2020 Commission Regulation (EC) No 244/2009 Commission Regulation (EC) No 245/2009 Commission Regulation (EU) No 1194/2012
	External power supplies Regulation	Commission Regulation (EU) 2019/1782
	TVs Regulation (+labelling) Regulation	Commission Regulation (EU) 2019/2021
	Electric motors Regulation	Commission Regulation (EC)No 640/2009
	Freezers/refrigerators Regulation	Commission Regulation (EU) 2015/1095 Commission Regulation (EU) 2019/2019 Commission Regulation (EU) 2019/2024
	Household washing machines Regulation	Commission Regulation (EU) 2019/2023
	Household dishwashers Regulations	Commission Regulation (EU) 2019/2022
	Air conditioners	Commission Regulation (EU) No 206/2012 Commission Regulation (EU) Regulation No 327/2011 Commission Regulation (EU) No 1253/2014 Commission Regulation (EU) 2016/2281
	Circulators Regulation	Commission Regulation (EC) No 641/2009 as amended by Commission Regulation (EU) No 622/2012 and Commission Regulation (EU) 2019/1781
	Water pumps	Commission Regulation (EU) No 547/2012
	Tumble driers	Commission Regulation (EU) No 932/2012
	Computers and servers	Commission Regulation (EU) No 617/2013 Commission Regulation (EU) 2019/424
	Vacuum cleaners	Commission Regulation (EU) No 666/2013

([201]) European Commission, DG for Climate Action, DG for Energy, DG for Mobility and Transport, De Vita, A., Capros, P., Paroussos, L., et al. (2021), EU Reference Scenario 2020: Energy, transport and GHG emissions - Trends to 2050.

	Cooking appliances	Commission Regulation (EU) No 66/2014
	Power transformers	Commission Regulation (EU) No 548/2014 Commission Regulation (EU) 2019/1783
	Heaters Regulation	Council Directive 92/42/EEC Commission Regulation (EU) No 813/2013 Commission Regulation (EU) No 814/2013 Commission Regulation (EU) 2015/1185 Commission Regulation (EU) 2015/1189 Commission Regulation (EU) 2016/2281
	Welding equipment	Commission Regulation (EU) 2019/1784
	Omnibus	Commission Regulation (EU) 2021/341
	Imaging equipment	Voluntary agreement – Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for imaging equipment COM/2013/023 final
	Game consoles	Voluntary agreement - Report from the Commission to the European Parliament and the Council on the voluntary ecodesign scheme for games consoles COM/2015/0178 final
2	Energy Labelling Directive and delegated Regulations covering: • lamps and luminaires, • air conditioners • Electronic displays • household washing machines • household refrigerating appliances • household dishwashers • household electric tumble-driers • Labelling of tyres Regulations • Cooking appliances Omnibus	Regulation (EU) 2017/1369 supplemented by Delegated Regulations and Commission Directives Commission Delegated Regulation (EU) No 874/2012 Commission Delegated Regulation (EU) No 626/2011 Commission Delegated Regulation (EU) No 1254/2014 Commission Delegated Regulation (EU) 2019/2013 Commission Delegated Regulation (EU) 2019/2014 Commission Delegated Regulation (EU) 2015/1094 Commission Delegated Regulation (EU) 2019/2016 Commission Delegated Regulation (EU) 2019/2018 Commission Delegated Regulation (EU) 2019/2017 Commission Delegated Regulation (EU) No 392/2012 Regulation (EU) 2020/740 Commission Delegated Regulation (EU) 2015/1186 Commission Delegated Regulation (EU) No 811/2013 Commission Delegated Regulation (EU) No 812/2013 Commission Delegated Regulation (EU) 2015/1187 Commission Delegated Regulation (EU) No 65/2014 Commission Delegated Regulation (EU) 2021/340 of 17 December 2020 amending Delegated Regulations (EU) 2019/2013, (EU) 2019/2014, (EU) 2019/2015, (EU) 2019/2016, (EU) 2019/2017 and (EU) 2019/2018
3	Energy Performance of Buildings Directive	Directive 2010/31/EU, as amended by Directive (EU) 2018/844, and Proposal for a revision of this directive (COM(2021) 802 final)
4	Energy Efficiency Directive	Directive (EU) 2023/1791

2 POWER GENERATION AND ENERGY MARKETS

Power generation and energy markets		
1	Completion of the internal energy market (including provisions of the 3rd package). Since March 2011, the Gas and Electricity Directives of the 3rd package for an internal EU gas and electricity market are transposed into national law by Members States and the three Regulations:	Directive 2009/73/EC Directive (EU) 2019/944

	- on conditions for access to the natural gas transmission networks	Regulation (EC) No 715/2009
	- on conditions for access to the network for cross-border exchange of electricity	Regulation (EU) 2019/943
	- on the establishment of the Agency for the Cooperation of Energy Regulators (ACER)	Regulation (EU) 2019/942
2	Energy Taxation Directive	Directive 2003/96/EC, and Proposal for recasting (COM(2021) 563 final)
3	Regulation on security of gas supply	Regulation (EU) 2017/1938
4	Regulation on market integrity and transparency (REMIT)	Regulation (EU) 1227/2011
5	Nuclear Safety Directive	Council Directive 2009/71/Euratom
6	Nuclear Waste Management Directive	Council Directive 2011/70/Euratom
7	Basic safety standards Directive	Council Directive 2013/59/Euratom
8	Directive on the promotion of the use of energy from renewable sources	Directive (EU) 2018/2001, as amended by Directive (EU) 2023/2413.
9	Guidelines on State aid for environmental protection and energy 2014-20	2014/C 200/01
	Guidelines on State aid for climate, environmental protection and energy 2022	C/2022/481
10	Hydrogen and decarbonised gas market package	Proposal for a directive (COM(2021) 803 final), and Proposal for a regulation (COM(2021) 804 final).
11	REPowerEU plan	Regulation (EU) 2023/435 amending Regulation (EU) 2021/241 as regards REPowerEU chapters in recovery and resilience plans and amending Regulations (EU) No 1303/2013, (EU) 2021/1060 and (EU) 2021/1755, and Directive 2003/87/EC.

3 CLIMATE POLICIES

(Cross-sectorial) Climate policies		
1	EU ETS Directive	Directive 2003/87/EC, as amended notably by Directive 2008/101/EC (aviation), Decision (EU) 2015/1814 (Market Stability Reserve), Regulation (EU) 2017/2392 (aviation "stop the clock" derogation), Directive 2018/410 (revision for 2030 climate and energy framework), Regulation (EU) 2023/435 (REPowerEU), Directive (EU) 2023/958 (aviation) and Directive (EU) 2023/959.
2	Directive on the geological storage of CO_2	Directive 2009/31/EC
3	GHG Effort Sharing Regulation	Regulation (EU) 2018/842, as amended by Regulation (EU) 2023/857.
4	European Commission proposal to revise the F-gas Regulation	Proposal COM (2022) 150 final, to amend Directive (EU) 2019/1937 and repeal Regulation (EU) No 517/2014 (provisionally agreed by co-legislators in October 2023).
5	LULUCF Regulation	Regulation (EU) 2018/841, as amended by Regulation (EU) 2023/839.
	Carbon Border Adjustment Mechanism (CBAM)	Regulation (EU) 2023/956.

6	Communication from the Commission Guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading post-2021.	2020/C 317/04

4 TRANSPORT-RELATED POLICIES

Transport-related policies		
1	CO2 emission performance standards for new passenger cars and light commercial vehicles	Regulation (EU) 2019/631, as amended by Regulation (EU) 2023/851.
2	CO2 emission performance standards for heavy-duty vehicles	Regulation (EU) 2019/1242, amending Regulations (EC) No 595/2009 and (EU) 2018/956. Proposal to amend Regulation (EU) 2019/1242 (COM (2023) 88 final)
3	Improving testing procedures - real driving conditions ('Real Driving Emissions' – RDE) and improved laboratory test ('World Harmonised Light Vehicle Test Procedure' – WLTP)	Commission Regulation (EU) 2018/1832 Commission Regulation (EU) 2017/1151 Commission Regulation (EU) 2017/1154 Commission Regulation (EU) 2016/646 Commission Regulation (EU) 2016/427
4	Regulation EURO 5 and 6, and EURO 7 standard proposal	Regulation (EC) No 715/2007, implemented by Commission Regulation (EU) 2017/1151 Commission Proposal COM(2022) 586
5	Directive on the promotion of the use of energy from renewable sources	Directive (EU) 2018/2001, as amended by Directive (EU) 2023/2413.
6	Fuel Quality Directive	Directive 98/70/EC, as amended by Directive (EU) 2015/1513
7	Regulation Euro VI for heavy duty vehicles	Regulation (EC) No 595/2009, implemented by Commission Regulation (EU) 582/2011
8	Eurovignette Directive on road infrastructure charging	Directive 1999/62/EC, as amended by Directives 2011/76/EU and (EU) 2022/362.
9	Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (in public procurement)	Directive 2009/33/EC, as amended by Directive (EU) 2019/1161
10	Regulation on the deployment of alternative fuels infrastructure	Regulation (EU) 2023/1804, repealing Directive 2014/94/EU.
11	Directive on weights & dimensions	Council Directive 96/53/EC, as amended by Directive 2015/719/EU, Decision (EU) 2019/894 and Regulation (EU) 2019/1242.

Transport-related policies		
		Proposal to amend Council Directive 96/53/EC (COM(2023) 445 final)
12	End of Life Vehicles Directive	Directive 2000/53/EC, as amended by Directive (EU) 2018/849
13	Mobile Air Conditioning in motor vehicles Directive	Directive 2006/40/EC
14	Directive on the sound level of motor vehicles	Regulation (EU) No 540/2014 as amended by Regulation (EU) 2019/839
15	Roadworthiness Package	Directive 2014/45/EU, Directive 2014/46/EU, Directive 2014/47/EU
16	Road infrastructure safety management	Directive (EU) 2019/1936
17	General safety regulation	Regulation (EU) 2019/2144
18	Intelligent Transport Systems Directive	Directive 2010/40/EU, as amended by Directive (EU) 2023/2661
19	Regulation concerning type-approval requirements for the deployment of the eCall in-vehicle system	Regulation (EU) 2015/758
20	Fourth railway package	Directives (EU) 2016/798 on railway safety, Directive (EU) 2016/797 on railway interoperability and the Directive 2016/2370/EU regarding the opening of the market for domestic passenger transport services by rail and the governance of the railway infrastructure
21	Directive establishing a single European railway area (Recast)	Directive 2012/34/EU
22	European Rail Traffic Management System European deployment plan	Commission Implementing Regulation (EU) 2017/6
23	Regulation on electronic freight transport information	Regulation (EU) 2020/1056
24	Regulation on noise-related operating restrictions at Union airports	Regulation (EU) No 598/2014
25	Regulations governing the performance and charging schemes as well as the network functions of the Single European Sky	Commission Implementing Regulations (EU) No 390/2013, 391/2013 and 677/2011; later replaced by Regulations (EU) 2019/317 and 2019/123
26	Inland waterways and port services	Directive 2016/1629/EU on technical requirements for inland waterway vessels and the Regulation on non-road mobile machinery (NRMM) Regulation (EU) 2017/352 establishing a framework for the provision of port services
27	Provision of port services	Regulation (EU) 2017/352
28	European Maritime Single Window	Regulation (EU) 2019/1239

Transport-related policies		
29	Directive on the sulphur content of marine fuels	Directive 2012/33/EU
30	Monitoring, reporting and verification of greenhouse gas emissions from maritime transport	Regulation (EU) 2015/757
31	Regulation on ensuring a level playing field for sustainable air transport – ReFuelEU Aviation	Regulation (EU) 2023/2405
32	Regulation on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC – FuelEU Maritime	Regulation (EU) 2023/1805
33	Action Plan to boost long-distance and cross-border passenger rail	Commission Proposal COM(2021) 810
34	Proposal for a Regulation on the accounting of greenhouse gas emissions of transport services	Commission Proposal COM(2023) 441
35	Proposal for a Regulation on the use of railway infrastructure capacity in the single European railway area	Commission Proposal COM(2023) 443
36	Proposal for a revision of the Combined Transport Directive	Commission Proposal COM(2023)702

5 INFRASTRUCTURE, INNOVATION AND RTD FUNDING

Infrastructure, innovation and RTD funding		
1	TEN-E guidelines	Regulation (EU) 347/2013
2	Regulation establishing the Connecting Europe Facility	Regulation (EU) 1316/2013
3	EEPR (European Energy Programme for Recovery) and NER 300 (New entrants reserve) CCS and innovative renewables funding programme	Regulation (EC) No 663/2009, ETS Directive 2009/29/EC Article 10a (8), further developed through Commission Decision 2010/670/EU and implementing decisions, e.g. EC(2014) 4493 and C(2015) 6882
4	Horizon 2020 support to energy research and innovation	Energy research under H2020: info available here: http://ec.europa.eu/programmes/horizon2020/en/area/energy
5	European Structural and Investment Funds ([202]):	
	European Regional Development Fund (ERDF)	Regulation (EU) No 1303/2013
	European Social Fund (ESF)	Regulation (EU) No 1301/2013
	Cohesion Fund (CF)	Regulation (EU) No 1304/2013
	European Agricultural Fund for Rural Development (EAFRD)	Regulation (EU) No 1305/2013
	European Maritime & Fisheries Fund (EMFF)	Regulation (EU) No 508/2014

([202]) As of May 2021, a revision of the regulations of the European Structural and Investment Funds has been agreed and is planned for publication.

Infrastructure, innovation and RTD funding		
	Social Climate Fund	Regulation (EU) 2023/955
6	TEN-T guidelines	Commission Proposal COM(2021) 812 final.

6 ENVIRONMENTAL POLICIES

Environment and other related policies		
1	General block exemption Regulation	Commission Regulation (EU) 2014/651, Commission Regulation (EU) 2017/1084, Commission Regulation (EU) 2023/1315
2	Landfill Directive	Directive 99/31/EC
3	Urban Wastewater Treatment Directive	Directive 91/271/EEC, Directive 98/15/EEC, Implementing Decision 2014/431/EU, Revision proposal COM(2022) 541 final
4	Waste Management Framework Directive	Directive 2008/98/EC
5	Nitrate Directive	Directive 91/676/EEC
6	Common Agricultural Policy (CAP)	e.g. Council Regulations (EC) No 1290/2005, No 1698/2005, No 1234/2007, No. 73/2009, Regulations (EU) No 1305-1308/2013, Regulation (EU) 2020/2220
7	Industrial emissions (Recast of Integrated Pollution and Prevention Control Directive 2008/1/EC and Large Combustion Plant Directive 2001/80/EC)	Directive 2010/75/EU, and revision proposal COM/2022/156 final/3
8	Directive on national emissions' ceilings for certain pollutants	Directive 2001/81/EC, Directive (EU) 2016/2284
9	Water Framework Directive	Directive 2000/60/EC
10	Substances that deplete the ozone layer	Relevant EU legislation implementing the Montreal protocol, e.g., Regulation (EC) No 1005/2009 as amended by Commission Regulation (EU) 744/2010, Regulation (EU) No 517/2014, Council Decision (EU) 2017/1541. Commission proposal to revise the Ozone Depleting Substances (ODS) Regulation (COM(2022) 151 final), provisionally agreed by co-legislators in October 2023.
11	Nature Restoration Law	Proposal COM/2022/304 final.

7 INTERNATIONAL POLICIES

Other policies at international level		
1	International Maritime Organisation (IMO) International convention for the prevention of pollution from ships (MARPOL), Annex VI	2008 amendments - revised Annex VI (Prevention of Air Pollution from ships) Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), IMO Resolution MEPC.203(62) GHG emission reduction targets agreed on in July 2023 as per MEPC 80/WP.12.

Other policies at international level		
2	Voluntary agreement to reduce PFC (perfluorocarbons, potent GHG) emissions in the semiconductor industry	
3	International Civil Aviation Organisation (ICAO), Convention on International Civil Aviation, Annex 16, Volume II (Aircraft engine emissions) and Volume III (CO_2 emissions standard for aircraft)	

8 IMPLEMENTATION OF POLICIES TO REDUCE NON-CO2 GHG EMISSIONS

Sector	Gas	Policy	Regional coverage	Policy description and implementation in GAINS
Agriculture	CH4	Feed-in tariffs or other subsidies to stimulate co-digestion of manure on farms	Italy, Netherlands, Latvia, Sweden, Cyprus, Austria, Croatia, Germany	Reflected via assumptions on uptake of farm-scale biogas technology consistent with information from EurObserv'ER (2020) on installed capacity. Future uptake follows trend in biogas production from anaerobic digestion as projected in the PRIMES model Reference scenario.
	CH4 & N2O	EU Common Agricultural Policy (CAP) and EU Nitrate Directive (EEC/676/1991) with revisions	EU-wide	Reflected in GAINS through input of CAPRI model data on trends in livestock numbers, milk yield and fertilizer use.
	CH4	Ban on burning of crop residues	EU-wide	Assumed not fully enforced. GAINS uses information derived from satellite images (e.g., MODIS) as approximate estimates of the mass of crop burned on fields.
Waste & wastewater	CH4	EU Landfill Directive (EC/31/1999) with amendment (EC/850/2018) and EU Waste and Packaging Directives (EC/851/2018, EC/852/2018)	EU-wide	Biodegradable waste diverted away from landfills (relative 1990 by -25% in 2006, -50% in 2009 and -65% in 2016). All landfill sites equipped with gas recovery by 2009. By 2035, countries must not landfill more than 10% of MSW generated. Member states that landfill more than 60% of MSW in 2013 are given a 5 years grace period but must not landfill more than 25% in 2035. GAINS Reference scenario assumes future targets will be met.
	CH_4	EU Waste Management Framework Directive (EC/98/2008)	EU-wide	The following hierarchy is to be respected in waste treatment: recycling and composting preferred to incineration/energy recovery, which in turn is preferred to landfill disposal. Considered in GAINS when simulating pathway for compliance with the Landfill Directive target.
	CH_4	Decree on waste landfill	Slovenia	Decree on landfill of waste beyond EU Landfill Directive. Includes partial ban on landfill of biodegradable waste.
	CH_4 & N_2O	Legislation to replace current composting with anaerobic digestion of food waste	Germany	In GAINS, the current composting of organic waste is phased-out linearly and replaced with anaerobic digestion between 2020 and 2050.
	CH_4	Ban on landfill of biodegradable waste.	Austria, Belgium, Denmark, Germany, Netherlands, Sweden	Complete ban on landfill of untreated biodegradable waste. Reflected in GAINS.

	CH_4	EU urban wastewater treatment directive (EEC/271/1991)	EU-wide	GAINS reflects an "appropriate treatment" of wastewater from urban households (all agglomerations > 2000 people) and food industry must be in place latest by end of 2005. This means discharge must ensure receiving waters meet relevant quality objectives.
Industry	N_2O, PFCs	EU ETS Directive (EC/29/2009): Primary aluminum production and production of nitric acid, adipic acid, glyoxal and glyoxylic acid.	EU-wide	Industry needs to aquire tradable emission permits under the EU emission trading system (EU-ETS).
	PFCs	Voluntary agreement in semiconductor industry	EU-wide	Semiconductor producers to reduce PFC emissions by 2010 to a level at 10 percent of 1995 emissions. Accounted for in GAINS to the extent it is reflected in national emission inventories to the UNFCCC.
F-gases	HFCs, PFCs, SF_6	EU F-gas regulation (EC 517/2014)	EU-wide	Phase-down of F-gas sold on the market, banning of use in applications where alternatives to F-gases are readily available, and preventing emissions from existing use of F-gases through leakage control and end-of-life recovery.
	HFCs	EU MAC Directive (EC 40/2006)	EU-wide	Mobile air conditioners: replacing the use of high GWP HFCs with cooling agents GWP100 < 150 in all new vehicle models placed on the market.
	HFCs	EU Directive on end-of-life vehicles (EC 53/2000)	EU-wide	Scrapped mobile air conditioners: recovery and proper handling
	HFCs, PFCs, SF_6	National F-gas regulations more stringent than EU regulation	Austria ("HFKW-FKW-SF6-Verordnung"), Belgium (end-of-life regulation from 2005 for large-scale refrigeration), Denmark (deposit-refund scheme since 1992, tax since 2001 and ban on import, sale and use since 2002), Germany ("Chemikalien-Klimaschutzverordnung" specify maximum leakage rates), Netherlands ("STEK" since 1992), Sweden (envirionmental fees since 1998, specific regulation since 2007)	
Energy	CH4	European Commission Proposal COM(2021) 805 final, for a Regulation on methane emissions reduction in the energy sector, amending Regulation (EU) 2019/942	EU-wide	Improved measurement, reporting and verification of energy sector methane emissions. Leak detection and repair and a ban on venting and flaring practices. A methane transparency requirement on imports.

Annex 12: Non-CO2 climate impacts of the navigation and aviation sectors

1 AVIATION

1.1 Scientific evidence

In its 1999 special report on aviation, IPCC ([203]) explored the sector's impacts on climate. Since then, updated assessments and studies ([204]) have been regularly published, improving the understanding of non-CO2 aviation effects.

In the scientific literature, those effects are mostly expressed in terms of "Effective Radiative Forcing" (ERF) ([205]) (Figure 19). The ERF from the sum of non-CO2 aviation impacts yields a net positive (warming) that is at least as large as those of CO2 alone. Despite uncertainties regarding the scientific knowledge on non-CO2 aviation effects, its contribution to global warming is clear.

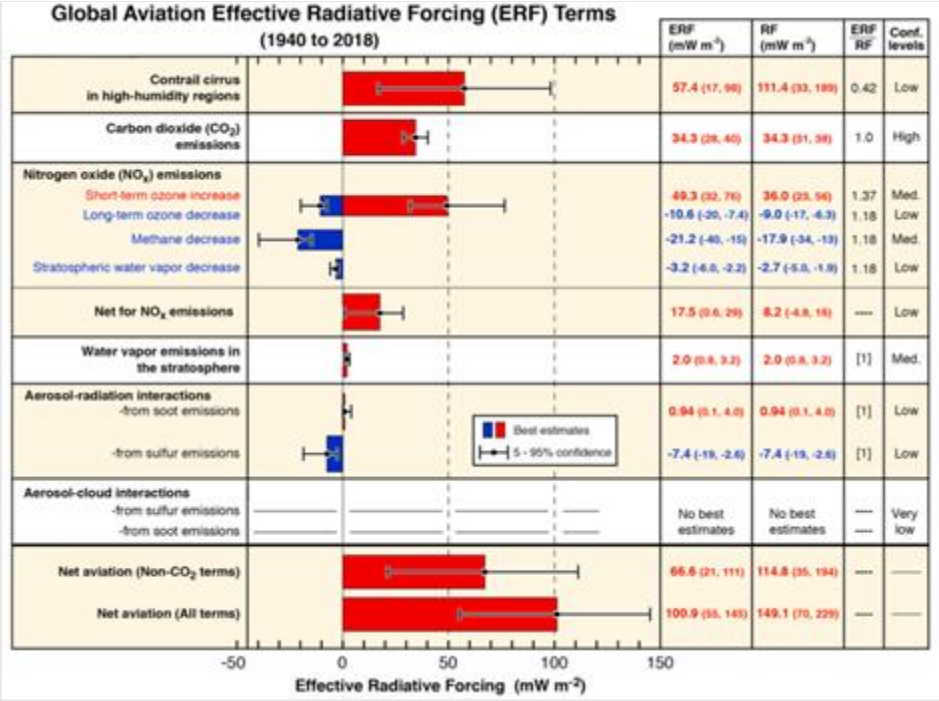
It must also be noted that the non-CO2 ERF ratios in Figure 19 are not fixed in time and the non-CO2 forcing from aviation is sensitive to the rate of growth of CO2, such that it grows faster under a scenario of increasing CO2 emissions, but equally, falls more quickly if CO2 emissions are reduced (Figure 20). Therefore, the growth of the sector in coming years and the fuels used will be determinant to the warming caused by the non-CO2 emissions.

([203]) IPCC (1999), Special Report Aviation and the global atmosphere

([204]) Sausen et al (2005), Aviation radiative forcing in 2000: An update on IPCC (1999); D.S. Lee et al (2009), Aviation and global climate change in the 21st century; D.S. Lee et al (2020), The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018; Klower et al (2021), Quantifying aviation's contribution to global warming.

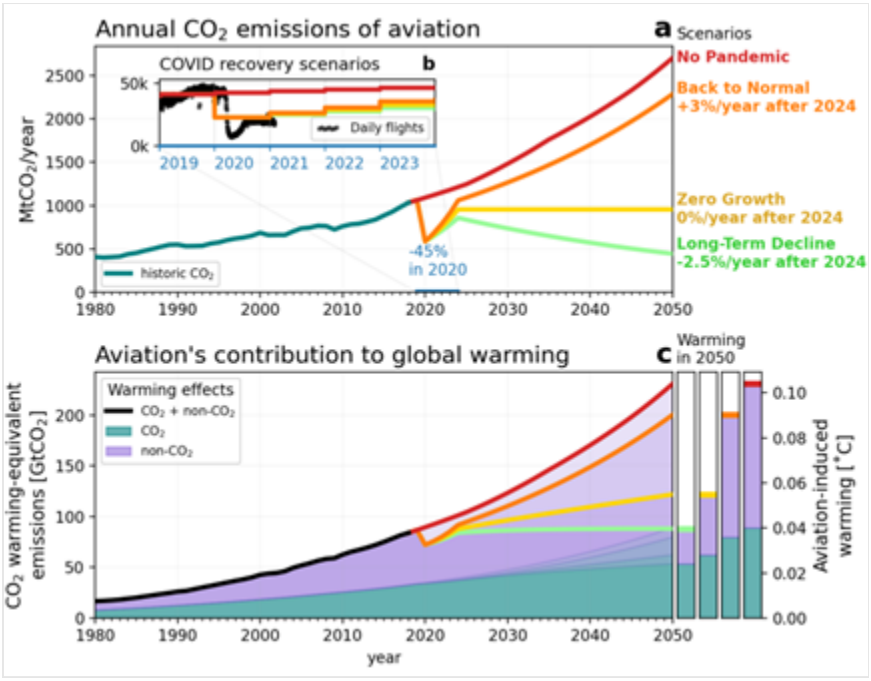
([205]) The "Radiative Forcing" (RF) metric stands for stratosphere-adjusted radiative forcing and it has been used as a proxy for predicting global mean surface temperature change. It represents the instantaneous change in total irradiation due to incoming short wave solar radiation minus the outgoing long wave terrestrial radiation (difference between sunlight energy received by the Earth and the energy Earth radiates back to space). In the Fifth Assessment Report (2013), in order to better take into account the complexities of heterogeneous distribution of certain forcing agents, the IPCC introduced the "Effective Radiative Forcing" (ERF) metric. ERF is considered to be a good predictor of the long-term change in global surface temperature caused through rapid adjustments in the atmosphere (e.g., thermal structure of the atmosphere, clouds, aerosols, etc.), while maintaining sea surface temperatures constant.

Figure 19: Global aviation contribution to anthropogenic climate forcing for 2000 to 2018



Source: Lee et al., 2020.

Figure 20: Quantifying aviation's contribution to global warming



Source: Klöwer et al., 2021.

The main aviation non-CO2 climate agents are water vapour (H2O), nitrogen oxides (NOx), sulphur dioxide (SO_2), and soot particles, as well as the atmospheric processes caused by such emissions, for example the formation of ozone (O3) and contrail cirrus.

As shown in Figure 19 the best estimates about the largest aviation non-CO2 impacts are those from NOx and contrails. The effects on climate of NOx emissions ("net-NOx effect") depends largely on their interaction with background emissions ([206]) and the location of the emissions. NOx contributes to the production of ozone (O3) and at the same time to the destruction of methane (CH4). This results generally in a net warming effect. Minimizing NOx can increase CO2 (decreased fuel efficiency *via* increased fuel burn), while optimising engines could lead to higher combustion temperatures and to more NOx emissions, which implies finding a balance between CO2 and NOx emissions.

Water vapour emissions resulting from hydrocarbon combustion have small direct climate effect for subsonic aircrafts at current cruise altitudes (up to 12-13 km), but they contribute to the formation of contrails (condensation trails). Contrail cirrus clouds are artificial clouds composed of ice crystals that form behind jet engines when the relative humidity in the engine plume increases reaching saturation. They occur at cold ambient temperatures between -35°C and -60°C. Water vapour condenses on condensation nuclei, with soot particles ([207]) being the effective nuclei. The water droplets freeze and grow as ice crystals until the humidity with respect to ice drops below saturation. Contrails generally cool during the day and always warm at night ([208]).

When it comes to hydrogen-powered aircrafts, the climate effect of water vapour (main exhaust product) needs to be further investigated and the warming effect will increase in the case of higher altitudes (e.g., supersonic) where water vapour is emitted into the drier stratosphere.

([206]) Background emissions refer to the levels of NOx and other emissions that already exist in the atmosphere from various sources unrelated to aviation.

([207]) The non-volatile particulate matter (nvPM) often referred to as "soot" (or "black carbon"), represents the inorganic and organic carbon in engine exhaust and plume. Soot emissions from aircraft engines contribute to contrail formation, where the number and size of ice crystals depend on soot concentration. The aromatic, and more precisely naphthalene content of jet fuel is associated with the production of soot particles. When it comes to vPM, sulphate particles originate from sulphur (S) in aviation kerosene fuel, which is oxidised to sulphur dioxide (SO2) during the combustion process and then to sulphuric acid to a minor extent in the combustor and to a major part, in the ambient atmosphere. Sulphuric acid can form, or coat pre-existing particles. These particles reflect solar radiation back to space as a "direct effect" and thus have a negative radiative forcing (cooling). This effect is small but needs to be noted as hydrotreatment (treating with hydrogen) of fuels to remove the impurities, and clean further the fuels, implies reduction of sulphur as well (sulphur particles, particularly those generated from combustion processes, can have detrimental effects on human health).

([208]) During the day, contrails clouds mostly reflect sunlight back into space, exerting a cooling effect. However, at night, the Earth's surface emits thermal radiation, and contrails act as a barrier, trapping some of this radiation within the atmosphere.

1.2 Policy context at global and EU level

At global level, in 2022 the IPCC ([209]) stated that current sectoral levels of ambition vary, with emission reduction aspirations in international aviation and shipping lower than in many other sectors.

At the same time, the IPCC report noted that between 2010 and 2019, aviation grew particularly quickly (on average, 3.3% per annum). With the end of the COVID-related travel restrictions this trend is returning quickly ([210]).

In October 2022, the 41st ICAO Assembly adopted a long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050 in support of the UNFCCC Paris Agreement's temperature goal ([211]). The ICAO LTAG does not cover non-CO_2 aviation effects.

At EU level, the 2006 Commission's Impact Assessment ([212]) on the inclusion of aviation in the EU greenhouse gas Emissions Trading System (EU ETS), as well as Directive 2008/101/EC recognised that aviation has an impact on the global climate through the release of non-CO_2 emissions.

Article 30(4) of Directive 2003/87/EC, as amended by Directive (EU) 2018/410, required the Commission to present an updated analysis of the non-CO_2 effects of aviation, accompanied, where appropriate, by a proposal on how to best address those effects. To fulfil that requirement, the European Union Aviation Safety Agency (EASA) conducted an updated analysis of the non-CO_2 effects of aviation on climate change and published its study ([213]) in November 2020. The findings confirmed what had been previously estimated, namely that the non-CO_2 climate impacts of aviation activities are, in total, at least as significant as those of CO_2 alone.

The revised EU ETS Directive ([214]), which concerns aviation's contribution to the Union's economy-wide emission reduction target and implementing a global market-based measure, concludes that non-CO_2 aviation effects can no longer be ignored in line with the precautionary principle. Regulatory measures are thus needed to achieve reductions of non-CO_2 emissions in line with the Paris Agreement.

([209]) IPCC (2022), Special Report Global Warming of 1.5°C

([210]) ICAO forecasts complete and sustainable recovery and growth of air passenger demand in 2023

([211]) By applying the goal to hold the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius, the Paris Agreement encompasses *de facto* all anthropogenic activities contributing to the warming of climate, aviation included.

([212]) COM(2006) 818 final

([213]) SWD(2020) 277 final

([214]) Directive (EU) 2023/958

Accordingly, from 1 January 2025, Member States shall ensure that each aircraft operator monitors and reports the non-CO_2 effects from each aircraft that it operates during each calendar year to the competent authority after the end of each year. For this purpose, the EU ETS aviation revised Directive instructs the Commission to adopt, by 31 August 2024, an implementing act based on the principles for monitoring and reporting set out in Annex IV to the EU ETS revised Directive, to include non-CO_2 effects in a monitoring, reporting and verification (hereinafter, MRV) framework. This MRV framework must contain, at a minimum, the three-dimensional aircraft trajectory data available, ambient humidity, and temperature to enable CO_2 equivalents per flight to be produced. The EU ETS revised Directive requires the Commission to ensure, subject to available resources, that tools are available to facilitate and, to the extent possible, automatise the monitoring, reporting and verification tasks in order to minimise any administrative burden. From 2026, the Commission will publish the results from the MRV framework once a year. By 31 December 2027, based on the results of the application of the EU ETS MRV framework of non-CO_2 aviation effects (i.e., monitoring, reporting and verifying CO_2 equivalents from non-CO_2 aviation effects), the Commission will submit a report and, where appropriate, a legislative proposal after having first carried out an impact assessment to mitigate such effects by expanding the scope of the EU ETS to include non-CO_2 aviation effects.

In addition, additional financial support is available to reduce aviation's non-CO_2 climate impacts from the EU ETS-funded Innovation Fund, which specifically provides for support for electrification and to reduce the overall climate impacts from aviation ([215]).

The provisional political agreement reached in April 2023 for sustainable aviation fuel mandates for aviation (ReFuelEU Aviation) is another milestone in the direction of reducing the GHG impact of aviation. This measure will reduce the CO2 impact of aviation. If the characteristics of the fossil fuel share of aviation fuels are not modified, the measure will also reduce the non-CO2 impacts of the sector. The agreement also requires monitoring and reporting of aromatics, naphthalene and sulphur content of the aviation fuels supplied, by EASA.

In its "Fly the Green Deal" report published in June 2022, the Advisory Council for Aviation Research and innovation in Europe (ACARE) European Technology Platform, defines quantitative targets for aviation non-CO_2 effects in Europe:

- By 2035 new technologies, fuels and operational procedures in service result in a 30% reduction in non-CO_2 climate effects of all intra-EU flights and those departing the EU relative to the 1990 baseline.
- By 2050 new technologies and operational procedures in service result in a 90% reduction in NOx and non-volatile particulate matter (nvPM) emissions, and warming contrail cirrus, from all intra-EU flights and those departing the EU relative to the year 2000.

([215]) Innovation Fund (INNOVFUND) Methodology for GHG Emission Avoidance Calculation Version 3.0 01 November 2023.

1.3 Mitigation technologies

A possible mitigation option for mitigation of non-CO2, as a co-benefit of reducing CO2 is the use of sustainable aviation fuels. Nevertheless, their potential to address the climate problem is currently uncertain. As shown by Becken et al ([216]), further analysis is needed on the level of effectiveness of SAFs in terms of reduced GHG footprint on a life-cycle analysis (LCA) basis and displacement of emissions.

Other more immediate options to reduce non-CO2 effects relate to operational measures to seek a climate-optimised flights (as the climate impact of non-CO2 emissions depends not only on the amount, but also on the location and time of emission) and the use of lower emissions, alternative kerosene. On the latter, research publications under Horizon 2020 projects ([217]) demonstrated that the use of low-sulphur, low-aromatics and low-naphthalene kerosene would have significant social benefits, as the climate benefits (and also the fuel cost savings and air pollution benefits) exceed the additional production costs and the external effects of emissions from fuel production.

Additionally, technical measures like improving the design of aircrafts (reducing weight and optimising aerodynamics) and the efficiency and combustion characteristics of aircraft engines, are promising as well, but subject to longer time spans compared to the two previous options.

1.4 Non-CO2 effects in the context of the 2040 climate target

While the 2030 Climate Target Plan did not cover aviation non-CO_2 effects, the 2040 Climate Target Plan needs to explore those, in line with the latest scientific findings and agreement on the EU ETS Directive. A qualitative approach is complimentary to a quantitative one when it comes to reducing the non-CO2 effects from aviation. In this regard, identifying cost-effective mitigation actions ([218]) that reduce the overall climate impact from both CO2 and non-CO2 aviation emissions, whilst also accounting for the uncertainties surrounding non-CO_2 effects, will be required. Qualitative and quantitative considerations for reducing aviation non-CO_2 effects will be further informed by the deliverables under the EU ETS Directive (see above), expected on 31 December 2027.

Modelling tools supporting the definition of the current EU climate targets do not refer to aviation non-CO_2 effects. Nevertheless, a number of already existing modelling tools demonstrate functions for producing figures on CO_2 equivalence of aviation non-CO_2 effects (e.g., AirClim model assesses the climate impact of aircraft emissions (i.e., altitude, longitude, and latitude of emissions) for a variety of previously calculated aviation scenarios over short- and long-time horizons, including different routings and technological options. Other models

([216]) Becken et al (2023), Implications of preferential access to land and clean energy for Sustainable Aviation Fuels, *Science of The Total Environment* 886, 163883. https://doi.org/10.1016/j.scitotenv.2023.163883

([217]) JET Fuel SCREENing and Optimization

([218]) Such actions need to take into account the uncertainties in non-CO_2 effects as part of a risk-based assessment in order to ensure confidence in robust mitigation gains.

exist as well (CoCIP, LinClim, OSCAR, etc.) and further analysis and eventual intercomparison of those would inform the work on mitigation of aviation non-CO_2 effects.

2 NAVIGATION

2.1 Scientific evidence

Maritime transport remains today heavily reliant on fossil fuels ([219]), which, once combusted, produce emissions of various greenhouse gases (GHG), including carbon dioxide (CO_2) but also methane (CH_4) and nitrous oxide (N_2O) which have global warming potentials much higher than CO_2 ([220]).The amount of emissions produced is primarily a function of the amount of fuel consumed, the characteristics of the fuel, the engine technology employed and its operation, and any post-combustion emission controls in place ([221]).

Other GHGs which might be associated to maritime transport activities, as fugitive emissions, include Hydro Fluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF_6) and Nitrogen trifluoride (NF_3). These are mostly used on-board ships as refrigerants in various types of machinery, including for air conditioning and cargo cooling processes ([222]).

Furthermore, maritime transport activities produce other air pollutants such as carbon monoxide (CO), oxides of nitrogen (NOx), non-methane volatile organic compounds (NMVOCs), particulate matter (PM_{10} and $PM_{2.5}$, commonly known as "black carbon"), and sulphur dioxide (SO_2). Although these latter pollutants are not direct greenhouse gases, some of them (CO, NOx, NMVOCs, $PM_{2.5}$) do contribute to climate change.

Methane

Small quantities of methane (CH_4) are emitted to the atmosphere as a result of the combustion of marine hydrocarbons fuels, as by-product of their incomplete combustion. Additional amounts of methane can be released into the atmosphere as fugitive and slipped emissions, when certain fuels and technologies are used on-board. This might occur when gas or dual fuel engines are on-board or from the cargo tanks in Liquified Natural Gas (LNG) carriers.

Nitrous oxide

Nitrous oxide (N_2O) is produced in small quantities during fossil fuel combustion when nitrogen in the air or fuel is oxidized in the high temperature environment of the engine. N_2O is also produced as a by-product of the combustion of ammonia in ammonia-fuelled vessels.

([219]) The use of alternative, renewable fuels, remains today extremely low, see IMO Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS (Reporting year: 2021), MEPC 79/6/1.

([220]) IPCC AR5 reports the global warming potential of methane as 28 and of nitrous oxide of 265.

([221]) CO_2, CH_4, and N_2O emissions from transportation water borne navigation, in Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.

([222]) The impact of such other GHGs is not accounted for in the figures reported above (IMO, 2020) as deemed negligible.

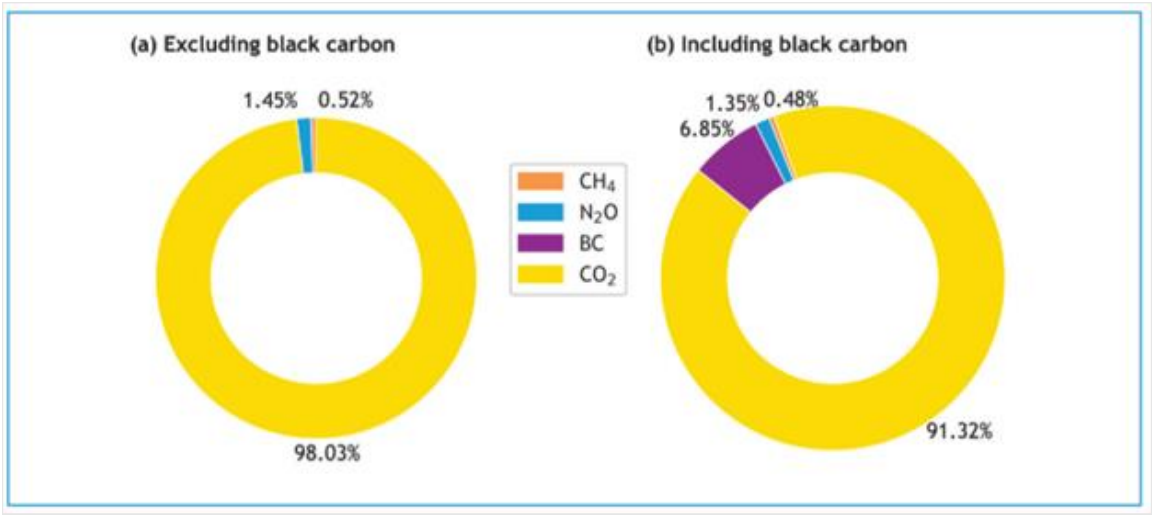
Black Carbon

As one component of fine particulate matter ($PM_{2.5}$), black carbon is a small, strongly light-absorbing dark particle which deteriorates air quality and causes health and environmental issues. At global level, black carbon is the second largest cause of climate impacts from the maritime sector and is contributing to the rapid decline in Arctic Sea ice ([223]). Black carbon emissions are mostly associated with the incomplete combustion of residual fuel oil, which leads to higher black carbon emissions compared to distillate fuels. As a result of its dark colour, black carbon absorbs a high proportion of incoming solar radiation and directly warms the atmosphere. Black carbon has a relatively short atmospheric lifetime, depositing on the Earth's surface a few days up to a few weeks after emission. However, when black carbon deposits onto light-covered surfaces, such as snow or ice, it reduces the albedo of the surface leading to a warming effect. The largest sources of black carbon emissions from maritime transport are from fossil fuel, biomass and biofuel combustion and its release by ships is mainly influenced by the type of fuel used, engine characteristics and load. ([224])

Emissions trends

While the bulk of greenhouse gases (GHGs) emissions from maritime transport are CO_2, when black carbon is included in the calculation of CO_2-equivalents ([225]), black carbon becomes the second most significant contributor at 6.85%, while the share of CO_2, CH_4 and N_2O go down to 91.32%, 0.48% and 1.35%, respectively ([226]).

Figure 21: Composition of non-CO2 GHG gases in the maritime sector



([223]) Comer, B., Olmer, N., Mao, X., Roy, B. & Rutherford, D., 'Black carbon emissions and fuel use in global shipping', *International Council on Clean Transportation*, 2015

([224]) The European Maritime Transport Environmental Report (EMTER).

([225]) Using a 100- year GWP of 900.

([226]) Fourth IMO GHG Study, 2020. The impact of other GHGs is not accounted for in the figures reported as deemed negligible.

Source: Fourth IMO GHG Study (2020).

Over the period 2012-2018, CO_2 emissions from international shipping increased by 5.6%. Methane emissions increased by 150%, far more than the 28-30% increase in the use of LNG as a marine fuel. This occurred as the LNG carrier fleet shifted from mostly using LNG as a fuel in steam turbine combustion engines to a larger share of the fleet using LNG-powered injection engines, which emit more unburnt methane. Black carbon emissions increased by 11.6% for total shipping (i.e., from 59 to 62 kilo tonnes) ([227]). An increase in the emissions of methane and nitrous oxide might be driven in the coming years by the deployment of dual fuel and Liquified-Natural-Gas-powered ships (for methane) and by the growing use of new fuels such as ammonia (for nitrous oxide) ([228]).

2.2 Policy context at EU and global level

The "Fit for 55" Package included several proposals to address maritime transport's climate impact, thus ensuring that the sector would contribute to the EU overall climate ambition. In this context, amendments to the EU Maritime MRV Regulation have been adopted in May 2023 ([229]), parallel to the inclusion of the maritime sector in the European Emission Trading System. The amended EU Maritime MRV Regulation recognises the increasing importance of climate impacts from non-CO_2 emissions by updating monitoring and reporting rules to allow the inclusion of methane and nitrous oxide emissions already from the year 2024, in a tank-to-wake logic (which accounts for emissions from both combustion and tank-to-wake slippage). This will allow for an extension of the scope to methane and nitrous oxides (in addition to CO_2) under the ETS Directive as applied to the maritime sector from 2026 onwards. Furthermore, the Commission will continue to assess every two years the overall impact of shipping activities on the global climate, including through non-CO_2 emissions or effects and now also particulate matter with a global warming potential, not covered by the regulation.

Additional support to the decarbonisation of the maritime sector will be provided by the EU ETS-funded Innovation Fund, where the Commission has stated that 20 million allowances (i.e., about €1.6 billion with a price of €80 per allowance) should be used to reduce climate impacts from maritime up to 2030. Special attention is given in the Innovation Fund to addressing the maritime sector's full climate impact, including from black carbon emissions. In addition, the FuelEU Maritime Regulation, ([230]) aims at boosting demand for renewable and low-carbon fuels by setting targets for the annual GHG intensity of the energy used on board ships (using a well-to-wake logic and accounting for the methane and nitrous oxides emissions), and by encouraging zero-emission technology when ships are at berth in ports.

([227]) Fourth IMO GHG Study, 2020.

([228]) Study on EU ETS for maritime transport and possible alternative options of combinations to reduce greenhouse gas emissions.

([229]) Regulation (EU) 2023/957 amending Regulation (EU) 2015/757 in order to provide for the inclusion of maritime transport activities in the EU Emissions Trading System and for the monitoring, reporting and verification of emissions of additional greenhouse gases and emissions from additional ship types.

([230]) Regulation (EU) 2023/1805 on the use of renewable and low-carbon fuels in maritime transport.

At the UN level, the EU is supporting the work at the International Maritime Organisation (IMO) for the development of guidelines on life cycle GHG intensity of marine fuels, which will allow for the calculation of emissions default values for fuels in a well-to-wake logic, including methane and nitrous oxide emissions in addition to carbon dioxide. Furthermore, the EU is supporting the work for the development of the IMO's mid-term decarbonisation measures, which will take the form of a global fuel standard and a global economic measure and are to be adopted by 2025 and enter into force by 2027. Those measures should deliver on the GHG reduction objectives of the 2023 IMO GHG Strategy (notably to reach net-zero well-to-wake GHG emissions by or around 2050). The EU is also supporting the revision of the IMO's short-term decarbonisation measures, which should also support the attainment of the 2023 IMO GHG Strategy goals.

Black carbon emissions are currently not directly regulated at international level. However, both the Arctic Council and the IMO are considering the impacts of black carbon in the Arctic. As part of these activities, the IMO agreed a reporting protocol and measurement methods for black carbon emissions with a view to investigating policy options. In 2021, the IMO approved a ban (with waivers) on the use of Heavy Fuel Oil and its carriage for use by ships in Arctic waters after 1 July 2024 ([231]) and adopted a resolution which urges Member States and ship operators to voluntarily use distillate or other cleaner alternative fuels or methods of propulsion that could contribute to the reduction of black carbon emissions from ships when operating in or near the Arctic.

2.3 Mitigation options and technologies

The reduction of non-CO_2 emissions from maritime transport can be pursued through technologies already available in the market, while additional ones are currently under development.

The application of currently available high-pressure dual-fuel injection engines could reduce methane emissions compared to low pressure engines, as thanks to the resulting combustion being nearly complete, methane slip is reduced to nearly zero ([232]). Additional methane emissions reduction technologies applied to the engine include exhaust gas recirculation (EGR), engine tuning and control software, and engine component design optimization. ([233])

Nitrous oxide emissions can be reduced by using catalytic emission treatment technologies that are well-known and commercially available. A wide range of different catalysts can be used, in different temperature and gas conditions, with or without reducing agents. ([234]) Plasma reduction systems (PRS) are currently being developed and could potentially be applied to reduce both methane and ammonia slip emissions. PRS systems, still in the early

([231]) See https://www.reuters.com/article/shipping-arctic-imo-idUKL8N2HY5IS.

([232]) Decarbonizing Maritime Transport: The Importance of Engine Technology and Regulations for LNG to Serve as a Transition Fuel, Lindstad, 2020.

([233]) Reducing methane emissions onboard vessels, The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, October, 2022.

([234]) Managing emissions from ammonia-fueled vessels, The Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, March, 2023.

stages of development, consist of a catalyst and an absorbent-free after-treatment technology aimed at producing a non-thermal plasma. The processing of the exhaust gas by means of plasma results in the conversion of pollutants in harmless molecules via a chain of chemical-kinetic reactions.

As black carbon emissions are largely influenced by the type of fuel used and engine characteristics, key available abatement technologies include fuel type selection (e.g., low-sulphur distillate fuels) and fuel treatment, better engine maintenance, better fuel combustion, and exhaust treatment systems. Operational practices aiming at improving fuel efficiency such as slow-steaming and de-rating can further contribute to black carbon emissions reduction ([235]).

2.4 Non-CO2 effects in the context of the 2040 climate target

Modelling tools supporting the definition of the current EU climate targets refer to non-CO_2 emissions from the maritime sector only in relation to N_2O and CH_4.

Black carbon from international maritime transport is estimated to account for about 2% of total global black carbon emissions ([236]) and between 8% to 13% of all black carbon diesel emissions. ([237]) Projections on the future impact of maritime black carbon emissions are subject to considerable uncertainty but suggest the marine sector will maintain and even increase (up to 35%) its share in total diesel black carbon emissions by 2030 compared to 2010 level ([238]).

While maritime transport has traditionally relied on the use of conventional fossil fuels, today several alternative fuels and energy technologies have the potential to decarbonise shipping, including biofuels and biogas, e-fuels and e-gas, ethyl and methyl alcohols, hydrogen, ammonia, and electricity. At present it remains unclear which of these will play the biggest share in the energy transition of the sector but the composition of the future fuel mix of the global fleet will affect the relative impact of the different greenhouse gases on total emissions from maritime. Overall, the uptake of alternative fuels will reduce CO_2 emissions and, to a certain extent, non-CO_2 emissions as well. In parallel, the decrease of CO_2 emissions from fossil fuel combustion will also increase the relative importance of non-CO_2 emissions, such as N_2O emissions from ammonia combustion, CH_4 from incomplete hydrocarbons combustion (irrespective of their origin), or black carbon from biofuels. Wind assist technology also has a significant potential to reduce GHG emissions from shipping.

The further reduction of non-CO_2 emissions will be possible both through the deployment of existing abatement technologies but also through regulatory measures incentivising the

([235]) Comer, B., et al., 2017, Black carbon emissions and fuel use in global shipping, 2015, International Council on Clean Transportation.

([236]) Bounding the role of black carbon in the climate system: A scientific assessment, Bond et al., 2013, Journal of Geophysical Research: Atmospheres, 118(11).

([237]) This share refers to the year 2010.

([238]) Azzara et al., 2015. Needs and opportunities to reduce black carbon emissions from maritime shipping. The International Council on Clean Transportation. Working Paper 2015–2.

reductions. The upcoming inclusion of CH_4 and N_2O emissions into the ETS for the maritime sector will create an incentive for their reduction, while regulatory developments on black carbon are ongoing and further action may need to be considered.

Annex 13: Literature review of 2040 net GHG reductions

This annex provides a review of recent analyses (published or in preprint in 2023) of GHG pathways to climate neutrality looking at the level of emissions in 2040.

Table 1 shows a range of reductions of net GHGs in 2040 compared to 1990 of around 85-95%. To be noticed that the scope considered in the analyses varies from "domestic" to "including international bunker fuels".

The different analyses highlight how achieving 90% or more requires managing scale-up challenges, such as the sustainable use of biomass for bioenergy, the large-scale development of carbon capture or the supply of raw materials, but still lies within the feasibility limits of fast technological development ([239]). More sustainable lifestyles can contribute positively to overcoming such challenges.

([239]) ESABCC (2023). Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050. DOI: 10.2800/609405.

Table 1. 2040 GHG level in recent analyses of 2040 climate targets for the EU

Projections	Approach	Level of net GHGs 2040 vs 1990	Scope
ESABCC ([240])	Analysis of IPCC AR6 + more recent scenarios	88-92% considering environmental risk and technological challenge	Intra-EU
		88-95% if technological challenge by 2030 can be overcome	
PBL ([241])	Analysis of IPCC AR6 scenarios	86% for climate category C1 92% if selecting only trajectories meeting climate neutrality by 2050	Intra-EU
ECEMF ([242])*	Multi-model analysis based on integrated assessment models	84-89%	Including international bunker fuels
		86-92%	Intra-EU
PIK ([243])*	Integrated assessment model, under different assumptions	87-91%	Including intra-EU aviation
Strategic Perspectives ([244])	CLIMACT "2050 Pathways Explorer"	85-95%	Including international bunker fuels
CLEVER ([245])	Sufficiency scenario, sectoral approach	93%	Domestic
Agora Energiewende ([246])	Sectoral modelling	89%	Domestic

*Note: *These publications are undergoing a scientific peer-review process.*

The ESABCC analyses a large number of scenarios and excludes a vast majority of them on the basis of concerns on data quality and plausibility, consistency with EU and global climate goal and geophysical, technological and sociocultural feasibility criteria. 36 "filtered" scenarios projecting a wide range of emission reduction outcomes are selected and further assessed according to their environmental risk and technological deployment challenges. The

([240]) ESABCC (2023). Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050. DOI: 10.2800/609405. Scenario database: https://data.ece.iiasa.ac.at/eu-climate-advisory-board/#/login?redirect=%2Fworkspaces

([241]) Hooijschuur, E, den Elzen, M.G.J., Dafnomilis, I. and van Vuuren, D.P. (2023), Analysis of cost-effective reduction pathways for major emitting countries to achieve the Paris Agreement climate goal, The Hague: PBL Netherlands Environmental Assessment Agency.

([242]) ECEMF, *ECEMF Policy Brief: Insights on EU2040 targets based on a model intercomparison exercise of EU Climate Neutrality Pathways*, 2023. DOI 10.5281/zenodo.8337667 https://zenodo.org/record/8337668

([243]) Rodrigues et al: "2040 greenhouse gas reduction targets and energy transitions in line with the EU Green Deal", *Nature Communication*, 2023. Under Review.

([244]) Kalcher, L. et al., (2023). The post-2030 climate target debate starts now, *Strategic Perspectives and Climact*. https://strategicperspectives.eu/the-post-2030-climate-target-debate-starts-now/

([245]) CLEVER, *Climate neutrality, Energy security and Sustainability: A pathway to bridge the gap through Sufficiency, Efficiency and Renewables – Final Report*, 2023. https://clever-energy-scenario.eu/wp-content/uploads/2023/08/CLEVER_final-report.pdf

([246]) Graf, A., et al. (2023). Breaking free from fossil gas. A new path to a climate-neutral Europe. Agora Energiewende. A-EW_292_Breaking_free_WEB.pdf (agora-energiewende.de)

environmental risk considers the extent to which scenarios count on large-scale uses of carbon capture (including removals) and bioenergy. Technological deployment challenges consider the implication of conservative estimates for the deployment potential of PV and wind energy, and hydrogen technologies. In the document, the levels at which the use or deployment of certain mitigation options can represent an environmental risk or a technological challenges are not defined as "hard" values, therefore examples from the literature are used. Out of the 36 filtered scenarios, 5 stays within the environmental risk and technological deployment challenge levels, leading to a range of 88-92% emission reductions in 2040 (vs 1990). If the challenges of deploying renewable energy can be overcome([247]), while still remaining within the environmental risk boundaries, the numbers of possible scenarios increases to 7, leading to a range of 88-95% emission reductions in 2040.

PBL shows a range of 76%-96% of domestic emission reductions for the EU for 2040 for climate category C1 ([248]), with a median value of 86%. The analysis follows a very similar approach to the one taken by the ESABCC, since the values are based on all IAM scenarios used in the IPCC AR6 report and its chapter on mitigation pathways compatible with long-term temperature goal and following least-cost consideration. The PBL study complements the ESABCC study since it also includes projections that do not reach net-zero in EU by 2050. Considering only scenarios in line with the EU climate target, hence reaching net-zero in 2050, the range of net GHG emission reductions in 2040 is 84-97%.

PIK provides a range of emission reduction of 87-91% (including intra-EU aviation), depending on emission levels and energy efficiency attained in 2030, availability of biomass and development of CCS in the long run. The study indicates the challenges related to the achievement of a highly electrified energy systems, including the need to invest significantly on grid infrastructure, to implement a large amount of flexibility solutions, and to address the strong contraction of gas network usage. It also mentions the requirements to limit the use of bioenergy according to sustainability constraints and the uncertainty on the development of carbon capture and carbon removal related to the creation of a robust regulatory framework that covers permits, monitoring, cross-border collaboration, local storage acceptance, remuneration and long-term liability across different EU countries.

ECEMF performs a multi-model intercomparison using 9 different models and provides a range of 84-89% (including international bunker fuels) and 86-92% (including only intra-EU

([247]) ESABCC, Table 6, defines such technological challenges as installed capacities in 2030 of solar (900 GW), wind (623 GW) and hydrogen (50 GW). In 2022, the total installed capacity of PV and wind in the EU were both close to 200 GW, including newly installed capacity that year of about 40 GW for PV and 15 GW for wind (source: Eurostat, Solar Power Europe, WindEurope).

([248]) Limit 1.5 °C with at least 50% probability, with limited or no overshoot. As per in Riahi, K., R. Schaeffer, J. Arango, K. Calvin, C. Guivarch, T. Hasegawa, K. Jiang, E. Kriegler, R. Matthews, G.P. Peters, A. Rao, S. Robertson, A.M. Sebbit, J. Steinberger, M. Tavoni, D.P. van Vuuren, 2022: Mitigation pathways compatible with long-term goals. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005. Table 3.2. Limited overshoot refers to exceeding 1.5°C global warming by up to about 0.1°C, high overshoot by 0.1°C-0.3°C, in both cases for up to several decades.

emissions). According to the paper, achieving such a level of ambitions requires a large effort to scale up carbon capture up by 2040 up to an average of 305 MtCO2, and a fast scale up of wind, solar, electric vehicles, and heat pumps.

Strategic Perspective analyses a 2040 net reduction between 85% and 95% (including international bunkers). This is achieved with a strong contribution of nature-based removals (i.e., around 470 MtCO2-eq of LULUCF in the case of a 95% reduction, i.e., above the environmental risk threshold of 400 MtCO2 identified by the ESABCC and above the levels considered in this impact assessment) and complemented by industrial based removals (between 35 and 60 MtCO2), mostly from BECCS. The scenarios discussed also project behavioural change trends: demand reduction plays a major role in decarbonisation of the industry and is responsible for 15% of the sectoral emissions reductions in 2040; a shift to other modes of transport, with public transport and "mobility as a service" reduces the car fleet by 20% while increasing mobility options, and a switch to a healthier and plant-based diet can contribute to reducing food demand by 12%.

The CLEVER scenario projects a reduction of 93% of emissions in 2040 vs 1990, implementing a modelling approach based almost exclusively on sufficiency, efficiency, and renewable energies. In the scenario, sufficency alone can be responsible for reducing final energy consumption (FEC) by 20-30%, through a reduction of total passenger traffic by around 21% in 2050 compared to 2019 through a mobility switch from road and air to active and rail, and a reduction of industrial demand for energy intensive materials such as steel (-15%) and cement (-38%). Additional efficiency measures, an increasing share of renewables in the energy mix to above 50% and reduced meat (-40%) and milk (-20%) consumption, complete a picture that reaches reductions above 90% with very limited carbon capture, and no strong enhancement of the LULUCF net sink. The pathway prioritising these three specific aspects is considered capable to limit the possible challenges and risks associated to the ambitious target, such as: technical feasibility for deep renovation, material and metal resource depletion, sustainability of bioenergy production, adaptation of electricity networks, and timely delivery of large-scale new technologies (e.g., nature-based, and industrial carbon removals, e-fuels and new nuclear).

Agora Energiewende suggests a domestic 2040 target of 89%, and its analysis focuses on possible pathways to replace existing consumption of fossil gas. They describe uncertainties related to a correct estimation of sustainable and affordable biomethane potential, as well as the need to carefully manage the transition from gas (including LNG) to alternative sources (electricity, hydrogen, and e-fuels) to adapt the corresponding infrastructure and avoid the risk of stranded assets.

TABLE OF FIGURES

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