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3. Challenges and enablers for EGD objectives

Building on the findings of the flagship report “Delivering the EU Green Deal - Progress towards targets“ [1], this chapter further explores existing challenges and potential enablers that will shape the implementation of the green transition. The European Green Deal’s success relies on the effective navigation of potential challenges and the leveraging of opportunities across multiple policy areas and sectors.

To offer a comprehensive understanding of these challenges and opportunities, this chapter covers the seven thematic areas of the European Green Deal, complemented by the cross-cutting theme of critical raw materials. The inclusion of critical raw materials reflects the growing policy significance of this issue for the three transformational pillars to boost competitiveness [2]: closing the innovation gap, decarbonise the EU economy and reducing excessive dependencies.. This integrated approach provides a holistic perspective on these interconnected challenges.

Within each thematic area, this chapter identifies key challenges and enablers that will influence the pace and extent of the green transition. While not exhaustive, these factors highlight critical considerations for policymakers, stakeholders, and practitioners in designing and implementing effective strategies for a successful transition.

Notably, several common challenges and enablers emerge across the thematic areas, including investment needs, innovation, skills development, and monitoring systems. Some of these cross-cutting issues are explored in greater detail in Chapter 4 ‘Strengthening the green transition’ and Chapter 5 ‘Governance for transformative change’, providing a comprehensive framework to address these shared challenges.

This analysis draws on a thorough literature review and experts judgement informed by the latest science for policy work conducted by the Joint Research Centre (JRC).

3.1 Climate ambition

3.1.1 Reducing the Greenhouse Gas emissions

GHG emissions reduction target of 55% within 2030 (EU27 domestic plus international aviation emissions) is one of the key objective of EGD climate policies, of the Fit for 55 package, and it is central to the second pillar of the competitiveness compass for the EU [2]. To a large extent, the 30.4% GHG emission reduction achieved so far was driven by the expansion of renewable energy and increased energy efficiency over the past two decades, but the successful implementation of several elements and objectives of the EGD are crucial for full achievement of this target.

The Emission Trading System (ETS) keeps playing a central role to drive emissions down

The EU ETS has recorded a stable and well-functioning market, driving emissions from power and industry installations (reaching an historic reduction of 16.5% [3] during the last year), while generating over EUR 200 billion [4], [5] in auction revenue for distribution to Member States [6], [7].The anticipated tightening of the emissions cap in the EU ETS has led to significant increases of the carbon price[8]up to the current price of about 70 EUR/tCO2 [9]. According to OECD analysis [9], this **carbon price should be further augmented by other climate policies** by 2030 to be aligned with the targets, andwould have to be applied to a much broader range of economic activities. **Emissions from agriculture and land use are not planned to be covered by a carbon price for the time being.** The EU ETS has been reformed with the Fit for 55 package. In particular, the cap trajectory has been adjusted to contribute to reaching the 55% emission reduction target in 2030. Phasing out free allocation of allowances enhances the price signal faced by affected EU industries as GHG emissions are gradually getting associated with their real cost. It may also generate a price signal for consumers, incentivizing efficient resource use. The current ETS legislation provides a trajectory to eventually phase out allowances in the EU ETS in 2039, but this needs to be revisited in the context of the ETS review in 2026. While adjusting the trajectory of allowances and hence the amount of remaining ETS emissions may cause uncertainty for affected industries, not revisiting this would cause even larger inefficiencies due to diverging efforts across the sectors covered and those not covered by the ETS.

Other barriers to the implementation of Fit for 55 package are related to the economic burden **of these policies**, and especially the **possible economic impact of the ETS2 on household budgets and impacts on small industry**. Carbon pricing for road transport and buildings will affect more low-income households, as they spend a higher share of their income on energy [10], [11] .

While the EU raises its own climate ambition, less stringent climate policies might prevail in many non-EU countries, leveraging the risk of so-called ‘carbon leakage'. To maintain similar competition level and to prevent carbon leakages, the **Carbon Border Adjustment Mechanism** (CBAM) was created[[1]](#footnote-2).

There are, however, still open questions related to CBAM, and not addressing them could **undermine EU competitiveness and lead to emissions leakage**. These concern mainly EU exports to third countries. JRC calculations for the CBAM impact assessmentshow [12] that the phasing out of free ETS allowances weakens the position of EU exporters on global markets. The same may hold true for producers of products that use a high content of inputs from sectors covered by CBAM (“downstream sectors”). While CBAM could be extended to cover more downstream products, this could have drawbacks too as these products are more heterogeneous and complex, making it more difficult to assess the carbon emissions associated with their production.

An international level playing field can also be put at risk by the different policy approaches that are applied by EU’s main trading partners – e.g. USA and China are using subsidies to promote green technologies while the EU is relying more on carbon pricing. This difference in approaches has an effect on energy and basic material prices, which are reduced by climate policies in the US and China but are increased in the EU. This will, of course, also affect downstream industries that use energy or energy intensive products as inputs.

One example is the Inflation Reduction Act (IRA) of 2022 in the US, which was allocated in tax provisions in the order of $400 billion over ten years, aimed at advancing clean energy usage and domestic energy production. The introduction of the IRA has triggered a wave of concern within the European Union regarding the potential economic repercussions. The crux of these concerns revolves around the IRA’s generous tax credits and fiscal incentives that focus on renewable energy, electric vehicle incentives, home energy efficiency upgrades, and advanced manufacturing processes. Critics argue that such measures may catalyse a shift in investment and production from the EU to the U.S., thereby impacting the competitiveness of European industries, particularly those involved in green technology and sustainable practices.

**Potential enablers include:**

* Reforming the ETS is also expected to generate more revenues for Member States, which could increase funding to assist the green transition of industries, e.g. through the **Innovation fund** (which has already funded projects with significant amount of ETS revenues), or be **used to reduce other taxes** (e.g. labour taxes to foster employment creation).
* Moreover, given the need for EU level investments into green technologies to promote the transition while creating synergies among Member States, **the Commission proposed to direct 30% of ETS revenues to the EU budget as a new own resource,** together with revenues from the introduction of the CBAM. These two measures could generate around 8.5 billion euros annually, which would still fall significantly short of the amounts allocated to the green transition in the national Recovery and Resilience Plans.
* The ETS carbon price could also **incentivize emissions removals to offset emissions that are difficult or impossible to avoid**; this would however require adjustments to the ETS – first steps in this direction are being made with the industrial carbon management strategy.
* The scope extension of the ETS to these sectors is tied to the introduction of a **Social Climate Fund** to shield the most vulnerable and to support the transition in these sectors.

Curbing the emissions from the food system: the “polluter-pays principle” needs financial and technical assistance

The EU food system is also a largely emitting sector and key barrier to climate change mitigation relates to the ***complexity of Polluter-Pays Principle***. Implementing the polluter-pays principle within agriculture is challenging, given the sector’s heavy reliance on subsidies and the variety of GHG sources (e.g., enteric fermentation, manure management) (ECA, 2021, EC DG CLIMA 2023). Shifting this responsibility to farmers could face resistance and economic hurdles, particularly for smaller or less profitable farms that may lack resources for mitigation measures.

**Potential enablers include:**

* **Financial and technical assistance** and the enhancement of **innovative practices**. The EU provides funding and technical support to MSs to update and manage their carbon datasets. This support helps alleviate the burden on less-resourced states and enhances data reliability and precision in emissions monitoring across the EU. In addition, the “lighthouses” initiative, part of the Horizon Europe (HE) mission to “Restore our Ocean and Waters,” promotes innovative, localized practices for carbon reduction and serves as a model for sustainable farming and aquaculture (EC DG CLIMA 2021). These examples can help disseminate best practices and create a culture of sustainability within the EU food system.

*The private sector faces challenges to align with the GHG emission reduction goal*

Increased demand for clean tech equipment (e.g. wind turbines and electric vehicles) driven by EU decarbonisation policies can facilitate decarbonisation in non-EU countries through the effects of cost reductions and increased manufacturing capacity. In addition, expertise gained in deploying low-emission equipment in the EU can benefit non-EU countries through the expansion of EU-based companies and workers into non-EU markets. An important barrier may be related to the **accessibility of critical raw materials**, and to the geopolitical implications, as imports are sourced from a limited number of countries. Dependency on few suppliers, in some cases, can challenge the operationalization of specific targets or the uptake of specific technologies (see paragraph 3.3.3, “Critical Raw Materials for the green transition”). Accessibility to critical raw materials (CRMs): compensatory mechanisms can improve the penetration of clean technology in the private sector and at the same time address energy poverty.

Companies have not been obliged to **disclose their emissions** and if they do they might use different reporting systems [13]. However, since January 2023, the [Corporate Sustainability Reporting Directive (CSRD)](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464) entered into force and a broader set of large companies, as well as listed SMEs, will now be required to report on sustainability.

**Potential enablers include:**

* A number of **dedicated funds** are in place (Just transition fund, Social climate fund, Modernisation fund, Innovation fund, and Cohesion fund) [14].
* The “*Green Deal Industrial Plan for Net-Zero Age”* [6]aims at “net-zero industry” in Europe by providing dedicated funds, simplify the regulatory environment and open trade for resilient supply chains.
* In general, the EU needs to strengthened its **just portfolio of climate policies, with a balanced instrument mix to jointly combat climate change and address energy poverty**. Without compensatory mechanisms or financial incentives for marginalized groups, the burden of climate policies like carbon pricing may exacerbate inequalities, slowing societal acceptance and implementation.
* The adaptation and mitigation actions that prioritize equity, climate justice, **right based approaches**, social justice and inclusivity, lead to more sustainable outcomes, reduce trade-offs, support transformative change and advance climate resilient development [15].
* Reporting costs will be reduced for companies over the medium to long term by harmonising the information to be provided. Companies will have to apply the new rules for the first time in the 2024 financial year, for reports published in 2025. It is fundamental to ensure robust corporate reporting system (including the supply chains), and introducing third-party certification bodies, such as the CSRD. This institutional infrastructure could be inspired by existing regulations (e.g. deforestation free regulation) [13] (see chapter “On financing the green transition for more information”).

*Socio-economic and health benefit can go hand in hand with the GHG emissions reductions*

Decarbonisation is expected to lead to significant **health benefits**, mostly through improved air quality, and these can also be related with an **economic benefit** that balances the direct costs of decarbonisation mentioned above [16].

**Potential enablers include:**

* Citizens’ behaviours can directly impact GHG emissions reduction in the mobility, building, energy, and food sectors. Studies highlighted two types of behavioural leverages to boost climate mitigation in households [15], [17]:

1. **Direct governmental expenditures**: investment in infrastructure, such as smart meters; subsidies.
2. **Procedural instruments:** voluntary contract with companies, schools and so on.

* In addition to financial incentives, it is advisable to implement **information dissemination** and environmental awareness rising policies, providing more understanding about renewable energy source (RES) technologies and benefits of energy renovations of multi-flat buildings as well as to ensure middle actors [18] activities in the market by increased assignment of energy efficiency renovation specialists.
* Well-shaped social and behavioural policies can contribute to **educating consumers,** helping households to make right decisions, creating initiatives to improve the quality of homes, to save energy and, in turn, to reduce their energy poverty. There are two main approaches developed by behavioural economics insights: **boosting and nudging.** Both can address important behavioural barriers of climate change mitigation [18]. The IPCC estimated that demand-side measures and new ways of end-use service provision can reduce global GHG emissions in end-use sectors by 40 to 70% (worldwide) by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources [15] (Figure 4.4).

3.1.2 Leveraging the carbon sink of the LULUCF and agriculture sectors

According to the EGD, the land should provide a carbon sink of at least -310 Mt CO2e/y by 2030. However, **the sink has gradually decreased since 2013** from -348 to -236 Mt CO2e in 2022 [20]. This decline is due to a combination of factors, including an increase in harvest demand, age structure of the forests, increase of natural disturbances such as droughts and wildfires, and other climate-related impacts [21].

The forests act as a carbon sink if the biomass in the forests increases. Also harvested wood products can contribute to the LULUCF carbon sink, if more wood products are produced than they decay or are combusted. In addition, forest biomass can be used for bioenergy [21], [22]. Emissions from wood-based bioenergy are included in the LULUCF sector estimates, and they are therefore zero-rated in the energy sector reporting of greenhouse gas inventories. There is a **trade-off between the renewable energy directive that promotes renewable energy source uses, including bioenergy, and the LULUCF regulation** (which shows wood burning as a decrease of the carbon sink).

The LULUCF sector is inherently dependent on the natural conditions in the EU MS, and therefore **no single solution fits all**, but preferable practices might differ between northern and southern EU MS [23].

It is important to find more ways to promote **synergies between climate change mitigation, adaptation, biodiversity and social values of the forests**. In fact, **forests are** the only currently available option for large-scale carbon capture and the **cheapest way to carbon sequestration**. Direct air capture is only at the experimental stage and its cost is estimated to be between 25 and 60 times higher [24] . However, managed forests promoted for enhanced carbon uptake may be more susceptible to climate extremes, leading to higher mortality rates, making it harder to reach the theoretical capacity wished by the mitigation targets [25]. In many cases, this would mean limiting the harvest levels through e.g. lengthening rotation times where applicable (now they have instead been decreasing), making sure that thinning is done in time to promote growth (and that they are not too strong), and making sure that new forest is regenerated as soon as possible after harvest. Large sink capacity of degraded ecosystems can be channelled by developing **biome or site-specific best management practices (BMPs),** the main objectives of which are to achieve integrated nutrient management, a year-round soil cover, enhanced soil structure, and rhizospheric processes as well as reduced loss to prevent erosion and leaching [26]. After all, fulfilling the climate goals set for EU would not mean abandoning forest management, but rather ensuring that it is made in a climate-smart manner – in effect, the GHG emissions targets for the EU-wide LULUCF sector are less than the reported sink before 2016.

Forest monitoring tools need improvement (**small team sizes**, institutional and capacity barriers are currently inhibiting inventory changes ([27] pp. 2021–2025) together with financial instruments for climate smart forest-management, carbon credits and the carbon farming. Some of the main drivers of the decreasing LULUCF sinks are maturing forests and the related increase in harvests and increasing natural disturbances. Incentives to lengthen rotation times and improve resilience through tree species diversity and paying attention to forest and soil health are key in this work.

The agriculture sector is generally seen as ‘difficult’ and expensive to achieve reductions. The sector is steered by the CAP policies, which have had limited success to achieve substantial emission reductions in the past decade (refer to chapter “3.6 Preserving and protecting biodiversity”, for more details). Essentially, there are two main emission sources, the largest source is livestock farming (65%), mostly methane emissions from enteric fermentation and manure management, followed by nitrous oxide emissions from soil management (31%) [28].

**Potential enablers include:**

* There are synergies between the land footprint under the EUDR, the legislative framework proposal for forest monitoring and strategic plans, the CAP, the carbon farming proposal (as announced under the Sustainable Carbon Cycles communication), the proposed revision of the legislation related to forest reproductive material, Soil Health Law, as well as the Nature Restoration Law.
* It is important to understand both **immediate economic motivations and deeper societal, cultural, and policy-related factors** influencing land use decisions [29], [30].Examples are: recognizing the **varied motivations of landowners**, including economic gains, conservation, and recreational uses and leveraging these for sustainable land management [30].
* **Support for Carbon Farming:** The EU’s promotion of carbon farming, along with schemes for monitoring, reporting, and verification, incentivizes farmers to adopt practices that capture carbon (EC DG CLIMA 2021). These practices can include regenerative agriculture, agroforestry, and improved soil management, which not only reduce emissions but can also enhance soil health and productivity.
* There are (relatively expensive) strategies to reduce methane emission from livestock, such as breeding and feeding techniques including diet formulation and the use of feed additives [31]. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050.[[24]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush" \l "_ftn24) They work in the laboratory and field trials, but large scale implementation has not yet been demonstrated. Technology-driven solutions (e.g. enhanced-efficiency fertilizers) and optimization of fertilizer rate may have a considerable mitigation potential. Agroecological mitigation practices (e.g. organic fertilizer and reduced tillage), while potentially contributing to soil quality and carbon storage, may enhance N2O emissions (Grados et al., 2021[[25]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush" \l "_ftn25)). All the strategies on soil management are largely affected by pedoclimatic and farming conditions.

3.1.3 Climate Adaptation and Resilience in the European Union

*The Evidence for Urgent Action*

The European Environment Agency (EEA) reports temperatures in the EU rising faster than the global average, projecting increases of 1.4-4.2°C by 2100 (compared to 1986-2005) [32]. The severity of this challenge became evident in summer 2022, when **record-breaking heat waves** led to over **61,000 excess deaths** across Europe [33]. –The competitiveness compass for the EU highlights includes the creation of a “European Climate adaptation Plan” as a flagship action for the third pillar of competitiveness on increasing security. However, while the European Climate Law sets legally binding targets for emissions reduction, **adaptation lacks concrete, enforceable goals** [34].

**Economic Impacts**: The scale of financial risk is substantial. The EEA documents **€520 billion in losses** from climate-related events within the period 1980-2020 [35]. Future **adaptation costs** are projected to range from €35-62 billion annually in the 2020s, escalating to €158-518 billion by the 2050s [36]. The **JRC's PESETA IV study** presents a stark outlook: under a 2°C warming scenario, Europe faces annual **wealth loss** of 1.9% of GDP by 2050, with potential **infrastructure damage** increasing tenfold under business-as-usual conditions [37].

**No standardized and clear assessment of adaptation needs and adaptation benefits:** Investments for climate adaptation differ from those in climate mitigation in several aspects, which have a bearing on the incentives to raise private funding (Mullan & Ranger, 2022). First and foremost, there are **no unique standards and methodologies to assess physical risk** and the reduction thereof from adaptation investments. This hinders the definition of any clearly quantified and internationally agreed targets for adaptation, as well as the assessment of its economic benefits. Additionally, market actors suffer from **information asymmetries and knowledge gaps**, which reduce their incentive and ability to invest in adaptation (Stout 2022). As a result, many companies are underestimating the threat of physical climate risks, leading to a potential increase in the costs and the risks resulting from a late adoption of adaptation plans (S&P Sustainability Research 2024).

**Sectoral Vulnerabilities**: Climate impacts create interconnected challenges across sectors. **Water stress** will affect 89.6 million Europeans by 2030 according to EEA forecasts [38]. **Agricultural productivity** faces severe threats, with yields potentially declining by up to 50% in Southern Europe by 2050, which are not expected to be compensated by increased yields in northern countries [39], [40]. The **Mediterranean region** particularly exemplifies these compound risks, facing doubled **wildfire risk** by century's end while also managing increased drought frequency and intensity [41], [42].

**Implementation Status**: The current response shows mixed progress. While all 27 Member States have adopted **adaptation strategies**, their effectiveness varies significantly. Some policy areas demonstrate successful **mainstreaming** - the Water Framework Directive and CAP now incorporate climate considerations. However, critical sectors like **energy** and **transport** still have to develop a consolidated adaptation planning. The EEA emphasizes that current adaptation actions must increase in both **pace** and **scale** to match growing climate risks [43], [44].

*From Challenges to Strategic Opportunities in the EU Adaptation*

**Systemic Barriers to Action**: Current adaptation efforts face four interconnected challenges, as documented by EEA [36], [43]. **Financial barriers** extend beyond initial investment costs - EIB and EEA identify uncertain returns and limited private sector engagement as key obstacles [45], [46]. **Institutional fragmentation** complicates coordination, highlighting disparities between governance levels [36], [47]. Such challenge is at the core of the EU competitiveness compass, which has identified “simplification” as the first horizontal enabler towards competitiveness [2]. **Information gaps** persist in local-level climate projections, while **behavioural barriers** include resistance to transformative changes in traditional practices [36], [48].

**Cross-Sectoral Opportunities**: Evidence shows adaptation actions can advance multiple EU priorities simultaneously. **Nature-based solutions** demonstrate clear co-benefits; (Griscom et al., 2017)[49] document enhanced carbon sequestration alongside adaptation benefits [49], [50]. In urban areas, **green infrastructure** delivers quantifiable improvements in air quality and public health [51], [52]. Vandeplas et al. (2022) identifies significant **job creation potential** through adaptation projects, particularly in vulnerable regions [52], [53].

**Innovation and Economic Potential**: The adaptation challenge presents opportunities for EU leadership. The European Commission identifies emerging markets for adaptation technologies and services [54]. **Cross-border cooperation** on shared climate risks can strengthen EU cohesion, while **technological innovation** in areas like early warning systems shows benefit-cost ratios exceeding 1:10[55], [56]**.**

**Reducing the information gap by providing data and methodologies to assess climate risks:** The EC is already engaged in providing better access to climate risk data and assessment, as proved by the 2024 European Climate Risk Assessment (a report from the EEA regarding the identification and evaluation of climate risks) [43]and the JRC Risk Data Hub (a multi-hazard geo-portal mapping climate risk into the EU territories) [57]. More and better climate-related risk and loss data is also advocated by the new EU Strategy on Adaptation to Climate Change (2021) [58].At the same time, the EC recognizes the need for a comprehensive framework for climate risk adaptation assessment [59] so further efforts will be necessary to extend data coverage and access and to diffuse harmonised risk assessment methodologies and standards. To address these barriers, EU MS can help by increasing the availability of data to assess localised climate risk and vulnerability

*From Analysis to Implementation*

The analysis has shown that while all EU Member States have adopted adaptation strategies, their effectiveness varies significantly, particularly in critical sectors like energy and transport. Moving forward requires addressing the fundamental challenge documented throughout this analysis: the lack of standardized methods to evaluate adaptation needs and benefits [60], [61], [62]. This gap affects both policy design and the capacity to mobilize private investment [45], [63], [64], [65].

The EU Adaptation Strategy provides a framework to address these challenges through three complementary approaches [66], [67]: Financial innovation to overcome investment barriers, policy integration to mainstream adaptation across sectors, and capacity building to address regional disparities. While the mechanisms for effective adaptation exist, accelerating implementation requires better coordination between governance levels and clearer methods for assessing progress.

Current evidence demonstrates that early, strategic action delivers multiple returns across EU policy objectives [68], [69], [70]. The mechanisms and frameworks for effective adaptation exist - the critical task is **accelerating implementation** at scale.

3.2 Clean, affordable and secure energy

The revised Renewable Energy Directive (RED III) took effect in 2023, setting a binding target for the EU's renewable energy share to at least 42.5% of final energy consumption by 2030, with an ambition to reach 45% (EC, 2023). In 2022, renewables accounted for 23% of the EU's final energy consumption. This section provides an overview of the main challenges and enablers facing renewable energy sources in the EU (solar, wind, ocean, offshore and renewable hydrogen), and will also address energy efficiency and buildings renovation.

3.2.1 Solar

Solar energy, particularly photovoltaics (PV), will play a central role in the EU and global energy transitions. Solar thermal energy also has significant potential, particularly in heating, cooling, and industrial processes. However, to achieve the massive expansion of solar energy, the EU needs to address several challenges.

*Deployment*

By 2030, the EU aims to **triple** its installed solar capacity in line with the REPowerEU policy. This growth is expected to continue as electrification expands to meet new energy demands in transport, buildings, and industrial sectors. However, uncertainties around climate policies and regulations may hinder PV industry growth. For instance, inconsistent national policies create a fragmented market, and delays in transposing EU directives into national law can slow down progress. Fragmentation in the national policies and markets is also identified as a pivotal issue in the Competitiveness Compass [2].

Photovoltaic electricity is now the cheapest source of power in most regions, yet streamlined planning and permitting processes are critical to facilitating expansion. Simplified procedures, from local to regional levels, and the identification of priority areas are necessary: for example, the European Solar Rooftops Initiative promotes rapid PV deployment by requiring Member States to ensure buildings are "solar ready."

Innovative deployment models, such as agrivoltaics, floating solar installations, PV-integrated motorway sound barriers, and solar-enabled parking lots, can reduce land-use competition [82].

Another challenge is the shortage of skilled workers in the PV industry. The EU is addressing this through the large-scale skills partnership under the Pact for Skills, which focuses on workforce development in the solar sector.

*System Integration*

Solar PV alone cannot meet energy needs—it depends on a robust, integrated energy system that balances supply, demand, and storage. Adapting distribution networks to accommodate decentralized solar installations is essential. The EU is improving electricity networks and market rules to make the energy system more flexible and efficient. This helps avoid problems like extremely low electricity prices during high supply periods and reduced profits for renewable energy producers. .

Innovative PV deployment methods, such as East-West-facing vertical panels in agrivoltaics and motorway barriers, can help balance uneven production patterns. Strengthening the transmission system is also vital, ensuring rapid-response backup capacity as a substitute for traditional spinning reserves.

*PV Manufacturing, R&D, and Strategic Autonomy*

The EU currently depends heavily on imports from China, which dominates the global PV market with 87% of cell production and 82% of module production. In contrast, the EU manufacturing capacity accounts for just 0.3% of global cell production and 0.9% of module production. New policies like the Net Zero Industry Act (NZIA) [83] aim to encourage investment in manufacturing capacities, reducing dependence on imports and increasing competitiveness.

Initiatives such as Ecodesign for photovoltaic modules will help promote European production by enforcing carbon footprint limitations on products sold in the EU. Expanding domestic manufacturing comes with material supply risks—such as silica, silver, and PV glass shortages—but measures under the Critical Raw Materials Act (CRMA) [84] will play a key role in addressing these issues. The European Solar PV Industry Alliance supports these efforts, fostering collaboration and investment.

To drive innovation and reduce costs, the EU must increase R&D funding and strengthen partnerships between industry and research institutions, such as the proposed PV Research and Innovation (R&I) Partnership. Currently, private R&D investment in the EU lags behind that of China and other countries, underscoring the need for enhanced efforts.

*Solar Thermal Energy*

Solar thermal energy currently plays a niche role in electricity production and heating and cooling. Growth is also low, except for solar water heaters in Mediterranean regions and as a supply for district heating systems. The EU has strengthened support for greater deployment in recent policies and continues to fund a broad range of research and innovation projects.

3.2.2 Wind, ocean, offshore

In 2023, the EU installed 16 GW of new wind capacity—13 GW onshore and 3 GW offshore—bringing the total capacity to 220 GW (201 GW onshore and 19 GW offshore). This marked a record year for offshore installations and the second-best year for onshore deployment. While these achievements are encouraging, they remain below the trajectory required to meet the EU's ambitious 2030 targets.

This overview highlights key challenges facing the wind energy sector and enablers that can facilitate its growth and align with the 2030 objectives.

Challenges in the wind energy sector include several significant barriers that hinder its growth and development. One major obstacle is administrative barriers, particularly the slow permitting process for new installations. This bottleneck often results in delayed project timelines and increased costs. Additionally, the sector faces supply chain risks due to the European Union's reliance on a single non-EU country for critical raw materials, such as rare earth elements, which can disrupt supply chains. Another challenge lies in grid integration and infrastructure, as incorporating wind energy into existing grids demands substantial investment in transmission and distribution networks to maintain grid stability and effectively balance supply and demand. Public acceptance is also a concern, as wind energy projects often encounter resistance from local communities or organized opposition groups, citing issues like noise, visual impact, and wildlife protection. Finally, achieving scalability and meeting ambitious 2030 targets will require significantly increasing annual deployment rates, which poses challenges in manufacturing capacity, logistics, and workforce development.

Despite these challenges, there are several enablers driving the growth of the wind energy sector. Competitive costs are a key advantage, with the cost of onshore wind dropping significantly to a global weighted average levelised cost of energy (LCoE) of EUR 31 per MWh [85], making it highly competitive with fossil fuels. The EU also boasts a strong manufacturing capacity, with European companies dominating both the domestic onshore and offshore markets. Furthermore, the EU is a leader in public research and development (R&D) investment in wind energy, with Member States contributing 35% of all public investment in the sector from 2013 to 2022. New deployment opportunities are presented by innovations such as floating offshore wind technology, particularly in countries with steep shorelines. Lastly, implementing recycling and circularity practices not only promotes innovation but also alleviates supply chain pressures and enhances public acceptance of wind technology.

**A Path Forward**

While the EU wind energy sector faces notable challenges, such as administrative barriers, supply chain risks, and infrastructure limitations, several key enablers offer a pathway forward. The Action Plan for Affordable Energy outlines eight short-term measures to strengthen the Energy Union, ensuring competitiveness, affordability, security, and sustainability. Competitive costs, robust manufacturing capacity, R&D leadership, and emerging technologies like floating offshore wind provide a strong foundation for growth. By addressing these challenges and leveraging its strengths, the EU can advance towards its 2030 targets and contribute significantly to the transition to a low-carbon economy.

3.2.3 Renewable Hydrogen

Renewable hydrogen has the potential to be a key driver in decarbonising energy-intensive industries and transport, playing a crucial role in achieving net-zero emissions by 2050. It is particularly suited for sectors where direct electrification is challenging. The deployment of renewable and low-carbon hydrogen is intrinsically tied to the availability of renewable electricity, inheriting the challenges associated with scaling renewable energy sources.

**Hydrogen applications**

Current uses for renewable hydrogen include replacing fossil-based hydrogen in oil refining, fertiliser and methanol production, electronics, glassmaking, and metal processing. Emerging applications include steelmaking via direct iron reduction, heavy-duty transportation, hydrogen-based fuel production (e.g. ammonia and synthetic hydrocarbons), biofuel upgrading, high-temperature industrial heating, and electricity storage and generation.

Although demand for low-carbon or renewable hydrogen grew by nearly 10% in 2023, it still accounts for less than 1% of global hydrogen demand [86]. Its higher cost compared to fossil-based hydrogen remains a significant barrier, necessitating policy intervention to close the cost gap and stimulate adoption in new and existing applications.

**Policy frameworks**

The EU has developed a comprehensive regulatory and policy framework to support hydrogen's role in the energy transition. This includes the Delegated Act [87], which outlines the methodology for renewable fuels of non-biological origin and defines the eligibility criteria for renewable hydrogen. As well as the EU hydrogen and gas decarbonisation package that introduces a regulatory framework for hydrogen infrastructure, enabling repurposing of natural gas assets for hydrogen use and promoting the use of renewable and low-carbon gases.

**Technological readiness**

Key hydrogen technologies, such as water electrolysers and fuel cells, are commercially available and scaling rapidly. Initiatives like the Clean Hydrogen JU are improving efficiency of these technologies, addressing supply chain issues, reducing reliance on critical raw materials and addressing issues related to sustainability and recycling. Large-scale projects, such as Yara’s 24 MW electrolyser in Norway (the largest in Europe as of 2024 [88]) showcase progress, though efforts to enhance recycling and reduce reliance on critical raw materials persist.

**Policy and regulatory gaps**

The European Court of Auditors [89] has criticized the EU's hydrogen strategy for setting overly ambitious targets without sufficient impact assessments.

A lack of harmonisation across EU policies and ISO standards for assessing GHG emissions of hydrogen production could slow down the hydrogen economy. A unified framework is essential to prevent greenwashing and ensure investor confidence.

**Demand uncertainty**

Only 12% of hydrogen projects in the EU have identified off-takers, with few securing binding agreements [90]. This lack of demand certainty delays investment decisions and project development.

**Competitive hydrogen production**

**High costs**: the rising electricity prices across European economies increase the levelised cost of hydrogen, weakening the business case for electrolysis technologies. European electrolyser systems, including both stacks and balance-of-plant components, are 3-4 times more expensive than their non-European counterparts.

**Global competition**: Europe leads in proton-exchange membrane (PEM) electrolyser technology, which is well-suited for renewable energy systems. However, Chinese companies are rapidly advancing in this area, offering significantly cheaper electrolysers and narrowing the quality gap.

Additionally, Europe relies heavily on imported critical raw materials and lacks a robust recycling infrastructure for electrolysis stacks. While cost-reduction strategies are underway, non-European countries have already surpassed Europe in manufacturing capacity for PEM electrolysers.

**Supply chain challenges**

The EU relies heavily on imports for critical raw materials used in electrolysers and fuel cells. The hydrogen industry depends on over 40 raw materials and 60 processed materials for electrolyser production, with significant supply chain challenges:

**Limited EU resources**: the EU supplies only 1% of the raw materials needed for PEM electrolysers and 5% for solid oxide electrolysers. For PEM technology, 43% of critical raw materials are sourced from China, while for anion exchange electrolysers, this figure rises to 63%.

**Global dependence**: key suppliers of raw materials include China, South Africa, and Australia, while processed materials are predominantly supplied by the EU, US, China, and India.

**Precious metal constraints**: catalysts like iridium and platinum, essential for PEM electrolysers and fuel cells, are primarily sourced from South Africa, Russia, and Zimbabwe. Iridium supply, in particular, is a bottleneck for large-scale deployment unless advancements in catalyst loading and recycling are achieved.

**Infrastructure Deficits**

The EU lacks a mature hydrogen transport, storage, and distribution network, as well as reliable offtake agreements for renewable hydrogen.

**Environmental Concerns**

Large-scale electrolyser deployment may result in environmental risks, such as the release of per- and polyfluoroalkyl substances (PFAS) in wastewater. This area requires comprehensive data and further research [91].

**Reducing Manufacturing Gaps**

Although Europe holds a strong position in component manufacturing, it accounts for only 12% of global fuel cell production, lagging behind other regions. In contrast, Europe is a leading producer of electrolyser stacks [92].

**Improving Electrolysers performance**

The intermittent nature of renewable energy sources creates additional challenges for the performance and safety of electrolysers [93]. Developing standardised methods is crucial to understand how intermittency affects electrolyser efficiency and durability.

**Potential enablers include:**

* **Policy reforms**: Harmonize EU and international standards for hydrogen GHG assessments and certifications to ensure consistency and prevent "greenwashing".
* **Cost reduction**: Invest in scaling up production, recycling, and innovative designs to lower costs and improve competitiveness.
* **Supply chain diversification**: Reduce reliance on non-EU suppliers for critical raw materials and strengthen recycling capabilities to secure long-term resource availability.
* **Infrastructure development**: Establish a dedicated hydrogen transport, storage, and distribution network to support widespread adoption.
* **Market activation**: Create demand-side incentives and secure long-term contracts to provide certainty for investors and stakeholders.

3.2.4 Buildings and energy efficiency

The European Union is making significant progress in enhancing energy efficiency but still faces challenges in meeting its ambitious 2030 energy efficiency targets. This overview highlights key obstacles and potential enablers in the building sector, particularly regarding heating and cooling.

*Retrofitting Challenges in Existing Buildings*

Most buildings in the EU were constructed before modern energy efficiency standards were established, making retrofitting a substantial and resource-intensive endeavour. While energy-efficient technologies like heat pumps, geothermal systems, and district heating are available, they may not be universally applicable. For instance, heat pumps require well-insulated buildings to function optimally. However, a shortage of skilled professionals to install and maintain these advanced systems presents a barrier. Retraining gas boiler installers to work with new technologies, such as heat pumps, offers an opportunity to bridge this skills gap.

*Health and Safety Risks in Renovation Projects*

The Renovation Wave strategy, while promising, raises health concerns, particularly related to asbestos exposure for construction workers and occupants. Inadequate documentation on asbestos presence and removal across the EU exacerbates this issue [94], with few countries addressing it in their Long-Term Renovation Strategies. Unexpected asbestos discoveries can delay renovation projects and pose health risks. Regions with both high asbestos use and seismic activity require special attention, as earthquakes can release harmful fibers. Addressing these risks is essential to ensure safe indoor environments and maintain progress toward energy efficiency goals.

*Human-Centric Design and Social Equity*

A human-centric approach is critical to achieving energy efficiency while ensuring occupant well-being, especially given climate-change-driven risks like summer energy poverty, which disproportionately affects vulnerable populations. Efficient subsidy schemes are necessary to make energy-efficient investments more attractive to building owners.

In rural areas, larger, less compact buildings present energy efficiency challenges, but higher rates of homeownership (around 78%) may facilitate renovations. Conversely, urban areas benefit from more energy-efficient building typologies, though lower ownership rates may complicate financing efforts.

*Technological Advances and Digitalization*

Innovations such as heat pumps, clean technologies, and renewable energy integration significantly enhance energy efficiency and reduce greenhouse gas emissions from heating and cooling systems. These advances also boost EU competitiveness and secure the supply of key components and materials. Smart grids and demand-response systems enable real-time energy monitoring and management, optimizing consumption and reducing peak demand. AI-driven data collection and analysis can further support digitalization and efficiency improvements in the building sector.

*Policy and Financial Support*

Governments and regulatory bodies play a vital role in advancing energy efficiency through policies like building codes, tax incentives, and subsidies. Green financing mechanisms, including green bonds and energy performance contracts, provide building owners and managers with the resources needed for energy-efficient renovations. Additionally, private investments and diversified funding options serve as critical enablers.

*Defining Deep Renovation*

Establishing numerical energy and emissions benchmarks for deep renovations ensures that projects meet nearly zero-energy and zero-emission standards, avoiding lock-ins and supporting 2050 decarbonisation goals. Significant funding has been allocated to these efforts, including EUR 21.1 billion from EU Structural Funds (2021-2027) and EUR 81.1 billion from the Recovery and Resilience Facility (2021-2026) [95].

*Adopting a Whole Life Cycle Approach*

A life-cycle perspective that minimizes carbon footprints, embodied emissions, and resource consumption can drive the building sector toward climate neutrality. This approach promotes sustainability and climate resilience while integrating the sector into a circular economy.

*Enhancing Occupant Engagement*

Combining advanced technologies, such as adaptive thermal controls, with traditional strategies like natural ventilation ensures balanced energy efficiency and occupant comfort. Behavioural interventions, such as default energy-efficient temperature settings and digital literacy training, encourage sustainable energy use. Participatory design that accounts for diverse occupant needs and cultural practices further enhances well-being while reducing energy consumption.

Providing educational resources, training programs, and consultations empowers building owners and policymakers to make informed decisions about renovations and technologies. Together, these strategies align the building sector with the EU's 2030 energy efficiency and 2050 decarbonisation targets.

3.3 Circular economy

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The 2020 CEAP has prompted a series of ambitious and innovative legislation and policies. Most policies on waste and circularity succeeded in improving recycling and material recovery but did not have as much impact on upstream circular policy objectives (e.g., minimising waste through design) with greater environmental savings potentials[1], [108]. From a sectoral perspective, the European Commission announced several circularity initiatives, such as the Strategy for Sustainable and Circular Textiles [109] and the 2023 Batteries Regulation [110]; however, policy action for electronics & ICT and construction sectors needs to be accelerated. The circularity of different resource groups varies, for instance metals show the highest circularity levels, thanks to well-established recycling systems and favourable economics. Nonetheless, metals still offer substantial scope for further circularity improvements, which could contribute to resource savings, decarbonisation, and reduced environmental impacts.

Some circular economy policies introduced in recent years can be characterised by a high degree of complexity and have placed additional regulatory burden on EU institutions and, more critically, on EU businesses. How effective these intricate policies actually are in fostering a more circular economy still remains to be fully assessed. As the European Commission shifts focus to cultivating lead markets, including those for sustainable, circular, and low-carbon materials, it is crucial to avoid overly prescriptive regulations dictating the precise materials and sources for certain products. Any regulatory proposals that increase bureaucratic hurdles must be carefully considered, ensuring these have a significant likelihood of achieving the intended outcomes without inadvertently distorting the market through inaccurate predictions of technological and market evolutions.

Unsurprisingly for a relatively recent environmental policy work stream with such a large scope and complexity, the flagship report “Delivering the EU Green Deal - Progress towards targets“[1] showed that little or no progress has yet been achieved to meet the overarching ambitions of decoupling economic growth from resource use, reducing and keeping EU’s consumption footprint within planetary boundaries (see Chapter 2), increasing circular material use rate and reducing waste generation. Until now, circular economy policies have largely been used as a means of reconciling economic growth with environmental protection, with a rather defensive approach. However, an opportunity now exists to adopt a more proactive stance, leveraging circularity to enhance the competitiveness and resilience of the EU economy.

3.3.1 Moving to an economic and legal framework that supports circularity for competitiveness

*Removing subsidies for linear models and internalising externalities in prices*

Despite the growing political commitment of the EU towards a CE, **high levels of fiscal support to linear business models still prevail**, to the detriment of the competitiveness of circular alternatives and their uptake [111]. Overall, resource extraction is still subsidised directly by government budgets and tax measures, and indirectly through economic instruments that distort price signals by not reflecting the full social costs associated with environmental externalities in material production and consumption [112]. This means that prices of many primary raw materials remain low compared to those of secondary raw materials, thus affecting negatively the demand for recycled materials (which can only compete if their price is below that of primary raw materials and their quality is perceived as equivalent or at least sufficient quality) [112]. This is particularly relevant for Critical Raw Materials (CRMs), whose market is largely dominated by primary raw materials, given that recovery of CRMs in key waste streams is still immature, both in technical and economic terms [113].

As the EU continues to develop circular economy policies, it becomes clear that existing economic instruments have primarily increased the costs of natural resource use, polluting and carbon-intensive activities, and potentially impacting EU industries' competitiveness. There is now an opportunity to explore an alternative approach: **making recycled, sustainable, and decarbonised materials cheaper through subsidies and obligations** to foreign and EU companies to finance the recycling or reprocessing of waste that stems from the products that they placed on the EU market. By recalibrating economic incentives, it may be possible to strengthen EU businesses' competitiveness, while still pursuing a more sustainable production and consumption systems and accelerating the transition to a carbon-neutral economy.

**Potential enablers** to be consideredcould include:

1. Shifting subsidies from primary to secondary raw materials, product reprocessing and dematerialisation
2. Accounting for the environmental impact of mining and processing primary raw materials through higher VAT tax at sales points or lower VAT for recycled material sales
3. Capping the use of primary raw materials – for instance, it could follow a similar approach to the Energy Efficiency Directive and could target primary raw materials entering the economy (which for imports could tie with a CBAM-like measure), while also aiming at a common-denominator approach (cf. GHG) as first concept. However, the design, implementation specificities as well as costs and benefits of such policy instrument need to be further assessed.

*Adapting our legal framework*

The linear economic model is largely based on cost reduction to offer attractively-priced new products, resulting in a competitive relationship with suppliers. By contrast, a circular business model encourages all actors in a supply chain to work together to preserving value along the supply, production, use and reuse chain. Also, the circular economy changes the hierarchy between products and services, with the latter embedding products use in the nature of transactions. This development known as ‘servitisation’ is based on the premise that by integrating services with products, companies can create bundles that are more valuable than products alone: people want light instead of light bulbs, thermal comfort instead of heating or cooling systems.

**Potential enablers** to be considered could include:

1. Study legal and fiscal frameworks enabling the switch from ownership to ‘usership’ models be it through sharing or servitisation, such as changes in liability rules, facilitating vertical agreements for circularity or aligning patent legislation with the sharing and collaborative nature of circular practices.

*Fostering demand for circular economy models*

The Draghi Report [114] has placed CE at the centre of EU competitiveness, for example by advocating for vertical convergence in key value chains (e.g., batteries and vehicles), thus calling for full integration of circularity in value chains to improve competitiveness. While vertical convergence of waste management, recovery of secondary raw materials and producing new materials (e.g. steel) may help harness the value of materials contained in waste, open questions remain on the alignment between individual corporate interests (particularly of multinational companies) and public interest in improving competitiveness and resilience of the whole EU economy.

CE-related innovation has been confined to niche markets, as such there are difficulties in scaling up and transitioning from R&D to large scale productions, which are considered a prerequisite for ensuring sufficient returns on investment [115]. Circular practices, such as repair and remanufacturing, struggle to financially compete with massive-scale linear production practices [111]. Whilst these practices could potentially contribute to the creation of local jobs, the increased labour component would also likely lead to making several circular products more costly than linear products [115]. European consumers show little demand or willingness to pay for circular products/business models, due to higher prices and lack of understanding of benefits, including environmental 24 . Finally, the lack of economic incentives and the prevailing labour-oriented tax system can also affect negatively the competitiveness of circular business models [112].

**Potential enablers** to be considered could include:

1. Requiring large corporates to steadily increase the share of secondary/virgin materials or remanufactured/reprocessed parts in their supplies.
2. Increase, through instruments such as ESPR, the opportunities for repair, remanufacture, refurbishment and reuse of products and facilitate their trade through economic instruments (beyond extant VAT exemption).
3. Labour tax reduction for servicification of access to circular or shared products.
4. Set sectoral public procurement rules with regard to minimum % share of circular products or secondary material use (i.e. buildings, infrastructure, transport, IT for refurbished products).
5. Set minimum circularity criteria in State Aid eligibility rules.

*Fostering investments in recycling and better designed economic instruments for waste management*

The recovery of high-quality materials is essential to ensure circular flows across the economy, as well as the displacement of primary raw materials and less reliance on resource extraction. Investing on high quality sorting and recycling operations requires high up-front investments associated with high transaction and search costs to predict quality of input waste feedstock for recycling, their pre-treatment and implement quality assurance systems to ensure recycled materials’ quality to be used in manufacturing [112][[2]](#footnote-4). This combined with volatile prices for virgin raw materials and high risks and uncertainty of investing in new processes and technologies has led to a lack of investor trust in investing in CE-related activities [112].

Furthermore, a weak waste management tax system and insufficient accounting of environmental externalities linked to some practices of waste management still make recycling an economically unattractive option. Particularly, for concrete, insulation materials, bricks, and glass. For instance, EEA has estimated that the average EU-27 landfill tax on municipal waste is approximately 38 EUR per tonne, whilst for mineral waste JRC and EEA estimate approximately 19 EUR per tonne [116], [117]. Simply increasing landfill taxes does not appear to be the best solution. An on-going JRC project[[3]](#footnote-5) focusing on construction and demolition waste has emphasised that high landfill tax can deter landfilling, not towards higher levels of the waste hierarchy (e.g., recycling), but rather towards counterproductive measures, such as illegal dumping. Other policy measures, such as an advance fee paid at the moment of purchase (rather than at the moment of disposal) could be further analysed for different materials and products. In addition, the introduction of “pay-as-you-throw” waste collection systems (i.e., differentiated fees for sorted and unsorted waste) could encourage citizens to actively sort recyclables for separate collection. While, the expansion of Extended Producer Responsibility (EPR) schemes to waste streams, such as textiles, can contribute to increased collection and recycling rates.

**Potential enablers** to be considered could include:

1. Leveraging public-private initiatives to stimulate investments in recycling capacity and technologies.
2. Set-up a cap and trade system for landfilled waste and national level, with an annual predictable decreasing factor.
3. Identify and map missing capacity for the recycling and treatment of key materials and their use as secondary raw materials.
4. Research agenda for affordable recycling technologies for high quality secondary materials.

3.3.2 Developing and improving the functioning of Secondary Raw Material markets

Secondary Raw Material markets enable the circulation of high-quality recycled materials in the EU economy, potentially substituting primary raw materials and decreasing the need to extract natural resources as a result [111]. Establishing well-functioning EU secondary raw material market has been highlighted as a key component of the CEAP, however currently the secondary raw material market for wood, plastics, bio-waste, aggregates from construction and demolition waste, and textiles are not functioning well [112].

*Supply: Circular product design and demand*

The ESPR [118] will contribute to overcoming several challenges related to product design and manufacturing, as it will enable the setting of ‘ecodesign requirements’ for physical products [119], facilitating products’ disassembly, repair and recycling. In addition, ESPR will enable mandatory Green Public Procurement (GPP) criteria, which can further incentivise the uptake of more sustainable products and potentially contribute to the demand for circular products and secondary raw materials [112].

Products’ complexity and the *plethora* of additives and chemicals used in everyday consumer products make it difficult for recyclers to identify whether substances of concern are or not in their products and ensure a constant quality output. The digital product passport (implemented under the ESPR and other legislation, such as Batteries and waste Batteries Regulation) aims to improve transparency by providing information about products’ composition and when relevant dismantling information, which will not only contribute to improving recycling, but also to identify and improve material recovery, including of critical raw materials [120]. Increased knowledge on the presence of substances of concern in products covered under ESPR, made available via the DPP, should contribute to address the need to reduce the use of substances of concern that have a negative effect on recycling and/or reuse.

**Potential enablers** to be considered could include:

1. Measures that foster design for recycling (through ESPR, and minimum requirements), including restrictions on substances and/or design characteristics hindering material recovery and recycling in all products containing relevant quantities of valuable resources.
2. Extending and harmonising the application of eco-modulated fees for EPR schemes, this could create strong incentives to design products for increased repairability and recyclability, as producers would pay less to producer responsibility organisations if they are putting more repairable or recyclable products on the market.
3. Introducing a minimum circularity criterion as a market entrance condition for relevant material streams (e.g., electric and electronic equipment), following a similar approach as that used in the Packaging and Packaging Waste Regulation for packaging.

*Improving waste management*

The new Waste Shipment Regulation [121] has limited the export of waste to non-OECD countries, thus aiming to increase the availability of waste feedstocks for the EU’s secondary raw material markets. However, ensuring supply of adequate waste feedstocks for maximum recycling continues to be a challenge. Furthermore, considering the current shifts affecting the principles on which trade policies have been based in recent decades, key questions arise such as, will it become possible and convenient to openly pursue a ‘Recycle in Europe’ strategy or an initiative for secondary raw materials that are needed by the energy-intensive, strategic or critical industries for the sake of competitiveness or resilience and for which materials and waste streams could this be beneficial.

The lack of separate collection obligations and/or Extended Producer Responsibility (EPR) schemes for some waste streams and the lack of harmonised collection systems continues to affect the functioning of the single market for waste and secondary raw-materials [112]. For example, selective demolition of buildings is not currently ‘mandatory’. Similarly, for textiles, separate collection is currently mainly done by NGOs and charities to retrieve good quality re-wearable clothes (app. 30%), whilst the rest ends up in residual waste. In this regard, JRC is currently working on a labelling systems for packaging and waste containers that will enable consumers to better sort their waste and help produce higher quality of secondary raw materials [122]. Under the proposed Packaging and Packaging Waste Regulation (PPWR) [123], uniformed waste sorting labels will be mandatory. Harmonised waste sorting labels could be further expanded to tackle emerging challenges related to new materials (e.g., bioplastics) and risks associated with label proliferation and unreliability.

Significant losses exist at collection, sorting and processing of recyclable materials. For example, sorting losses for plastic packaging are very high (up to 40% for some polymers) and the final recycling rate is estimated at ca. 25%, including exported for recycling [124]. The lack of harmonised of End-of-waste (EoW) criteria at EU level impedes the development of a single market for secondary raw materials, hindering trade among Member States. This also creates administrative and economic burdens, especially for SMEs [112]. JRC has developed proposals for EoW criteria for steel, aluminium, plastics [125], glass cullet, waste paper and a series of waste-derived fertilisers and is currently working on proposals for textiles and construction & demolition waste [126]. This has been done in an overall policy context, in which free-trade of safe waste-derived materials was desirable. In an environment where keeping waste derived materials in the EU as a source of autonomy and resilience is a relevant factor, the approach to end-of-waste might be worth reconsidering.

Insufficient waste sorting and recycling capacity can limit the expansion of EU secondary raw materials markets [127]. In addition, the lack of suitable recycling technologies at competitive costs can impact the price of secondary raw materials, making these less attractive for producers. Thus, there is a need to develop cheaper solutions to cope with specific features of each material stream. For example, recovering and recycling of metals and other materials from batteries and WEEE might require different processes for each of the different metals and materials [112].

**Potential enablers** to be considered could include:

1. Strengthen and expand EPR schemes to more products.
2. Improving and harmonising waste collection systems – developing harmonised waste sorting labels; use of economic instruments to reduce the generation of unsorted waste (e.g., “pay-as-you-throw” schemes) and awareness-raising and information campaigns.
3. Developing a framework and criteria to categorise recycling quality.
4. Developing and harmonising EoW criteria for more waste streams, while including safeguards to avoid by-passing of extra-EU waste export restrictions under the Waste Shipment Regulation that would facilitate leakage of those secondary raw materials.
5. Consider radically changing the approach to end-of-waste so that EoW status is only applied when a material has been fully recycled (e.g., into steel products).
6. Assessing the costs and benefits of pursing a ‘Recycle in Europe’ or similar initiative and identifying which materials and waste streams could benefit from such a policy measure.

*Stimulate demand for high-quality of secondary raw materials*

Ensuring steady and long-term demand of secondary raw materials is essential to continue developing secondary raw materials markets. Recycled content requirements (including minimum mandatory rates) is one of the policy options to stimulate demand.

Setting recycled content requirements is often rather complicated and administration-intensive. Policy makers need to understand in much detail not only how recycling markets and technologies will develop over time, but also the specific nature of technological progress for the products in which recycled materials should be used. For instance, in the case of batteries, it is a daunting task to anticipate how changes to battery chemistries, but also progress in recycling technologies will affect the demand for specific metals, as well as the composition of waste batteries. At the same time, compliance monitoring on recycled content is not possible without stringent reporting and verification schemes involving all relevant economic players along value chains (e.g., for non-EU secondary raw materials, challenges may be anticipated when verifying the origin of recycled materials). In the short to medium term, such monitoring can lead to additional administrative burden and new reporting obligations, especially when completely new digital systems are not yet operational.

Current work on recycled content targets (e.g., in packaging, batteries, and potentially soon in vehicles) will seek to develop fit-for-purpose technical guidance and assess the real costs and benefits of this policy option, depending on materials and products in scope. EU competitiveness and EU open strategic autonomy (e.g., sharp rising prices for recycled materials affecting EU secondary raw materials versus non-EU secondary raw materials) will also be considered. Alternative policy instruments for stimulating demand of secondary raw materials with comparatively lower administrative burden than recycled content targets should also be explored.

Demand for some secondary raw materials is still negatively influenced by quality issues and risks associated with recycled materials by manufacturers, brand owners and consumers [112]. In this sense, establishing standards for secondary raw materials could ensure quality and technical performance of recycled outputs that also take into consideration the technical and economic feasibility of depolluting the relevant material flows. These actions should lead to increasing trust in the market and recycled materials’ potential to safely displace primary raw materials. For example, in the construction sector, metal, wooden and concrete structural elements are not covered by standards suitable for recyclates [112].

Furthermore, it is important to stress that weak demand is not always the main problem affecting secondary raw material markets. In some cases, such as for some types of scrap metal, it is expected that the decarbonisation of the energy intensive industries will almost automatically lead to a reinforced demand in the near to mid-term future. Therefore, one should assess for specific types and quality grades of secondary raw materials, if indeed demand is the weak side in the market, or if additional supply support measures are warranted.

**Potential enablers** to be considered could include:

1. Further exploring and holistically assessing benefits and costs of recycled content targets for different types of materials contained in various products.
2. Assess the possibility to require large corporates to source an increasing share of specific secondary materials in their supplies.
3. Extend and harmonise the application of eco-modulated fees for EPR schemes based on recycled content.
4. Enhance certification schemes for SRMs to increase industry’s and consumers’ trust and ensure the growth of safe and high-quality SRMs markets in the EU.

3.3.3 Critical Raw Materials for the green transition

*Achieving the EGD objectives will lead to an unprecedented critical raw materials demand, leading to supply risks*

In addition to EU’s drive towards digitalisation, energy transition and decarbonisation of strategic sectors (e.g., transport) are driving the rising demand for raw materials; including many that are already classified as critical raw materials (i.e., high risk of supply disruption and important to key economic sectors).

The demand for critical raw materials, such as germanium, lithium, cobalt and graphite is also expected to increase in the coming decades. For example, future demand for several rare-earth elements (e.g. neodymium, praseodymium and dysprosium) will grow as a result of their use in permanent magnets for electric vehicle motors [128]. Major concern exists related to the announced trade restriction for some of these materials (e.g., China trade restrictions on graphite, antimony and gallium). The exact implications to the EU industry are being examined, partly because use is strongly outside of the EU but could potentially affect key strategic sectors.

Currently, the EU relies heavily on third countries for the supply of critical raw materials and/or for components containing these. For instance, 77% of the world’s lithium supply is extracted in Australia and Chile, whilst 56% is processed in China and 32% in Chile. China also dominates the extraction and processing of praseodymium, terbium, neodymium, dysprosium (used for permanent magnets used in electric vehicles (EVs) and wind turbines) and gallium (used in electronics and solar panels). 73% of global boron reserves are concentrated in Türkiye, which are used for wind technologies.

Several key risks linked to critical raw material supply exist, such as concentration of resources among a few countries and companies, potential disruptions in global supply chains, and geopolitical tactics that could impact global trade and security. Natural resource shortages, like water scarcity, are also seen as threats to critical raw material production [129]; including due to climate change impacts. For example, EU’s hydrogen industry faces some key challenges associated with limited EU resources supply, global dependence both for raw and processed materials and precious metals constraints (e.g., iridium supply is a bottleneck for large-scale deployment). Electrolyser production requires more than 40 raw materials (including CRMs, such as iridium and palladium) and 60 processed materials. China (37%), South Africa (11%) and Russia (7%) are major suppliers of raw materials for electrolysers, whilst the EU only produces 2%. Even though, EU’s shares increase towards the final product in the electrolyser value chain, it does not go much beyond a fifth of the global shares for processed materials and a third of the necessary components.

Other sectors, such as solar PV, are not directly affected by high-risk supply of CRMs, since for now the EU is primarily importing final products and not primary raw materials. Nonetheless, considering the planned large-scale EU domestic PV manufacturing and the commitment to increase EU competitiveness, critical raw materials supply, supply chain dependency on China, and economic availability of CRMs used in current module designs may become in the short-term crucially relevant [92].

*Implementing Critical Raw Materials Act*

To help address supply risks and dependencies, in 2024 the EU adopted the so-called the Critical Raw Materials Act (CRMA) [84], which focuses on diversifying and substituting supply while improving EU’s self-sufficiency and its capacity to monitor and mitigate disruption risks. For example, the CRMA introduces a benchmark to diversify imports of strategic raw materials, ensuring that by 2030 no third country would account for more than 65% of the Union’s annual consumption of strategic raw materials. At the same time, the CRMA promotes sustainable raw material production and enhances circularity, while aiming to mitigate adverse impacts within the EU and in third countries with respect to labour rights, human rights and environmental protections.

*Challenges related to circularity: recovery and recycling of CRMs*

Circularity can play a key role to enhance resilience and reduce dependence on critical raw material imports. Secondary raw materials currently only meet a modest fraction of EU demand and this will take time to change, if technically and economically feasible (e.g., measures to ensure key technology issues, feasibility to separate/recycle and economics are clear). The CRMA has set out an ambitious recycling capacity benchmark of producing at least 25% of the Union’s annual consumption of strategic raw materials by 2030. The CRMA contains various articles aiming at increasing circularity, including permanent magnets, and at increasing transparency of environmental impacts of CRM extraction and production.

Certain value chains/sectors, such as automotive, batteries, consumer electric and electronic goods are key for the recovery of critical raw materials. Even though the EC has put recently forward legislative measures to increase CRMs recovery and recycling from end-of-life vehicles [130] and batteries [131], CRMs recovery from WEEE is still characterised by high losses during collection, pre-processing and recycling processes (e.g., absence of recycling processes at industrial scale for neodymium, for example) [112].

For instance, PV modules waste generation is expected to grow exponentially (i.e., from 45,000 tonnes in 2016 to reaching 1.7-8 million tonnes globally by 2030). The PV modules contain both critical raw materials, precious metals (e.g., silver) and highly energy intensive materials (e.g., silicon wafer) that are worth being recovered and/or reused [132]. These are listed under the Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19 and, therefore, subject to recovery and preparation for re-use and recycling targets (85% and 80%, respectively). However, these targets are mass based and, in the case of PV modules, do not encourage the development of an efficient recovery of materials present in smaller traces [133], thus missing an opportunity of recovery and recycling critical and precious materials (e.g., silicon). Furthermore, waste legislation should be coupled with product design considerations, as it is necessary to know the material composition of the PV modules placed on the market [108], [134].

As highlighted in the Section 3.3.1, recycling requires high up front investments, and the low profitability of recycling many CRMs and other materials (e.g., lithium, copper, aluminium) can still act as a barrier. Nevertheless, the increasing value of some scarce metals, such as indium or tellurium, may eventually justify the investment in large-scale recovery and in the recycling of certain electronic items (e.g. touch screens) [112].

Official data (e.g. ESTAT) do not exist at this time to quantify the CRM Act benchmarks, especially in the case of material consumption, which can be estimated using different methodologies. Nevertheless, information already exists in the EC’s Raw Materials Information System - RMIS (a commitment of the EC in the Circular Economy Action Plan, 2015) from various sources (EC or Member States as far as possible, projects, etc. and particularly from the EC’s critical raw materials assessment and material flow analyses for specific materials). RMIS is currently being enhanced further, building on new projects and increasing MS developments. For the overall recycling benchmark, calculation methods for the recycling capacity compared to EU demand are not defined yet. Nevertheless, some data exist in the RMIS from Material System Analysis, from the CRM assessments, from sector/tech specific modelling for battery-specific materials, among others.

**Potential enablers** **include**:

1. Overarching recycling capacity benchmark in the CRMA could be further broken down into individual targets for each strategic raw material, since even aspirational and non-binding guidance could provide greater clarity on where particular efforts are needed to improve circularity.
2. Developing calculation methods for recycling capacity compared to EU demand
3. Provision of data for specific raw materials, rather than groups of materials, for imports, exports, and production.
4. Provision of data for recycling of specific raw materials.

*Increasing EU’s CRMs extraction capacity: social and environmental trade-offs*

Demand for many raw materials, including critical raw materials, is likely to continue to increase in coming years to meet digitalisation, renewable energy, and other needs. In at least the short term, these will predominantly still come from mining for most CRMs. Specific materials, like many critical raw materials, require extensive processing. Positively, many of these are often coming anyway from wastes (tailings) of base materials, such as copper. Nonetheless, these require additional processing of the tailings to extract them.

The CRMA puts forward for example an extraction capacity benchmark of at least 10% of the Union’s annual consumption of strategic raw materials by 2030, while aiming to provide “strategic projects” with expedited approval processes to boost critical raw material production, raising environmental and social concerns.

Opening of new mines for EU’s critical/strategic as well as other raw materials can lead to impacts on ecosystems and social systems (in particular, resource extraction can affect local communities) and generate trade-offs with environmental protection policies, such as the Nature Restoration Law. On the other hand, demand will probably be met by supply from extra EU countries, if this is not within the EU. The conditions and impacts associated with non-EU supply might be even greater.

In the case of metals, exploiting lower grade deposits of minerals (i.e. mineral deposits with lower concentrations of the desired mineral or metal) will require increased processing and might result in the risk of partially offsetting the climate change targets and other environmental targets that are pursued by a number of other EGD policies (e.g. nature restoration law, zero pollution, biodiversity, etc.). At the same time, preserving healthy ecosystems is vital in order to support the provision of biomass and other ecosystem services which allows the fulfilment of a variety of human needs.

Social opposition to mining activities and lack of public acceptance can delay or derail projects. Moreover, there is limited public awareness of the social and environmental impacts associated with increased CRM extraction and processing, particularly when such activities are outsourced to regions with lower standards. At the same time, society wants renewable energy, digitalisation, and healthcare devices, among others. Equally, this desire will be met, even if extraction and processing is not based in the EU, thus increasing potential supply risks, lowering competitiveness (and, hence, reducing jobs and welfare in the EU), and potentially exacerbate other global issues (such as climate change).

**Potential enablers** **include**:

1. Meaningful engagement of stakeholders and local communities at the earlier stage of the mining project, in order to ensure social acceptance
2. Trade-offs must be better understood and analysed, considering both social as well as environmental impacts at both EU and global scales.
3. Activities to improve mining projects, such as the Best Available Techniques reference documents (BREFs) development under the Industrial Emissions Directive, must be supported to ensure good environmental and social practices
4. EU competitiveness must be supported through development of policy that promotes sustainable mining and processing for both domestic production as well as imports, a fair level playing field. Preference should be given to more sustainable materials
5. Production from existing mining operations for base metals of CRMs must be analysed and supported
6. The consequences on societies and environment of not mining in the EU (spill-over effects) must be understood and communicated, including the trade-off risks/impacts and geo-political implications of increasing reliance on China, Russia, among others for the supply of ores and processed raw materials on society and the environment.

*Ensuring that materials imported from extra EU countries are produced in a sustainable and responsible manner*

While the objectives of the CRMA aim to increase the domestic supply of both primary and secondary materials, a certain level of international supply will continue to be essential to fulfil the EU’s materials demand. Many critical raw materials are essential for renewable energy technologies, batteries, and other green innovations, as well as sectors such as electronics and mobility. They will continue to be predominantly imported from some developing countries with low governance capacities. In these regions, the extractive sector can create severe environmental and social impacts, such as deforestation, pollution, violation of indigenous people rights, unsafe working conditions, and human rights violations, particularly in artisanal and small-scale mining (ASM) sectors. ASM, while providing livelihoods to millions, operates largely informally, increasing vulnerabilities to exploitation, resource mismanagement, and the perpetuation of conflicts in resource-rich areas [135], [136].

For some critical raw materials, the main extraction sites are in areas of conflicts; or even promote conflicts and support problematic regimes. Materials extraction in such areas can further contribute, directly or indirectly, to armed conflict, gross human rights violations and hinder economic and social development. Regulations, such as the Conflict Minerals Regulation and the EU Batteries Regulation [131], enforce due diligence in sourcing, emphasizing transparency, risk management, and sustainability. Both regulations mandate third-party audits and public reporting to enhance accountability and support responsible sourcing practices. The Corporate Sustainability Due Diligence Directive [137] extends these principles across corporate value chains, aiming to foster responsible business practices globally.

**Potential enablers** include:

1. Implement robust due diligence frameworks in key supply chains (as being done for batteries) for companies in the downstream phase of the supply chain
2. Strengthen capacity-building efforts targeted at resource-rich developing countries (e.g. by offering training, improving infrastructure, and fostering partnerships) in order to mitigate the adverse impacts of mining activities and encourage sustainable resource management; complementing e.g. EU Raw Material Partnerships
3. Enhance requirements on products to promote minimum standards linked to environmental and social footprints, for example for materials

3.4 Sustainable and smart mobility

3.4.1 GHG Emissions reduction in transport

The transportation sector is responsible for about a quarter of EU greenhouse gas emissions and it is the only sector exhibiting substantial emissions increases since 1990. Road transport accounts for 76% of these emissions. To achieve economy-wide **carbon-neutrality in the EU by 2050 and 90% abatement of transport GHG emissions** it is necessary to act on several fronts, such as road vehicle stock, its efficiency and activity, traffic management, transport infrastructure, alternative fuels infrastructure, and the production of energy carriers (electricity, renewable fuels etc.). In line with the EGD objectives, in January 2025, a “strategic dialogue on the future of the European automotive industry and industrial action plan” and a “sustainable transport plan” have been announced as one of the flagships actions of the EU competitiveness compass [2]. These two plans will have to face the challenges and enablers included in this section.

*Ambitious road transport electrification is essential for reaching climate neutrality in an energy efficient way.*

As of today the **electrification of road transport** in the EU is not progressing at a sufficient pace, and the deployment of electric vehicles or zero-emissions vehicles and charging infrastructure must accelerate (Krause et al, 2024)[[46]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush#_ftn46) [1]. **Budgets, infrastructure, software, and supply chains are the main bottlenecks for a competitive automotive sector**

From a technological standpoint, there are not any serious barrier to electrification (said, electrification is not necessarily decarbonisation if the system does not improve). A JRC team is gathering data on why EU cars, particularly EVs appear to be unaffordable, and unprofitable, but it will take time for solid conclusions. However, **EU investment in both industrial and the public domain are insufficient, and this is the main prerequisite for any transition**.

The current electricity prices are higher than the ones assumed during the policy design process, therefore, if the situation does not change, **a slower diffusion of electric vehicles in the EU market should be expected**. Moreover, upfront technology costs of zero- and low-emission vehicles (ZEV and ZLEV respectively) are higher than those of conventional vehicles, and there is a delay between long-term net consumer benefits and higher upfront capital costs. Other factors that affect the total cost of ownership of zero emission vehicles are national incentives, charging infrastructure cost (the cost of a house charger is above 5000 Euro, a significant extra cost to burden the vehicle), and taxation.

As a final observation, it should be noted that **zero and low emission vehicle deployment is highly dependent on the pricing policy of manufacturers and production costs.** Raw material access and costs, supply chain issues and potential discontinuation of subsidies may create price volatility for battery and vehicle costs, posing a barrier to maintaining stable and affordable pricing for zero- and low-emission vehicles.

**Main enablers:**

* The EU should heavily invest with consistent budgets, infrastructure, interoperability, software, and supply chains (currently the main bottlenecks for a competitive automotive sector), for the eV market totake off.
* Ensure a stable supply of materials and a high level of reuse, remanufacturing and recycling, in particular for batteries, magnets (for high-efficiency engines), electronics and sensors (for automation, connectivity, sharing) etc. (link to the CRM deep dive).
* On pricing policy it has been observed that OEMs are preferring high end high profit vehicle configurations at lower number sales, to more affordable high volume sales.
* Prices are influenced by disruptions in supply chains, critical materials availability and infrastructure. Targeted investment in these three directions is crucial for ensuring affordable uninterrupted production in the future.

*Inadequate or lack of access to affordable transport can exacerbate inequalities and create risks of transport poverty and social exclusion if transition to zero-emission vehicles is not managed inclusively (e.g. lack of financial support and incentives to low-income groups, lack of infrastructure and affordable alternatives).*

The energy consumed by zero-emission vehicles is linked to potential high upstream energy inefficiencies in the production and/or transportation of electric power (note that The ETS (absolute) cap for electricity production emissions guarantees that there are no emissions from additional electricity demand from transport).

To assess the **economic feasibility of a mobility transition**, the JRC has carried out an analysis quantifying the total costs of ownership under different CO2 standard scenarios. For Light Duty Vehicles (LVD), based on 30 scenarios run with the JRC DIONE cost model to support the EC impact assessment for strengthened car and van CO2 standards within the EC’s Fit for 55 package, it was concluded that, over the use period, **net consumer benefits result, and they increase with stricter targets and over time**. Net savings are substantially higher for High Duty Vehicles (HVD) than for LDV, due to their high annual and lifetime activity.

**Main enablers:**

* **A technology neutral holistic approach is necessary** in order to ensure that the energy demand of future road vehicles does not increase disproportionally, and remains within the capacity of EU’s power supply system.
* Benefits arise because savings in fuel/energy expenditure during vehicle use overcompensate the higher upfront capital costs of more efficient and zero- and low-emission vehicles.

*The recharging and refuelling infrastructures and the update of electric grid are lagging behind*

A key potential barrier to implementation for zero- and low-emissions road vehicles lies with the availability of appropriate recharging and refuelling infrastructure. Development of recharging and refuelling infrastructure for zero- and low-emission vehicles has progressed slowly so far, and also EU member states plans for infrastructure build-up (NIRs) are presently lagging behind targets[1]: Increased electrification of transport also requires enhancing the integrity and resilience of the electrical infrastructure, in particular upgrading of the grid system, enhancing its stability and capacity.

Many electrical vehicles (EVs) are not accessible to persons with disabilities (including, for example, the lack of wheelchair-accessible doors and ramps, due to the batteries places under the floor, insufficient space for wheelchair users, and difficulty with charging infrastructure accessibility)

*Socio-cultural and behavioural barriers to ZEV adoption include “resistance to change” and “range anxiety”*

The “resistance to change”, is when individuals prefer the current state and resist change, have limited awareness of the benefits of EVs, and under cost-saving uncertainties demonstrate a preference for immediate gains [138], [139]( Reyes et al., 2020;). “Range anxiety” constitutes a behavioural barrier for the public.

**Main enablers:**

Build-up of appropriate infrastructure for recharging and refuelling in EU Member States, especially of fast chargers and on motorways (to deepen the topic, see section xx, on behaviour barriers and enabler).

*The Fuel Cells Electric Vehicles (FCEV) uptake is limited by technological and infrastructural gaps*

The use of FCEVs is expected to grow significantly in the European transport sector, and is also expected to make its way into the railway sector, with the potential to replace [diesel](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/diesel) enginetrains. Certainly, FCEV technology can offer benefits for urban delivery applications, long ranges and high energy consumption (e.g. large trucks), but they still have a **very limited uptake** due to a series of challenges such as:

* The high costs of FCEV technology makes it accessible only to high-income consumers or for specific [niche applications](https://www.sciencedirect.com/topics/engineering/niche-application) and case-specific investment opportunities,
* The fuelling infrastructure are lacking, and the fuelling network is still poorly developed: the global availability of [hydrogen stations](https://www.sciencedirect.com/topics/engineering/hydrogen-station) was estimated in 2021 at 385 active and 167 stations in deployment phase,
* The design and operation of FCEVs need to be optimised and a reliable [fault detection systems](https://www.sciencedirect.com/topics/engineering/system-fault-detection) still needs to be developed,
* FCEVs need to be integrated with existing transportation systems while ensuring compatibility and efficient operation,
* The durability and lifetime of the [fuel cell stack](https://www.sciencedirect.com/topics/engineering/fuel-cell-stack) needs improvement,
* FCEVs are less energy-efficient than BEVs (even though they offer higher range and quicker refuelling).

**Main enablers:**

Overall, FCEV technology appears to be a promising solution for [reducing energy consumption](https://www.sciencedirect.com/topics/engineering/reducing-energy-consumption) in vehicles compared to [internal combustion engines](https://www.sciencedirect.com/topics/engineering/internal-combustion-engine) or hybrid vehicles, but it is crucial to improve understanding in what scenarios FCEVs can offer advantages over other vehicle technologies, in terms of performance, energy consumption, and climate and environmental impacts.

*Gradually shift targets assessment towards real world emissions*

GHG emissions can be higher than found under certification measurements, due to the gap between certification and real world emissions. Therefore, to assess the effectiveness of policy measures on transport to curbing climate change, it is crucial to consider emission reductions achieved in **real-world vehicle operation** [140], [141], and to monitor energy consumption in real driving conditions.

**Main enablers:**

A first step has been already made through the adoption of fuel consumption monitoring systems that allow the Commission to follow the progress of CO2 emission reduction under in-use conditions. However presently **there is no link between the official certification-based monitoring and the in-use performance**. Therefore, future initiatives aiming at strengthening the real world monitoring of CO2 emissions and energy consumption are essential, as well as working on possible remediation initiatives in case significant divergences from the targets are observed.

*Inverting the trend of increasing transport demand is an overlook opportunity*

Addressingthe **rising** **demand for transportation**, particularly within rapidly growing and emission-intensive sectors like aviation, shipping and private road transport, is a critical yet often overlooked component of EU efforts to reduce emissions. The European Scientific Advisory Board on Climate Change (2024) has pointed out that "the growth in **overall transport demand in the EU needs to slow down**" if we want to achieve the established GHG emission reduction objectives. At present, this necessary moderation is not adequately reflected in legislation, as it was not “considered as an option in the EU’s Sustainable and Smart Mobility Strategy” ([142], pg. 103).

A possible rebound can be linked to higher energy efficiency and higher comfort due to connected and automated vehicles (as well as the possible increase in the energy consumption of connected and automated vehicles). These improvements make the car, privately owned or consumed as a service, even more attractive and therefore put it even more at the centre of the mobility landscape [143]. However, so far these effects have been assessed only marginally.

In general, the shift to more sustainable transport modes will be crucial to achieve substantial and continuous emission reductions in road transport [144].

**Potential enablers include:**

A range of options exists that could **reduce vehicle activity or change present day mobility patterns** (for this incentives/rewarding tools should be considered as well), with a beneficial impact on total vehicle activity, energy consumption and emissions. These options include:

* Promoting active mobility including walking, cycling etc. and micromobility
* enhancing **the quality of public transport** and shared/collective mobility services
* re-orient urban planning to encourage active forms of transportation that can contribute to health improvements
* foster the development of **Mobility-as-a-Service (MaaS)[[4]](#footnote-7)** and of multimodality
* expand **Sustainable Urban Mobility Plans (SUMPs)** to include connections with surrounding suburban and rural areas.

To change present mobility patterns, behavioural changes are required supported by a new balance between trust in services, notably in terms of availability, safety, reliability and affordability, personal convenience and a collective ecological identity linked to the need to respect our planetary boundaries.

In the medium and **longer term,** options that can be explored to ensure full carbon neutrality include:

* Properly designed measures to accelerate the **turnover of the fleet**, while avoiding perverse/unwanted incentives, at a point in time where zero carbon alternatives are available and economically viable.
* **Connected and automated vehicles** to i) improving traffic efficiency and reducing the overall energy intensity of the transport sector, and ii) reshaping the governance of the transport system in a way that optimizes the energy required to satisfy citizens’ mobility needs.
* Support shifting of passenger and freight transport towards low-emissions and energy efficient transport modes – **modal shift**).
* Promote informative and educational (information campaigns promoting walking, cycling and public transport, training on eco-driving, promotion of car-sharing and car-pooling).

### 3.4.2 Renewable Fuels of Non-Biological Origin

Renewable Fuels of Non-Biological Origin (RFNBOs) offer a promising alternative for sectors that are hard to electrify, such as aviation, maritime, and heavy road transport. They can function as drop-in fuels, requiring no technical modifications to existing engines, thereby reducing dependency on fossil fuel imports. Their adoption enhances energy security and diversification.

Technological advancements have significantly **improved RFNBO production processes**, with Europe leading the way due to strong policy support and industrial capabilities. Production involves key technologies across the value chain, including hydrogen production, carbon capture (or nitrogen separation), and fuel synthesis. Despite progress, large-scale deployment remains limited due to high costs, energy requirements, and the need for robust infrastructure [146].

Advancements in electrolysis, carbon capture, and renewable energy generation are critical to scaling RFNBO production. However, the upstream processes, particularly hydrogen production and carbon capture, need large-scale development to reduce costs. Currently, there is low availability of cost-effective hydrogen.

**Key challenges** to RFNBO adoption include achieving **cost competitiveness** with fossil fuels, addressing **technological barriers**, and building the necessary **infrastructure**. While existing fuel infrastructure can be utilized with minimal investment, constructing new facilities entails high upfront costs. Significant investment and innovation are required to scale the technology for widespread commercial use.

*RFNBO production depends heavily on the availability and cost of surplus renewable electricity.*

While solar and wind power provide flexibility, they also compete with other renewable energy demands. Challenges such as intermittent power generation, the need for energy storage, and grid balancing solutions must be addressed. Furthermore, high energy conversion losses in RFNBO production contribute to costs exceeding those of fossil fuels.

Currently, there is a slow market uptake due to insufficient incentives. Other challenges for RFNBO market uptake include all the techno-economic aspects related to the limited capacity of the renewable electricity distribution grid to integrate renewable electricity generation and slow progress in carbon capture solutions. The phase-out of fossil-based CO2 for industries (post-2035 for power companies, post-2041 for steel and cement) [147] introduces additional barriers. Competing markets, such as fertilizers, and environmental concerns about greenhouse gas savings, add complexity.

*RFNBOs have substantial market potential, especially in sectors with limited alternatives, such as such as hard-to-abate transports and heavy industry.*

Energy system models like JRC’s POTEnCIA and POLES [148], [149] project rapid growth in EU RFNBO production starting in 2025, positioning them as a key low-carbon fuel source for sectors like aviation and maritime.

**Main enablers:**

1. **Opportunities lie in creating new value chains** based on renewable hydrogen and carbon capture, leveraging existing fuel infrastructure, and integrating bio-based value chains for CO2 recovery. Technologies such as Haber-Bosch and Fischer-Tropsch processes are already compatible with renewable hydrogen and can be retrofitted. However, other technologies face limitations due to the unavailability of hydrogen or CO2 supplies [147].
2. Overcoming cost and infrastructure barriers will be critical for RFNBOs to fulfill their potential. However, with continued technological advancements, policy support, and investment, RFNBOs are well-placed to play a central role in Europe’s decarbonization strategy. Beyond decarbonization, RFNBOs can support energy security, create new value chains, and generate job opportunities along the supply chain, including skilled labour.

### 3.4.3 Advanced biofuels

Advanced biofuels present a viable solution for reducing greenhouse gas (GHG) emissions in hard-to-decarbonise sectors such as aviation, shipping, and heavy road freight transport. With significant GHG reduction potential, they contribute to energy supply diversification, enhance energy security, and reduce dependency on fossil fuel imports.

Advanced biofuels are derived from sustainable feedstock like wastes and residues, though their production faces constraints, including feedstock availability, regional limitations, and competition from alternative uses [150]. Over the long term, feedstock availability and affordability may become increasingly challenging.

These biofuels can integrate with existing fuel infrastructure, requiring minimal additional investment. They can be blended with fossil fuels or used as drop-in replacements without engine modifications. Biorefineries create synergies by combining traditional fuel and chemical production, maximizing the use of existing infrastructure and logistics.

However, several barriers hinder large-scale production:

* Industrial scale: Large facilities are essential to achieve economies of scale.
* Logistics: Collection, transport, and storage of feedstock are complex due to their low energy density and variable characteristics.
* Technologies: Production relies on thermochemical and biological processes, many of which are still at different stages of development.
* Costs: High initial investments and reliance on low-cost feedstock result in elevated production costs compared to fossil fuels.
* Incentives: A lack of robust policy incentives hampers large-scale deployment and the establishment of biomass supply chains.

Overall, advanced biofuel production currently carries significant technological and economic risks.

**Economic Impact.** The **biofuel sector is a significant economic contributor** in the EU, driving GDP growth and employment. Between 2015 and 2022, biofuel consumption in EU transport rose from 19 million litres to over 25 million litres, with biodiesel accounting for around 70% of the share [151].

Despite this growth, market uptake remains slow due to inadequate incentives, technological challenges, and the failure to achieve cost competitiveness through scaling.

**Research and Innovation**. Several advanced biofuel technologies are nearing commercialization [150]. However, others, like aquatic biomass conversion and dark/light fermentation to hydrogen, remain unproven in commercial settings [152]. Additionally, advancements in electric vehicle technologies for heavy-duty road transport electrification may limit the progress of biofuels in this sector.

**Policy Landscape.** The lack of a stable, long-term policy framework remains a critical barrier to the development and deployment of advanced biofuels. Clear and consistent policy direction is essential to foster investment and innovation in the sector.

**Social Acceptance**. Public awareness and acceptance of advanced biofuels remain low. Addressing this gap through education and outreach can help build broader support for their adoption.

**Potential enablers include:**

**Employment Opportunities**. The biofuels industry has been a vital source of employment within the EU, generating both direct and indirect jobs. In 2018, it supported 239,600 jobs, but this number declined to 149,700 by 2022 [153], [154]. Efforts are underway to transition skilled workers from fossil fuel industries to biofuels, preserving expertise while addressing workforce needs.

Biorefineries offer additional employment and business opportunities along the supply chain, particularly in rural areas, where advanced biofuels can drive agricultural, forestry, and industrial development. Attracting workers to these regions remains a challenge, but policies supporting rural biorefineries could enhance their appeal.

**Trade**. The EU's trade in biofuels, specifically biodiesel and bioethanol, has shown distinct trends and challenges over the past few years. In 2023, the majority of EU biofuels imports and exports consisted of biodiesel, followed by bioethanol. Extra-EU exports of biodiesel increased by 47% compared to 2022, reaching almost EUR 2.1 billion. On the other hand, extra-EU imports of biodiesel decreased by 27%, amounting to around EUR 3.2 billion. This led to a significant reduction in the trade deficit, which shrank from nearly EUR 3 billion in 2022 to EUR 1.1 billion in 2023 [ref].

**Environmental Impact**. Advanced biofuels can contribute to the remediation of marginal and degraded lands when feedstock cultivation complies with sustainability criteria. Their environmental benefits depend on ensuring compliance with robust standards and avoiding unintended negative impacts.

In conclusion, advanced biofuels hold immense potential for reducing GHG emissions in sectors where alternatives are limited. Despite technological and economic challenges, continued investment, innovation, and policy support can position advanced biofuels as a cornerstone of Europe’s energy transition. Addressing production barriers, enhancing public acceptance, and fostering a supportive policy environment will be critical to unlocking their full potential.

3.5 Food Systems

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The EU food system provides food for over 450 million people in Europe, contributing significantly to economic development, employment and well-being in the region. Achieving the EU’s sustainability goals, including a 55% net reduction in greenhouse gas (GHG) emissions by 2030, reducing hazardous pesticides and nutrient losses, expanding organic farming, minimizing food waste, and improving energy efficiency, requires coordinated efforts [1]

Policies such as the Farm to Fork Strategy (F2F), the Common Agricultural Policy (CAP) and the Common Fisheries Policy (CFP) are crucial enablers, fostering sustainability, fairness, and resilience across the food system. The transition towards sustainable food systems is inevitably linked to the EU One Health approach to protect the health of people, animals and ecosystems. Additionally, the EC recently published a Vision for Agriculture and Food [155], building on the Strategic Dialogue on the Future of EU Agriculture [156] and aligning with the EC’s Competitiveness Compass [2]. This vision aims to secure the long-term competitiveness and sustainability of the EU's farming and food sector, emphasizing technological advancements, decarbonisation, and economic growth, while ensuring agriculture and the food system contribute to the EU’s broader economic and environmental objectives.

Current trends indicate that accelerated efforts are needed across many areas of the considered EGD targets relevant for the food system. In particular, there is a need to contribute to the reduction of GHG emissions, expand organic farming, reduce the use of hazardous pesticides, nutrient losses and food waste. In addition, unsustainable food consumption patterns and resource use inefficiency continue to compromise progress towards climate and biodiversity goals [1]. At the same time, unhealthy diets threaten EU public health, being a main contributor to the health and economic burden linked to excess weight and non-communicable diseases.

This section examines barriers and enabling measures across the environmental, economic and social dimensions of sustainability. The environmental section focuses on cross-cutting issues, since specific aspects related to climate change, pollution, biodiversity, resource use (land and soil, water, energy and aquatic living resources), are covered in the respective thematic sections of this report. This also applies to elements related to just and fair transition, and governance, which are addressed in Section X.X.

*Adopt and encourage systemic approaches to support a transition towards sustainable food systems*

Systemic approaches are essential to achieving sustainable food systems due to their complexity and interconnectedness, being influenced by numerous social, economic, environmental, and policy factors. However, many actions and policies related to food systems tend to adopt linear, sectoral approaches prioritizing short-term goals which often lead to unintended consequences or small impact [157]. In contrast, a systemic approach aims to identify interdependencies and enable structural, long-term, adaptive solutions. It is central to recognize the interlinkages of elements and policies addressing the food system, engaging with all actors of the food system while considering all potential sustainability impacts. Synergies and trade-offs in the path to strengthen the resilience of the EU food system through the transition to sustainability need to be identified. This in turns calls for ensuring policy coherence, coordination and articulation, as policy intervention should create long-lasting synergies for sustainable development [158].

*Measures could include:*

* Commit to long-term sustainability. Emphasise the importance of sustainability for the long-term viability of the food system as a societal benefit, acknowledging the economic challenges and addressing them through strategic measures.
* Support the development of food systems strategies at EU and national levels. For instance, EU countries could design more inclusive and effective strategies to transform food systems [159].
* Foster inclusive food system governance by engaging all food system actors in policy development ensuring better coordination, accountability and alignment towards sustainable food environments.
* Update national food-based dietary guidelines with sustainability goals to better guide policies towards healthy eating supportive of sustainable food systems.
* Promote urban food policies that mainstream sustainability goals in the local context where there is an opportunity to deal closer with the reality of food system activities and actors.
* Strengthen research and innovation as a catalyst for transforming food systems. This includes creating more attractive and sustainable food products, developing more sustainable practices and processes, and re-designing food systems through policy and social innovation.
* Improve knowledge, data and capacity to support better decision-making and evidence-based policies. Adequate monitoring of a transition towards sustainable food systems is critical for navigating the complexity of food systems and support systemic approaches.

*Foster the adoption of more sustainable production practices and consumption patterns across the whole food value chain*

The consumption footprint of food shows an increasing trend (See Chapter 2), primarily driven by animal-based products (despite recent decreasing trends of pro-capita consumption for bovine and pig meat). Environmental impacts of the entire supply chain of food products (including beverages) consumed in the EU (i.e., considering from the extraction of raw materials to the management at the end of life, including trade) have increased around 20% since 2010. The EU food system contributes to the transgression of some planetary boundaries [160]. This results from barriers to transformative change as highlighted namely in the respective sections on climate, pollution, biodiversity, energy.

Possible measures can be considered across the whole value chain and include:

* Environmental implications of the market projections show that improvement across environmental and climate impacts can be driven by declines in animal numbers and reduction of utilised agricultural area over time, and the adoption of sustainable farming practices [161].
* A shift towards a more healthy and sustainable plant-based diet is key reduce environmental impacts. Emerging trade-offs (e.g. for food waste, resource use mineral and metals, land use and water use) could be tackled by specific actions [162].
* This shift can be driven by selected policy intervention, such as the promotion of sustainable public procurement. This can act as a leverage to foster the adoption of more sustainable production practices and consumption patterns, fostering a more sustainable food environment which can, in turn, further promote innovation and the wider availability of more sustainable products.

*Strengthen policies, foster partnerships, and promote behaviour change to reduce food waste in the EU*

The importance of a system approach addressing circularity of resources is well highlighted by the attention gained by food loss and waste reduction [163]. In the EU, over 59 million tonnes of food waste (132 kg/inhabitant) are generated annually [164]; more than half of the total food waste is generated by households [164].

Key barriers to reduce food loss and waste in line with the EGD targets are insufficient consumer food management leading to food waste generation at consumer level, inefficiencies and trade-offs in the food supply chain, lack of understanding and certainty regarding food safety standards (including possible misinterpretation of date marking labels) [11].

*Measures could include:*

* Establish an enabling institutional, policy and regulatory framework. Facilitate the coordination of actors, enable investments and incentivise the adoption of best practices in food waste reduction.
* Develop national food waste prevention strategies. Empower national authorities in Member States to design tailored food waste prevention programmes that address relevant behavioural and market drivers, backed by solid evidence.
* Implement the “Target-Measure-Act" approach. Adopt the evidence-based approach recommended by the United Nations Environment Programme (UNEP) [165], focusing on measurable targets, tracking progress and taking targeted actions for food waste prevention.
* Promote public-private partnerships and collaboration. Facilitate collaboration between government and supply chain actors to develop a common roadmap for food waste reduction at the national level.
* Launch consumer behaviour change campaigns to raise awareness and change consumer behaviour around food waste.
* Support the legislative proposal 2023/0234 (COD), with legally binding food waste reduction targets, to ensure sufficient and consistent response by all Member States to reduce food waste, in line with that of front-runners.

*Ensure fair economic sustainability and viability for all actors in the food supply chain while delivering affordable sustainable foods*

At the heart of building a food system that is both economically robust and environmentally responsible lies ensuring fair profit distribution for all players involved, from primary producers to processors and service providers. Achieving affordability for consumers is equally important.

There are multiple barriers to overcome in the path to fair economic viability [165]. Here the focus is on market and economic, structural and institutional factors *(*human capital knowledge factor is described in *Common challenges section 4.0.6).*

Market and economic factors: These barriers relate to market dynamics, economic conditions, and financial constraints and include ineffective incentives, market power imbalances, sunk costs related to processing and investments in R&D and advertising, market concentration, low innovation spending and slow uptake of new technologies, the trend towards an export-oriented model for at least some sectors or commodities, and externalities that are not reflected in the food prices, leading to market distortions [166], [167, p. 2], [168], [169], [170].

Structural and institutional factors: These barriers stem from the underlying structure of the food system, including policies, regulations, and power dynamics. Intensification of food trade can result in consumption of products not being produced locally or even regionally. The prices and means of production of these commodities are not well understood by consumers. In addition, product imports can be cheaper than local production, or exports can result in higher profits. As a result, consumers may no longer be “connected” to the production resources and making informed choices becomes more difficult [171]. Also, in some cases the political environment leans towards 'food sovereignty' or 'self-sufficiency' [172], [173], and trade can be viewed as a hindrance to achieving food security [174], which may also not be the most sustainable or fair option.

It should be noted that some of these barriers can fit into multiple categories, as they often interact with each other. These barriers are also linked to natural resource limitations, environmental impacts, and climate change such as pressure from land use competition, scarcity of natural resources (water or soil) and environmental externalities (*See section TA6 on biodiversity of soil*).

*Measures could include:*

* Utilise a multi-faceted approach: Strengthen knowledge and public awareness of consumers on the economics of food systems e.g. impacts of sustainable production practices on food prices. At the same time, provide financial support and incentives for farmers transitioning to more sustainable practices to overcome barriers and adopt practices that contribute to both environmental sustainability and long-term profitability. Redirect subsidies towards sustainability. A fundamental shift away from inefficient subsidies towards investments in sustainable practices is indispensable.
* Revitalise and strengthen local food supply chains to enhance food quality, reduce environmental impact, and strengthen rural-urban connections.
* Adopt technological advancements and improved management practices that support agricultural productivity while mitigating climate change. Prevent excessive market concentration and secure domestic production to ensure a resilient food supply chain.
* Develop a robust trade strategy and support Open Strategic Autonomy that prioritises sustainability and supply chain resilience, balancing competitiveness, sustainability and fairness to ensure a stable and equitable food supply.

*Create food environments that make healthy and sustainable food choices easier for consumers*

Diets are central to shape food systems, driving significant environmental and climate impacts by influencing food production activities, energy use and pressure on water, land and natural resources and biodiversity [175]. Creating food environments that make healthy and sustainable food choices easier is critical for supporting a dietary shift better aligned with nutrition, health and environmental goals. Food environments can also empower consumers to make food choices that support the economic viability of an ethical and fair value chain. Key barriers that prevent consumers of making healthier and more sustainable food choices include [175], [176] affordability of nutritious and sustainably produced foods; 2) lack of capacity and motivation across food system actors to mobilise and transform food environments; 3) lack of adequate and understandable information to support consumers knowledge and awareness towards the economic, environmental and social sustainability impacts of food choices, but also exposure to marketing and advertisement of unhealthy foods which shape food preferences; 4) cultural preferences, habits and social norms which often prevent consumers of choosing more sustainable and healthy food choices; 5) the limited provision of sustainable and nutritious foods in different physical food environments contexts (ex: schools, public institutions, retailers, restaurants); 6) limited availability of attractive, tasty and convenient sustainable food options.

Of note, promoting change in food choices and diets is a great challenge for policy makers and very linked to a lack of systemic and coherent actions.

To support more sustainable food choices, a comprehensive approach that addresses the complex dimensions of food environments coherently is needed for achieving a more impactful outcome. While no single solution exists to achieve sustainable diets, policy makers can implement a combination of integrated and aligned measures, as outlined below, to better support the transition towards healthier and more sustainable foods.

*Measures could include:*

* Make sustainable and healthy food affordable. Implement fiscal measures to make sustainable food options more affordable compared to unsustainable alternatives, addressing inequalities and reducing food insecurity.
* Increase knowledge and promote awareness of how food choices affect health and sustainability by enhancing access to reliable information. Key actions include improving food labelling, advertising, promotion, and supporting local initiatives and educational campaigns on sustainable diets. Education can boost food literacy, values, and social norms for sustainable eating. Updating national dietary guidelines to include sustainability goals can shape school education, inform consumers, and guide national food policies toward sustainable practices.
* Reduce exposure of marketing of unhealthy foods. Limit exposure to advertisements promoting unhealthy foods, especially targeting children.
* Engage local communities, such as schools, public institutions and local farmers to create sustainable connections that strengthen awareness, motivation and values supportive of sustainable supply chains and food choices.
* Increase provision of sustainable food options. Ensure their availability in various food environments (e.g. restaurants, retailers, schools, public meals), improving access to sustainable and healthy alternatives. Sustainable public procurement can influence food provision of public meals in line with sustainability goals.
* Support food reformulation and innovation. Provide incentives to align the quality of sustainable food products with consumers’ preferences, providing healthier, convenient and tasty options that increase demand for sustainable choices.
* Invest and foster social innovation. Social innovation can boost transformative connections, new food systems design and shape food environments.

*Strengthen EU food system resilience through integrated policies across economic, environmental, and social sustainability dimensions*

The resilience of the EU food system is essential for food security, economic stability, and environmental sustainability. Ensuring a resilient, food-secure future requires adaptive strategies, technological innovation, and policies that balance sustainability with economic viability [177].

One of the key challenges is climate change, with more frequent extreme weather events, poses direct threats to agricultural productivity and ecosystem health [178]. Additionally, the EU’s reliance on global markets for essential inputs like fertilizers and feed increases vulnerability to disruptions [179], as shown by the COVID-19 pandemic and Ukraine crisis, where high costs limited farmers’ capacity to invest in resilience adaptation measures [180]. Social inequities also weaken resilience, as access to affordable, nutritious food remains limited, especially for vulnerable populations [181].

To address these challenges, the EU requires cohesive policies with better coordination across EU member states and across economic, environmental, and social dimensions [182], [183].

*Measures could include:*

* Revising domestic and foreign food trade policies to improve sustainability provisions across EU agri-food trade.
* Increasing support for small and medium-sized enterprises through subsidies that prioritise resilience and environmental outcomes over output.
* Promoting sustainable farming practices like crop diversification, landscape elements, agroecology, can address environmental degradation, restore soil health, and support a stable agricultural productivity over the long term.

3.6 Preserving and protecting biodiversity

3.6.1 Challenges and data gaps in Monitoring and Tracking Biodiversity

Restoring and protecting biodiversity is a challenge that takes different shapes depending on the biome we are considering and the local biogeographical factors. The Nature Restauration Regulation is the first policy with legally binding targets to protect and restore biodiversity. While the EU Biodiversity Strategy had had time to start its implementation, and progress monitoring (see [EU Biodiversity Strategy Dashboard](https://dopa.jrc.ec.europa.eu/kcbd/EUBDS2030-dashboard/?version=1)), the Nature Restoration Regulation was approved very recently (June 2024), therefore several indicators and monitoring tools are still to be put in place.

At the EU level, it is important to integrate and harmonise relevant **datasets** and consistent, high-resolution, long-term **indicators,** with regular updatesand other products to establish a comprehensive mapping and monitoring system, incorporating diverse spatial and temporal resolutions, geographical coverage, and thematic granularity.

**Monitoring the progress** of the **EU biodiversity strategy** targets presents several challenges, from the lack of yearly high-resolution maps to track changes, to the absence of suitable ground-based biodiversity data for training and validation [184], [185]. The lack of local detailed biodiversity data hampers the understanding of ecosystems and, therefore, the ability to create and implement effective conservation strategies (UNEP - UN Environment Programme) [186]. Current efforts to mitigate these data constraints are on-going but not yet operational [185].

The Evaluation of the EU Biodiversity Strategy to 2020 has identified two key lessons from the shortcoming of the initiative itself. First, effective implementation requires **specific, measurable targets** with clear definitions, set timelines and assigned responsibilities for implementation. Second, actions to halt and reverse biodiversity loss need to cover the range of pressures on all ecosystem types and, therefore, a **mixture of policy instruments** is needed to deliver the biodiversity commitments.

The EU needs to monitor shifts in geographic ranges of species, multi-temporal and multi-taxa assessments, distribution and conditions of species population and habitats as a function of changing climate. This is particularly challenging in certain ecosystems, such as freshwater and wetland habitats. In freshwater ecosystems, there are knowledge gaps in understanding freshwater ecosystems and uncertainty on the type and magnitude of stressors affecting EU rivers ecological status [187]. Moreover, the diversity and connectivity of freshwater ecosystems not always properly mainstreamed into conservation policies and objectives [188]. In wetland habitats, MSs lack a common definition for wetlands, and their geographic coverage is low in quantity and quality [185].

***Potential enablers include:***

* Investing in better data collection and monitoring systems is essential.
* Improve ground observations for calibrating and validating remote sensing products, with ground observations.
* Improve the operationality and accuracy of bioclimatic modelling (under development by C3S) [185].
* Develop a comprehensive mapping and monitoring system, incorporating diverse spatial and temporal resolutions, geographical coverage, and thematic granularity.
* Apply principles of **adaptive standards, monitoring protocols and co-management** practices including comprehensive site pre-restoration baseline measures and ongoing monitoring of ecological, social and economic effectiveness of actions (functional ecosystemic approach) [189], [190]. Such an approach will require conducting detailed ecological studies and monitoring can provide the necessary data to design effective corridors that support biodiversity [190]. Notably, the Natura 2000 network of protected areas is aimed at this objective and is having positive results.
* Improve monitoring and assessment of freshwater ecosystems, including the development of indicators and metrics to track changes in ecological status.
* Develop a common definition for wetlands and improve their geographic coverage in terms of quantity and quality.
* Promote the use of remote sensing products and improve their multi-temporal comparability.
* Develop and implement effective conservation strategies for freshwater and wetland ecosystems.

3.6.2 The effort to restoration spans across ecosystems and human activities

Several challenges hinder **companies to measure and take into account their impacts and dependencies on biodiversity.**

The complexity of biodiversity, which cannot be captured by a single metric, the lack of good quality data, and the lack of data for a harmonised assessment are some of the main barriers. In reforestation efforts, the outcomes have limits, and they may not sufficiently deliver on carbon sequestration, biodiversity recovery, influence on climate and sustainable livelihoods [191], [192].

Additionally, the lack of consideration of biodiversity and habitat safeguards in large-scale restoration projects, limited infrastructure for seed/seedling production and restoration techniques for neglected ecosystems, and the use of pioneer and invasive non-native tree species in "restoration" projects can harm biodiversity and ecosystem services.

*Potential enablers include:*

* Develop and implement more effective reforestation strategies that take into account biodiversity and habitat safeguards.
* Promote the use of sustainable forest management practices, including the use of native tree species and the protection of old-growth forests.
* Support research and development of new technologies and methods for reforestation and afforestation.
* Develop and implement effective conservation strategies for biodiversity conservation and restoration.

3.6.3 Policy and Financial Frameworks for Biodiversity Conservation and Restoration

The mobilisation of public and especially private finance for biodiversity remains overall small (notably compared to climate finance). The substantial data gaps and inconsistencies on biodiversity financing flows and where they are directed hamper the assessment of their effects. The lack of policy coherence and coordination across different levels of government and sectors is a major barrier to effective biodiversity conservation and restoration. Additionally, the lack of financial incentives and economic benefits for biodiversity conservation and restoration can hinder the implementation of effective conservation strategies.

**Potential enablers include:**

* Develop and implement more effective policy and financial frameworks for biodiversity conservation and restoration.
* Develop biodiversity offset schemes, conservation funds, and economic incentives for sustainable practices.
* Promote the use of sustainable finance policies and practices, including the integration of biodiversity risks and opportunities into financial decision-making.
* Develop and implement effective conservation strategies for biodiversity conservation and restoration.
* **Natural and restored floodplains** support achieving multiple EU policy objectives. More specifically they provide flood protection, and other ecosystem services such as improved water quality, improved conditions for biodiversity conservation and improved recreational value [193].
* It is necessary to have an **emergency recovery plan for freshwater biodiversity loss at EU level** [194].

3.6.4 Land and soil ecosystems

*Agricultural intensification remains one of the main drivers of biodiversity loss and ecosystem degradation and GHG emissions in Europe*

Agricultural intensification remains one of the main drivers of biodiversity loss and ecosystem degradation in Europe (e.g., the use of pesticides is the main driver of the decline of pollinators, the excessive use of fertilisers it is the main driver of coastal eutrophication, both pesticides and fertilizers together with mono-cultures drive loss of key soil organism groups), and sustainable agricultural practices are essential for the restoration of ecosystems. Moreover, the agricultural sector accounted for about 11% of the EU's domestic GHG emissions [142]. Several EGD targets related to food production, biodiversity protection, carbon sequestration, reduction of GHG emissions and pollution are entangled across their respective thematic areas (1, 5, 6 and 7) and are addressed jointly in this part.

The **CAP contribution has not halted the decline of biodiversity on farmland[[1]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush#_ftn1)**. The key barriers in the formulation of the agriculture targets are: 1) that targets are hard to monitor; 2) the lack of coordination between EU policies and strategies; 3) policies do not address the decline in genetic diversity; 4) the tracking of CAP spending for biodiversity is unreliable. Moreover, both the Commission and the MSs have favoured low-impact options.

The key enablers that the Commission could leverage are to: 1) improve the coordination and design of the post-2020 EU biodiversity strategy (including better tracking expenditure); 2) enhance the contribution of direct payments to farmland biodiversity; 3) increase the contribution of rural development to farmland biodiversity; and 4) develop reliable indicators to assess the impact of the CAP on farmland biodiversity.

**Enablers could include**:

* Models indicate that conserving at least 20% semi-natural habitat within farmed landscapes could primarily be achieved by spatially relocating cropland outside conservation priority areas, without additional carbon losses from land-use change, primary land conversion or reductions in agricultural productivity [195].
* MSs call for launching an EU-wide benchmarking system in agriculture and food systems aiming to harmonize methodologies of on-farm sustainability assessments, including monitoring and verification tools with common metrics and indicators. It should be financed by a Just Transition Fund that will be established outside the CAP [196]. Some data collection is ongoing, (see the LUCAS, EMBAL, INSGNIA projects), and a future step is linking it to actual farming practices.
* Well-designed measures for biodiversity protection, restoration and sustainable use can **bridge wider environmental and socio-economic benefits.** This includes tackling the conflict between soil conservation and implementation of REPowerEU-related initiatives and trade-offs between nature conservation and restoration and bio-economy objectives and their associated socio-economic dynamics, which might lead to land use intensification.

*In farmland, ecosystems accounting and management gaps could be met by innovative policy designs*

Insects decline is a major problem in biodiversity loss: the EU needs to improve the **monitoring and understanding of insects decline**. There is a limited understanding of the effects of environmental changes on insect communities. Enhance understanding of insects decline and their role in ecosystem services requires research and data collection, developing effective conservation strategies and mainstreaming the information to the stakeholders [197]**.**

Regarding chemical pressures, single, **substance-specific assessments** limit ecosystem-wide risk evaluations, **and does not account for cumulative impacts** under changing climate and ecological pressures [191], [192].

**Resistance management** also becomes challenging when availability limits the rotation of pesticides, leading to increased resistance risks [199]. Although low-risk pesticides and biopesticides offer promising alternatives, the lengthy development and approval processes hinder their timely availability, often forcing farmers to rely on conventional chemicals [200].

**Enablers could include**:

* Use integrated approach helps prevent “pollution swapping,” where improvements in one area increase pollution in another (Åkerman et al., 2020). **Moving beyond farmer-centric policies to include other agri-food stakeholders,** such as manufacturers and wastewater treatment companies, could strengthen overall policy impact [201].
* Shifting regulatory focus to **product and design standards for fertilizer manufacturers**, similar to fuel efficiency standards in the automotive industry, could drive innovation and encourage enhanced efficiency fertilizers, reducing nitrogen runoff at the source [201].
* Strengthening pesticide **risk indicators** is critical for assessing and managing pesticide impacts effectively. Tools like the Pesticide Load Indicator (Kudsk et al., 2018), the soil risk indicators under development [202], or the Aggregated Total Applied metric (Schulz et al., 2021) align with global initiatives, fostering data-driven decision-making and regulatory alignment across countries [199]( Tang et al., 2021).

Boosting actions to ensure soil ecosystem protection

The EU Soil Health Dashboard shows that 62% of EU soils are not in healthy condition. Thelack of understanding of soil biodiversity, with only 10% of species identified, is major knowledge gap, which combined with the complexity of soil ecosystems, makes it difficult to develop effective conservation strategies[[7]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush#_ftn7). Furthermore, there are many unknowns about **the biodiversity losses and tipping points for soil**. Unlike for physical and chemical soil properties such as texture [203], pH, and NPK [204], **high-resolution and molecular tools needed to investigate soil biodiversity** have been applied only recently at EU-level and harmonized datasets are just starting to emerge (i.e., LUCAS Soil Biodiversity module - [205]).

Soil degradation (in particular when combined with global warming) not only harms soil-related ecosystem services but also depletes the **soil organic carbon (SOC) stock** [206]. Recarbonizing soil by creating a positive soil carbon budget (wherein carbon input exceeds carbon loss) can alleviate these effects [207]. However, two key aspects need to be considered regarding soil recarbonization. The first is that with increasing soil carbon input, a new equilibrium state will be eventually achieved, leading to carbon gain attenuating after a few decades [208], [209]. Secondly, the carbon gains achieved through changes in management practices are reversible, i.e., much or all of the carbon gained can be lost if management practices are not maintained in the long term. It is worth noting the potential of **biochar** (depending on specific conditions and source material for the biochar) in improving the long-term SOC balance [210] [65].

, strategies and plans (e.g., Soil Strategy for 2030) have presented **carbon farming and soil actions in the EU**. However, more recently scenario has changed with legislative initiatives taken, namely proposal for a Soil Monitoring Law and the Carbon Removals and Carbon Farming (CRCF) Regulation. Policymakers and other stakeholders revealed that the main barriers to the adoption of carbon farming policies are **concerns over carbon leakage** and competitive advantage, the **need for a just transition, and structural issues in the food value chain**. Despite being regarded by researchers as a main barrier to carbon farming, the **agricultural lobby** is not perceived as a barrier by policymakers, who emphasize the importance of involving farmers in the policy process.

The ultimate aim of introducing soil carbon management practices (SCMP) is to introduce carbon into the agricultural system to ensure the soil’s long-term productivity and resilience. This requires a framework in which regulations and policy support are important for signalling and responding to societal expectations, but advice and engagement are equally important ingredients in helping to encourage sustained behavioural change on the ground. Ultimately, farmers need to understand the long-term benefits of SCMP and be encouraged and empowered to find long-term solutions. Given the **dual benefits of increased soil carbon** in restoring soil health and combatting climate change this might be a worthwhile investment for policy-makers [81].

1) The introduction of specific **economic incentives** to assist with, for example, the purchase or sharing of specialist machinery or to cover the transitional periods without benefits.

2) Improvements in **farmers’ technical skill**s, particularly in relation to the more technically challenging practices, such as minimum tillage and cover crops (**conservation agriculture** [23], [211], [212]).

3) The facilitation of **networks for farmer-to-farmer** **learning** opportunities to help farmers to identify and build their confidence in SCMPs that will work in their local area.

**Enablers could include**:

* Any incentives to encourage the uptake of **soil carbon management practices** (SCMP) cannot be implemented at an EU-wide level, rather regional-wide policies, including subsidies and communicative interventions, need to be tailored to overcoming specific local and regional agronomic, technical, social and cultural barriers to SCMP uptake [81]. Similar conclusions have been reached in relation to encouraging the uptake of **agri-environmental or climate change practices in agriculture** [81].
* MSs could boost uptake of **biological control of plant pests**, and reduce the influence of agro-chemical companies, promote agro-biodiversity, to reduce external inputs, improve nutrient management, advance in the decarbonisation of mineral fertilizers as well as develop and use **biocontrol**. Precision agriculture techniques that **optimize** fertiliser **and pesticide applications** on plants help reduce losses, minimizing environmental impact [200], [213]).
* **Organic farming** plays a key role in the transition to sustainable land management in the EU [196], [214]( EC AGRI 2023). Conversion to organic farming includes the high transition costs, insufficient technical knowledge among farmers, lower yields, and limited access to quality organic inputs, increased food price, financial risks and complex regulatory challenges related to organic certification. Conversely, there is a growing consumer demand and enhanced market access for organic products, education and training programs, and collaborative initiatives among farmers for resource sharing. Supportive EU policies, subsidies and financial incentives can promote organic farming and facilitate sustainable practices [196, p. 20], [214](, EC AGRI 2023,). Changes in production practices would be more effective if combined with reduced consumption levels and changes in patterns of demand (EEA SOER 2020).
* The creation of **a nature restoration fund** (outside of the CAP) should support farmers and other land managers to restore and manage natural habitats at the landscape level [196], [199], [201], [215].

*Farmland and soil ecosystems can be restored in synergy.*

At MSs level a better use of **integrated land use planning** would allow harmonizing the conservation goals with other land uses [190]. Moreover, successful management of **multifunctional landscapes** (including, for example, biodiversity corridors in farmland) requires the combination of context-specific land-sharing and land-sparing measures within spatially well-connected landscape mosaics, resulting in land-sharing/-sparing connectivity landscapes [216].

**Stakeholders engagement is key** to address all of the above barriers: inadequate involvement of local communities in conservation efforts may reduce the effectiveness of initiatives on soils and their biodiversity. Indeed, between the main barriers in easing the tension between the necessary food-production activities and the biodiversity protection are **short-term economic pressures:** farmers and policymakers frequently prioritize immediate economic benefits over long-term soil health and biodiversity.

**Rewarding and incentivizing farmers is needed to establish and to continue providing ecosystem services**, with environmental payments that “go beyond what is required by EU legislation and aim at the highest ambition in a system to be linked to quantifiable results using robust indicators” . To this end, a **Temporary Just Transition Fund** should be established outside the CAP [196].

To take into account the EU green transition goals, according to the **next CAP** should focus on [196]: (1) providing socio-economic support targeted to the farmers who need it most; (2) promoting positive environmental, social, and animal welfare outcomes for society; and (3) invigorating enabling conditions for rural areas. Implementing practice-based incentives (e.g. subsidizing beneficial methods for soil biodiversity protection) to encourage farmers to adopt sustainable practices, and coupling those with regulatory soil protection legislation with incentive-based instruments could help in making CAP more effective in promoting soil and its biodiversity conservation [217].

The European Commission should conduct a full review of EU **food** **labelling** legislation, as well as publish a report evaluating the current measures relating to the marketing to children role[196]. Moreover, fiscal tools in the form of tax reduction for consumers should be provided to foster coherent price signals and Member States should foresee measures to safeguard food affordability for lower income consumer segments through social and fiscal policies.

**Diet changes** (consuming “less meat”)**, reduced post-harvest losses, and reduced food waste** contributes to eradicate poverty and promote wellbeing and sustainability. Improved forest management (next paragraph), soil carbon sequestration, peatlands and coastal blue carbon management (covered below) can enhance biodiversity and ecosystem functions, and increase the employment in those sectors [15].

3.6.5 Water ecosystem

Overfishing, eutrophication and Invasive alien species are the main challenges in marine ecosystem restoration

Key barriers include **overfishing and destructive fishing practices** (EU, 2020), stagnant and poorly sustainable aquaculture (Guillen et al., accepted), pollution from agricultural runoff, industrial activities, and wastewater (EEA, 2020), and inadequate governance and enforcement of environmental regulations (EC, 2019), including for the EU aquaculture [218], [219].

Notably, **eutrophication** is exacerbated by climate change [218]. The trend and rate of alien species introductions are increasing [220], [221]. Marine invasive alien species (IAS) are primary drivers of biodiversity loss, through habitat modification, competition with native species, predation, disease agents or vectors [222]. Their diverse and widespread impacts means that they affect all marine conservation programs including: marine protected areas; habitat management (effects of fishing); marine mammal conservation, etc.(e.g., Katsanevakis et al,. 2014b; Tsirintanis et al. 2023; IPBES 2023[[40]](https://euc-word-edit.officeapps.live.com/we/wordeditorframe.aspx?ui=en-US&rs=en-IE&wopisrc=https%3A%2F%2Feceuropaeu.sharepoint.com%2Fteams%2FGRP-Shapinggreentransition-LeadershipTeamchannel%2F_vti_bin%2Fwopi.ashx%2Ffiles%2F05f5269ac0fb4355b777840993416665&wdorigin=TEAMS-MAGLEV.teamsSdk_ns.rwc&wdexp=TEAMS-TREATMENT&wdhostclicktime=1734508112726&wdenableroaming=1&mscc=1&hid=A5AE6EA1-0008-A000-105B-A7CCBBCF39B0.0&uih=sharepointcom&wdlcid=en-US&jsapi=1&jsapiver=v2&corrid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&usid=5fe037a0-757b-11d1-c547-bf1a0e42c97b&newsession=1&sftc=1&uihit=docaspx&muv=1&cac=1&sams=1&mtf=1&sfp=1&sdp=1&hch=1&hwfh=1&dchat=1&sc=%7B%22pmo%22%3A%22https%3A%2F%2Feceuropaeu.sharepoint.com%22%2C%22pmshare%22%3Atrue%7D&ctp=LeastProtected&rct=Normal&csc=1&instantedit=1&wopicomplete=1&wdredirectionreason=Unified_SingleFlush" \l "_ftn40))[223]

**Potential enablers include:**

**Blue Carbon Initiatives:** Pilot programs on blue carbon farming link the food system to aquatic and marine ecosystems, focusing on reducing emissions in fisheries and promoting sustainable aquaculture. This integration broadens the approach to climate change mitigation, including a lesser-known carbon sink.

Again**, policy coherence** is key. For marine ecosystems, it is necessary to review policies that present risk of supporting unsustainable fishery and eliminate support to such practices. Also make the support (energy related support e.g.) conditional on vessels carrying their flag and authorised to fish in their waters [[224], p. 2]~~.~~

The Water Framework Directive (WFD) monitoring and assessment systems

It is insufficient monitoring to identify the cause of degradation (due to poor linkage between pressures and effects on the ecosystem).

Suggestions to enhance the **WFD Monitoring and assessment systems** [225] include

1) communicate progress toward good status more effectively; 2) Incorporate innovation into monitoring and assessment, 3) Improve diagnosis of cause of deterioration. Moreover, **WFD Policy needs** integration with other sectors, especially agriculture [225]~~.~~

Along the same lines, it is recommended to consider **hydrological connectivity** into freshwater conservation [188]~~.~~

At the regional level, managing species and ecosystem diversity at the landscape scale implies identifying and preserving specific and very often marginal habitats within forests, such as water springs, watercourses, wetlands, peatlands, rocky sites and topographically extreme sites with lower tree density, provide excellent opportunities to maintain and promote biodiversity. - land sharing, land sparing, Triad management [226].

3.7 Towards a Zero-Pollution ambition

The Zero Pollution EGD thematic area builds on pre-existing and well-established policies, like the Water Framework Directive [227], the Nitrate Directive [228], the Marine Strategy Framework Directive [229] which predate the EGD and that have been implemented in the last decades. Some of them have been recently reviewed, like the Ambient Air Quality Directive [230]. A rich literature exists on the implementation of these policies, highlighting challenges and possible solutions for the achievement of the Zero Pollution objective. This section focuses around three potential levers for the implementation of these policies: 1) adopting holistic concepts and mitigation strategies; 2) addressing nutrient pollution in agriculture through an agri-food chain lens 3) promoting participatory and bottom-up approaches in environmental monitoring.

3.7.1 Adopting holistic concepts and mitigation strategies

The Water Framework Directive (WFD) explicitly recognizes the interconnected nature of water systems and the diverse societal, environmental, and economic factors influencing them. However, monitoring strategies often focus on single drivers and fail to capture the complex interactions between pressures, leading to an incomplete understanding of ecosystem properties. In particular, many Member States have designed their monitoring programs based on individual parameters rather than overall ecosystem health, leading to persistent issues with water quality and ecosystem management. This indicates a need for more comprehensive monitoring and pressure-impact analysis to ensure effective water management and compliance with WFD goals [231], [232] .

In the field of nitrogen pollution, generally most policies have a siloed approach as they have policies specific for a certain sink: for instance, in the EU, NO3 pollution is controlled under the Nitrates Directive, while ammonia (NH3) and NOx emissions are subject to the EU National Emission Ceilings legislation. This can result in "pollution swapping," where measures to reduce one type of Nitrogen pollution may inadvertently increase another [201] .

The development of more holistic, coherent mitigation approaches could be important several cross-cutting fields such as nitrogen pollution, water management, etc. Concepts developed in social-ecological science, e.g. the ecosystem services and “one health” approach may help overcome fundamental obstacles in the implementation of environmental policies as they have the potential to integrate different policies and administrative areas and to capture the connections between environmental and socio-economic systems. Similarly, in the field of chemicals pollution the development of the Safe and Sustainable by Design concept and framework allows to integrate considerations related to human health risk assessment with the environmental and social sustainability assessment in the early stage of the innovation process. This allows taking into account potential burden shifting and avoid regrettable substitution of hazard chemicals.

**Potential enablers include:**

* Promotion of interdisciplinary and more integration in the policy making, encouraging cross-pollination across policy makers.
* Establishing multi-disciplinary research units or teams on environmental health topics in local health authorities, in order to enhance collaboration between medical staff and environmental agencies and integrate competences for mutual benefit.

3.7.2 Addressing nutrient pollution in agriculture through an agri-food chain lens

The agricultural sector is a relevant source of pollution of water bodies, air and soil. Fertilization and use of pesticides are among the major polluting components of drinking water. Moreover, the application of mulch films and sewage sludge are also sources of microplastics. The Environmental Implementation Review highlights that limited progress was achieved in the reduction of pollution of water bodies due to excessive fertilization in the primary sector. In particular, many Member States have problems in relation to the implementation of the Nitrates Directive and should step up their efforts to further reduce nitrate pollution from agriculture in groundwater and eutrophication [233].

The current policies on nitrate pollution reduction focus on changing farmer behaviour, but policymakers might consider targeting actors in the agri-food chain beyond the farm. For instance, the fertilizer industry and wastewater treatment companies can contribute to influence farm-level nitrogen management. This approach would shift the regulatory burden away from farmers and transform a complex non-point-source problem into a series of more manageable point-source approaches [201].

Fostering research and innovation is a primary objective within the EC Competitiveness Compass [2]. This is particularly important for the development of enhanced-efficiency fertilizers, which can significantly reduce nitrogen pollution. Indeed, globally, the fertilizer industry has a limited number of R&D policies and a reduced budget is devoted to nitrogen pollution are in place compared to, e.g., the pharmaceutical and seed industries [194].

The ‘Knowledge for INMAP’ project, developed by the JRC during the year 2021, aimed to gather scientific knowledge and data available in the EU to support the discussion and preparation of the INMAP (Integrated Nutrient Management Action Plan). The plan covers all sectors and environmental compartments involved in the nitrogen (N) and phosphorus (P) cycles. The JRC project included the description of the current flows of N and P in the EU, considering all sources and sectors involved (agriculture, industries, urban, energy and transport) and all environmental losses in air, water, and soils. It evaluated the distance to environmental targets and analysed the possible measures to reduce nutrient pollution at different intervention points in the nutrient cycle. The project conclusions highlighted the following measures for the reduction of the nitrogen pollution [234]:

* Optimize agricultural practices promoting balanced mineral fertilization to adjust nitrogen application in areas with surplus or deficit
* Adopt agro-ecological practices, including cover cropping, residue management, and agroforestry, to improve soil health and reduce nitrogen losses.
* Develop and implement novel techniques for nutrient recovery from organic waste (e.g., manure, sewage sludge, and bio-waste) and increase recycling efforts to transform waste into nutrient-dense, safe fertilizers.
* Upgrade domestic wastewater treatment to reduce nitrogen discharges into aquatic systems.
* Encourage shifts in dietary patterns to reduce reliance on animal protein, which would decrease nitrogen-intensive livestock production.
* Utilize diverse modelling tools to assess impacts, adapt measures to specific regional contexts and integrate multiple measures (e.g., wastewater treatment, emission reduction, and agricultural improvements) to achieve significant reductions in nitrogen losses to air, soil, and water systems.

3.7.3 Participatory approaches and citizen science initiatives

The assessment of air quality related targets shows that improvements in the air quality have been achieved, considering the trends in years of life lost per 100 000 inhabitants for PM2.5 [1]. At the same time, The Environmental Implementation Review [233] highlights that in many Member States the limit values for these pollutants are persistently exceeded, leading to infringement proceedings for key pollutants, such as particulate matters and nitrogen dioxide. In some of these cases, the Court of Justice of the EU has already handed down judgments. Infringement cases against two Member States focus on shortcomings in monitoring networks.

Flawed reporting with incomplete and incorrect assessments of activities also affects water bodies, demonstrating a lack of precise information and knowledge as well as assessment and monitoring capacities in environmental management.

Among other strategies, adopting participatory and bottom-up approaches and involving citizens in the pollution monitoring can contribute to improving air pollution and water quality monitoring [232], [232], [235], [236]. Civil society can play an active role in co-producing air quality information. Citizen science practices for measuring air pollution introduce a new dynamic by leveraging citizen-generated air quality data to address the air pollution problem and enhance monitoring efforts. This citizens’ involvement can lead to greater awareness and a change of behaviour, which in turn could contribute to better compliance with air quality standards. With growing citizen awareness and concern about air pollution's health impacts, there's a push for their active participation in air quality monitoring [233].

In recent years, numerous cities have initiated citizen science projects to monitor air pollution, actively involving residents in decision-making processes. For instance, in Gothenburg, locals construct sensors that provide real-time air quality data. Similarly, Brussels' 'Curieuzenair' project distributed NO2 tubes to measure air pollution in areas beyond standard measuring stations. These projects not only raise awareness about air pollution among citizens but also empower them to participate in data collection that informs decision-making. Furthermore, cities can enhance public awareness about clean air by highlighting the health benefits of improved air quality. For example, in Krakow, better air quality has been linked to a reduction in children's asthma cases [237].

In the case of water quality, participation in environmental governance (e.g. participatory river basin management planning) improved the environmental outcome and the quality of the Water Framework Directive implementation. In particular, an increasing quality of outputs was observed with increasing intensity of local participation [238]. It was also demonstrated that citizens are central stakeholders in the development of the UN treaty on plastic pollution [239].

The JRC initiative Gems of Water is another example of citizen engagement project for water quality monitoring. It connects local groups concerned with water quality issues around the world to scientists, who provide methodological, technical and analytical support to monitor pollution caused by organic contaminants.

Citizen science also has a clear role to play in monitoring soil health, e.g. in generating data on soil biodiversity, vegetation cover, soil organic carbon, nutrients, etc. A recently started Horizon Europe project called Engaging citizens in soil science: the road to healthier soils (ECHO, 2023–2027) has citizen science as its primary focus. The project aims to engage citizens by enhancing their knowledge and interest in soil health, motivating them to protect and restore soils [240]. A review of citizen science tools related to soil suggests that engagement of citizen can be facilitated through providing feedback protocols on their scientific contribution and assigning qualified mediators or activity leaders to support participants throughout the project [241]. Citizen science approaches have been applied also in biodiversity related project, e.g. for reversing the decline of wild pollinating insects [242]and control the invasive species [243]..Despite the demonstrated potential, challenges remain in legitimizing citizen-generated data as scientific evidence [236]. The most commonly reported barrier to academics’/research organisations’ and decision-makers’ use of citizen science data and knowledge relates to their openness and perceived lack of quality. Measures to enhance the use and the quality of citizen science could include the following [244]:

* Raise awareness of citizen science for environmental monitoring and promote it within public institutions;
* Give visibility and recognition to citizen science outcomes;
* Support the creation, extension and/or upscaling of pan-European citizen science initiatives in priority areas under the Green Deal;
* Support the establishment of open data portals and platforms where citizen science initiatives and public authorities can publish, preserve and curate monitoring data and information.

1. CBAM is a tool to put a fair price on the carbon emitted during the production of certain carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. The CBAM will initially apply to imports of goods and selected precursors whose production is carbon intensive and at most significant risk of carbon leakage: cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. [↑](#footnote-ref-2)
2. JRC Expert - Fiche on Textiles [↑](#footnote-ref-4)
3. On-going JRC project from B5 for DG ENV.B3 focused on construction and demolition waste, publication awaiting [↑](#footnote-ref-5)
4. Mobility-as-a-Service describes the combination of various mobility services into a single digital platform, facing the difficulties to integrate data of diverse transport operators [145].  [↑](#footnote-ref-7)