Synergies and trade-offs in EU adaptation and mitigation policy

Policy analysis report

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Executive Summary

This report, 'Synergies and trade-offs between EU adaptation and mitigation policies', analyses EU-level policy, including European Green Deal policies and the EU Adaptation Strategy. The report identifies overlaps, gaps, synergies and trade-offs between mitigation and adaptation policies in the EU.

The policy analysis compares current EU policy documents on land, energy, and finance to the EU Climate Law-aligned "iconic" mitigation pathways identified by the European Scientific Advisory Board on Climate Change (ESABCC). The iconic pathways vary in the GHG emissions between 2030-2050, needed CDR and energy mix, which determines their names: (i) demand-focused, (ii) high renewables, and (iii) mixed. In addition to the analysis of respective policies, the report considered scientific publications and relevant grey literature into consideration to qualitatively suggest the level of alignment between current policies, mitigation narratives aligned to climate mitigation goals, and future adaptation needs. Analysis is separated into two sections, focusing on mitigation alignment and adaptation alignment.

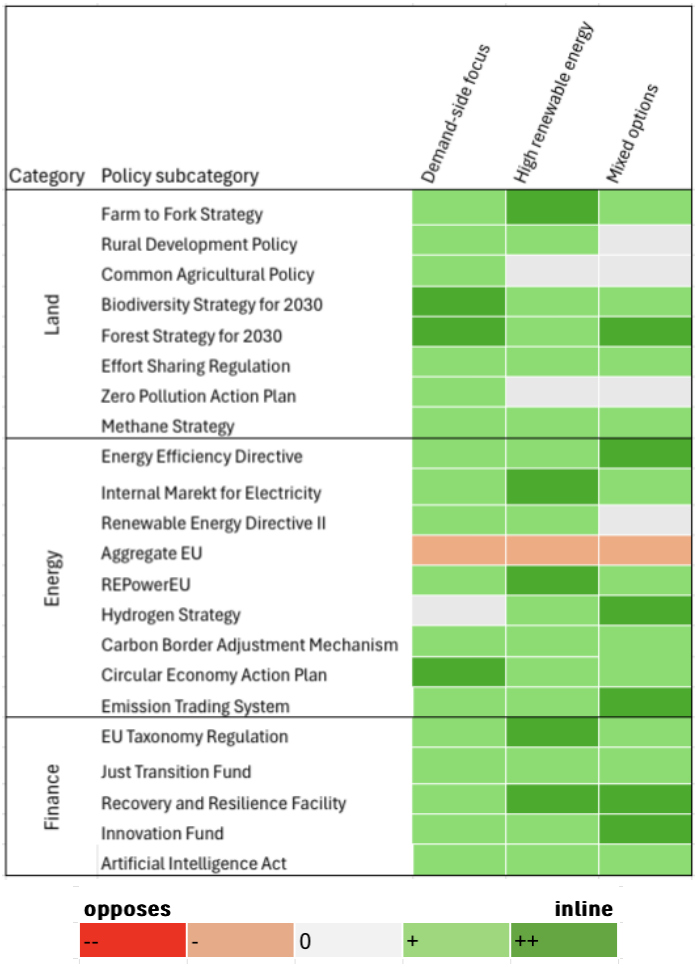

Figure 1. Overview of mitigation policy alignment with each ESABCC "iconic pathway", which includes unique combinations of climate mitigation measures in satisfaction of EU legislated climate targets.

The mitigation analysis, summarised in Figure 1 above, highlights that EU sectoral policy alignment varies across the ESABCC iconic pathways and that policies are not strongly aligned with any of the pathways. Land-focused policies show promising alignment with the Demand-focused pathway, while financial policies correspond more closely with the Mixed pathway. These trends suggest opportunities to further incorporate ESABCC guidance into EU-level strategies.

This report outlines various policy-specific recommendations, as well as underscoring a need for greater policy adherence across Member States but also offers general suggestions in terms of increasing the EU's climate ambition. Key findings include:

- Demand-side measures are needed to shift consumer behaviour, with specific and pronounced examples in reducing demand for livestock and energy consumption.
- Greater integration of GHG reduction targets into agricultural policies (i.e., CAP) is necessary.
- Careful inclusion of land within the ETS can incentivise land protection and biodiversity goals, and the policy can increase carbon pricing for greater action.
- Member State variations regarding the Effort Sharing Regulation present challenges to cohesive EU climate progress, highlighting opportunities to strengthen support mechanisms and ensure consistent effort. Some cases of low ambition imply a need for increased support, while other examples suggest stricter compliance mechanisms and the elimination of the ability to transfer accomplishments between annual budgets.
- The Methane Regulation can incorporate binding targets and pricing mechanisms.
- Further compliance mechanisms in the Renewable Energy Directive can reduce the number of underperforming Member States.
- Redirecting financial support from fossil fuels toward clean energy and hydrogen production would enhance coherence with EU climate commitments and accelerate the energy transition.

The adaptation policy analysis assessed future adaptation needs based on the trade-offs of mitigation actions included in ESABCC pathways. Adaptation-relevant policies were considered, as well as grey literature, to determine illustrative, qualitative scores ranging from vulnerable to resilient. The analysis suggests the largest likely vulnerabilities are implied by measures employed in the Mixed options pathway, due to increased disaster risks for land-based CDR, low social and health benefits, and high capital cost challenges. Higher vulnerabilities discovered in the analysis imply greater social support needs, which may be particularly helpful in agricultural and rural regions during transition. Similar to findings of the mitigation analysis, EU adaptation can also benefit from greater uniformity between Member States' ambitions. Figure 2 provides an overview of comparative findings by pathway. Key findings include:

- Member States would benefit from further coordinated strategic planning and targeted research.

- Improved early warning systems for land-based CDR and the careful siting of energy infrastructure will be important to synergise mitigation and adaptation, particularly in water-scarce regions.
- Economic resilience should be reinforced through reskilling (including topics such as AI), welfare investments, and strong public and corporate finance, especially in vulnerable regions.
- As climate transitions create socioeconomic trade-offs, targeted support and policy dialogues can ease tensions. In this sense, AI regulation will continue to be needed to avoid misinformation.
- Greater financial backing for the Union Civil Protection Mechanism is needed.
- Long-term investment strategies would present an opportunity beyond the Recovery and Resilience Facility.

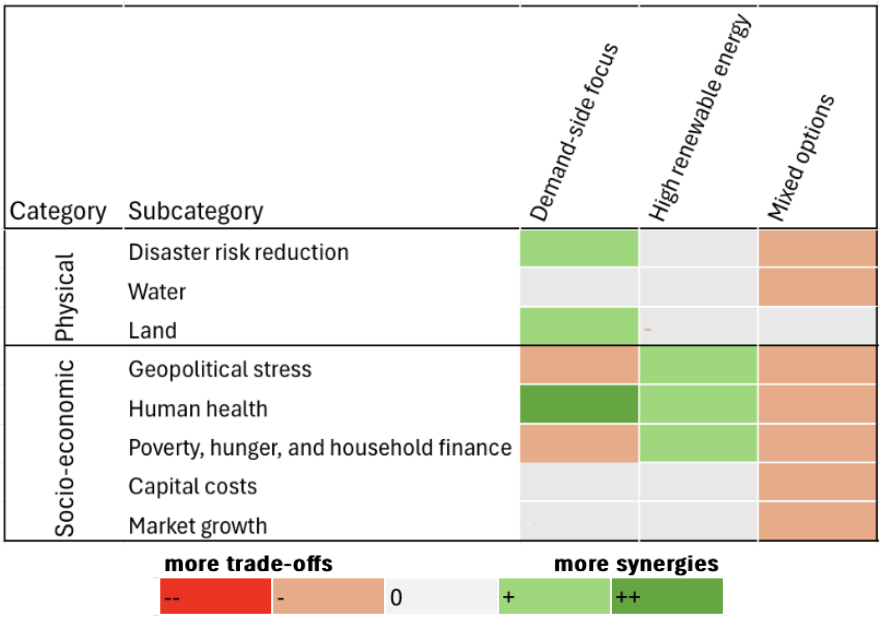

Figure 2. Overview of comparative resilience or vulnerability in physical and socioeconomic risk subcategories according to each ESABCC "iconic pathway", which includes unique combinations of climate mitigation measures to reach EU legislated climate targets.

About this report

The selection of policy areas and specific policies reflects the focus of the SPARCCLE project, leveraging the modelling capacities of project partners. Within the project, this analysis has contributed to the co-development of stress-testing scenarios with multiple stakeholders. These scenarios, which will be modelled by project partners, are expected to yield new insights that will be presented in the final report, *Europe under Stress*, scheduled for release at the end of 2026.

Key Words

European Union; mitigation; adaptation; mitigation trade-offs; mitigation synergies; adaptation synergies; adaptation trade-offs; climate risk;

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1 Introduction

This report evaluates the alignment of EU policies with EU Climate Law legislated targets, as well as associated gaps, synergies, and trade-offs between mitigation and adaptation. The "iconic pathways" to achieve EU Climate Law goals, outlined by the European Scientific Advisory Board, are referred to regarding select policies relevant to land, energy, and financial policy. By analysing policies, the report provides insights into the alignment of EU policy with 1.5°C climate scenarios, to highlight areas for improvement. The "iconic pathways" are further analysed to explore potential adaptation trade-offs and synergies implied by ESABCC mitigation pathways, discussing areas that could be strengthened for a more resilient EU. While adaptation is context-specific (OECD, 2021), an EU overview is a valuable step toward a better understanding of EU-level adaptation-mitigation synergies and trade-offs.

The report begins by introducing the ESABCC "iconic pathways" in Section 2. The methodology of the policy analysis is outlined in Section 3. Mitigation policy analysis is discussed in Section 4 while adaptation policy analysis is in Section 5. Finally, Section 6 concludes the analysis and discusses future needs for a resilient EU and subsequent research. The findings aim to inform policymakers on areas where adjustments are needed, as well as to showcase instances where EU policies already align with these ambitious climate goals. Such findings offer valuable insights for future EU policy, and Member State policies, as well as the SPARCCLE consortium, contributing to more informed and effective decision-making.

2 Introduction to EUSABCC Iconic Pathways

The Paris Agreement set the goal of avoiding climate change by holding global warming to well below 2°C and pursuing efforts to limit it to 1.5°C, relative to pre-industrial levels (UNFCCC 2015, Article 2.1a as in European Scientific Advisory Board on Climate Change., 2023). The European Climate Law, adopted in 2021, pursues the long-term temperature goal of the Paris Agreement by setting binding targets for achieving climate neutrality in the European Union (EU) by 2050. The law includes intermediate targets to reduce GHG emissions by 55% by 2030, reach net-zero GHG emissions by 2050, and negative emissions after 2050, as compared to 1990 GHG levels (European Commission, n.d.-d). Such goals led to the adoption of several 'Fit for 55' package elements (i.e., EU emissions trading system (EU ETS), Effort Sharing Regulation (ESR), Regulation on Land Use, Land Use Change, and Forestry (LULUCF) and the establishment of the ESABCC (European Scientific Advisory Board on Climate Change, 2023). The ESABCC is an independent body, mandated by the EU Climate Law, comprised of 15 independent scientific experts who provide the EU with knowledge, expertise, and relevant advice on climate mitigation and adaptation (European Scientific Advisory Board on Climate Change, 2023).

The ESABCC was requested by the European Commission to provide scientific advice on i) GHG emission budgets for 2030-2050 and ii) GHG emission reduction targets for 2040, to inform legislation consistent with EU Climate Law (European Scientific Advisory Board, n.d.). To answer these questions, the ESABCC conducted scenario assessments to model relevant budgets and reduction targets in line with the EU Climate Law, entailing a comprehensive scenario vetting process (illustrated in Figure 3 below) (European Scientific Advisory Board on Climate Change, 2023). Considering aspects such as fairness and feasibility, a select number of scenarios led to the ESABCC recommendation that the EU's cumulative GHG emissions should be kept below 11-14 Gt CO_2e between 2030 and 2050 and support a reduction target of 90-95% GHG emissions by 2040, relative to 1990 (European Scientific Advisory Board on Climate Change, 2023). These budgets serve as a basis for policy developments, suggesting high ambition in domestic emission reductions, direct emission reductions outside of the EU and pursuit of sustainable net negative emissions after 2050 (Edenhofer, 2023).

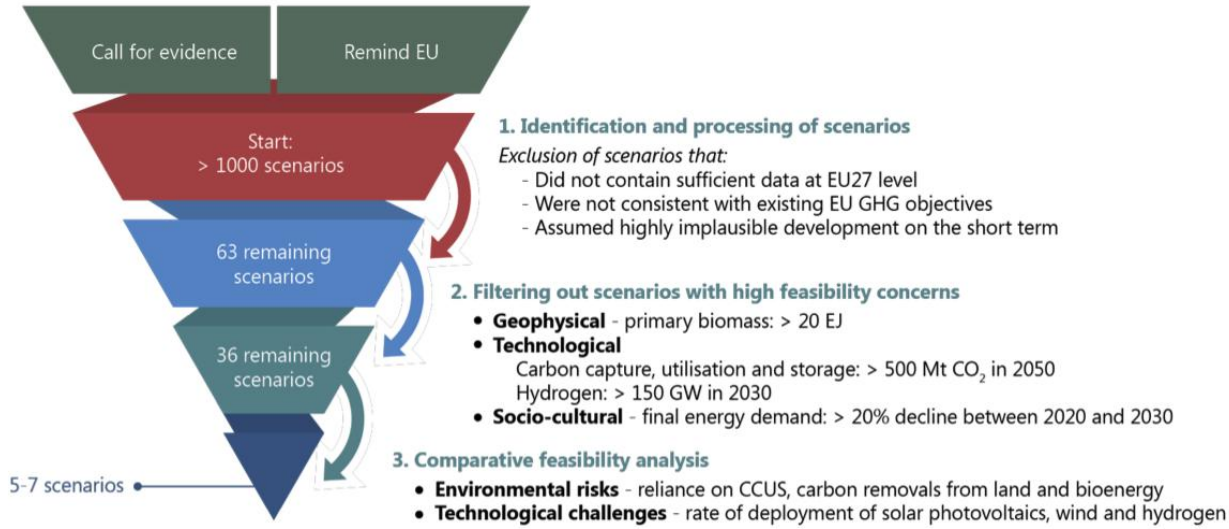

Figure 3. Consideration of the latest scientific evidence on emission scenarios compatible with 1.5°C and EU targets for scientific advice for an EU 2040 target and GHG budget for 2030–2050 (Edenhofer, 2023).

2.1 The ESABCC Iconic Pathways

Three "iconic pathways" of GHG emission scenarios are detailed in the 2023 ESABCC report to illustrate different ways that the EU can achieve its overarching goal of climate neutrality by 2050 (European Scientific Advisory Board on Climate Change, 2023). The pathways focus on (1) carbon-neutral energy shifts which would be heavily reliant on renewables, phasing out fossil fuels, and leveraging electrification across sectors; (2) circular economy & efficiency to target resource intensity reductions through recycling, resource efficiency, and waste reduction to decrease production and consumption emissions; and (3) carbon dioxide removal (CDR) to enhance carbon sequestration in natural ecosystems, implement negative emissions technologies like Bioenergy with Carbon Capture and Storage (BECCS), and promote soil carbon enhancement (European Scientific Advisory Board on Climate Change, 2023). The "iconic pathways" are consistent with the highest levels of ambition identified in the IPCC 6th Assessment report of Working Group 3 scenarios assessment, have comparatively lower feasibility concerns, and are considered an equitable and fair EU emissions reductions contribution to global climate change mitigation (Riahi et al. 2022).

Across each pathway, the power sector is decarbonised with near-to-zero emissions by 2040, with a power mix based on renewable energy sources (70-90% of the mix in 2040), very low to no power generation from unabated gas-fired or coal generation by 2040, and an almost doubling of the share of electricity in final energy demand(European Scientific Advisory Board on Climate Change, 2023). Large-scale deployment of renewable energy and electrification technologies across pathways suggests a considerable increase in critical materials demand, though no pathway offers direct

results on these demand changes. All scenarios require alternative non-fossil energy carriers for applications that are hard to electrify (i.e. industry and transport). The use of hydrogen is scaled up in all pathways, with production of 5-10 Mt by the 2030s. Total final energy demand decreases considerably across scenarios (20-40% from today), supported by higher electrification, and sectoral energy demand decreases, such as in transport (30-60%), industry (20-45%) and residential and tertiary sectors (15-35%) (European Scientific Advisory Board on Climate Change, 2023).

The "iconic pathways" include considerable reductions in non-CO_2 GHG emissions (20-60% below today's levels), including changes in nitrogen fertiliser use (ranging from nearly 35% reductions to a 50% increase) and increases in agricultural and energy crop production (European Scientific Advisory Board on Climate Change, 2023). All pathways foresee large reductions in methane emissions from waste (45-60%), due to reductions in landfills, and energy use (70-90%), due to reduced fossil fuel use. Some estimates from the scientific literature place potential carbon removals from the LULUCF sectors between 100-400 Mt CO_2. CDR through BECCS and Direct Air Carbon Capture and Storage (DACCS) varies considerably between 50 and 200 Mt CO_2 in 2040 in scenarios. Net oil imports decrease from 50-100% by 2040, as compared to today. Net gas imports decrease between 35-100%. The large-scale deployment of renewable energy and electrification technologies across pathways suggests demand for critical materials should increase considerably, though none of the pathways offer direct results on changes in critical material demands (European Scientific Advisory Board on Climate Change, 2023).

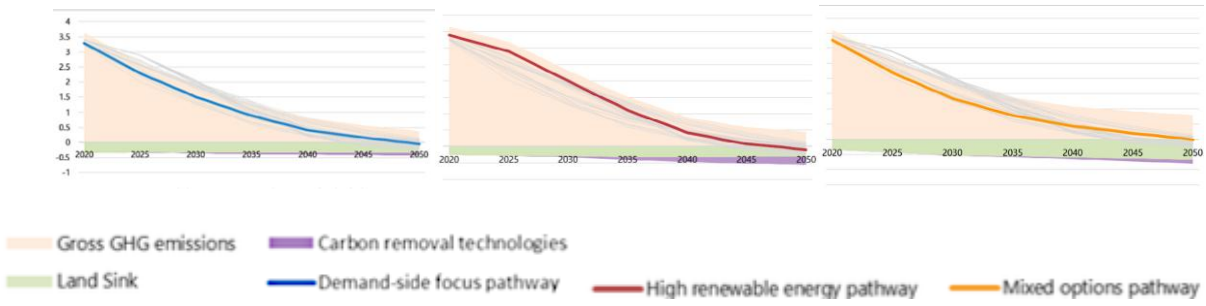

Figure 4. Emission reduction trajectory illustrations (from left to right: Demand-side focus, High renewable energy, and Mixed options) detailing the net GHG emissions (in Gt CO2e) on the y-axis and emissions taken up by land sinks and carbon removal technologies by pathway (European Scientific Advisory Board on Climate Change, 2023).

The three ESABCC "iconic pathways", titled 'Demand-side focus', 'High renewable energy' and 'Mixed options', consider the achievement of legislated climate targets of a 55% reduction in GHGs by 2030 and net-zero GHGs in 2050. Thus, they have various similarities as described in the above section. The next sections explain narrative differences between pathways. Table 1 below details GHG budgets, GHG reductions, and other key parameter differences between iconic pathways.

	Iconic pathway		
	Demand-side focus	**High renewable energy**	**Mixed options**
Greenhouse gas budget 2030-2050 (Gt CO_2e)			
Intra-EU bunkers only	11.7	13.8	11.1
All bunkers	13.7	16.8	13.2
Greenhouse gas reduction below 1990, including intra-EU bunkers			
By 2040	91.2%	90.9%	90.8%
By 2050	-101.1%	-102.0%	-100.3%
Other key parameters			
Final energy demand (% change in 2040 vs 2015)	-40%	-38%	-23%
Electrification (electricity share of final energy demand in 2040)	45%	50%	45%
Share of electricity production in 2040 (%)			
Non-biomass renewables	90%	87%	72%
Nuclear	3%	7%	23%
Natural gas (with and without CCS)	2%	2%	4%
Net imports			
Fossil fuels in 2040 (EJ)*	6.1	5.8	8.0
% change since 2015	-81%	-82%	-70%
Bioenergy consumption (primary) in 2040 (EJ)	10.3	7.1	5.3
Hydrogen production in 2040 (EJ)	1.7	1.6	3.5
Carbon capture, utilisation and storage (Mt CO_2 captured per year by 2050)			
Total	145	308	417
of which biomass *	*77*	*234*	*147*
Land sink (net LULUCF Mt CO_2 removed annually)*			
In 2040	351	323	601
In 2050	351	312	669

Table 1. GHG budgets for 2030–2050 and 2040 reductions by ESABCC iconic pathway (European Scientific Advisory Board on Climate Change, 2023).

2.1.1 Demand-side focus pathway

The Demand-side focus pathway combines ambitious mitigation policies with the global achievement of the UN Sustainable Development Goals (Soergel et al., 2021 as in European Scientific Advisory Board on Climate Change, 2023). It considers demand changes toward less resource-intensive lifestyles and a shift to EAT-Lancet diets, decreasing demand for livestock by 58% from 2019–2040, the share of livestock in total food demand from 29–13%, and feed crops for livestock demand by 41%. Plant-based proteins in the total dietary protein supply will increase from 40% to 80% between 2015 and 2050 while avoiding an increase in food prices (Soergel et al., 2021 as in European Scientific Advisory Board on Climate Change, 2023). The share of food waste decreases by 24% between 2019 and 2040. Nitrogen fertiliser use is reduced by 21% between 2020 and 2040. A higher level of methane emissions is included, 61% between 2019 and 2040. Nitrous oxide emissions from agriculture will be reduced by 7–52% between 2020 and 2050. This pathway has the lowest reliance on carbon removals from Carbon Capture Storage (CCS) and land sinks by 2050 (European Scientific Advisory Board on Climate Change, 2023).

The Demand-side focus pathway will reach 43% electrification in 2040 (European Scientific Advisory Board on Climate Change, 2023). It exhibits the lowest final energy demand by 2040, with significant reductions in material demands and increases in the recycling of energy-intensive materials (Rissman, J. et al., 2020 as in European Scientific Advisory Board on Climate Change, 2023). It includes a 22% reduction in final energy demand in residential, commercial, and public sectors from 2019 to 2040 due to efficiency gains from high electrification and continuous declines in fossil fuel use. Such sectors rely on 54% electricity, 11% heat, and 9% bioenergy in 2040. Growth of electrification slows after 2040. Hydrogen use will expand after 2020, but slowly and begin to stagnate around 2035. The demand-side pathway shows higher wind, the lowest solar, the lowest nuclear, and the highest biomass deployment for fuel and electricity generation by 2040, out of the three pathways. Dietary shifts away from meat and dairy imply more available land for energy crops. This pathway has the highest share of energy crops in croplands. Bioenergy use will be highest in this pathway by 2050, while BECCS deployment is the lowest (European Scientific Advisory Board on Climate Change, 2023).

2.1.2 High renewable energy pathway

The High renewable energy pathway assumes agricultural, economic and land-use limitations to renewable energy expansion (European Scientific Advisory Board on Climate Change, 2023). Thus, the pathway relies on limited bioenergy, through sustainably sourced biomass, production of 7.5 EJ per year. It considers constraints to accelerating emission reductions in the short term (i.e., does not assume the overachievement of the 2030 target) and has the largest GHG budget of the iconic pathways. Methane emissions are reduced from 35-50% between 2019-2040, with agricultural methane emissions particularly dropping by 15-40% (European Scientific Advisory Board on Climate Change, 2023).

The highest rate of electrification (39%) by 2040 is assumed and necessitates less than half the amount of hydrogen (11%) in 2050 as compared to the Mixed options pathway (European Scientific Advisory Board on Climate Change, 2023). By 2040, the High renewable energy pathway will have fuel and electricity generation with the largest deployment of solar and wind energy. Transportation is characterised by low energy demand, partially due to efficiency gains from high electrification as well as continuous declines (49% of final transportation energy by 2040 and 34% by 2050) in fossil fuel use. Final energy use by industry is reduced by 36% from 2019-2040. Final energy demand is reduced in the residential, commercial, and public sectors by 34% between 2019-2040. By 2040, these sectors will rely on 63% electrification, 9% bioenergy, 10% heat, and 18% fossil fuel energy. Reduction in final energy demand continues after 2040. Fossil-gas-powered electricity will decline continuously after 2025 to reach 0.1% by 2050 (European Scientific Advisory Board on Climate Change, 2023).

2.1.3 Mixed options pathway

The Mixed options pathway combines aspects such as the greatest deployment of CO_2 removal through sustainable land-based carbon removals, a gradual reduction in the share of livestock in food demand, and the greatest increase in nuclear energy production (European Scientific Advisory Board on Climate Change, 2023). Developed as part of a global scenario set exploring how to limit warming to 1.5C with low overshoot (Riahi et al., 2021 as in European Scientific Advisory Board on Climate Change, 2023), this pathway leads to the lowest cumulative emissions in the 2030-2050 period. The share of livestock food demand reduces by 47% between 2019-2040 and the share of livestock in total food demand (kcal/capita/day) drops from 32% to 17%. The use of nitrogen fertilisers declines by 25% between 2020-2040. Methane emissions reduce by 35-50% between 2019-2040, and methane emissions from agriculture specifically by 15-40%. This pathway has the highest deployment of afforestation, with the amount of net LULUCF CO_2 removed annually reaching 601 Mt by 2040 and 669 Mt by 2050, almost double the rate of the other pathways. CCS deployment will account for 30% of primary fossil gas consumption by 2040, and its use (rather than the use of BECCS) is related to the prioritisation of carbon removals from land, therefore also the least primary biomass for energy production (European Scientific Advisory Board on Climate Change, 2023).

Reduction in final energy demand (14% between 2019-2040) and the electrification share of final energy by 2040 are the lowest in the Mixed options pathway (European Scientific Advisory Board on Climate Change, 2023). Final energy use in industry reduces by 26% by 2019-2040. 34% of electrification will be reached by 2040. In terms of residential and commercial sectors, 18% is provided through direct heat supply, 54% through electricity, 7.5% bioenergy, and 15.5% through fossil energy. The Mixed options pathway exhibits an increase in nuclear power over time and roughly twice as much hydrogen production by 2040 as compared to the other pathways. This suggests substantial energy is needed to produce nuclear and hydrogen energy. Coal will contribute minimally to electricity generation by 2040. There is a decrease in the use of bioenergy over time, and energy crops increase by only 0.6 million tonnes by 2040 (European Scientific Advisory Board on Climate Change, 2023).

3 Methodology

This analysis aims to assess trade-offs and synergies between EU policies and ESABCC pathways, to signal where policy could be strengthened on mitigation in alignment with the EU Climate Law legislated goals. The policy analysis simultaneously illustrates adaptation-relevant synergies and trade-offs associated with the mitigation options included in ESABCC pathways, to inform future policy needs in boosting resilience in harmony with mitigation action. By assessing these elements, the policy analysis helps to uncover gaps, strengthen current frameworks, and guide the development of future policies.

Policy analysis is a tool for evaluating existing policies against established goals. This analysis illustrates trade-offs through qualitative research, comprehending ideas and experiences through non-numerical data analysis in words and making insights based on other data collected through publications and reports (Punch, 2013). The analysis includes insights from other qualitative and quantitative sources, considering relevant evidence. The policy analysis focuses on the EU, rather than considering individual Member State policies, which are highly relevant but highly differentiated across the EU.

3.1 Mitigation policy analysis methodology

The mitigation policy analysis aims to demonstrate the degree of alignment between the scientifically established pathways and their combination of mitigation measures employed to achieve the legislated EU Climate Law goals. As these pathways include various elements in combination to reach the ambitious targets, recognition of which policy components are less aligned can suggest recommendations for additional initiatives. Based on this, general areas for improvement of the policies are identified. Where possible, the report aims to discuss where policy needs to extend features to meet common recommendations or may only align with a component relevant to one pathway. Three main policy areas are used to categorise the policies: 1) Land-based mitigation policies, 2) Energy policies, and 3) Finance. These categories were determined based on the relevance of the ESABCC mitigation pathways and SPARCCLE project capacities in terms of stress test development and modelling. Subsections for each of these categories consist of the individual policies included in each category. While ESABCC pathways do not explicitly make note of how finance is assumed to support associated land use and energy transition, finance is a key enabler for the implementation of climate mitigation. Some policies, which included finance components, were rather grouped in the first-mentioned categories if they also included substantial support specifically for energy or land, as this grouping was determined to be most consistent. The EU policies specifically considered are shown below in Table 2.

Category	Sub-category	Policy title	Date	Update	Responsible body
Land mitigation	Agriculture	Farm to Fork Strategy	2020	2020	DG SANTE
		Rural Development Policy	2013	2021	DG AGRI
		Common Agricultural Policy 2021-2027	1962	2021	DG AGRI
	Biodiversity	EU Biodiversity Strategy for 2030	2020	---	DG ENV
	Forestry	New EU Forestry Strategy for 2030	2021	--	DG AGRI
	LULUCF & forestry	Effort Sharing Regulation	2018	2023	DG CLIMA
		Zero Pollution Action Plan	2020	--	EU Parliament & Council
	Energy & land-use	EU Methane Strategy	2024	--	EU Parliament & Council
Energy mitigation		Directive on Energy Efficiency	2012	2023	EU Parliament
		Internal Market for Electricity	2019	2024	EU Parliament & Council
		Renewable Energy Directive II	2018	2024	EU Parliament & Council
		Aggregate EU	2022	2023	DG ENER
	Energy & environment	Circular Economy Action Plan	2020	--	DG ENV
	Energy & finance	REPowerEU	2022	2023	DG SG
		Hydrogen Strategy	2020	2020	DG ENER
		Carbon border adjustment mechanism	2023	2025	DG TAXUD
		Emission Trading System	2003	2024	EU Parliament & Council
Finance mitigation		Sustainable Finance Agenda	2018	2023	DG FISMA
		EU Taxonomy Regulation	2020	--	EU Parliament & Council
		Just Transition Fund	2020	--	DG REGIO
		Recovery and Resilience Facility	2021	2024	EU Parliament & Council
		New Industrial Strategy for Europe	2020	--	DG SG
		Innovation Fund	2003	2022	DG CLIMA
		Artificial Intelligence Act	2024	--	DG CONNECT

Table 2. List of EU policies analysed, as per information available on EUR-LEX.

The policies selected within these three mitigation categories were compared, in terms of their aims and implementation, to each of the ESABCC "iconic pathways". As EU Climate Law legislates ambitious climate mitigation action, mitigation policies are rated from strongly opposing the mitigation action included within the narrative pathway to strong alignment. These coherence ratings can be translated to an illustrative numerical score ranging from -2 to +2, namely, "strongly opposes pathway narrative" (--), "partially opposes pathway narrative" (-), "neither aligns nor opposes pathway narrative" (0), "partial alignment with pathway narrative" (+), and "strongly in line with pathway narrative" (++).

3.2 Adaptation policy analysis methodology

The IPCC (2022) defines adaptation as the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. Similarly, resilience is defined as the capacity of social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance in ways that maintain their essential function, identity and structure, being a positive attribute within the capacity for adaptation or transformation (Arctic Council, 2016 as in IPCC, 2022). Vulnerability is defined as the propensity or predisposition to be adversely affected, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2022). Considering these definitions, the adaptation analysis assesses adaptation capacity on a scale from resilient to vulnerable.

The adaptation policy analysis 1) explores known resilience trade-offs associated with mitigation measures included in ESABCC pathways and 2) considers areas for improvement in supporting adaptation policy within the EU. Adaptation analysis grouped adaptation-relevant themes into the categories of physical or socio-economic adaptive capacity. Physical adaptation includes subcategories of disaster risk, land and land ecosystems, and water availability/ecosystem risks. Socio-economic adaptation includes subcategories of geopolitical stress, health, hunger/poverty & household finance, capital costs, and market growth.

The analysis considers adaptation-relevant components of the policies considered in mitigation analysis, as well as additional particularly adaptation-relevant policies (see Table 3 below). Additional reports and literature were consulted regarding assessing comparative vulnerability or resilience for each pathway. For example, the European Climate Risk Assessment (EUCRA) provided insights into present-day areas of highest vulnerability within the EU. Additionally, the 2023 ESABCC report includes the identification of trade-offs and synergies between pathways and sustainable development goals, which provides insight into the adaptation challenges or benefits of each pathway.

Sub-category	Policy title	Date	Responsible body
General adaptation	EU Strategy on Adaptation	2021	DG CLIMA
Water	EU Action Plan on Water Scarcity and Drought	2007	DG ENV
Disaster risk reduction	EU Civil Protection Mechanism	2022	EU Council
	European Union Disaster Resilience Goals	2023	DG ECHO
Health	Building a European Health Union	2020	DG SANTE
	Public Health	1957	Member States
Social	European Pillar of Social Rights Action Plan	2021	DG EMPL
Technology	Artificial Intelligence Act	2024	DG CONNECT

Table 3. List of EU policies considered within adaptation analysis. None of these documents were subject to an update since their original document date, as per the online accessible EUR-LEX website for EU law.

Adaptation categories and subcategories were rated according to whether the pathway narrative suggests vulnerability or resilience in each subcategory, comparatively between ESABCC pathways.

These ratings were illustrative and meant to compare which pathways suggested relative adaptation trade-offs or synergies. The illustrative coherence ratings given in mitigation policy analysis, the ratings included more trade-offs (--), some trade-offs (-), neutral (0), some synergies (+), and more synergies (++).

4 Policy analysis

4.1 Mitigation

While many EU policies contribute to climate mitigation, EU progress is insufficiently aligned with Paris Agreement action according to sources such as the Climate Action Tracker (2024) and the 1.5°C National Pathway Explorer (Climate Analytics, 2024). Though most assessed policies are partially in line with the principles of ESABCC iconic pathways, evidence is not conclusive that such policies are achieving transitions to the extent necessary.

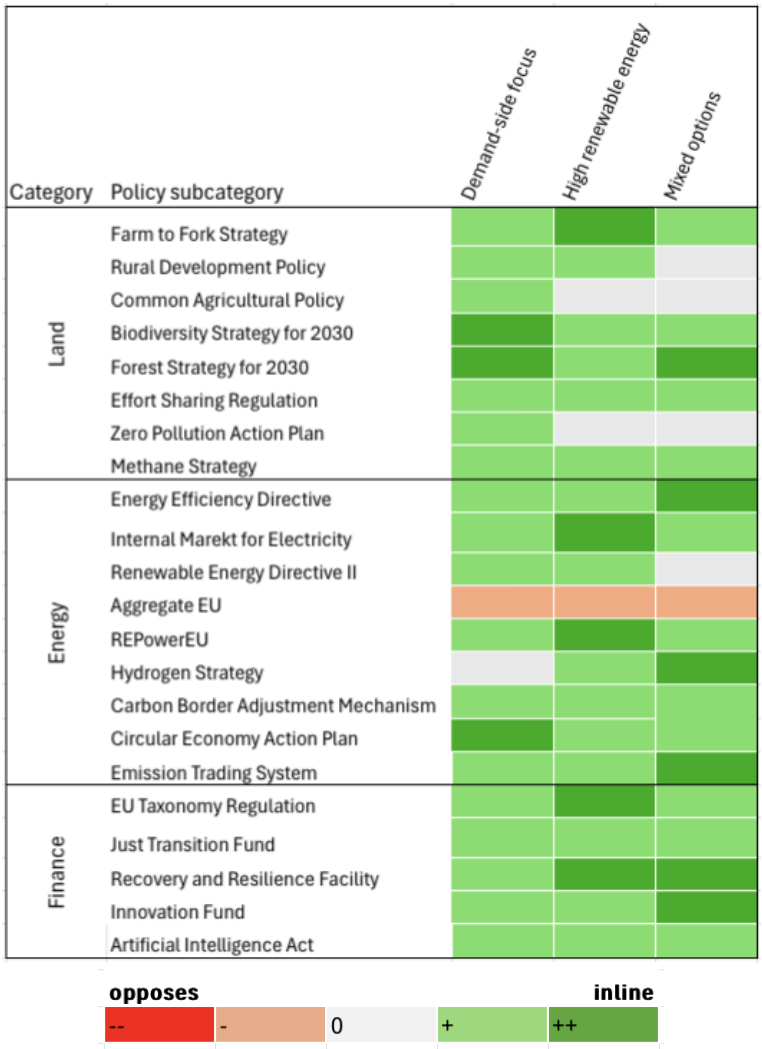

Figure 5. Mitigation policy coherence scores, assessed by category, across ESABCC pathways.

In general, current EU land policies appear to be most aligned with the Demand-side focus pathway (due to land conservation goals and efforts to encourage lower resource intensity production) and least aligned with the Mixed options pathway (see Figure 5 above). However, EU land policies need a further increase in ambition to reach Demand-side focus emission pathway action, notably to support greater plant-based diet transitions and less resource-intensive lifestyles (including in

terms of lower energy use). However, the expectation for such changes to be taken up by voluntary consumer responsibility in place of policy aimed to influence consumer behaviour is unlikely to result in sufficient changes in line with the Demand-side pathway (European Scientific Advisory Board on Climate Change, 2024). EU energy policy is in closest alignment with the High renewable energy pathway, due to policy flexibility in support of renewable energy. The lack of specific recommendations and preferences for specific types of renewable energy makes it difficult to confirm strong alignment with the pathway-specific energy mixes but allows Member States to choose the most productive and available renewable sources, as solar power may better suit the needs of southern Member States while wind may better suit northern Member States. The High renewable energy pathway may also be most in line with current EU policy as this pathway has the highest carbon budget and much progress is needed in the EU to transition away from fossil fuels. Lastly, the Mixed options pathway appears to be most in line with current financial EU policy. An illustration of comparisons between analysis categories is offered below in Figure 5. The subsequent subsections further detail the evaluation and recommendations for policies.

4.1.1 Land

Eight EU land policies are assessed in the following subsections, in terms of overall findings concerning strengths and criticisms of the policies and explanation behind their ESABCC pathway coherence rating. Generally, EU land-based policy does not aim to influence demand as strongly as is described in the ESABCC pathways. This is most apparent in the shifts toward sustainable, plant-based diets that occurs rather suddenly in the Demand-side focus pathway and gradually in the Mixed options pathway. Plant-based diets have some encouragement in EU policy, but actionable measures for implementation are not so strong. Meanwhile, land-based policies often do not prioritise climate mitigation, rather aiming to satisfy the protection of forest and biodiversity, or support EU agriculture, with subsequent climate mitigation is often considered a co-benefit. Sustainable biomass production is supported by several policies but could perhaps benefit from further research to inform best practices. The Methane Strategy should incorporate binding methane reduction targets in agriculture, which is a common feature of all ESABCC iconic pathways.

These policies also vary in implementation across EU member states. The EU Forestry Strategy is aimed at the protection of "old-growth forests", although a common EU definition for this does not exist. Further action will be required to achieve European Green Deal goals, such as the need for negative emissions to compensate for emissions that cannot be eliminated by 2050 in the forestry and land sector (Kulovesi & Oberthür, 2020). While the EU should aim to continue to offer flexibility, this flexibility must not be at the expense of European climate action.

4.1.1.1 Farm to Fork Strategy

The Farm to Fork Strategy supports sustainable agricultural practices. It aims to make food environmentally friendly and reduce GHG emissions, natural resource demands, and biodiversity loss associated with European food systems (European Commission, 2020b). The goal for the policy to "have a neutral or positive environmental impact" (European Commission, 2020b) may however point to a lack of priority in climate mitigation. An economic analysis found that the Farm to Fork Strategy implies a quantitative decline in EU agricultural production, consumer surplus, and GHG emissions (Wesseler, 2022). Dietary change support measures, an increase in organic agriculture, and a reduction of animal product consumption are assumed to contribute to GHG emission reduction (Wesseler, 2022). The European Scientific Advisory Board on Climate Change (2024) reports that the Farm to Fork Strategy includes initiatives which could offer additional emission reductions.

A possible reduction in overall agricultural production would be aligned with the Demand-side focus pathway, however demand-side measures to reduce demand and stronger measures to reduce livestock demand specifically are missing to reach mitigation options within this pathway. A reduction in synthetic fertilizers is also likely aligned with the Demand-side focus pathway, however, the implied continuation of livestock to offer organic fertilizers is less aligned. The Mixed option pathway also includes dietary shifts, stronger than those supported by this policy. As the High renewable energy pathway does not include dietary details or strong agricultural changes, the Farm to Fork Strategy is likely well aligned.

Further technological and institutional changes could be effective in avoiding an agricultural production decline (Wesseler, 2022), if reduction of agricultural demand is not a goal of EU climate action. Further technological and institutional improvements could reduce the likelihood of production decline associated with the policy. Maintaining agricultural yields and reducing fertiliser use can be achieved through options such as precision agriculture, legume cultivation, and technological innovation (European Scientific Advisory Board on Climate Change, 2023)., which can be further incentivised. Dedicated policies to promote healthy diets or plant-based diets are absent at the EU level and suggest a policy gap (European Scientific Advisory Board on Climate Change, 2024). Voluntary consumer interests to shift diet demands are unlikely to deliver dietary shifts (European Scientific Advisory Board on Climate Change, 2024). The incorporation or inclusion of demand-based measures to promote dietary shifts is recommended (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Offers some support to plant-based diets, does not support agricultural expansion, but does not directly promote the extent of demand changes implied
High renewable energy	++	Sustainable food systems are beneficial for the pathway, though not described in its narrative, therefore may exceed the pathways ambitions
Mixed options	+	Offers some support to plant-based diets, does not support agricultural expansion, but does not directly promote plant-based diet demand

Figure 6. ESABCC coherence rating breakdown for the Farm to Fork Strategy by ESABCC pathway.

Policies are sufficient to meet the ambition of High renewable energy pathway. To better align with the ambitious action of other pathways, policy should incorporate measures to promote dietary changes from the demand side.

4.1.1.2 Rural Development Policy

The Rural Development Policy funds agricultural-environmental-climate measures to increase agricultural sustainability and sustainable biomass deployment in rural communities but does not primarily aim to reduce carbon emissions. Regression estimates by Balogh (2023) suggest the CAP's Rural Development Policy encourages abatement of emissions by increasing the share of organic agriculture. Organic agriculture can reduce nitrous oxide emissions due to reduced chemical fertiliser use (European Court of Auditors, 2024b), but the link between organic agriculture and animal husbandry also implies some sustained cattle related GHG emissions (Wesseler, 2022). For example, livestock emissions are mainly driven by cattle and represent around half of agricultural emissions which remain stable since 2010 (European Court of Auditors, 2024b). A study by Tzilivakis et al. (2017), showed that many Rural Development Policy measures do not result in a decrease in emissions for environmental objectives without specific GHG emission reduction goals (i.e. forest management activities to improve woodland/grassland cultivation).

The ESABCC pathways include the expansion of bioenergy, especially primary biomass, compared to today's level (European Scientific Advisory Board on Climate Change, 2023). Implied increases in organic agriculture may imply some alignment with lower agricultural production and demand, though livestock practices implied by organics may not be highly aligned with the Demand-side focus pathway. While the Demand-side focus and High renewable energy pathways assume increases in primary energy use, primary bioenergy use decreases in the Mixed options pathway (European Scientific Advisory Board on Climate Change, 2023).

The European Scientific Advisory Board on Climate Change (2024) recommends extending EU emissions pricing to agricultural sector to encourage climate action, offering clear financial incentives to farmers which could be redistributive and support further mitigation or adaptation. Further research could be beneficial to better inform policies regarding organic agricultural targets. The inclusion of specific GHG emission reduction goals would benefit mitigation co-benefits of agricultural-environmental measures the policy employs.

Pathway	Rating	Explanation
Demand-side focus	+	Supports sustainable biomass production, but does not imply strong dietary demand changes; organic agriculture supports livestock farming; likely leads to lower demand
High renewable energy	+	Supports sustainable biomass production
Mixed options	0	Supports sustainable biomass production, which is limited in this pathway

Figure 7. ESABCC coherence rating breakdown for the Rural Development Policy by ESABCC pathway.

Policies appear partially sufficient for Demand-side focus and High renewable energy pathway ambitions due to support for sustainable biomass deployment. Policy should further integrate GHG emission reduction goals into environmental activities promoted. Additional research into how the Rural Development Policy support for organic agriculture can support emission abatement is of interest.

4.1.1.3 Common Agricultural Policy 2021-2027

The CAP is the biggest EU policy for agriculture, which encourages environmentally sound practices via eco scheme encouragement (European Parliament, 2021b). However, it offers substantial flexibility to Member States, who compose their CAP Strategic Plans (European Court of Auditors, 2024b). Member States cite difficulty in designing mitigation interventions within their strategic plans regarding the number of livestock, completing calculations, and reporting achievements (European Court of Auditors, 2024b). A panel regression analysis by Balogh (2023) showed that direct agricultural subsidies (such as single area and farm payments) have encouraged agricultural carbon emissions in line with the expansion of intensive farming activities, while GHG emission reductions are encouraged by organic agricultural expansion and rural development expenditures. Other sources have shown a mixed effect of CAP reforms on GHG mitigation (Gocht et al 2017; Za-Feiriou et al., 2018 as in Balogh, 2023), noting that the CAP does not match the EU's ambition for climate and could benefit from Member State exchanges on good practices and a stronger CAP monitoring framework (European Court of Auditors, 2024b). Most mitigation measures supported by the CAP have low mitigation potential, for example, cattle represent around half of agricultural emissions and have been stable since 2010 (European Court of Auditors, 2024b). CAP objectives related to the climate and environment are not clearly defined or linked to quantified targets, which complicates monitoring of objective achievement (European Court of Auditors, 2024b).

The CAP's inclusion of eco-schemes and support for pesticides and nitrogen fertiliser reduction appears most aligned with the Demand-side focus pathway narrative, however, lacks the measures or mechanisms to spur necessary dietary changes and therefore cannot be considered strongly aligned. A potential expansion of intensive farming activities would be opposed to land needed for renewable energy sources and/or CDR implied by the High renewable energy and Mixed options pathway.

The European Scientific Advisory Board on Climate Change (2024) states recommends for the CAP to incorporate an emissions reductions objective, establish mandatory good practices for

reduction of methane and nitrous oxide and soil carbon increase, and shift support away from emission-intensive agriculture (i.e., livestock production).

Pathway	Rating	Explanation
Demand-side focus	+	Supports reduction of pesticides and nitrogen fertilizer (i.e., lower resource production), but does not affect demand or give adequate support to plant-based diets
High renewable energy	0	Supports reduction of pesticides and nitrogen fertiliser, but potential support for agricultural expansions would challenge land for renewable energy production (i.e., wind, solar, and bioenergy)
Mixed options	0	Supports reduction of pesticides and nitrogen fertilizer, but potential support for agricultural expansion would challenge land for energy generation

Figure 8. ESABCC coherence rating breakdown for the CAP by ESABCC pathway.

The CAP appears partially sufficient for the ambitions of the Demand-side focus pathway. To improve alignment, the CAP and other agricultural policies should include pricing mechanisms to promote emissions-neutral practices, commit to specific GHG emission goals, and offer incentives for good climate practices.

4.1.1.4 EU Biodiversity Strategy for 2030

The EU Biodiversity Strategy aims to expand protected areas for 30% of the EU land and sea by 2030 (European Commission, 2020c). It offers protection to a minimum of 30% of EU land area, 30% of EU sea area, strictly protecting 1/3 of the EU's protected areas (i.e., primary and old-growth forests), and sets conservation objectives and measures for monitoring protected areas. However, goals to increase forest area and protect old growth forests may not offer significant mitigation contributions, as old forests can cease to accumulate carbon (Gundersen et al., 2021 as in Köhl et al., 2021). Furthermore, definitions of old growth forests differ between Member States, which complicates the suggested implications of the policy (Schmidt et al., 2024). The strategy supports the restoration of ecosystems like wetlands, forests, and grasslands (European Commission, 2020c). It indirectly supports sustainable biomass and supports enhancement of carbon sequestration through nature-based solutions (European Commission, 2020c). Certain species have been observed to prefer managed areas (i.e. observations of Romanian bears preferring managed forests) (Schmidt et al., 2024), which suggests potential complications in biodiversity benefits assumed from the policy's land protection.

Some land protection is relevant in all three iconic pathways. The Demand-side pathway assumes greater land protection due to less resource-intensive production and lifestyles, which is well aligned. The Mixed options pathway assumes greater land protections associated with increased land-based CDR, in which case old-growth forests are likely not the forests with the highest CDR capacity. The High renewable energy pathway assumes some land protections which limit land available for renewable energy infrastructure, but otherwise land conservation is not a key aspect.

The policy could benefit from greater consideration of climate goals and carbon content of forests in terms of protection priorities. Harmonisation over the definition of 'old growth forest'

between Member States would be beneficial to determine the effects of the Biodiversity Strategy. Further research should aim to better inform habitat preferences for important and endangered species.

Pathway	Rating	Explanation
Demand-side focus	++	Ecosystem protection and restoration in line with less resource intensive production; indirect biomass support
High renewable energy	+	Expansion of protected lands and carbon sequestration not aligned with mitigation choices central to narrative
Mixed options	+	Support for highly relevant land carbon sequestration, but may not meet targets for sequestration implied in narrative

Figure 9. ESABCC coherence rating breakdown for the EU Biodiversity Strategy for 2030 by ESABCC pathway.

The Biodiversity Strategy is likely aligned with the ambition of the Demand-side focus pathway, in promotion of natural land protection. The policy could be further aligned by integration with the ETS to incentivize neutral and/or negative emissions.

4.1.1.5 New EU Forest Strategy for 2030

The EU Forest Strategy protects forests, encourages practices to enhance carbon storage, and encourages sustainable biomass (European Commission, 2021c). More specifically, it limits harvesting of biomass so as not to compromise forest health or biodiversity. It aims to balance carbon removal in forests with forest ecosystem health and prioritises long-lived wood products over wood for bioenergy. The strategy calls for planting of three billion trees by 2030 despite juvenile trees having less carbon sequestration potential (Köhl et al., 2021). In comparison, policy could potentially be strengthened by further support for peatland protection. A study on global peatland found that only 17% of global peatlands are within protected areas, which is remarkably lower than other "high-value ecosystems" such as tropical forests (Kemen G. et al., 2025). The same study found a significant amount (47%) of European temperate biome peatlands with high human pressure for development (Kemen G. et al., 2025).

The policy's focus on protecting forests and enhancing carbon storage suggests the highest alignment with the Mixed options pathway, though primary biomass use eventually also declines in this pathway. Support for forest ecosystems and sustainable biomass suggests high alignment with the Demand-side focus pathway, which displays increasing primary biomass use over time. The High renewable energy pathway suggests alignment but may be less strongly aligned given the pathway's focus rather on offering some land protection but otherwise needing land for an increase in renewable energy production.

The Forest Strategy can further consider the carbon content of different forest types in terms of priorities for protection. Further research, monitoring, or data availability on carbon content of forests could help better align the policy. Furthermore, given the comparable benefit of

peatlands, similar policy should be leveraged to protect remaining peatlands from human development pressures.

Pathway	Rating	Explanation
Demand-side focus	++	Limits agricultural expansion; supports limited sustainable biomass; little support for biomass and no agricultural demand shifts as highly relevant
High renewable energy	+	Supports limited sustainable biomass; but not otherwise highly narrative relevant
Mixed options	++	Supports land carbon sequestration, supports limited sustainable biomass, additional trees should contribute to land-based CDR however not to the extent implied

Figure 10. SABCC coherence rating breakdown for the New EU Forest Strategy for 2030 by ESABCC pathway.

The New EU Forest Strategy for 2030 is likely sufficient to meet the Mixed option pathway and Demand-side pathway's ambitions. Forestry strategy could collaborate with the ETS to incentivize carbon neutral/negative farming, inclusion of more effective compliance mechanisms, and greater protection for peatlands.

4.1.1.6 Effort Sharing Regulation

The current Effort Sharing Regulation (ESR) came from an update to the previous Effort Sharing Decision by the 2030 Climate and Energy Policy Framework (Kulovesi & Oberthür, 2020). The ESR expects Member States to reduce emissions in agriculture, buildings, waste, and transportation using law for binding reduction targets, covering different sources than the ETS (Peeters & Athanasiadou, 2020). The ESR is more lenient than the previous policy in certain aspects, as the Commission has the discretion to conclude that a Member State did not make significant progress on emission reduction (Peeters & Athanasiadou, 2020). The possibility for Member States to borrow accomplishments in the ESR between annual budgets can promote mitigation delays (Romppanen, 2020 as in Kulovesi & Oberthür, 2020). The binding targets per Member State are based on per capita GDP (Kulovesi & Oberthür, 2020) and cost-effectiveness for countries with an above average GDP per capita The 2030 Climate and Energy Policy Framework updated the Effort Sharing Decision to the current Effort Sharing Regulation (ESR) (Kulovesi & Oberthür, 2020). To maintain ambition targets were increased by 0.7 percentage points for Member States whose targets were not more ambitious than cost-effective projections (European Commission, n.d.-b, pp. 2021–2030). Presno et al. (2021) documented substantial differentiation between Member States in the same period, some overperforming and others underperforming. The ESR is a key part of the Fit for 55 package, which the achievement of the 2030 target is dependent on (European Scientific Advisory Board on Climate Change, 2024).

The European Scientific Advisory Board's assessment denotes that the ESR is an important policy aspect to reach the ambition of the European Climate Law, which is relevant to all iconic pathways. However, criticisms noted in the literature also point to potential deficiencies in specific Member States reaching binding targets, thus all pathways are classified as partially aligned.

The EU should try to reduce heterogeneity in Member States reaching their determined targets, through either providing aid to address underlying difficulties for Member States where applicable and/or reducing leniency. This assumes clarification, perhaps through research, on why certain Member States have not reached their targets. The EU should consider further effective compliance mechanisms and could reduce the time lag implied by the 5-year ESR formal compliance check cycle between compliance assessment and conclusions (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Reduces agricultural and transport emissions, but does not reduce emissions to needed extent; does not specifically affect agricultural emissions with livestock/diary demand reduction
High renewable energy	+	Reduces agricultural and transport emissions, but does not reduce emissions to needed extent
Mixed options	+	Reduces agricultural and transport emissions; does not affect agricultural emissions to needed extent

Figure 11. SABCC coherence rating breakdown for the Effort Sharing Regulation by ESABCC pathway.

The Effort Sharing Regulation is partially sufficient to meet the ambition of all iconic pathways but should include further compliance mechanisms to reduce the degree of differentiation in performance between Member States.

4.1.1.7 Zero Pollution Action Plan

The Zero Pollution Action Plan aims to reduce air, water, and soil pollution, which may lead to more energy efficient water treatment, indirectly reduce GHG emissions, reduce agricultural pollutants in water systems, and agricultural activity emissions. Kumar et al. (2024) anticipates improvement in lower nitrogen levels in European surface bodies by 2050, though some areas may still exceed nitrogen thresholds in that timeframe.

The reduction of nitrogen fertiliser use is included in Demand-side focus and Mixed options pathways. The Demand-side focus pathway exhibits substantially greater reductions over time, 21% decline between 2020 and 2040 (Soergel et al., 2021 as in European Scientific Advisory Board, 2023). Aspects such as more efficient water treatment suggest support for less resource-intensive production, a key aspect of the Demand-side pathway. Thus, while the policy does not aim to directly influence GHG emissions, it is determined to be partially aligned with the Demand-side focus pathway.

Kumar et al. (2024)'s findings suggest that the plan can include more proactive measures to reduce nitrogen inputs in harvesting, utilising, and attenuating built-up storage. Measures to further reduce nitrogen inputs, particularly in reducing point source inputs in Eastern European rivers, can further aid in achieving the Zero Pollution Action Plan goals.

Pathway	Rating	Explanation
Demand-side focus	+	Indirectly contributes to reduction of nitrogen fertilisers; could reduce food waste through indirect effects of less resource intensive production
High renewable energy	0	Indirectly contributes to reduction of nitrogen fertilizers, which is not detailed in scenario narrative
Mixed options	0	Indirectly contributes to reduction of nitrogen fertilizers; could reduce food waste through indirect effects of less resource intensive production, but not highly narrative relevant

Figure 12. SABCC coherence rating breakdown for the Zero Pollution Action Plan, by ESABCC pathway.

The Zero Pollution Action plan is partially sufficient to meet the ambition of the Demand-side focus pathway. More proactive, direct measures should be considered to reduce nitrogen inputs, such as fertilisers.

4.1.1.8 EU Methane Strategy

The EU Methane strategy covers agriculture, waste, coal, oil and gas sectors, but mainly focuses on energy, a comparatively small source of EU methane emissions (European Commission, 2020d). It supports the acceleration of the market for biogas to substitute fossil-based methane, including those from sustainably sourced food-derived biogas, even though food derived biogas increase methane emissions (European Commission, 2020c as in Stern, 2021). Its diplomatic outreach campaign suggested that mitigation achievement would be possible from the strategy through persuasion and engagement rather than financial penalties and compulsion (Stern, 2021). The strategy does not include reduction targets but rather focuses on reporting improvements, for aspects such as agricultural ethane emissions (European Parliament, 2024). Policy package revisions have introduced new requirements for monitoring and reporting of fossil fuel industry methane emissions (Climate Action Tracker, 2024), but binding targets, especially for agricultural methane emissions, could be beneficial. Additionally, as of 2024, a new regulation obligates the measurement, monitoring, reporting, and verification of methane emissions from the fossil gas, oil and coal industries in Europe (DG ENER, 2024).

The Methane Strategy is an important step in limiting methane emissions. However, further recommendations suggest that the policy may not yet be strongly aligned with the methane emission reductions of the iconic pathways. While improvements in methane reporting are necessary, further binding targets would improve alignment with targets of the iconic pathways.

The regulation's ambition level depends on implementation adopted by the European Commission (European Scientific Advisory Board on Climate Change, 2024). Without pricing upstream GHG emissions from fossil fuels, in the EU or abroad, climate externalities are not fully internationalised (European Scientific Advisory Board on Climate Change, 2024). To build on this regulation, the European Scientific Advisory Board on Climate Change (2024) suggests expanding the EU ETS to include fugitive emissions from domestic fossil fuel operations while introducing a border adjustment mechanism for upstream GHG emissions from fossil fuel import. Such

changes would contribute to the necessary phase-out of EU fossil fuel use (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Advocates methane reductions; does not set binding targets for agricultural methane reductions; does not satisfy the narrative's highest level of methane emission reduction from energy sector or agriculture
High renewable energy	+	Advocates methane reductions; does not set binding targets for agricultural methane reductions; supports biogas, though may need more ambition
Mixed options	+	Advocates methane reductions; does not set binding targets for agricultural methane reductions; supports biogas, though may need more ambition

Figure 13. ESABCC coherence rating breakdown for the EU Methane Strategy, by ESABCC pathway.

The Methane Regulation is partially sufficient to meet the ambition of all iconic pathways in reducing methane emissions, but should incorporate stronger elements such as pricing to fully internalise externalities and include more binding measures to reduce agricultural methane.

4.1.2 Energy

Rapid and widespread electrification is a common theme across ESABCC iconic pathways, which could be better supported in EU energy policies. While support for electrification is a key focus, the EU still lacks clear electrification targets for all sectors (Climate Analytics, 2024). Energy efficiency is also a priority (European Commission, n.d.-c), which can presumably continue to benefit from further research and investment. Much of the EU energy policies which promote renewables may offer a range of flexibility on which renewable sources are applicable, supporting energy supply diversity and competition. The biggest potential threat to climate mitigation from current policy originates from efforts taken to ensure energy security amidst geopolitical pressure above transition. While such efforts often attempt to respond to current demand rather than support increases in traditional fossil fuel energy demand, they risk contributing to transition delay.

Further concentration on technologies could enhance electricity efficiency, such as methane pyrolysis (Talus et al., 2024). The amount of renewable energy consumption in national energy profiles still substantially varies and Member States' efforts may not be enough to meet EU renewables targets for 2030 (Sakız & Gencer, 2023). EU policies which support Carbon Capture and Utilisation (CCU) or CCS, bioenergy, and hydrogen should be better targeted to applications with no other or very limited mitigation options (European Scientific Advisory Board on Climate Change, 2024). There is a policy gap for dedicated to moderate or reduce transport demand, while there is also a lack of progress in policy reducing energy demand or achieving modal shifts (European Scientific Advisory Board on Climate Change, 2024). According to the European Scientific Advisory Board on Climate Change (2024), electrification rates are substantially below sufficient for 2040 requirements, while wind and solar PV energy supply support should also increase. The deployment of solar photovoltaic and wind energy must increase to achieve the 2030 renewable energy objective and a net-zero electricity system by 2040 at the latest (European Scientific Advisory Board on Climate Change, 2024). Deployment is negatively affected by inadequate infrastructure

planning, development, spatial planning, permitting, workforce skills, and supply chains (European Scientific Advisory Board on Climate Change, 2024).

4.1.2.1 Directive on Energy Efficiency

Achieving 2030 targets depends on the effective implementation of the Energy Efficiency Directive (EED), which sets specific objectives, but relies on the ambition of national policies and measures (European Scientific Advisory Board on Climate Change, 2024). The directive of energy efficiency additionally aims to minimise energy demand and prioritise sustainability. Binding efficiency targets have been set in the updated 2023 Directive for an 11.7% reduction in final energy consumption by 2030 (compared to 2020 reference), as well as headline obligations that increase annual savings from 0.8% to 1.9% by 2030 (European Parliament, 2023a). Key energy end-use sectors (industry, transport, and buildings) are addressed and supported through several additional targets and legislation.

The Directive on Energy Efficiency likely meets the ambition of the Mixed Option pathway, as this pathway does not include or rely on strong improvements on energy efficiency (European Scientific Advisory Board, 2023). Thus, while energy efficiency improvements are key to the ambition of Demand-side focus and High renewable energy pathways, additional support and further efficiency measures may be needed to ensure alignment with their targets of energy efficiency improvements by 2050.

The European Commission's assessment of draft updated NECPs found collective ambitions inefficient to achieve the 2030 targets (European Scientific Advisory Board on Climate Change, 2024). Generally, while the directive is positive, the strength of its implementation is not clear enough to suggest it is strongly in line with ESABCC pathways.

Pathway	Rating	Explanation
Demand-side focus	+	energy efficiency, supports renewable hydrogen and bioenergy, minimises energy use, not much on rapid electrification or reduction in demand
High renewable energy	+	improves energy efficiency in buildings, supports low-carbon innovations, supports renewable (and hydrogen) energy, not enough support for electrification
Mixed options	++	supports direct heat supply, increases energy efficiency in buildings industry and transport, support for renewable hydrogen and other low-carbon innovations, but could be more focused on electrification

Figure 14. ESABCC coherence rating breakdown for the Directive on Energy Efficiency, by ESABCC pathway.

The Directive of Energy Efficiency is likely sufficient for the ambitions of the Mixed options pathway and partially sufficient for the Demand-side focus and High renewable energy pathways. Additional measures to support greater energy efficiency by 2050 can be beneficial to increase ambition, as well as measures to ensure strong implementation at Member State level.

4.1.2.2 Internal market for electricity

The 2030 Climate and Energy Policy Framework revised energy efficiency directives, including legislative acts on the Electricity Market Regulation, but suggests incrementation change via main legal instruments rather than radical changes (Kulovesi & Oberthür, 2020). The Internal market for electricity emphasizes the need to reduce fossil fuel dependency and increase renewables. However, implementation details for bioenergy and hydrogen could be stronger, as could measures to reduce industrial and transportation energy demands. Furthermore, it supports consumer-driven electrification and decentralized energy, supporting fossil phase-out via prioritisation of renewables.

Despite these aims, the amount of renewable energy consumption in national energy profiles still substantially varies and Member States' efforts may not be enough to meet EU targets for 2030 (Sakız & Gencer, 2023). Zachmann et al. (2024) note that further market integration will require substantial political investment, in which domestic political constraints increase challenges to further investment. A clearer determination of governance for the policy, best implementation, and what degree of integration is feasible and best suited, will be beneficial for future policy progression (Zachmann et al., 2024).

Pathway	Rating	Explanation
Demand-side focus	+	aims to enhance energy efficiency, increase renewables (bioenergy and hydrogen), but lacks specific measures and necessary implementation for rapid electrification; promotes consumer driven electrification and prioritises renewables, but may be too focused on hydrogen and does not mention decrease of energy demand
High renewable energy	++	supports renewables and energy efficiency, but may lack strong implementation and lacks enough support for rapid electrification; supports renewable hydrogen production and prioritises electrification (consumer driven)
Mixed options	+	emphasizes a need for renewables, supports renewable hydrogen production, increasing energy efficiency, but needs stronger implementation and support for rapid electrification and nuclear

Figure 15. ESABCC coherence rating breakdown for the Internal Market for Electricity, by ESABCC pathway.

The Internal Market for Electricity offers sufficient ambition for the High renewable energy pathway, and likely sufficient ambition for the Demand-side focus and Mixed options pathways. Improvements to governance and implementation may improve the alignment and ambition of the policy, which faces issues of political investment.

4.1.2.3 Renewable Energy Directive

The Renewable Energy Directives (REDs) supported renewable bioenergy production and facilitated the integration of renewable sources (bioenergy, wind, solar, etc.) into the energy mix (European Parliament, 2018). It assists renewable self-consumers with aggregation and storage systems while requiring assessment of potentials of district heating/cooling for system services (i.e., demand response and storage of excess electricity) (European Scientific Advisory Board on Climate Change, 2024). Köhl et al. (2021) notes that when taking the whole rotation period of harvesting wood energy into account, wood energy could result in considerable emissions

savings to increase sustainable biomass in total EU energy mix. Kulovesi & Oberthür (2020) determined it was still unclear in 2020 if forest biomass problems were addressed in RED II. While the achievements of RED II were on track to achieve 20% renewable energy in energy consumption share, considerable differences between Member State achievements were noted (Kulovesi & Oberthür, 2020). The follow-up policy, RED III, introduced storage and demand-side flexibility targets, but EU experience suggests that indicative targets may not be sufficient to drive fast transformational change. Bioenergy promotion included in RED I and II created substantial volumes of national subsidies for bioenergy use, including in sectors which are applicable for other more efficient mitigation options with lower land-use and biodiversity risks (i.e., electricity and low-temperature heat production) (European Scientific Advisory Board on Climate Change, 2024).

The policy is most aligned with the High renewable energy pathway ambition, in terms of support for renewables. Further support for electrification and energy efficiency could improve its alignment with the Demand-side focus pathway. Further support for hydrogen or nuclear energy would further align the policy with Mixed option pathway measures.

The European Scientific Advisory Board on Climate Change (2024) states that achieving 2030 is dependent on the effective implementation of the Renewable Energy Directive (RED III) particularly within the Fit for 55 package and the ambition of Member State policy. The European Commission's recent assessment of draft updated NECPs found their collective ambition insufficient for 2030 EU targets (European Scientific Advisory Board on Climate Change, 2024). To complement RED III, timely adoption and implementation of the electricity market reform, the Net-Zero Industry Act, and Critical Raw Materials Act can reinforce long-term investment signals towards scale-up of wind and solar photovoltaics (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	support for integration of bioenergy and renewables into energy mix, lacks rapid electrification support or efficiency specifically
High renewable energy	+	good for renewable energy; highly relevant for pathway narrative, but lack rapid electrification
Mixed options	0	good support for integration of renewables into the energy mix, but not focused on delivering main mitigation ambitions of rapid electrification, nuclear, or hydrogen

Figure 16. ESABCC coherence rating breakdown for the Renewable Energy Directive, by ESABCC pathway.

RED policy is likely sufficient to meet the ambition of High renewable energy pathways but could shift focus from bioenergy for better alignment with the Mixed options pathway and would benefit from efforts to increase the ambition of underperforming Member States.

4.1.2.4 Aggregate EU

Aggregate EU supports demand aggregation for liquified natural gas (LNG) to prioritise energy security amidst geopolitical risks, prompted by Russia's war on Ukraine (European Council,

2022a). While Aggregate EU aims to answer existing demands rather than supporting further demand (European Commission, n.d.-a), continued usage is not aligned with legislated climate mitigation goals. Further support for energy transition, which can also contribute to energy security, would be more beneficial. The European Commission (n.d.-a) states that the related EU Energy Platform is a first phase of a learning process which may offer potential implementation of demand aggregation for renewable hydrogen in the future. Energy import capacity has increased with Norway, the Middle East, and Caspian Basin countries, leading to an overall increase in EU LNG purchases (Kanapiyanova, 2023). This policy is therefore determined to be misaligned with ambition illustrated in all iconic pathways.

The European Scientific Advisory Board on Climate Change (2024) warns that Member States should fully and urgently phase out fossil fuel subsidies, even suggesting that such subsidies for vulnerable households should be redirected toward interventions that address regressive effects while incentivising energy savings and shifts toward renewable energy sources.

Pathway	Rating	Explanation
Demand-side focus	–	maintains reliance on natural gas to prioritise energy security and supply over demand reduction or investment in renewables
High renewable energy	–	maintains reliance on natural gas to prioritise energy security and supply over investment in renewables
Mixed options	–	maintains reliance on natural gas to prioritise energy security and supply over investment in renewables

Figure 17. ESABCC coherence rating breakdown for Aggregate EU, by ESABCC pathway.

AggregateEU is misaligned with the ambition of all iconic pathways. Support and subsidies for fossil fuels should end promptly, with specified timelines for full phase-out and subsidies for vulnerable households being redirected toward energy transition efforts.

4.1.2.5 REPowerEU

The REPowerEU plan includes three main components, diversification of energy supplies, green energy investment, and promotion of energy savings (Taydaş, 2024). The plan boosts renewables such as solar photovoltaics, wind energy, heat pumps, biomethane, and hydrogen production and importation (Taydaş, 2024). Transport electrification is sought through the promotion of alternative fuels and green freight transport (European Commission 2022a as in Taydaş, 2024). The plan estimates investments of 113 billion euros for renewables, 56 billion for energy efficiency and heat pumps, 41 billion for phase-out in industry, 37 billion to increase biomethane production, 29 billion for power grids to increase electricity use, 10 billion in liquified natural gas and pipeline gas imports, and up to 2 billion for oil supply security (European Commission 2022f as in Taydaş, 2024). The plan suggests limitations in fossil fuel phase-out between short- and long-term targets (Taydaş, 2024). Though the policy aims to increase energy savings from 9% to 13% and increase the share of renewable energy production in total EU energy balance to 45% by 2030, findings from Kanapiyanova (2023) suggest that the EU may not be able to reach the aim

of removal of Russian energy dependence by 2027. It aims to substantially increase biomethane production and use (to 35 billion cubic metres per year by 2030), though this could suggest negative impacts in extended use of fossil fuels (blended biomethane with fossil gas) and stall electrification. Biomethane emissions could occur along the value chain because of constraints on local availability of sustainable feedstocks, transport, and fugitive emissions (Bakkaloglu et al., 2022; ICCT et al., 2021 as in European Scientific Advisory Board on Climate Change, 2024).

The RePowerEU plan is likely aligned with the High renewable energy pathway, through its support for energy transition. Further inclusion with energy demand reduction and/or support for nuclear and hydrogen energy would allow better alignment with the Demand-side focused and Mixed options pathways.

The promotion of green energy should be the only EU long-term policy option (Taydaş, 2024). The REPowerEU plan should target deployment of CCU/CCS only to applications with no or limited other mitigation options (European Scientific Advisory Board, 2024). Adoption of the Electricity Market Reform, Net-Zero Industry Act, and Critical Raw Materials Act would complement the REPowerEU plan, reinforce long-term investment for solar photovoltaics scale-up, and aid in overcoming bottlenecks in renewable energy deployment (European Scientific Advisory Board on Climate Change, 2024). The REPowerEU policy should also address the risks associated with increased biomethane production and importation (European Scientific Advisory Board, 2024). An additional 29 billion Euros will be needed for the electricity grid investment by 2030, which must still be offered, according to the policy (EC, 2022m as in European Scientific Advisory Board, 2024).

Pathway	Rating	Explanation
Demand-side focused	+	supports energy efficiency, transition to renewable sources, advocates for rapid electrification, though does not aim to affect demand
High renewable energy	++	supports energy efficiency, transition to renewable sources, advocates for rapid electrification
Mixed options	+	supports energy efficiency, transition to renewable sources, advocates for electrification, but little hydrogen specific support or nuclear

Figure 18. ESABCC coherence rating breakdown for REPowerEU, by ESABCC pathway.

The REPowerEU plan is likely sufficient to meet ambitions of the High renewable energy pathway and partially sufficient for the Demand-side focus and Mixed options pathways. To improve, policy should add support to reduce risks of extended fossil fuel use and greater biomethane production and importation, while adopting other policies to reinforce long-term investments for scale-up of renewable energy deployment.

4.1.2.6 Hydrogen Strategy

The EU Hydrogen Strategy prioritises hydrogen production capacity expansion and investments in electrolysis. It sets the objective to produce up to 10 million tonnes of renewable hydrogen

(European Commission, 2022 as in Talus et al., 2024). It specifically targets sectors that cannot decarbonise with electrification alone. Establishment of a hydrogen market to scale up hydrogen for sectoral decarbonisation has been a positive accomplishment (Climate Action Tracker, 2024). Despite the strategy's targets, imports of Renewable Fuel of Non-Biological Origin are estimated to increase only after 2035 with potentially low uptake due to costs, thus this focus may be too narrow for full potential of renewable hydrogen promotion (Talus et al., 2024). Further concentration on technologies that can enhance electricity efficiency, such as methane pyrolysis, would assist goals set out in the strategy (Talus et al., 2024). Noting that hydrogen production requires significant energy, the strategy gives little emphasis to needs for direct energy demand reductions.

The policy is most aligned with the Mixed options pathway, due to the pathway's increased use and production of hydrogen. While the Demand-side focus and High renewable energy pathways display similar amounts of hydrogen production by 2040, the lack of emphasis on energy reduction or improved efficiency, as key traits of the Demand-side focus pathway, suggest lesser alignment for that pathway.

The European Scientific Advisory Board on Climate Change (2024) recommends deployment of hydrogen towards activities with no or limited alternative mitigation options as indirect electrification though the use of hydrogen is less efficient and faces sustainability risks compared to other mitigation options (i.e., energy efficiency improvements, direct electrification). While hydrogen is crucial to achieving climate neutrality by 2050, hydrogen for priority sectors within EU energy system integration strategy is not progressing fast enough (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	0	supports hydrogen and focuses on reducing industrial energy use, but less focus on bioenergy/biomass, electrification indirectly supported, little emphasis on direct energy reduction, doesn't reduce energy demand
High renewable energy	+	renewable hydrogen prioritised, indirectly supporting electrification, does not directly support renewable expansion past hydrogen
Mixed options	++	supports hydrogen electrification, indirectly supports electrification, reduces industrial energy use, but no mention of nuclear energy though this is supposed to gradually increase

Figure 19. ESABCC coherence rating breakdown for the Hydrogen Strategy, by ESABCC pathway.

The Hydrogen Strategy is sufficient to meet the Mixed options pathway ambitions due to hydrogen and electrification support. To improve related ambition, the EU should implement measures for quicker integration of hydrogen within the energy system and aim to deploy hydrogen in hard to decarbonise activities.

4.1.2.7 Carbon Border Adjustment Mechanism

The Carbon Border Adjustment Mechanism (CBAM) reduces emission leakage through border taxes for the GHG emissions of imported goods (EC, 2021a as in Wesseler, 2022). Importers can

buy carbon certificates corresponding to the carbon price they would have paid if the goods were produced under EU carbon pricing rules (EC 2021b as in Wesseler, 2022). Analysis from Zhu et al. (2024) suggests CBAM successfully addresses carbon leaks in Chinese imports, the largest source of EU import embodied carbon emissions. CBAM currently includes industries where carbon emissions calculations are comparably less complicated, as calculations can be very complex in industries such as agriculture, where the policy could also discriminate against environmentally friendly production methods (Wesseler, 2022). As free allocation allowances are not long-term solutions for carbon leakage risks, the number of free allocation allowances for sectors covered by the new CABM will be gradually phased out, eventually reaching zero by 2034 (European Scientific Advisory Board on Climate Change, 2024). Before the complete removal of free allocation allowances, the EU will continue to be exposed to carbon leakage and risks of distortions that reduce mitigation incentives for downstream industries (European Scientific Advisory Board on Climate Change, 2024).

ESABCC pathways illustrate the need to phase out net fossil fuel energy imports but do not explicitly discuss the import and trade of other CBAM relevant sectors such as cement, fertilisers, aluminium, iron and steel. CBAM is thus considered partially aligned with each iconic pathway, though increasing the scope of CBAM will ensure strong alignment with legislated climate goals.

The EU should aim to incentivise emissions reductions in line with targets through adequate carbon price signals, increasing convergence of the carbon price between the two emissions trading systems, and targeted measures to introduce further border adjustment mechanisms for upstream emissions from fossil fuel imports (European Scientific Advisory Board on Climate Change, 2024). The European Scientific Advisory Board on Climate Change (2024) suggests building a border adjustment mechanism onto the Methane Regulation and ETS for upstream GHG emissions from fossil fuel imports, pricing upstream emissions contributing to the phase-out of these fuels. Alternatives to free allocation need to address the risk of carbon leakage for sectors currently outside of CBAM, especially as the cap further reduces towards neutrality (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	indirectly encourages lower-emission industrial energy practices, but does not directly otherwise affect energy demand
High renewable energy	+	Indirectly encourages lower-emissions industrial/energy practices
Mixed options	+	indirectly encourages lower emission industrial/energy practices

Figure 20. ESABCC coherence rating breakdown for the Carbon Border Adjustment Mechanism, by ESABCC pathway.

The Carbon Border Adjustment Mechanism is partially sufficient to meet the ambition of all pathways. Further targeted measures toward emissions reductions should introduce further border adjustment mechanisms for upstream GHG emissions from fossil fuel imports and address carbon leakage risks for additional industries not currently included.

4.1.2.8 Emission Trading System

The Emissions Trading System (ETS) encourages industrial clean production, indirectly supporting renewable energy and incentivising emissions reductions and carbon sequestration. It is a main funding source for the European Green Deal (Sakız & Gencer, 2023). ETS puts a cap on GHG emissions, setting emissions prices within sectors such as power generation, iron, steel, chemical, oil refinery, pulp, paper, and cement (Kulovesi & Oberthür, 2020). By 2020, the EU ETS covered approximately 11,000 large industrial and aviation company installations (Peeters & Athanasiadou, 2020a). Severe demand shocks resulting from the ETS prompted the creation of the Market Stability Reserve to adjust to extreme supply or demand (Kulovesi & Oberthür, 2020). Presno et al. (2021) found considerable differentiation between Member States in performance. The initial operation of the ETS (i.e., for buildings, road transport) can inform future adjustments and design choices (European Scientific Advisory Board on Climate Change, 2024). While revisions have strengthened the EU ETS, there is not yet a clear strategy to prepare the carbon market for when the cap, determining emissions allowances allocated to the market, reaches zero, which would occur before 2040 (European Scientific Advisory Board on Climate Change, 2024). In the long-term, different prices for 1 tonne of CO_2 may not encourage emissions reductions where they are least expensive and could create distortions and less optimal incentives (i.e., discouraging electrification if energy included in ETS is subject to a higher carbon price than fuels for heating buildings included in ETS II) (European Scientific Advisory Board on Climate Change, 2024).

Alternatives to free allocation should be developed to address the risk of carbon leakage for sectors not yet covered by CBAM, particularly when the cap reduces towards zero (European Scientific Advisory Board on Climate Change, 2024). Recent revisions of the ETS significantly extend the scope of the EU GHG pricing regime, from 36% of total emissions and removals today to 74% by the end of the decade, however, the remaining 26% would still be excluded from any EU-wide GHG pricing regimes which signify a policy gap (European Scientific Advisory Board on Climate Change, 2024). Most of this gap is due to the absence of a pricing mechanism in agricultural and LULUCF sectors, for which the European Commission should introduce pricing mechanisms to incentivise farmers and forest managers to reduce emissions and increase removals and incentivise consumers to reduce consumption of emissions-intensive products (European Scientific Advisory Board on Climate Change, 2024). The EU should aim for a higher carbon price to incentivise emission reductions and increase convergence of carbon prices between the two emissions trading systems, while also considering provisions and measures to address adverse socio-economic effects (European Scientific Advisory Board on Climate Change, 2024). Policy measures to reduce differentiation and heterogeneity between Member State performance would also assist ambitions.

Pathway	Rating	Explanation
Demand-side focus	+	incentivises emissions reductions; incentivises efficiency improvements; promotes low carbon industrial processes; incentivizes land protection, though for carbon credits
High renewable energy	+	Incentivises emissions reductions; incentivises efficiency improvements; promotes low carbon industrial processes; support for low carbon processes indirectly supports renewables, but may suggest higher natural land (for CDR) than included in narrative
Mixed options	++	Incentives emissions reductions; incentivises efficiency improvements; promotes low carbon industrial processes; support for low carbon processes indirectly supports renewables; incentivises land-based carbon sequestration

Figure 21. ESABCC coherence rating breakdown for the Emissions Trading System, by ESABCC pathway.

The ETS is in greatest ambition alignment with the Mixed options pathway, due to its focus on carbon dioxide removal technologies. The ETS can be improved with the incorporation of agricultural and LULUCF emission reductions into carbon pricing schemes and greater alignment with other pricing schemes.

4.1.2.9 Circular Economy Action Plan

The Circular Economy Action Plan (CEAP) includes emphasis on reducing food waste, eco-design, and cleaner production. It supports the removal of contaminants and the promotion of green technology uptake through registration with the EU Environmental Technology Verification scheme as an EU certification mark (European Commission, 2020a). Furthermore, the policy aims to analyse the impact of economic circularity on climate change mitigation, improve modelling tools to capture circular economy emission reduction benefits at EU and national levels and promote strong inclusion of circularity in NECPs and other climate policies (European Commission, 2020a). The Eco-design Directive sets energy efficiency requirements for some products sold in the EU (Kulovesi & Oberthür, 2020). The CEAP could also deliver additional emissions reductions after its conclusion (European Scientific Advisory Board on Climate Change, 2024).

The reduction of resource intensity implied by CEAP's emphasis on reduction of food waste, clean production, and green technology appears highly aligned with the Demand-side focus narrative, which also relies on technological advances. It is partially aligned with the High renewable energy and Mixed options pathways, additionally, considering aspects such as energy savings, which may be possible through CEAP's reduction of material waste.

The EU should further incentivise the reduction of energy and material demand through efficiency improvements and behavioural changes (European Scientific Advisory Board on Climate Change, 2024). Policies should establish structures and introduce end-use innovations to increase the quality, affordability and convenience of lower-emission products and services (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	++	Supports less resource intensive lifestyles; reduces food waste; supports energy savings; sets energy efficiency requirements; adds to research on mitigation impacts
High renewable energy	+	Supports energy savings; sets energy efficiency requirements; adds research on mitigation impacts, but not highly relevant for this narrative
Mixed options	+	Reduces food waste, somewhat relevant in this narrative; reduces food waste; supports energy savings; sets energy efficiency requirements; adds to research on mitigation impacts

Figure 22. ESABCC coherence rating breakdown for the Circular Economy Action Plan, by ESABCC pathway.

The Circular Economy Action plan is likely aligned with the Demand-side focus pathway. The policy can further incentivise the reduction of energy and material demand through efficiency improvements and mechanisms to induce behavioural changes.

4.1.3 Finance

While finance-relevant initiatives for sustainable transitions are present in the EU, such finance still experiences gaps. Annual investments in climate mitigation need to be multiplied (i.e. from 200-300 billion Euros per year to 1.250-1.400 billion Euros per year up until 2030) (European Scientific Advisory Board on Climate Change, 2024). This would require a reorientation of investments and an increase in energy and transport sector investments by at least 500 billion Euros annually (European Scientific Advisory Board on Climate Change, 2024).

The Commission has stated that the financial system is not transitioning fast enough (European Commission, 2020 as in Busch et al., 2021). Climate financial contributions must be increased, and greater market incentives created (Climate Action Tracker, 2024). Greater monitoring and monitoring improvements can contribute to the avoidance of greenwashing. Commercial banks can experience a lack of translation into practice even when climate principles are adopted (Ahairwe & Bilal, 2019), which requires further consideration. The uneven application of mitigation finance across Member States may signal a need to increase awareness, resources, and capacity to apply for financial opportunities in underperforming regions. Finance toward further research is also of importance. Streimikiene et al. (2024) found a strong relationship between EU Green Deal objectives and finance for research and development of renewable energy resources, as compared to sustainable finance.

The European Scientific Advisory Board on Climate Change (2024) suggests that the EU adopts a revision of the Energy Tax Directive which aligns energy taxation with climate objectives. A revision should set higher minimum tax rates for fossil fuels and remove environmentally harmful tax exemptions, such as for aviation, maritime and professional road transport fuels (European Scientific Advisory Board on Climate Change, 2024). The return of CBAM revenues could offer additional mitigation funding (Climate Action Tracker, 2024). Private investments can also be boosted by an increase in bankable climate mitigation, through acceleration of permitting timeframes, removal of regulatory uncertainties, and tailored financing incentives and solutions

where investments are not yet profitable in current carbon price trajectories (European Scientific Advisory Board on Climate Change, 2024).

4.1.3.1 EU Taxonomy Regulation

The EU Taxonomy Regulation establishes criteria determining whether economic activities or investments are sustainable (Busch et al., 2021). Determination is made through EU Commission adopted delegated acts (Busch et al., 2021). The regulation aims to define what sustainability means in practice, based on a common taxonomy to tackle greenwashing tendencies (Zhang 2019 as in Ahairwe & Bilal, 2019). It is a regulatory tool and data source for Green Deal sustainable financing (Sakız & Gencer, 2023). Explicit support is made for renewables like solar, wind, hydropower, and geothermal energy. Bioenergy can be supported under strict sustainability criteria, though the potential inclusion of nuclear energy has sparked debate in the past. Some fossil fuel activities are considered "transitional" within the taxonomy under strict conditions.

The EU Taxonomy could better align with the 2050 climate neutrality objective (European Scientific Advisory Board on Climate Change, 2024). The inclusion of fossil gas, though under strict conditions, is one example. The European Scientific Advisory Board on Climate Change (2024) notes an implementation gap in appropriate impact assessments, with public consultation and climate neutrality checks, for the establishment of taxonomy criteria for sustainable investment (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Indirectly supports resource non-intensive lifestyles through setting of sustainability criteria; offers support to sustainable bioenergy, but offers support to some fossil fuels
High renewable energy	++	Offers support to broad renewables such as solar, hydro, wind, and geothermal energy; offers support to some fossil fuels, though this pathway has the highest GHG budget
Mixed options	+	Offers support to broad renewables, such as BECCs, though nuclear support may be less supported, but offers support to some fossil fuels

Figure 23. ESABCC coherence rating breakdown for the EU Taxonomy Regulation, by ESABCC pathway.

The EU Taxonomy Regulation is largely aligned and sufficient to meet ambitions of the High renewable energy pathway. The inclusion of fossil gas should be removed, with sufficient checks by the European Commission, for further high ambition support.

4.1.3.2 Just Transition Fund

The Just Transition Fund offers support for green technologies, particularly in improving energy efficiency and renewable energy support. The fund indirectly supports reducing public and commercial energy demand and biofuels, especially in transition regions, while supporting economic diversification of territories which could be most negatively impacted by green transitions. Such support is offered in reskilling workers, investing in small- and medium-sized enterprises, research, innovation, and existing carbon-intensive installation transformation.

The Just Transition Fund may lack the design and ambition for the scale of transition in specific regions and sectors (European Scientific Advisory Board on Climate Change, 2024). Eligibility criteria and funding should be better targeted to regions and sectors at greatest risk (European Scientific Advisory Board on Climate Change, 2024). Assessments of socioeconomic impacts with participatory decision-making is recommended for policies such as the Just Transition Fund (European Scientific Advisory Board on Climate Change, 2024). Such assessments should be transparent, with public consultations likely increasing public support for such policies and measures (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Support for energy efficiency; supports renewable energy; indirectly reduces energy demand; supports biofuels
High renewable energy	+	Support for energy efficiency; supports renewable energy; indirectly reduces energy demand
Mixed options	+	Support for energy efficiency; supports renewable energy; indirectly reduces energy demand; supports biofuels

Figure 24. ESABCC coherence rating breakdown for the Just Transition Fund, by ESABCC pathway.

The Just Transition Fund shows some alignment with ambition of all three iconic pathways. To improve alignment, further systematic and context specific assessments as well as public consultations can help increase social and climate policy synergies.

4.1.3.3 Recovery and Resilience Facility

The Recovery and Resilience Facility (RRF) supports coordinated planning and financing of cross-border infrastructure, national infrastructure, energy projects, and energy reforms in line with REPowerEU (Kanapiyanova, 2023). It requires Member States to spend at least 37% of funds received from the RRF on climate objectives (i.e., investments, reforms), including renewable energy deployment, energy efficiency improvements, and green infrastructure investments (European Scientific Advisory Board on Climate Change, 2024). 134 billion euros from the facility are also available for digital investment, which can support AI development (European Commission, 2025c). Implementation varies based on Member State proposals, though the commission has reported that all Member States have exceeded that required threshold (European Scientific Advisory Board on Climate Change, 2024). It offers significant funding, in the billions, for green transition, but may prioritise economic recovery over systematic climate reforms and may include some risks of green washing without robust monitoring. Methodology flaws in tracking climate spending can result in over reporting (European Scientific Advisory Board on Climate Change, 2024).

The RRF is expected to end after 2026, without announcement of whether another instrument will replace it after that timeframe, which could limit the outlook for investors (European Scientific Advisory Board on Climate Change, 2024). Continuing the common debt approach under the current Recovery and Resilience Facility should be considered beyond 2026 to increase public investment in climate action and investor certainty (European Scientific Advisory Board on

Climate Change, 2024). There is no structural, common fiscal capacity based on common EU debt beyond the RRF (European Scientific Advisory Board on Climate Change, 2024).

Pathway	Rating	Explanation
Demand-side focus	+	Supports energy efficiency; supports energy projects and reforms including renewables; invests in green infrastructure, but does not address demand changes
High renewable energy	++	Supports energy efficiency; supports energy projects and reforms including renewables; invests in green infrastructure
Mixed options	++	Supports energy efficiency; supports energy projects and reforms including renewable hydrogen; invests in green infrastructure

Figure 25. ESABCC coherence rating breakdown for the EU Recovery and Resilience Facility, by ESABCC pathway.

The Recovery and Resilience Facility is most aligned with ambition narratives of the High renewable energy pathway and Mixed options pathway, while showing considerable ambition in line with the Mixed options and Demand-side focus pathways. The lack of contingency planned for the end of the RRF's timeframe, and a follow-up proposal should be planned and announced to best boost relevant ambition.

4.1.3.4 Innovation Fund

The EU's Innovation Fund aims to reduce industrial process energy intensity through efforts such as steel, cement, or chemical production advancements (European Parliament, 2023b). The fund offers finance to technologies which would significantly reduce emissions but are in very early stages of development and commercialisation and may still encounter market barriers. The amendment of Directive 2003/87/EC ensures the Innovation Fund can award support through competitive bidding for low or zero carbon product production, especially contributing to scaling up innovative techniques, processes, and technologies toward broad EU roll-out (European Parliament, 2023b). The act came into force in summer 2024.

While the effort to support decarbonisation of sectors historically slow to decarbonise is very valuable, financing offered is likely to be insufficient to cover long term needs. In the future, the possibility for projects to receive funds which are already receiving public support should be restricted (European Parliament, 2023b).

Pathway	Rating	Explanation
Demand-side focus	+	Improves energy efficiency in industries; invests in technological advancement; supports electrification
High renewable energy	+	Improves energy efficiency in industries; invests in technological advancement; supports electrification
Mixed options	++	Improves energy efficiency in industries; invests in technological advancement; supports electrification; offers grants for fossil CCS and BECCS

Figure 26. ESABCC coherence rating breakdown for the Innovation Fund, by ESABCC pathway.

The Innovation Fund is aligned to the ambition of the Mixed options pathway. An increase of available finance via the fund is likely to improve ambition across pathways.

4.1.3.5 Artificial intelligence act

The development and adoption of AI is described as essential for European competitiveness in the global economy (Luise et al., 2024). The EU's AI Act was the first AI regulatory policy to be implemented globally, and some further actions have been taken up since its start. AI opportunities have been recognised in achieving cleaner transportation, manufacturing efficiency, and cheaper sustainable energy (DG COMM, 2025). Underutilization is considered a threat to the EU in terms of missed opportunities for programme implementation (i.e., EU Green Deal) and the EU's competitiveness (DG COMM, 2025). To combat such threats, the AI Act creates AI categories based on risk, requires data sets which train AI to be as complete and error-free as possible and creates rules and regulations to subject high-risk systems (Madiega, 2024), which include reporting energy consumption (Parker, 2025). In alignment with the AI Act, AI Gigafactories have been established across the EU with over 100,000 advanced AI processors and an emphasis on energy efficiency, as well as supply chain reliability and power capacity (European Commission, 2025b).

As AI is quite new, its real impact on climate mitigation is still to be determined and displayed. Innovation through technology-push, investment, increase of trained professionals, and technology transfer are beneficial for technological improvements needed in all ESABCC pathways (European Scientific Advisory Board on Climate Change, 2023). Thus, the precedent of the AI Act and associated further work is determined to be somewhat aligned with each pathway. However, these documents and regulations do not specifically encourage or support AI use for immediate climate mitigation, as the report 'Policy and investment recommendations for trustworthy Artificial Intelligence, never mentions 'climate' in terms of the earth system, rather only once in the context of 'lucrative climate of investment'. The AI Continent Action Plan lists 'environment and climate' and 'energy and fusion research' as two key sectors for AI strategy, amongst twelve others (European Commission, 2025a). All three pathways could be best pursued with additional support for AI being employed toward reduced energy consumption, particularly in the residential, commercial, and public sectors (European Scientific Advisory Board on Climate Change, 2023). To achieve further alignment between specific pathways, for example, further incentivization to reduce clothing, product, and food consumption could be beneficial for the demand-side focus pathway.

A review of over 70 AI-enabled use cases for climate action identified impactful mitigation-relevant examples such as tracking industrial site GHG leakages, improving industrial process energy efficiency, and reducing food waste through improved demand planning (Thieullent et al., 2021). However, a minority (13%) of surveyed organisations are using AI to drive climate mitigation (Thieullent et al., 2021). AI can support innovations in improving the efficiency of CCS projects in the capture and sequestration phases (*Powering Possible*, 2025). AI reportedly supported reduction of GHG emissions by 13% in some use cases and improved power efficiency by 11% within the use case organizations and thus estimated that AI could help organizations fulfil the 11-45% of the Economic Emission Intensity targets of the Paris Agreement by 2030, dependent on the scale of AI adoption (Thieullent et al., 2021). Thieullent et al. (2021) estimate that AI could potentially deliver 8

percentage points of the 37% automative sector reduction target by 2030. Cowls et al. (2023) suggests establishment of an observatory documenting mitigation efforts to help identify best practices, greater collaboration public and private sectors toward effective utilization, utilizing Recovery Fund or other resources to incentivize AI-uptake in climate work, develop mechanisms for ethical auditing, develop disclosure of energy consumption to align the field, assess carbon footprints of popular models, incentivize efficiency metrics of AI research and development, assess AI infrastructure in terms of energy management and carbon mitigation strategies, and requiring measurement and reporting of estimate energy consumption and GHG emissions for EU funding conditional on applicants measuring and reporting their estimated energy consumption and GHG emissions. These measures would develop a better understanding of the trade-offs between AI in terms of energy use and climate change mitigation efficiency options (Cowls et al. 2023). A reduction of technological deployment challenges, particularly with the scale-up of hydrogen and solar photovoltaic renewable energy, is especially valuable (European Scientific Advisory Board on Climate Change, 2023), if possible, through AI.

Pathway	Rating	Explanation
Demand-side focus	+	Possibility to reduce food and production waste; possibility to increase energy efficiency in line with technological advancements, but 'market-based' AI uses may be less aligned for a society with lower market demands for end-products; but would benefit from greater guidance to do so
High renewable energy	+	Possibility to increase energy efficiency; but would benefit from greater guidance to do so
Mixed options	+	Possibility to increase energy efficiency; possibility to benefit critical infrastructure and security; but would benefit from greater guidance to do so

Figure 27. ESABCC coherence rating breakdown for the Artificial Intelligence Act, by ESABCC pathway.

The Artificial Intelligence Act is somewhat aligned with all three iconic pathways. For better alignment, the EU should further incentivise AI uptake specific to the mitigation actions illustrated in the pathways.

4.2 Adaptation

Climate adaptation refers to adjustments to ecological, social, economic, and/or infrastructure systems to respond to actual or expected climatic effects (IPCC, 2022). Adaptation can take many forms, including changes in practices, processes, or structures to increase resilience to such events. Some examples of adaptation include building culverts or seawalls for flooding, green spaces or ecological corridors for heat relief, redesigning warning systems, and delivering disaster funds for storms (IPCC, 2022). Rapid mitigation action would not eliminate the need to adapt to current climate risk levels, and perfectly informed adaptation cannot compensate for unabated and continued GHG emissions; therefore, climate mitigation and adaptation action are needed. Adaptation and mitigation action generally benefit one another; however, the recognition of synergies and trade-offs between specific adaptation and mitigation options is still a complex, growing area of research.

Adaptation began to gain importance, and increased policy response developments in the late 1990s and early 2000s (Burton et al., 2002). Mitigation efforts were successfully coordinated at national, EU, and international levels while adaptation decisions were more often locally led, by affected actors and institutions (Klein et al. 2007 as in Rayner & Jordan, 2010). EU adaptation policy began to develop in a piecemeal manner after national adaptation policies (Rayner & Jordan, 2010). EU adaptation policy development has been hindered by the complexity of choosing measures based on speculative analysis at some future time to an uncertain future climate in an unknown socio-economic context (Burton et al., 2002). Adaptation finance is also comparably low, though tracking adaptation finance is also subject to complexities (Naran et al., 2024). Historically, some Member States have struggled to secure EU financial support for adaptation (interview, Bryan Boult, Hampshire County Council, 22.10.08 as in Rayner & Jordan, 2010). European Court of Auditors (2024a) notes that reaching EU Mission Adaptation goals would require an estimated additional 10 billion Euros and how such an amount will be raised is unclear. Most risks assessed by the EUCRA found co-ownership of risks between the EU and Member States (European Environment Agency, 2024). Relevant adaptation policies are often implemented unevenly across member states, due to ranges in national priorities and capacity.

The analysis outlines adaptation challenges and synergies implied for the EU, dependent on mitigation efforts. Within this EU adaptation policy analysis, adaptation-relevant aspects of EU policy, adaptation needs assessments, and ESABCC mitigation pathways are discussed in terms of synergies and trade-offs with mitigation, to reveal policy recommendations. While not explicitly included or discussed in ESABCC mitigation pathways, adaptation efforts can be generally assumed as beneficial in all ESABCC pathways. This analysis denotes qualitatively determined coherence ratings of relative resilience or vulnerability implied by the ESABCC pathway mitigation option combinations. Recent, available adaptation assessments and studies were reviewed to inform ratings. The analysis subcategories are thematic in terms of adaptation topics, rather than specific to select policies because many policies which are not adaptation-specific offer aspects which contribute to adaptative capacity or resilience. Figure 29 below displays an illustrative comparison of the categories of adaptation considered in this analysis and is further explained in the following subsections.

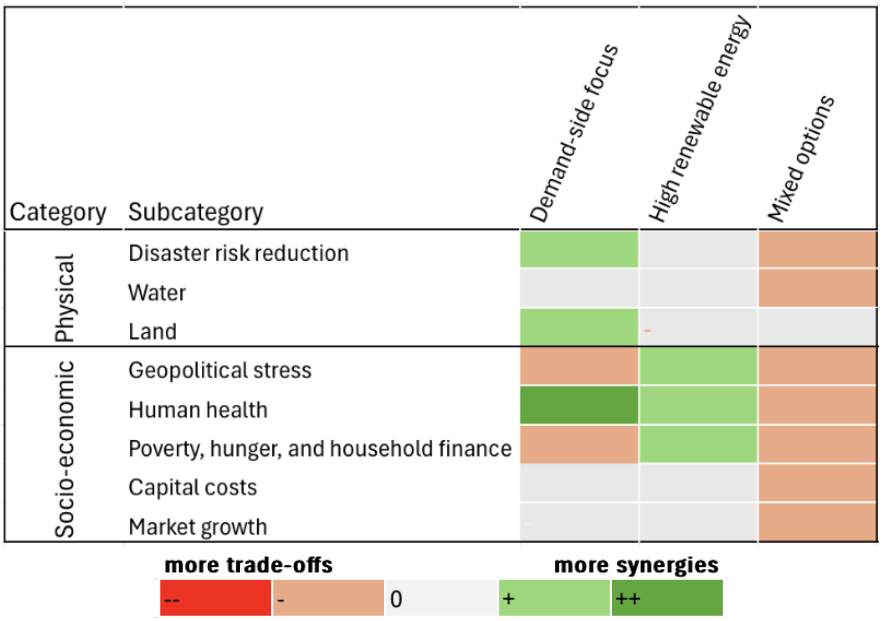

Figure 28. Illustrative comparison of adaptive capacity scores in terms of physical and socioeconomic risks by ESABCC pathway.

Physical risk trade-offs are comparatively highest in the Mixed options pathway, due to the increased risk of carbon sequestration losses from land CDR in the event of extreme weather, for example, drought or wildfire, which the pathway relies heavily on. Such events, without additional monitoring and protection, would negatively affect both the physical adaptation potential for land ecosystems and introduce sudden mitigation trade-offs. Europe is already facing high wildfire and heat risks in southern Europe (European Environment Agency, 2024). The Demand-focus pathway would also encounter higher land-based risks, due to the increased amount of natural land; however, the lack of reliance on this land for carbon sequestration somewhat reduces sudden mitigation trade-offs that would occur in such events, thus suggesting comparatively lesser immediate adaptation needs. Additionally, the Mixed options pathway invests in new and less developed technologies (i.e., hydrogen, CDR), which exhibit trade-offs for human health resilience (European Scientific Advisory Board on Climate Change, 2023). The Demand-side pathway exhibits high synergies for health, well-being, and ecosystem resilience; however, the sudden demand transitions implied would likely cause upset within some EU regions, adding geopolitical tension and immediate economic stress to households affected by sudden transitions, outlining additional needs for socioeconomic support in specific regions and sectors. These findings are further discussed in the following sections and subsections. To better even out EU adaptation-relevant implementation, more training, capacity building, and binding priorities/measures would be ideal, as well as continued and strengthened support for early warning systems and solidarity mechanisms between Member States.

The EUCRA notes that societal preparedness remains low and policy implementation lags behind the rapidly increasing risk levels, which are often co-owned by the EU and Member States (European Environment Agency, 2024). Looking forward, the EU aims to be more systematic across fields and sectors in building climate resilience but has specifically outlined a prioritised interest in integrating

adaptation in macro-fiscal policy, nature-based solutions, and local adaptation action (European Commission, 2021a). The EU Adaptation strategy stated support for instruments such as the Digital Europe Programme, Horizon Europe, the Intelligent Cities Challenges, and local uptake of data, digital and smart solutions for adaptation to regional specificities to empower direct action (European Commission, 2021a). As a goal, it aims to achieve climate resilience in society by 2050, which can achieve adaptation to unavoidable climate change impacts, in line with the Paris Agreement and European Climate Law (European Commission, 2021a). All Member States have a national adaptation strategy or plan, and the Climate-ADAPT platform is established as a knowledge platform (European Commission, 2021a).

4.2.1 Physical adaptation

The EUCRA calls for urgent adaptive action on pluvial flooding, fluvial flooding, coastal and marine ecosystems, southern European biodiversity, wildfire risks in southern European carbon sinks and southern crop production (European Environment Agency, 2024). More action is needed on coastal flooding, damage to infrastructure, heat-related energy disruption, southern drought risk, wildfire risks, species distribution shifts, invasive species risks, aquatic ecosystem risks, soil health, and crop production (European Environment Agency, 2024). The majority of these risks are considered 'medium' in terms of policy readiness and have risks co-owned between the EU and Member States, suggesting considerable gaps for resilience (European Environment Agency, 2024).

To promote the resilience of the EU natural environment and reduce disaster risks, multiple policies promote each other. In terms of land, the EU Soil Strategy links soil health to food security, climate mitigation, and biodiversity support, proposing robust data collection and monitoring systems such as asserting a methodology and indicators to assess desertification and land degradation (European Commission, 2021d). The Zero Pollution Vision offers soil quality support through nutrient loss and chemical pesticide reduction for terrestrial ecosystem mitigation and adaptation benefits (Kumar et al., 2024). Green urban spaces are supported in the Biodiversity Strategy for ecosystems and heatwave reduction, specifically suggesting new trees planted, creating requirements for large cities to develop Urban Greening Plans, remediation of contaminated soil sites, and reducing species endangered by invasive alien species (European Commission, 2020c). The CEAP contributes to similar goals in reducing hazardous chemicals and textile waste (European Commission, 2020a). The OECD (2021) notes that adaptation and mitigation linkages are most often discussed in terms of land use sectors, such as agriculture and forestry, specifically in G20 country National Adaptation Plans and Nationally Determined Contributions.

In terms of marine resilience, the EU Plan on Water Scarcity and Drought improved monitoring with the Global Monitoring for Environment and Security Services and early drought risk identification (European Commission, 2007). It suggested annual European assessments of Member State actions and drought management plans, however, relies on Member State initiatives, which may focus on short- to medium-term measures (European Commission, 2007). Measures for increased water retention capacity of soils are promoted (European Commission, 2021a). The Water Framework

Directive modifies authorisation procedures for hydropower to support climate mitigation, but to the potential detriment of biodiversity (Kampa, 2022). The Zero Pollution Vision for 2050 contributes to the reduction of waste and plastic to improve water quality (European Parliament, 2020). The EU Adaptation Plan discusses the needs to prepare for water supply disruptions, with residential water saving, supply, and/or storage infrastructure (European Commission, 2021a).

The EU Adaptation Plan focuses on high-level goals, rather than actionable steps for immediate implementation, which does not help clarify the path between adaptation planning to concrete action. The lack of a binding mechanism to guide national priorities and capacities for Member States can enable inconsistencies in efforts especially relevant for vulnerable regions (European Commission, 2021a). The Union Civil Protection Mechanism (UCPM) facilitates pooled resources and expertise toward collective responses to transnational disasters, such as natural disasters, pandemics, or industrial accidents (European Council, 2022b). Information and practice exchanges on drought risk management are facilitated with the UCPM, for example (European Commission, 2007). Limiting factors to its effectiveness include its dependency on voluntary Member State contributions, gaps in terms of its employment by Member States with fewer resources, and its focus on response rather than long-term resilience (European Council, 2022b). The UCPM was strengthened in 2021 to increase its capacity to respond to disasters, with disaster resilience goals based on forward-looking scenarios (European Council, 2022b). Disaster Resilience Goals encourage collaboration, improve disaster anticipation and management planning, increase risk awareness and preparedness, enhance early warning systems, increase UCPM response capacity and ensure robust civil protection (European Commission, 2023). However, Disaster Resilience Goals rely significantly on Member State commitments and their continuation, and some Member States may be less equipped to fully adopt measures due to the recognised disparity between financial and technical support (European Commission, 2023). The RRF can offer Member States financial support through loans toward reform set out in recovery and resilience plans and suspend such payments if corrective actions are insufficient according to EU recommendations (European Parliament, 2021a).

4.2.1.1 Disaster risk reduction

Extreme events, such as floods, wildfires, heatwaves, and droughts, can negatively impact humans, ecosystems, and infrastructure. The EUCRA calls for urgent action on floods and risks in southern Europe, for wildfire-induced carbon sink losses and crop production losses (European Environment Agency, 2024). CDR involving biosphere storage (i.e., afforestation, reforestation, soil carbon sequestration, biochar) faces risks of carbon content losses in biological decomposition or disaster events such as wildfires and pest outbreaks, which modelling generally does not reflect (Brunner et al., 2024). Risks of heat-related energy disruptions and droughts are also identified in EUCRA (European Environment Agency, 2024). Hot spells are known to cause losses in the generated outputs of nuclear power plants, resulting in less electricity being produced (Keller, 2024). Nuclear facilities also require water for ideal functioning but are built to high standards to avoid high-profile accidents. Historical data shows that heatwaves, storms, and droughts have minimal impact on

nuclear operations (IAEA, 2023). In 2022, for example, France experienced its second hottest summer on record with extreme aridity and record low river levels, but suffered less than 0.2% of annual production from affected power stations (IAEA, 2023). Nuclear plants are also designed to withstand earthquakes through safety programming and automatic shut-downs, as illustrated by the resilience of nuclear plants in Kobe after the 1995 severe earthquake (World Nuclear Association, 2021).

Considering the urgency of wildfire risks to southern European carbon stocks, stronger vulnerability would be implied for the Mixed options pathway, which relies on CDR (including biosphere storage) for mitigation and may imply increases in natural land in southern European areas at risk for drought and wildfire. If the energy infrastructure of the Mixed option pathway (i.e., nuclear, hydrogen) were compromised, this would suggest high risk. Though nuclear energy facilities follow high building standards, the consequences of any malfunction could be significantly more hazardous than failures of other renewable energy facilities. The high natural land of the Demand-side pathway implies higher wildfire risks, however, may also suggest lower damages from flooding and lower risk of heatwave energy disruptions, due to lower energy demand. The High renewable energy pathway suggests energy infrastructure risks related to flooding and heatwaves but may suggest lower wildfire risks if forest natural land is prioritised outside of southern Europe.

Robust monitoring, forecasting, and early warning systems are important to prepare for and respond to disaster risks. AI has been able to offer faster, more accurate medium range weather forecasting (Mazzai, 2024). Research on ideal species selection (i.e., to reduce wildfire risks or withstand droughts) and land management can further inform adaptation strategies, forest management, and land-based CDR. For example, Madrigal et al. (2017) found that Mediterranean forest biomass harvesting can reduce fire hazard if both tree and shrub strata are managed regionally while other biomass harvest practices showed no impact on disaster risk reduction. The urgent status of various risks to southern Europe may suggest increasing efforts to boost financial and technical support to southern Member States who experience underemployment of the UCPM.

Pathway	Rating	Explanation
Demand-side focus	+	Higher natural land may suggest higher drought and wildfire risks, but lower flood risks; Lower energy consumption suggest lower energy disruption risks by heatwave or disaster
High renewable energy	0	Disaster risks to energy infrastructure and risks for heat-induced energy production losses, but lower natural land at risk of wildfire
Mixed options	–	Higher drought, wildfire, and earthquake risks for nuclear, hydrogen, and CCS infrastructure; Higher disaster risk for land sequestered carbon

Figure 29. Illustrative comparison of resilience or vulnerability in terms of disaster risk, by ESABCC pathway.

Lower energy consumption needs suggest higher resilience in terms of disaster risk reduction. Reliance on land-based CDR and employment of higher-risk energy production (i.e., nuclear and hydrogen) suggest greater vulnerabilities. Financial and technical support is recommended to increase the employment of UCPM by any southern Member States with comparably lower disaster risk resilience commitments.

4.2.1.2 Water vulnerability

Risks of pluvial flooding, fluvial flooding, marine ecosystem losses, and crop production losses due to drought in southern Europe require urgent action, according to the EUCRA (European Environment Agency, 2024). Hydropower, deployed at similar levels across pathways, has the potential to alter fish migration, sediment transport, and water quality thus potentially negatively affecting marine ecosystems (Bradford 2022 as in Badrudeen et al., 2024). Other energy deployment options, such as nuclear and hydrogen energy, increase water demand in energy production. Land-based CDR requires water availability for the continuation of carbon storage. Protective infrastructure against water risks can aid mitigation objectives while contributing to risk reduction, such as concrete carbon sequestration (Xi et al., 2016 as in OECD, 2021).

The European Scientific Advisory Board on Climate Change's (2023) assessment of the alignment of iconic pathways with SDGs outlines that the largest trade-offs for water vulnerability would occur in the Mixed options pathway. The employment of land-based CDR, nuclear energy production, hydrogen production, and CCS would imply greater human water demands. Given current drought risks in southern Europe, ideal placement of such facilities would be important to avoid additional vulnerability. Both the Demand-side focus and High renewable energy pathways include trade-offs and synergies of almost equal weight in terms of water availability and ecosystem SDGs and are thus determined to be neutral (European Scientific Advisory Board on Climate Change, 2023).

As CDR technologies are relatively new, further research into non-land-based options could increase water resilience in areas of future CDR deployment. Though nuclear facilities are built to high standards (IAEA, 2023), their location in the case of increased European deployment should be considered alongside heat and drought risks to avoid seasonal production reductions. Though hydropower is similarly employed in each pathway, further ecosystem research and consideration will be beneficial to marine resilience.

Pathway	Rating	Explanation
Demand-side focus	0	Less resource intensive lifestyles and lower energy consumption should reduce water demands, allowing more water availability and protection to marine ecosystems
High renewable energy	0	Both synergies and trade-offs are noted in terms of water availability and marine ecosystems
Mixed options	-	Higher hydrogen and nuclear power generation suggest higher water demands and trade-offs for water scarcity and negative ecosystem impacts

Figure 30. Illustrative comparison of resilience versus vulnerability in terms of water resources and ecosystems, by ESABCC pathway.

The greater deployment of CCS, nuclear energy production, land-based CDR, and hydrogen energy production suggests increased vulnerabilities in terms of water availability and ecosystems. The location of associated facilities and production should avoid areas with a higher risk of drought. Research should aim to further inform options to avoid hydropower-induced ecosystem damage.

4.2.1.3 Land vulnerability

Coastal ecosystems and biodiversity of southern Europe require urgent adaptive action, while species distribution shifts, soil health, and risks of invasive species are also of high priority (European Environment Agency, 2024). Certain renewable energy systems have been documented to present challenges to European animal species. Solar installations can contribute to habitat loss and fragmentation depending on placement (Kim et al 2021; as in Badrudeen et al., 2024). Similarly, wind turbines can negatively affect bird and bat habitats and migration (Laranjeiro et al 2018 as in Badrudeen et al., 2024). Trees are also a topic of European biodiversity, in which current policy may be improved. The European Court of Auditors (2024a) state that the lack of requirement to diversity forests to access CAP funding can promote single-species forests, which does not benefit forest resilience. Policy protections for old-growth forests and limits to forest management may increase vulnerability toward disturbances, such as wildfire (Köhl et al., 2021).

The European Scientific Advisory Board on Climate Change (2023) states that the Demand-side focus and High renewable energy pathways offer synergies toward environmental land SDGs. The deployment of solar and wind energy infrastructure included in the High renewable energy pathway should be carefully considered to minimise negative effects on biodiversity. The Mixed options pathway includes trade-offs for the Life on Land SDGs (European Scientific Advisory Board on Climate Change, 2023).

The proper siting of energy infrastructure (i.e., solar, wind, nuclear) should be prioritized within future EU policies to minimise potential negative land ecosystem effects. Further research on terrestrial biodiversity should aim to further inform European forestry and general ecosystem resilience.

Pathway	Rating	Explanation
Demand-side focus	+	Plant dominant landscapes likely to be more adaptable than livestock central agricultural areas and displays synergies with life on land SDG
High renewable energy	0	Inclusion of energy production options which can be disruptive to animal species, but displays synergies with life on land SDG
Mixed options	0	Carbon sinks, CCS, and energy waste facilities pose risks to the land environment and ecosystems, offers trade-offs with life on land SDG

Figure 31. Illustrative comparison of resilience versus vulnerability in terms of land adaptation, by ESABCC pathways.

Increases in protected and/or natural land offer adaptation benefits, as well as any implied climate mitigation benefits. Policy should avoid the promotion of single-species forests or ecosystems. Further biodiversity and ecosystem research should aim to better inform ideal land compositions and management and offer solutions to the negative impacts of renewable energy infrastructure on native species.

4.2.2 Socio-economic adaptation

Policies to encourage socioeconomic adaptive capacity are valuable to consider alongside mitigation measures, though socioeconomic aspects are various to consider. Mitigation can have disruptive and regressive socio-economic impacts disproportionately felt by low-income, vulnerable households (European Scientific Advisory Board on Climate Change, 2024). The EU Adaptation Plan focus on systematic adaptation, which can sometimes overlook the needs of marginalised communities (European Commission, 2021a). A gap is indicated by a low comprehension of climate policy implications at the household level, which may contribute to current limitations of mitigation-adaptation synergy recognition (European Scientific Advisory Board on Climate Change, 2024). Recognised breaches of Aarhus Convention rules are observed in the National Energy and Climate Plan public engagement, specifically a lack of public consultations or dialogues (European Scientific Advisory Board on Climate Change, 2024). The European Scientific Advisory Board on Climate Change (2024) suggests more systematic and context-specific impact assessments, public consultations on assessments, and ex-post evaluations to delineate local and national needs which can reinforce synergies between social and climate policies and aid the design of compensatory measures such as the Social Climate Fund and Just Transition Fund (European Scientific Advisory Board on Climate Change, 2024). The European Pillar of the Social Rights Action Plan states that at least 60% of adults should participate in annual training for a more resilient workforce (European Commission, 2021b). Increased knowledge, guidance, and capacity-building support can even be beneficial to increase CAP committed forestry measures (European Commission, 2021c). Support for the social recovery of jobs in green and digital transitions can be financed by RRF recovery investments (European Commission, 2021b).

Health policy, such as the Union on Public Health aims to increase EU knowledge and capacity (European Commission, 2008). The EU Health Union increases preparedness for health threats at the EU level (European Commission, 2023). Health challenges for the population are implied by urgent human heat stress adaptation needs and water scarcity risks, particularly relevant to southern European populations (European Environment Agency, 2024). Urgent action is suggested on European solidarity mechanisms and risks co-owned by the EU and Member States (European Environment Agency, 2024).

Potential climate impacts of increased water scarcity create economic risks for property and insurance markets, and public finance, especially in southern Europe (European Environment Agency, 2024). The EU Taxonomy Regulation provides classification systems to facilitate sustainable finance investment, including objectives for climate adaptation, sustainable use, circular economy transitions, pollution prevention, and protection of ecosystems (OECD, 2021). Financial institutions face higher probabilities of default and loss of asset value with uncertain risk severity due to a lack of stress tests and insufficient monitoring of supply chain vulnerabilities against future hazards, which portends increases in price for physical and transition climate risks being taken into account in investment, lending, and insurance activities (European Environment Agency, 2024).

Disaster financial support has been exceeded with increased frequency and existing assessments likely underestimate risks in terms of cascading, compounding, and tail risks of rare extreme events (European Environment Agency, 2024). The EU's Solidarity and Emergency Aid Reserve, with a maximum budget of 1.2 billion Euros, was exhausted in 2021, 2022, and 2023, thus raising a proposition for a raise to 2.5 billion for 2024–2027 (European Environment Agency, 2024). Solidarity funding through risk pooling at the EU level is one option to manage climate extremes (European Environment Agency, 2024). The RRF offers Member States financial support through loans to achieve targets of reform as set out in their recovery and resilience plans, with an option to suspend payments if a Member State receives successive recommendations on insufficient corrective actions (European Parliament, 2021a). The Solidarity Fund, UCPM, and other solidarity mechanisms need a robust increase of resources and use in incentivising adaptation actions at national levels (European Environment Agency, 2024).

4.2.2.1 Geopolitical stress

Immediate internal geopolitical stress as a short-term reaction to mitigation-relevant transitions could reduce adaptive capacity, at least in the short term. External geopolitical shifts or reactions to trade could further contribute. Internal geopolitical stress is already anticipated, as rising temperature impacts will likely lead to economic losses, increasing resource scarcity, internal migration, and greater political instability in the southern Member States (Weise, 2025). Carbon pricing disproportionately affects poorer households, and its perceived unfair distribution encourages populism, political extremism, and is subject to disinformation (Weise, 2025). The overuse of AI could suggest a threat to democracy, in terms of spreading misinformation or further political polarisation; however, the AI Act introduces requirements for AI-created content transparency to avoid such threats (DG COMM, 2025). As AI use cases and technologies further develop, the AI Act should be built upon and continually reviewed. EU social policy promotes aspects such as education and employment, which should reduce such stress, but lacks sufficient provisions to be implemented evenly across Member States due to national priorities, economic conditions, and institutional capacities (European Commission, 2021b). The CAP Rural Development Fund similarly funds technology investment for farmers and assists the establishment of young farms, but income support per hectare varies between Member States due to historical reference considerations to "converge" gradually, considering their range of wage and input costs (European Parliament, 2021b). Tensions from unequal burdens could weaken European cohesion, just as green policies have and may continue to (Weise, 2025). The 2024 agricultural protests in various Member States, highlighted various sometimes opposing concerns, such as the rising cost of energy, fertiliser use restrictions, reduced fuel subsidies, and insufficient aid for droughts and floods (Dwyer, 2024). In assessing the impact of CAP legislation, the European Court of Auditors (2024b) found that approximately a 5-10% reduction of farmer income was estimated due to budget reduction effects and additional requirements, while Petsakos et al.'s (2023) findings suggest CAP green architecture and eco-schemes would decrease farmer income by 2.1-3.5% compared to the previous CAP.

Considering the strong and comparably sudden shifts in energy, agricultural, and general consumption associated with the Demand-side focus pathway (European Scientific Advisory Board on Climate Change, 2023), the pathway appears most vulnerable to immediate internal geopolitical stress. Dietary changes are a contentious area of mitigation measures which can be received with hostility internally but would also suggest external geopolitical stress in terms of import and export changes likely. Conversely, the European Scientific Advisory Board on Climate Change (2023) asserts that the Demand-side focus pathway would offer medium synergies for education, strong synergies for social equality, and minor benefits for peace, justice, and strong institutions. The High renewable energy pathway implies SDG synergies for education, social equality, and minor benefits in terms of peace, justice, and strong institutions (European Scientific Advisory Board on Climate Change, 2023). The Mixed options pathway shows minor benefits for reduced inequalities, but trade-offs for peace, justice, and strong institutions (European Scientific Advisory Board on Climate Change, 2023).

The EU Adaptation Plan can improve on addressing vulnerability exacerbating social inequalities for systematic adaptation (European Commission, 2021a). Participatory methods and robust support measures for communities affected by transitions should be strengthened to increase resilience in terms of geopolitical adaptative capacity, most relevant to the long term.

Pathway	Rating	Explanation
Demand-side focus	–	Sudden and strong shifts in dietary, energy, and resource intensive demands may cause stress in agricultural and rural regions, but narrative supports many social SDG goals
High renewable energy	+	Transition to renewable energies and placement of certain renewables like solar and wind energy may suggest some stress in certain areas, but narrative supports many SDG goals
Mixed options	–	Location of hydrogen, nuclear, and CCS generation, storage, and/or waste may cause some tensions for communities; some social SDGs are supported, but peace, justice and strong institutions SDG shows trade-offs

Figure 32. Illustrative comparison of resilience versus vulnerability in terms of political stress, by ESABCC pathways.

Sudden consumption shifts (i.e., diets, energy) suggest higher immediate geopolitical vulnerability in the Demand-side focus pathway, though SDG synergies imply a reduction of such stressors in the long term. Support should be strengthened when employing mitigation action that suggests strong effects for certain regions and sectors. Public engagement and consultation can also be advantageous to support trust in governance and support for such mitigation measures.

4.2.2.2 Human health

The EU Health Union emphasizes the need for early detection and prevention of health risks while supporting European coordination and collaboration between health agencies in response to any such health crises (European Commission, 2008). Systematic vulnerabilities are addressed through resource pooling and joint procurement, alongside proposals to strengthen the European Commission Disease Control and European Medical Agency for surveillance and coordination (European Commission, 2008). However, health policy lacks mechanisms for uniform compliance,

indirectly relying on varying national resources and coordination, which cannot sufficiently address regional healthcare system disparities (European Commission, 2008). Balancing sovereignty and EU health measures can delay action (European Commission, 2008). Disparities among Member States can be due to infrastructure differences, for example. EU social policy includes aims to offer equal access to healthcare (European Commission, 2021b). AI has been predicted to offer benefits to healthcare and safer transport (DG COMM 2025), though further proof of benefits and best practices should be further developed.

The Demand-side focus pathway offers considerable health and well-being benefits (European Scientific Advisory Board on Climate Change, 2023). This is attributed to the shift to healthy, EAT-Lancet diets. In this case, the European population is implied to be healthier and therefore potentially more resilient to heatwaves and/or diseases. The High renewable energy pathway does not include dietary shift assumptions, offering some synergies as well as minor trade-offs with health SDGs (European Scientific Advisory Board on Climate Change, 2023). In contrast, the Mixed options pathway exhibits notable health trade-offs (European Scientific Advisory Board on Climate Change, 2023).

Synergies between the Demand-side focus pathway and health SDGs, further suggest that the EU should address the gap in policy measures to increase consumer behavioural changes toward healthier diets and lower resource consumption. While this has been discussed to offer benefits to climate mitigation, the health resiliency benefits would also be beneficial to climate adaptation.

Pathway	Rating	Explanation
Demand-side focus	++	Synergies for health SDGs; human resilience suggested by LANCET diet shifts
High renewable energy	+	Synergies for health SDGs, but also minor trade-offs
Mixed options	–	Trade-offs for health SDGs

Figure 33. Illustrative comparison of resilience versus vulnerability in terms of human health and physical resilience, by ESABCC pathway.

The Demand-side focus pathway is comparably resilient in terms of population health, due to dietary and demand shifts. Policy initiatives to incentivise healthy EAT-LANCET dietary shifts and reduction of energy and material demand should be pursued, rather than continuing reliance on voluntary consumer responsibility.

4.2.2.3 Hunger, poverty, and household finance

The EUCRA denotes that EU-external climate impacts could have catastrophic effects on food security later in the century (European Environment Agency, 2024). Risks of hunger and poverty are identified in the southern EU, related to potential crop failures in the case of drought (European Environment Agency, 2024). Considering an economic analysis of the Farm to Fork Strategy suggested overall agricultural production reductions (Wesseler, 2022), planning should ensure

recovery from hunger or poverty in the short term. The EU Social Policy (European Commission, 2021b) sets out to reduce poverty by creating fair wages and job opportunities; however, it lacks provisions which specifically consider long-term economic shocks or climate risks. The effects of AI should be carefully monitored, with additional actions being built upon the AI Act where necessary, as AI is both expected to eliminate many jobs while creating "better" jobs (DG COMM, 2025). The availability of education and training aligned with such new and "better" jobs will be crucial to prevent enduring unemployment and offer a skilled workforce in regard to such changes (DG COMM, 2025).

The Demand-side focus pathway suggests vulnerabilities for poverty and hunger SDGs in terms of supply, but benefits for hunger reduction in terms of demand (European Scientific Advisory Board on Climate Change, 2023). Sudden shifts toward plant-based diets could be a nutritional challenge to areas with culturally high animal product consumption, which could underline the need for further nutritional education and support in such regions. The High renewable energy pathway implies minor benefits toward reducing poverty and hunger (European Scientific Advisory Board on Climate Change, 2023). The Mixed options pathway narrative implies both minor trade-offs and synergies for hunger and poverty (European Scientific Advisory Board on Climate Change, 2023).

The continuation and strengthening of rural development measures for farmer investment in environmentally friendly facilities or technology (European Parliament, 2021b) will be valuable to reduce changes in hunger and poverty among populations affected by transitions. The EU should bolster civil protection support to prepare for and respond to drought-induced agricultural losses. Education programs on plant-based nutrition, or nutritional options in case of specific crop failures, could be additionally beneficial for areas with traditional reliance on livestock.

Pathway	Rating	Explanation
Demand-side focus	–	Narrative suggests trade-offs for reducing hunger, risks initial short-term trade-offs for nutrition while populations shift to plant-based diets
High renewable energy	+	Narrative suggests minor benefits toward reducing poverty and hunger
Mixed options	–	Narrative suggests minor risks for hunger

Figure 34. Illustrative comparison of resilience versus vulnerability in terms of disaster risk by ESABCC pathway.

The reliance on longer-standing and better-tested renewable energy deployment suggests higher resilience in terms of hunger, poverty, and household finance in the High renewable energy pathway. Support mechanisms for heavily affected industries and robust civil protection mechanisms will be important to further boost resilience in the case of agricultural failures.

4.2.2.4 Capital costs

Renewable energy development suggests upfront investments for infrastructure and technology installation (Best & Trueck 2020 as in Badrudeen et al., 2024). Solar and wind energy investment

implies the need to establish further energy storage facilities and backup systems to ensure energy security in climatic variations (Ravestein et al 2018; Amir et al 2023 as in Badrudeen et al., 2024). Economic repercussions may ensue in the short term for communities currently dependent on fossil energy production (Wysocka 2023 as in Badrudeen et al., 2024). Improvements and/or expansions to early warning systems or forecasting of drought, fire, or heatwaves could require investment to limit damages to new capital costs for energy infrastructure or carbon sequestration. Such losses are already identified as highly relevant in the context of the EU, as discussed in the EUCRA (European Environment Agency, 2024).

As the Demand-side focus pathway considers a reduction in energy demand and lower resource-intensive demand, this pathway is considered to have comparably lower associated capital costs. The Demand-side focus pathway notes vulnerabilities in workforce adjustment for rapid transitions, though higher affordability and energy supply are available long-term (European Scientific Advisory Board on Climate Change, 2023). The High renewable energy pathway, in contrast, includes some slightly higher cost energy investments, such as higher geothermal energy, and solar energy production (European Scientific Advisory Board on Climate Change, 2023). The Mixed options pathway includes the largest capital cost assumptions due to an increase in comparably more expensive renewable energy infrastructure (i.e., nuclear and hydrogen). The Mixed option pathway may also imply upfront costs associated with CDR establishment and related monitoring.

If climate mitigation transitions with higher capital costs are pursued at EU level, greater attention needs to be paid to long-term economic resilience. Renewable energy policies should strategically focus on investments and energy storage technologies, while renewable energy policies should empower individuals both consuming and producing energy to stimulate local investment and foreign direct investments in technologies (Hu & Chang 2023 as in Badrudeen et al., 2024). Integration of local content in renewable energy schemes is paramount to balance the economic and environmental objectives of renewables (Badrudeen et al., 2024).

Pathway	Rating	Explanation
Demand-side focus	0	Comparably lower infrastructure investment costs, lower energy production infrastructure costs, suggests economic shifts and transitions in energy, agriculture, and general production
High renewable energy	0	Comparably higher need for new energy infrastructure, however solar, wind, and geothermal are comparably lower cost renewables
Mixed options	-	Comparably higher infrastructure investment costs for higher nuclear and hydrogen deployment; Implies monitoring for land-based carbon sequestration; Transitions implied in energy; implies later and more gradual dietary shifts

Figure 35. Illustrative comparison of resilience or vulnerability in terms of capital costs by ESABCC pathway.

The increased deployment of hydrogen and nuclear energy implies higher initial capital costs, suggesting the highest relevant vulnerability in the Mixed option pathway. Investments toward transition should aim to empower local investment and attract foreign investments.

4.2.2.5 Market growth

Standard macroeconomic estimates of economic costs of mitigation in the IPCC AR6 denote GDP loss (2.6–4.2%) globally by 2050 in pathways consistent with 1.5 (European Scientific Advisory Board on Climate Change, 2023). Some macroeconomic losses can be assumed for all ESABCC pathways, as well as growth in renewable energy sectors. For the best long-term economic outcomes, there is a necessity to evaluate reliability, availability, and maintainability between economic and environmental trade-offs (Badrudeen et al., 2024). The underuse of AI, due to unbalanced mistrust, may lead to lower innovation in Europe and relative economic stagnation (DG COMM, 2025). Similarly, the misuse of AI could suggest a lack of competitiveness and biased "findings" in terms of research and scientific advancement (DG COMM, 2025). This again suggests the importance of training and best practice learning opportunities to avoid threats.

Both Demand-side focus and High renewable energy pathways offer benefits to industry, innovation, sustainable cities, and communities (European Scientific Advisory Board on Climate Change, 2023). From a supply side, the Demand-side focus pathway offers greater synergies for industry, innovation, and infrastructure, while the High renewable energy pathway suggests trade-offs (European Scientific Advisory Board on Climate Change, 2023). Specifically, mitigation measures of fossil fuel-CCS, included in the Mixed options pathway, suggest trade-offs for decent work and economic growth (European Scientific Advisory Board on Climate Change, 2023). Behavioural responses to reduce building and transportation demand, included in the Demand-side focus pathway, exhibit slight trade-offs for economic growth (European Scientific Advisory Board on Climate Change, 2023).

Economic resilience indicators to boost short-term economic absorption after a climate impact, such as reskilling opportunities, corporate finances, public finance, quality of welfare, and investments, can be advantageous to improve in Member States to ensure resilience through the EU (Hafele et al., 2023). Boosting economic resilience indicators, particularly in education & skills, governance and social progress and cohesion, can help boost economic resilience toward adaptation after damaging climate events, especially in Member States disproportionately hindered in absorbing, recovering and/or adapting to climate economic shocks (Hafele et al., 2023). The EU can support private sector early-movers by incentivising adaptation through procurement mechanisms and dedicated adaptation support for small to medium enterprises (European Environment Agency, 2024). Dedicated finance and market-pull mechanisms are recommended for inclusion in EU policies to incentivise business-led adaptation, which is currently limited to investments in nature-based solutions in large-sized enterprises due to low climate risk awareness and a lack of risk data (European Environment Agency, 2024).

Pathway	Rating	Explanation
Demand-side focus	0	Synergies with industry, innovation, and infrastructure SDG; lower growth assumed with reduced agricultural, product, and energy demands
High renewable energy	0	Synergies and trade-offs to industry, innovation, and infrastructure SDG
Mixed options	-	Low synergies and medium trade-offs with decent work, economic growth, industry, innovation, and infrastructure SDGs

Figure 36. Illustrative comparison of aspects of resilience or vulnerability in terms of economic growth relevant by ESABCC pathway.

The mitigation options to invest in fossil CCS can negatively impact economic growth on the demand side, while measures to reduce building and transportation demand negatively impact demand-side economic growth to an extent. To ensure that the EU's economy can absorb climate-induced shocks in the short term, focus on even opportunities and capacity for reskilling, welfare, and strong corporate finance, public finance, and investments can help increase resilience within the transition.

5 Conclusions

The review of EU policies, EU Climate Law aligned pathways from the ESABCC, and various relevant literature culminated in the identification of policy and measure suggestions for EU adaptation and mitigation policy improvements. These findings synthesise various trade-offs and synergies between mitigation and adaptation, to further inform European resilience.

In terms of EU land and physical environments, EU policy on forestry, agriculture, water, and disaster resilience should consider greater alignment with binding targets for mitigation, more directly considering climate change risks and binding targets for GHG emissions reductions. Binding targets for methane emission reduction in agriculture can assist mitigation, while potentially supporting human health resilience through shifts to healthy, plant-based diets. Measures to support rural and agriculturally dependent communities should complement such mitigation efforts to avoid reductions in adaptive capacity due to geopolitical stress or weak household finances. As consumer behaviour is unlikely to change voluntarily toward greater climate mitigation on its own, or necessarily lead consumers to greater resilience, demand-side measures should be incorporated into policy, in terms of energy, resource or dietary consumption.

To accelerate achieving EU Climate Law targets, the EU should end support options for fossil fuels, rather shifting focus to ensuring energy security in strengthening renewable transitions. The best placement of renewable energy infrastructure can either suggest relative vulnerability or resilience, depending on the pronounced risks of such infrastructure. As southern Europe already faces high risks of drought and wildfire, measures such as land-based CDR and hydropower may be beneficial to consider elsewhere. EU technical and financial support can help Member States to evenly access available funding for transition and promote local adaptive capacity. Increasing opportunities for reskilling, research, capacity to engage communities on transitions, and support sectoral workers during various sectoral transitions.

Further research on adaptation-mitigation trade-offs and synergies can further focus on energy, economics, and social aspects to ensure that vulnerable communities are less negatively impacted by climate ambition measures. A reduction of the heterogeneity in adaptation and mitigation ambitions and accomplishments between Member States can promote a more adaptive Europe. According to other current analyses, such as the EUCRA, taking regional circumstances into account will be important to avoid heat-related health risks, agricultural failures due to drought, and damage to carbon stocks, resources, lives, and ecosystems due to wildfires (European Environment Agency, 2024).

5 Bibliography

Ahairwe, P., & Bilal, S. (2019). *Boosting EU climate finance: Mitigate more without neglecting adaptation in poorer countries*. European Centre for Development Policy Management. https://doi.org/10.55317/CASC001

Badrudeen, T. U., Opeyemi David, L., & Nwulu, N. (2024). Management of environmental and economic tradeoffs for the optimization of renewable energy scheme. *International Journal of Sustainable Energy*, *43*(1), 2355645. https://doi.org/10.1080/14786451.2024.2355645

Balogh, J. M. (2023). The impacts of agricultural subsidies of Common Agricultural Policy on agricultural emissions: The case of the European Union. *Agricultural Economics (Zemědělská Ekonomika)*, *69*(4), 140–150. https://doi.org/10.17221/51/2023-AGRICECON

Brunner, C., Hausfather, Z., & Knutti, R. (2024). Durability of carbon dioxide removal is critical for Paris climate goals. *Communications Earth & Environment*, *5*(1), 645. https://doi.org/10.1038/s43247-024-01808-7

Burton, I., Huq, S., Lim, B., Pilifosova, O., & Schipper, E. L. (2002). From impacts assessment to adaptation priorities: The shaping of adaptation policy. *Climate Policy*.

Busch, D., Ferrarini, G., & Grünewald, S. (Eds.). (2021). The European Commission's Sustainable Finance Action Plan and Other International Initiatives. In *Sustainable Finance in Europe: Corporate Governance, Financial Stability and Financial Markets*. Springer International Publishing. https://doi.org/10.1007/978-3-030-71834-3

Climate Action Tracker. (2024). *EU* (Climate Action Tracker). https://climateactiontracker.org/countries/eu/

Climate Analytics. (2024). *The European Union* (1.5°C National Pathways Explorer). https://1p5ndc-pathways.climateanalytics.org/countries/european-union

Cowls, J., Tsamados, A., Taddeo, M., & Floridi, L. (2023). The AI gambit: Leveraging artificial intelligence to combat climate change—opportunities, challenges, and recommendations. *AI & SOCIETY*, *38*(1), 283–307. https://doi.org/10.1007/s00146-021-01294-x

DG COMM. (2025). Artificial intelligence: Threats and opportunities. https://www.europarl.europa.eu/topics/en/article/20200918STO87404/artificial-intelligence-threats-and-opportunities

DG ENER. (2024, May). New EU Methane Regulation to reduce harmful emissions from fossil fuels in Europe and abroad. *DG Energy News*. https://energy.ec.europa.eu/news/new-eu-methane-regulation-reduce-harmful-emissions-fossil-fuels-europe-and-abroad-2024-05-27_en

Dwyer, O. (2024, February). Analysis: How do the EU farmer protests relate to climate change? *Carbon Brief*. https://www.carbonbrief.org/analysis-how-do-the-eu-farmer-protests-relate-to-climate-change/

Edenhofer, O. (2023, July). *Scientific advice for an EU-wide 2040 climate target and a greenhouse gas budget for the period 2030-50*. https://www.climatecouncil.ie/media/climatechangeadvisorycouncil/contentassets/documents/councilmeetingdocuments/2023/230719_CCAC_EU%20Budget%20WEB%20EVI.pdf

European Commission. (n.d.-a). *AggregateEU – questions and answers*. European Union. https://energy.ec.europa.eu/topics/energy-security/eu-energy-platform/aggregateeu-questions-and-answers_en

European Commission. (n.d.-b). *Effort sharing 2021-2030: Targets and flexibilities - European Commission*. Retrieved 25 February 2025, from https://climate.ec.europa.eu/eu-action/effort-sharing-member-states-emission-targets/effort-sharing-2021-2030-targets-and-flexibilities_en

European Commission. (n.d.-c). *Energy efficiency targets*. Retrieved 25 February 2025, from https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-targets_en

European Commission. (n.d.-d). *European Climate Law*. https://climate.ec.europa.eu/eu-action/european-climate-law_en#:~:text=The%20European%20Climate%20Law%20writes,2030%2C%20compared%20to%201990%20levels.

European Commission. (2007, July). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Addressing the challenge of water scarcity and droughts in the European Union*. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0414:FIN:en:PDF

European Commission. (2008, May). *Consolidated version of the Treaty on the Functioning of the European Union—PART THREE: UNION POLICIES AND INTERNAL ACTIONS - TITLE XIV: PUBLIC HEALTH - Article 168 (ex Article 152 TEC)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A12008E168

European Commission. (2020a, March). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A new Circular Economy Action Plan For a cleaner and more competitive Europe*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A98%3AFIN

European Commission. (2020b, May). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A Farm to Fork Strategy for a fair,*

healthy and environmentally-friendly food system. European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381

European Commission. (2020c, May). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EU Biodiversity Strategy for 2030 Bringing nature back into our lives*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020DC0380

European Commission. (2020d, October). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on an EU strategy to reduce methane emissions*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0663

European Commission. (2021a, February). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Forging a climate-resilient Europe—The new EU Strategy on Adaptation to Climate Change*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A82%3AFIN

European Commission. (2021b, March). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Pillar of Social Rights Action Plan*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A102%3AFIN

European Commission. (2021c, July). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS New EU Forest Strategy for 2030*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0572

European Commission. (2021d, November). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EU Soil Strategy for 2030 Reaping the benefits of healthy soils for people, food, nature and climate*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0699

European Commission. (2023, February). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS European Union Disaster Resilience Goals: Acting together to deal with future emergencies*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A61%3AFIN

European Commission. (2025a). *AI Continent Action Plan. https://digital-strategy.ec.europa.eu/en/library/ai-continent-action-plan*

European Commission. (2025b, June). *AI Factories*. European Commision. https://digital-strategy.ec.europa.eu/en/policies/ai-factories

European Commission. (2025c). *European approach to artificial intelligence*. European Commission. https://digital-strategy.ec.europa.eu/policies/european-approach-artificial-intelligence

European Council. (2022a). *COUNCIL REGULATION amending Regulation (EU) 2022/2576 as regards the prolongation of its period of application*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023PC0762&qid=1703174597780

European Council. (2022b, March). *Council conclusions on civil protection work in view of climate change*. https://data.consilium.europa.eu/doc/document/ST-7146-2022-INIT/en/pdf

European Court of Auditors. (2024a). *Climate adaptation in the EU Action not keeping up with ambition*. https://www.eca.europa.eu/ECAPublications/SR-2024-15/SR-2024-15_EN.pdf

European Court of Auditors. (2024b). *Common Agricultural Policy Plans Greener, but not matching the EU's ambitions for the climate and the environment. 20*. https://www.eca.europa.eu/ECAPublications/SR-2024-20/SR-2024-20_EN.pdf

European Environment Agency. (2024). *European climate risk assessment*. Publications Office. https://data.europa.eu/doi/10.2800/8671471

European Parliament. (2018, December). *Consolidated text: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018L2001-20240716

European Parliament. (2020, December). *Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance)*. https://eur-lex.europa.eu/eli/dir/2020/2184/oj

European Parliament. (2021a, February). *Consolidated text: Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02021R0241-20240301

European Parliament. (2021b, December). *REGULATION (EU) 2021/2115 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013*. https://eur-lex.europa.eu/eli/reg/2021/2115/oj

European Parliament. (2023a, September). *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance)*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766

European Parliament. (2023b, November). *Commission Delegated Regulation (EU) 2023/2537 of 15 September 2023 amending Delegated Regulation (EU) 2019/856 supplementing Directive 2003/87/EC of the European Parliament and of the Council with regard to the operation of the Innovation Fund*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R2537

European Parliament. (2024, June). *REGULATION (EU) 2024/1787 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 June 2024 on the reduction of methane emissions in the energy sector and amending Regulation (EU) 2019/942 (Text with EEA relevance)*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401787&qid=1737129227586

European Scientific Advisory Board. (n.d.). *About the Advisory Board*. https://climate-advisory-board.europa.eu/about

European Scientific Advisory Board on Climate Change. (2023). *Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050.* Publications Office. https://data.europa.eu/doi/10.2800/609405

European Scientific Advisory Board on Climate Change. (2024). *Towards EU climate neutrality: Progress, policy gaps and opportunities: assessment report 2024*. Publications Office. https://doi.org/10.2800/73564

Hafele, J., Bertram, B., Lannou, L.-A. L., Demitry, N., Korinek, L., & Barth, J. (2023). *The Economic Resilience Index: Assessing the ability of EU economies to thrive in times of change*. ZOE Institute for Future-fit Economies. https://zoe-institut.de/wp-content/uploads/2023/09/Economic_Resilience_Index_Final-1.pdf

IAEA. (2023). *Nuclear Energy in Climate Resilient Power Systems*. International Atomic Energy Agency.

IPCC. (2022). Annex II: Glossary. In Möller, V, J.B.R. Matthews, R. van Diemen, C. Méndez, S. Semenov, J.S. Fuglestvedt, A. Reisinger (Ed.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2897–2930). Cambridge University Press.

Kampa, E. (2022). Policy Framework for Hydropower Mitigation. In P. Rutschmann, E. Kampa, C. Wolter, I. Albayrak, L. David, U. Stoltz, & M. Schletterer (Eds.), *Novel Developments for Sustainable Hydropower* (pp. 1–11). Springer International Publishing. https://doi.org/10.1007/978-3-030-99138-8_1

Kanapiyanova, Zh. (2023). END OF FOSSIL DEPENDENCY – "REPOWEREU" PLAN. *Farabi Journal of Social Sciences*, *9*(2). https://doi.org/10.26577/FJSS.2023.v9.i2.04

Keller, C. (2024, July). *Built close to water – do increasing droughts and hot spells affect nuclear power plants?* Gesellschaft Für Anlagen- Und Reaktorsicherheit (GRS) gGmbH. https://www.grs.de/en/news/built-close-water-do-increasing-droughts-and-hot-spells-affect-nuclear-power-plants#

Kemen G., A., Elsen, P. R., Coronado, E. N. H., DeGemmis, A., Gallego-Sala, A. V., Harris, L., Kretser, H. E., Melton, J. R., Murdiyarso, D., Sasmito, S. D., Swails, E., Wijaya, A., Winton, R. S., & Zarin, D. (2025). Mismatch Between Global Importance of Peatlands and the Extent of Their Protection. *Conservation Letters*, *18*(1), e13080. https://doi.org/10.1111/conl.13080

Köhl, M., Linser, S., Prins, K., & Talarczyk, A. (2021). The EU climate package "Fit for 55"—A double-edged sword for Europeans and their forests and timber industry. *Forest Policy and Economics*, *132*, 102596. https://doi.org/10.1016/j.forpol.2021.102596

Kulovesi, K., & Oberthür, S. (2020). Assessing the EU's 2030 Climate and Energy Policy Framework: Incremental change toward radical transformation? *Review of European, Comparative & International Environmental Law*, *29*(2), 151–166. https://doi.org/10.1111/reel.12358

Kumar, R., Nguyen, T. V., Sarrazin, F. J., Ebeling, P., Schmidt, C., Beusen, A., Bouwman, L., & Fleckenstein, J. H. (2024, January). *Towards realizing the EU 2050 Zero Pollution Vision for Nitrogen Export*. EGU. https://meetingorganizer.copernicus.org/EGU23/EGU23-12024.html

Luise, G. (2024). The European Path to Artificial Intelligence: The Innovation of the 21st Century. *Perspective Politice*, *17*(0). https://doi.org/10.25019/perspol/24.17.0.10

Madiega, T. (2024). *Artificial intelligence act* (PE 698.792; Members' Research Service). European Parliament. https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/698792/EPRS_BRI(2021)698792_EN.pdf

Madrigal, J., Fernández-Migueláñez, I., Hernando, C., Guijarro, M., Vega-Nieva, D. J., & Tolosana, E. (2017). Does forest biomass harvesting for energy reduce fire hazard in the Mediterranean basin? A case study in the Caroig Massif (Eastern Spain). *European Journal of Forest Research*, *136*(1), 13–26. https://doi.org/10.1007/s10342-016-1004-5

Mazzai. (2024, March). *What if AI could save lives? A paradigm shift in weather forecasting*. Foresight. https://www.climateforesight.eu/articles/what-if-ai-could-save-lives-a-paradigm-shift-in-weather-forecasting/

Naran, B., Buchner, B., Price, M., Stout, S., Taylor, M., & Zabeida, D. (2024). *Global Landscape of Climate Finance 2024: Insights for COP29* (Global Landscape of Climate Finance). Climate Policy Institute.

OECD. (2021). *Strengthening adaptation-mitigation linkages for a low-carbon, climate-resilient future* (OECD Environment Policy Papers 23; OECD Environment Policy Papers, Vol. 23). https://doi.org/10.1787/6d79ff6a-en

Parker, J. Busting the top myths about AI and energy efficiency. *Atlantic Council* https://www.atlanticcouncil.org/content-series/global-energy-agenda/busting-the-top-myths-about-ai-and-energy-efficiency/#:~:text=MYTH%3A%20AI%20is%20consuming%20more%20energy%20than%20it%20will%20save.&text=The%20insights%20that%20an%20AI,%2C%20manufacturing%2C%20and%20drug%20discovery (2025).

Peeters, M., & Athanasiadou, N. (2020). The continued effort sharing approach in EU climate law: Binding targets, challenging enforcement? *Review of European, Comparative & International Environmental Law*, *29*(2), 201–211. https://doi.org/10.1111/reel.12356

Petsakos, A., Ciaian, P., Espinosa, M., Perni, A., & Kremmydas, D. (2023). Farm-level impacts of the CAP post-2020 reform: A scenario-based analysis. *Applied Economic Perspectives and Policy*, *45*(2), 1168–1188. https://doi.org/10.1002/aepp.13257

Powering Possible AI and Energy for a Sustainable Future. (2024). ADNOC. https://www.adnoc.ae/en/ai-and-energy-report

Presno, M. J., Landajo, M., & González, P. F. (2021). GHG emissions in the EU-28. A multilevel club convergence study of the Emission Trading System and Effort Sharing Decision mechanisms. *Sustainable Production and Consumption*, *27*, 998–1009. https://doi.org/10.1016/j.spc.2021.02.032

Punch, K. F. (2013). THEORY AND METHOD IN SOCIAL SCIENCE RESEARCH. In *Introduction to Social Research Quantitative and Qualitative Approaches*. Sage.

Rayner, T., & Jordan, A. (2010). Adapting to a changing climate: An emerging European Union policy? In A. Jordan, D. Huitema, H. Van Asselt, T. Rayner, & F. Berkhout (Eds.), *Climate Change Policy in the European Union* (1st ed., pp. 145–166). Cambridge University Press. https://doi.org/10.1017/CBO9781139042772.009

Riahi, K., R. Schaeffer, J. Arango, K. Calvin, C. Guivarch, T. Hasegawa, K. Jiang, E. Kriegler, R. Matthews, G.P. Peters, A. Rao, S. Robertson, A.M. Sebbit, J. Steinberger, M. Tavoni, D.P. van Vuuren, (2022) Mitigation pathways compatible with long-term goals. In IPCC, 2022: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005

Sakız, B., & Gencer, A. H. (2023). *European Union's Green Deal and Sustainable Finance*. 307–316. https://doi.org/10.36880/C15.02773

Schmidt, S., Tan, E., Zeller, Z., Öllerer, B., Bognar, J., Hesselbarth, M., Lessa Derci Augustynczik, A., Kunttu, J., Hurmekoski, E., Menke, I., & di Fulvio, F. (2024, December). *ForestNavigator 2nd Stakeholder-Workshop Report*. https://www.forestnavigator.eu/wp-content/uploads/2nd-Stakeholder-Workshop-September-2024.pdf

Stern, J. P. (2021). *Methane emissions from natural gas and LNG imports: An increasingly urgent issue for the future of gas in Europe* (165; OIES Paper). The Oxford Institute for Energy Studies. https://hdl.handle.net/10419/246568

Streimikiene, D., Mikalauskas, I., Lėckienė, V., Pisula, T., & Mikalauskiene, A. (2024). The role of sustainable finance in the context of the European green course. *Economics & Sociology*, *17*(2), 54–79. https://doi.org/10.14254/2071-789X.2024/17-2/3

Talus, K., Pinto, J., & Gallegos, F. (2024). Realism at the end of the rainbow? An argument towards diversifying hydrogen in EU regulation. *The Journal of World Energy Law & Business*, *17*(4), 217–233. https://doi.org/10.1093/jwelb/jwae007

Taydaş, A. Ö. (2024). REPowerEU as a Crisis Response: Immediate Diversification and Green Transition. *Ekonomi İşletme ve Maliye Araştırmaları Dergisi*, *6*(Özel Sayı 1), 79–86. https://doi.org/10.38009/ekimad.1502909

Thieullent, A., Robey, J., Andrillon, F., Boreel, L., Trier, K., Perrin, J., Vie, P., Buvat, J., Sengupta, A., Nath, S., Khadikar, A., & Khemka, Y. (2021). *Climate AI: How artificial intelligence can power your climate action strategy*. Capgemini Research Institute. https://www.capgemini.com/de-de/wp-content/uploads/sites/5/2020/11/Report_Climate_AI_Capgemini_Research_Institute.pdf

Tzilivakis, J., Warner, D. J., Green, A., & Lewis, K. A. (2017). Spatial and temporal variability of greenhouse gas emissions from rural development land use operations. *Mitigation and Adaptation Strategies for Global Change*, *22*(3), 447–467. https://doi.org/10.1007/s11027-015-9680-x

Weise, Z. (2025, February 12). *Climate change threatens EU's survival, German security report warns*. POLITICO. https://www.politico.eu/article/climate-change-eu-germany-bnd-report-security-global-warming/

Wesseler, J. (2022). The EU 's farm-to-forkstrategy: An assessment from the perspective of agricultural economics. *Applied Economic Perspectives and Policy*, *44*(4), 1826–1843. https://doi.org/10.1002/aepp.13239

World Nuclear Association. (2021, March). *Nuclear Power Plants and Earthquakes*. https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/nuclear-power-plants-and-

earthquakes#:~:text=Nuclear%20facilities%20are%20designed%20so,event%20calculated%20for%20each%20site.

Zachmann, G., Batlle, C., Beaude, F., Morawiecka, M., & Roques, F. (2024). *Unity in power, power in unity: Why the EU needs more integrated electricity markets* (03/24). https://www.bruegel.org/system/files/2024-04/PB%2003%202024.pdf

Zhu, J., Zhao, Y., & Zheng, L. (2024). The Impact of the EU Carbon Border Adjustment Mechanism on China's Exports to the EU. *Energies*, *17*(2), 509. https://doi.org/10.3390/en17020509