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ANALYSIS

Carbon Pricing in the EU and ETS2: Design and Economic Effects

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1 Executive Summary

- The **new EU Emissions Trading System (ETS2)**, scheduled to begin in 2028 for fossil fuels in the buildings/heating and road transport sectors, **has the potential to significantly increase the cost-efficiency of EU climate policy—provided specific institutional requirements are met.** The decisive factor is whether the ETS2 can function as a market-based lead instrument or whether its price signal will be permanently overshadowed by national budgets (Effort Sharing Regulation, ESR) and national, non-market-based measures.
- Measured as a change in welfare (consumption costs; excluding monetized climate damage avoidance), the cumulative economic costs of the current climate policy architecture in the EU for the period 2028–2048 amount to approximately EUR 5,257 billion (equivalent to 2.74% of consumption). **A strong ETS2 can reduce these costs—substantially so, depending on its design**:
    - By approximately EUR 247 billion (–4.7%), if the flexibilization of national CO_2 budgets (increased cross-border adjustment) is achieved, while national mandates and subsidy regimes largely persist.
    - By an additional EUR 824 billion (–20.4%), if the price signal is not additionally hampered by overlapping national, non-market-based measures and flexibility can take effect EU-wide.
- **The economic basis for these efficiency gains lies in overcoming current market fragmentation**. In the status quo, significant price and cost differences exist: while the ETS1 price is projected to rise to approximately EUR 180–200/tCO_2 by the mid-2040s, implicit CO_2 prices (marginal abatement costs) in the ESR sectors already reach an EU average of around EUR 360/tCO_2, accompanied by high country-specific divergence. This gradient signals substantial inefficiencies and highlights the untapped potential to reduce emissions EU-wide via "where-flexibility" where abatement costs are lowest.
- National, non-market-based supplementary measures—such as regulatory standards, technological mandates, or specific subsidy regimes—induce reductions outside the market. While this reduces the demand for emission allowances and thus dampens the price level in the ETS2, it can simultaneously lock in mitigation options with high marginal abatement costs and prevent market-based, more cost-effective adaptation paths. Consequently, **the primary determinant of economic policy costs is not the price level in the ETS2, but rather the steering capacity of the ETS2 price signal.**
- **Distribution and Political Viability:** A strong ETS2 shifts costs and relief between countries. States with previously "soft" ESR budgets (low implicit CO_2 prices) may face higher short-term burdens, while countries with high implicit ESR prices benefit from more affordable EU-wide mitigation options. The more effectively the ETS2 operates as an EU-wide market mechanism (increased cross-border flexibility, less overlap with national policies), the more distributional conflicts diminish over time.

Three areas for action emerge for the further development of EU climate policy:

1. **Institutional Coherence:** Resolving the fragmentation between ETS2 and ESR through flexibility mechanisms or sectoral unbundling. The ETS2 should be developed as an integrative lead instrument rather than an additional layer.
2. **Complementary Policy Mix ("Second-Best" Reality):** The economic superiority of CO_2 pricing does not preclude flanking measures. These should specifically target market barriers (e.g., information deficits, financing hurdles for low-income households) to increase responsiveness to the CO_2 price, rather than replacing the price signal.
3. **Compensation instead of distorting the market:** Distributional conflicts should be resolved through the redistribution of revenues from ETS2 allowance auctions (e.g., Social Climate Fund). Price caps or exemptions should be avoided as they undermine the steering effect; direct compensation secures public acceptance without loss of efficiency.

The **structure of the study** is as follows: **Chapter 2** contextualizes the ETS2 within the framework of EU climate policy and analyzes its interaction with the ETS1 and the Effort Sharing Regulation (ESR). A particular focus is placed on the extent to which national fragmentation and overlapping measures limit the flexibility and cost-effectiveness of the system. **Chapter 3** provides a quantitative assessment of alternative ETS2 scenarios. Using a macroeconomic simulation model, the overall economic efficiency and distributional effects for the EU-27 economies are calculated. This analysis demonstrates the degree to which potential savings depend on overcoming national CO_2 budgets and regulatory overlaps within the ETS2 sectors. Finally, **Chapter 4** derives conclusions for policy design, centering on the balance between a market-based price signal, a complementary policy mix, and a viable redistribution of revenues.

2 EU Climate Policy: Architecture and Flexibility Mechanisms

2.1 Objectives and instruments

Figure 1 illustrates the fundamental logic of EU climate policy. The starting point consists of politically defined reduction targets: a net GHG emissions reduction of at least 55% by 2030 compared to 1990 levels (anchored in the European Climate Law and operationalized through the 'Fit for 55' reform framework). For 2040—based on the current political agreement reached in the EU trilogue in December 2024—a target of at least a 90% reduction compared to 1990 levels is envisaged.[1]

These target marks determine the total amount of emissions still permissible across the EU—the EU-wide 'CO_2/GHG budget.' This budget is translated into temporal emission pathways (annually declining permissible emissions) and operationalized across Member States, sectors,

[1] "Net emissions" refers to GHG emissions minus removals/sequestration by sinks (e.g., land use/LULUCF and, if applicable, technical sinks). Furthermore, current discussions envisage that a limited share (up to 5%) of the target achievement may be realized through certified emission reductions outside the EU ('carbon credits'); these would then substitute for corresponding domestic EU reductions.

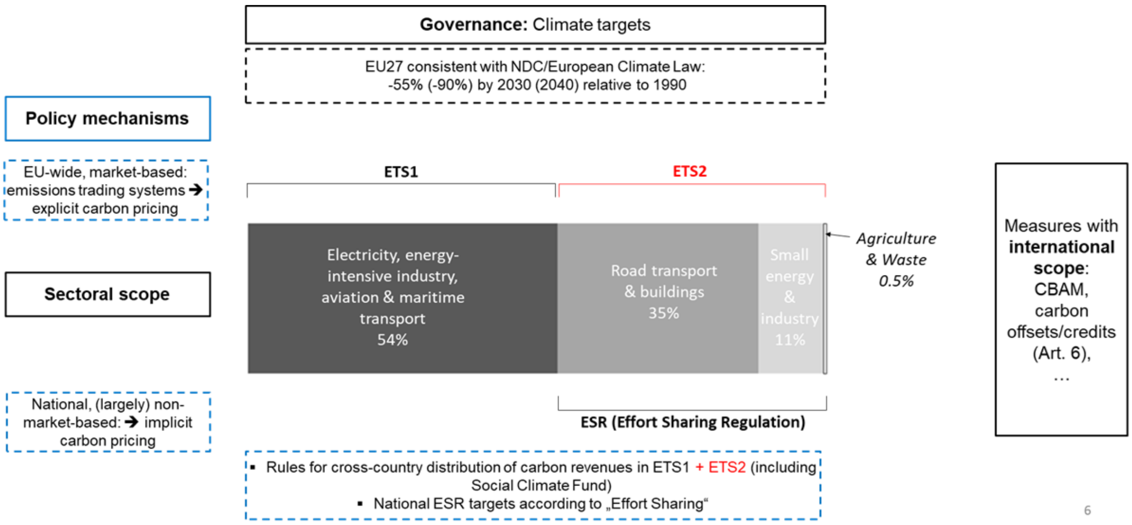

Figure 1: Overview of the key components of EU climate policy

Notes: Own representation based on relevant EU legislation. The percentages in brackets refer to the respective share of total EU27 CO2 emissions in 2024.

and instruments. This is precisely where the architecture shown in Figure 1 comes into play: The EU steers target achievement through an interplay of EU-wide mechanisms and national obligations, which step-by-step 'break down' the overall budget, thereby transforming politically set targets into verifiable rules and compliance requirements.

Figure 1 illustrates the central policy mechanisms that coexist or interlock in practice.

EU ETS (ETS1): Established in 2005, the ETS1 covers power and heat generation, energy-intensive industry, and aviation, accounting for approximately 40% of EU GHG emissions (and 54% of CO_2 emissions). Emission allowances (EU Allowances; EUAs) entitle regulated companies to emit a specific amount of CO_2. EUAs are predominantly auctioned; a portion continues to be allocated for free to certain companies.[2] Allowances are tradable: the EUA price reflects supply and demand, thereby establishing a variable, EU-wide uniform CO_2 price for the sectors covered by the ETS1 via a market mechanism. Through several structural reforms across four trading phases, the ETS1 has matured significantly and is today considered an effective instrument for CO_2 pricing.[3]

Effort Sharing Regulation (ESR): For the remaining sectors not covered by the ETS1 (including buildings, road transport, agriculture, and waste), binding national emissions budgets exist. These ESR emissions account for nearly 60% of domestic EU emissions. Annual Emission Allocations (AEAs) are established for each Member State, which are to be progressively reduced

[2] These free allocations accounted for approximately 42% of total verified emissions in 2024.

[3] Since 2005, covered emissions have fallen by around 51% across the EU and by around 47% in Germany; the EU-wide ETS1 reduction target of minus 62% by 2030 is therefore within reach.

until 2030.[4]

How Member States achieve their targets (regulatory law, subsidy programs, taxes/pricing) remains a national decision. Most EU Member States rely primarily on non-market-based instruments; in such cases, an explicit, market-determined CO_2 price is not visible, but instead emerges only indirectly ("implicitly") from target fulfilment. Since 2021, Germany has been using a market-based instrument for this purpose with its national fuel emissions trading system. Furthermore, the ESR contains a series of flexibility provisions.[5]

ETS2: The new emissions trading system for fuels in buildings and road transport (as well as emissions from smaller energy and industrial plants not covered by the existing ETS1) is scheduled to launch in 2028. It covers CO_2 emissions (but not other GHGs) and is organized "upstream": fuel suppliers, rather than end-consumers such as households or motorists, are obligated to surrender sufficient allowances. By passing on the CO_2 costs to end-consumers, the ETS2 acts as an explicit, EU-wide CO_2 price in these sectors. There will be no free allocation for the ETS2; i.e., all allowances will be distributed via auctions.

Additional international measures, such as the Carbon Border Adjustment Mechanism (CBAM) and the accounting of international credits, are mentioned here only marginally, as the focus lies on CO_2 pricing and the distributional logic within the EU (ETS1/ETS2/ESR). CBAM is intended to limit carbon leakage for certain CO_2-intensive imported goods (e.g., cement, steel, aluminum, fertilizers, electricity) by imposing a charge on embedded emissions since January 2026, based on the ETS1 CO_2 price. Concurrently, the political agreement on the 2040 climate target provides that a limited portion of target achievement may occur via "high-quality" international credits (Paris Agreement, Art. 6)—starting in 2036 and amounting to up to 5% of the EU's 1990 net emissions.

2.2 Rules for the redistribution of CO_2 revenues to EU member states

EU climate policy is not defined solely by the choice of instruments and target levels; equally central are distributional and financial rules (see Figure 1; bottom box), which determine how many emission rights are allocated to Member States and how revenues from CO_2 pricing (ETS1 and, in the future, ETS2) are distributed between the EU and Member States or flow back to individual countries.

[4] To achieve a "fair and just EU climate policy," all Member States contribute to the achievement of the EU-wide target. Member States with a higher GDP per capita generally have higher emission reduction targets, but cost-effectiveness considerations are also taken into account to avoid relatively high costs for some Member States. The targets for Member States range from 10% to 50% compared to their 2005 emissions.

[5] In years where emissions are below their AEA, Member States can bank surpluses (within certain limits) and use them in later years. In years where emissions exceed the annual ceiling, Member States can borrow a limited amount of AEAs from the following year. Since 2013, it has also been possible for Member States to buy and sell AEAs from/to other Member States; there are no fixed regulatory restrictions on cross-border trading of AEAs.

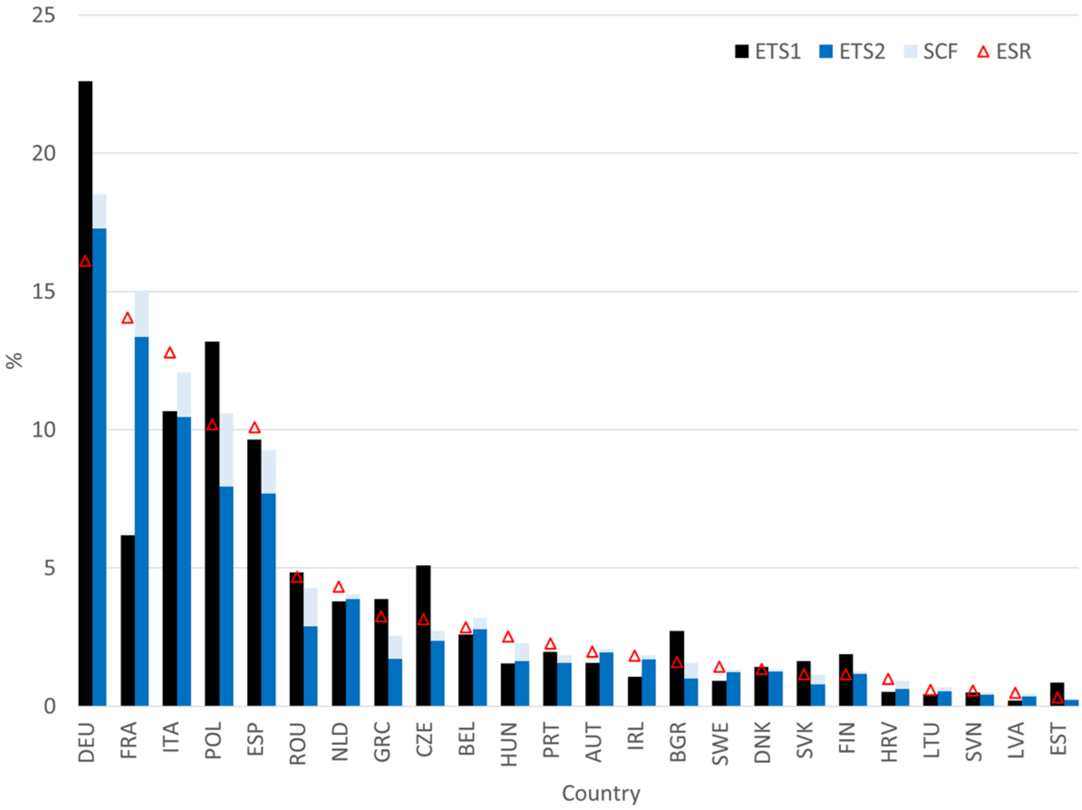

Figure 2: Revenue shares by EU member state from CO2 pricing (ETS1, ETS2) including SCF and national CO2 budget shares in the ESA

Notes: Own calculations based on relevant EU legislation. The calculation of revenue shares for ETS2 and SCF assumes that SCF does not account for more than 15% of a country's revenue from ETS2 and SCF. ESR shows for each country the CO_2 budget allocated under the EU Effort Sharing Regulation for ESR emissions as a share of the EU-wide ESR budget.

EU ETS (ETS1): The redistribution to Member States is essentially governed by which Member State is permitted to auction how many allowances and by the fact that auction proceeds generally accrue to national budgets. Auction volumes are distributed according to a combined principle of "polluter pays" ("those who previously emitted more receive more auction volume") and solidarity criteria (acceptance and investment capacity, particularly in lower-income countries): 90% are distributed among all Member States based on their share of historical verified ETS1 emissions (2005 or the average of 2005–2007, whichever is higher); 10% are redistributed to specific Member States as a solidarity component.

ETS2: In this system, redistribution is explicitly geared more toward social acceptance and targeted relief. First, a portion of the ETS2 volumes is set aside EU-wide for the **Social Climate**

Fund (SCF). [6] The distribution of the SCF among Member States follows a formula that combines exposure or need (population, risk of poverty in rural areas, household emissions, and energy poverty risk of households) with an explicit income progression (weighting according to national per capita income and adjustment relative to the EU average income). Second, the remaining ETS2 auction volumes are auctioned by the Member States and distributed among them based on their share of reference emissions according to the effort-sharing logic. The decisive factors here are reference emissions (average of 2016–2018) in road transport, buildings, and household emissions, which thus reflect the intended impact zone of the ETS2.

Figure 2 illustrates the revenue shares from CO_2 pricing in the ETS1 and ETS2 (including redistribution via the Social Climate Fund, SCF), as well as the allocation of the EU-wide ESR target among the individual Member States. In accordance with the redistribution logic of ETS1 and ETS2, this representation simultaneously reflects how emissions and market volumes are distributed across the respective regulatory segments in the Member States. The ESR effort-sharing is fundamentally oriented toward economic capacity: Member States with a lower GDP per capita generally receive less stringent reduction targets and thus larger CO_2 budgets (e.g., POL, ROU, GRC). At the same time, the distribution of burdens also reflects varying emission levels—large countries with higher emissions therefore possess a correspondingly larger CO_2 budget (e.g., DEU, FRA, ITA). Overall, the SCF is expected to have only a limited direct impact, as its share of financing is small compared to total revenues.

With the exception of the SCF, the volume of which is capped in absolute billion-euro amounts, the revenue shares from ETS1 and ETS2 for the Member States are independent of the respective CO_2 price level. The distribution of revenues is thus structurally 'locked in' within the regulatory framework and remains valid for future years (at least until 2030 and provided no political readjustment occurs); consequently, it will significantly influence how the future burdens of CO_2 pricing in the EU are distributed among the Member States.

3 The Status Quo: An Assessment

3.1 Market-based climate protection and flexibility

Emissions trading, as a market-based instrument for climate protection, unfolds its economic advantage when emissions are avoided where it is most cost-effective to do so ("where-flexibility"). This requires trade and a market that is as broad and permeable as possible. Under these conditions, a CO_2 price ensures that mitigation efforts across sectors and countries are guided by the lowest marginal abatement costs. In the EU, however, this flexibility is limited by fragmentation and overlap (as is already partially evident from Figure 1).

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[6] In addition to the fixed 150 million ETS2 allowances (the auction proceeds of which will flow entirely into the SCF until 2032), the ETS Directive provides that the Commission shall have an additional, variable quantity of ETS2 allowances from the remaining ETS2 volume auctioned such that—together with the proceeds from (i) the 150 million ETS2 allowances and (ii) the 50 million ETS1 allowances (transitional financing)—a maximum EU financing framework of EUR 65 billion is available for the SCF. This "additional quantity" is not defined as a fixed number because it depends on the allowance price: if the price is lower, more allowances are needed to reach the same Euro amount; if it is higher, correspondingly fewer are required.

3.1.1 Fragmentation between ETS1, ESR, and ETS2

ETS1 vs. Non-ETS1: CO_2 pricing is institutionally separated into the ETS1 and the non-ETS1 sectors (ESR/ETS2). Although specific "bridges" exist, they are strictly limited and have hardly been utilized to date. [7] With the introduction of the ETS2, two separate ETS systems (ETS1 and ETS2) will coexist; a clear mechanism for linkage or a timetable for future integration is currently not discernible.

Fragmentation within the ESR between countries: The ESR "hardwires" the EU-wide budget into national budgets (AEAs). This creates country-specific scarcities—and thus implicit, significantly diverging CO_2 "shadow prices" between Member States.

Virtually no trade in AEAs: Although AEA transfers between Member States have been possible since 2013, a liquid market does not exist de facto.[8] One reason is institutional: the actors are exclusively governments, while private market participants are excluded; furthermore, there is no trading or information platform, meaning that transactions must be organized bilaterally if needed.

Overallocation/lack of scarcity in parts of the ESR: Historically, the allocated AEAs in many countries exceeded verified emissions.[3] This indicates a partial overallocation of national budgets and, consequently, untapped efficiency gains. As a result, countries with generous ESR CO_2 budgets (e.g., Romania, Bulgaria, Greece, Portugal, or Spain) partly achieve their targets without additional measures, while more emissions are avoided across the EU than necessary.[9]

3.1.2 Overlap between ESR and ETS2

The ETS2 regulates emissions that simultaneously continue to play a role within the ESR framework (national budgets and responsibility). **Figure 1** shows that for energy-related CO_2 emissions, the coverage is almost complete: ETS2 corresponds to approximately 98.6% of ESR emissions. This implies an effective double regulation of ETS2 emissions; an entity causing emissions subject to the ETS2 must also comply with the same emissions under the ESR. The EU-wide ETS2, with a largely identical emissions coverage, is superimposed on a system of binding national ESR targets—and must therefore operate within an already existing, nationally anchored logic of targets and responsibility.

At the same time, it has not yet been regulated how the ETS2 and ESR should interact within this overlap. However, the ETS2 is not merely "another CO_2 price," but an intervention into an existing effort-sharing logic—with potential interactions regarding costs, distribution, and effectiveness that are central to the assessment of the instrument.

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[7] Under the ESR, nine Member States (Belgium, Denmark, Ireland, Luxembourg, Malta, the Netherlands, Austria, Finland, and Sweden) were permitted to use limited quantities of ETS1 allowances (approx. 4–7%, depending on the country) for ESR target compliance.

[8] Between 2013 and 2023, AEA transfers took place only between a few countries. Measured against the total ESR budget, the traded volume in each year amounted to less than 0.2%

[9] The same EU-wide emission reduction would then be possible with more cost-effective effort-sharing (e.g., fewer mitigation efforts in DEU, more in countries with overallocation).

3.2 National climate policy in interaction with the ETS2

In today's ESR sectors of buildings/heating and road transport, a broad national policy mix of non-market-based instruments already exists in all EU-27 countries. [10] These national measures can be roughly divided into three types that interact directly with the ETS2 price signal.

First: regulatory technology exclusions or phase-outs, which remove fossil options from the menu of choices or permit them only under specific conditions.[2] Such rules do not render the CO_2 price signal obsolete, but they limit its role: the price can then primarily influence residual consumption, frequency of use, or timing—no longer the fundamental choice between "fossil vs. fossil-free." Second: performance and minimum standards, i.e., mandatory efficiency/emission requirements (heating technology, vehicles), which force investment even when the CO_2 price is (still) low.[3] Due to these measures, the technology shift (electric vehicles, electric heat pumps) is at least partially predetermined. For example, in the transport sector, the impact of the ETS2 price signal shifts more strongly toward mileage, the composition and renewal of the existing fleet, and the (partial) fuel mix. Third: fiscal incentives such as investment grants, premiums, tax bonuses, or low-interest loans. They address real transformation barriers (liquidity, credit restrictions, split incentives in the rental market) but—if not clearly targeted at additional emission reductions—can also lead to deadweight effects and the inefficient use of funds.

In summary: through this mix of bans/phase-outs, standards, and subsidy frameworks, the transformation path in the ETS2 sectors is already partially predetermined in many EU countries, even regardless of a CO_2 price signal. The ETS2 price therefore frequently encounters markets where central technology decisions are politically (co-)steered. This has two consequences. First, shift in price response: Part of the reaction to the CO_2 price becomes a matter of timing and residual consumption rather than fundamental technology selection. In transport, for instance, the price signal effect of the ETS2 shifts more toward mileage, the composition and renewal of the existing fleet, and—only to a limited extent—the fuel mix. Second, reduction of "where-flexibility": Binding national requirements reduce the "where-flexibility" of cost-effective CO_2 avoidance. If specific technologies or efficiency levels are prescribed regardless of the price, emission reductions can occur less freely where they would be most cost-effective in the short term. This increases the risk of measures overlapping (or becoming unnecessarily expensive)—and the questions of coherence, efficiency, and policy conflicts between the European ETS2 and national regulatory law become all the more critical.

3.3 ETS2: From price signal to cost-effective climate protection

For the first time, the ETS2 establishes an EU-wide uniform, explicit CO_2 price signal in the buildings and road transport sectors. However, whether this actually results in additional emission reductions and efficiency gains depends less on the price signal itself than on the extent

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[10] These measures are officially reported by Member States as Policies and Measures (PaMs), see "*European Environment Agency Database on Integrated National Climate and Energy Policies and Measures in Europe*," and include implemented, adopted, and planned instruments, including sector allocation and instrument type. See also Figure 10 in the appendix.

to which this signal effectively "breaks through" within the existing policy mix—that is, the degree to which scarcity and flexibility can truly operate within the overall system. As described in Section 2.3, two factors particularly limit this effect: (1) national CO_2 budgets under the ESR (which remain binding) and (2) a dense array of national, non-market-based instruments (standards, bans/phase-outs, subsidy frameworks), which partially predetermine technology decisions regardless of price and thus restrict price-driven responsiveness ("where-flexibility").

Risk of a "Weak ETS2": The impact of the ETS2 remains limited if (i) the overlap with the ESR leads to scarcity being organized primarily through national ESR target fulfillment rather than the ETS2 market, and if (ii) national mandates and subsidy regimes in the ETS2 sectors are so binding that the CO_2 price primarily steers residual consumption, usage, and timing, but not core technology and investment decisions. In this constellation, the ETS2 is indeed an additional explicit price, but its steering effect remains limited—and in political perception, it may easily function more like a levy than a mechanism that systematically directs mitigation to where it is most cost-effective. Furthermore, the ETS2 does little to improve the cost-efficient distribution of burdens between countries: national target pathways remain the dominant "anchor," and an improvement in cost-effectiveness would thus be only limited. Additionally, (partial) overallocation for some countries in the ESR (in combination with complete overlap) could favor low ETS2 prices in the early years, because the ETS2 would then add no new scarcity "on top."

Prerequisites for a "Strong ETS2": A strong ETS2 therefore requires not only more flexibility between countries but also more room for price steering within the sectors themselves. This means: (i) the ESR obligation in the overlapping area must be scaled back or, in perspective, decoupled (or flexibilities such as AEA trading must be used in such a way that national budgets no longer "cement" abatement). The more consistent (and, from an efficiency standpoint, clearest) perspective would be to end double regulation in the medium term—i.e., to regulate ETS2 emissions entirely outside the ESR. And (ii) national, non-market-based instruments should be reduced or restructured so that they do not displace the ETS2 price signal but give it space (e.g., fewer rigid technology mandates as "permanent anchors," fewer broad-based subsidies without additionality). Only when the ETS2 is not simultaneously "squeezed" by national budgets and binding national technology pathways can its market-based steering through prices fulfill its potential.

Integration represents the efficiency endpoint—yet not necessarily the initial stage: From an efficiency standpoint, the long-term point of convergence would be a harmonized EU-wide CO_2 price (integrating ETS1 and ETS2). Under such a framework, emissions would be systematically mitigated where costs are lowest across all EU sectors. In practice, however, compelling political-economic rationale exists for accepting current fragmentation, at least temporarily during the inception phase. Marginal abatement costs in the buildings and transport sectors are frequently higher than those in the ETS1; consequently, rapid integration could lead to a significant escalation of costs and prices within the ETS1.[11]

[11] Furthermore, it appears not unrealistic that sectoral differentiation will persist in the EU even in the future—for instance, due to a continued lack of CO_2 pricing or a separate 'ETS3' for the agricultural sector.

4 Quantitative Estimates

In the following, the economic effects of different design options for CO_2 pricing in the EU are quantified and compared based on defined policy scenarios. These scenarios reflect the central rules of EU legal acts—in particular, quantity pathways and coverage (ETS1/ETS2), national effort-sharing within the framework of the ESR (allocation of national budgets), the relevant redistribution and revenue rules in the ETS1 and, prospectively, the ETS2 (see **Figure 2**), as well as non-market-based climate policy measures in the ETS2 sectors of buildings/heating and road transport.

The focus is placed on the following aspects:

- What macroeconomic burdens arise under alternative policy scenarios? How large are the efficiency gains resulting from a strong ETS2?
- What market prices and implicit abatement costs for CO_2 emissions emerge under different design options for European CO_2 pricing (ETS1 vs. ESR vs. ETS2)?
- At least as crucial for the acceptance and political viability of a market-based EU climate policy are the potential distributional effects between Member States resulting from the introduction of the ETS2.

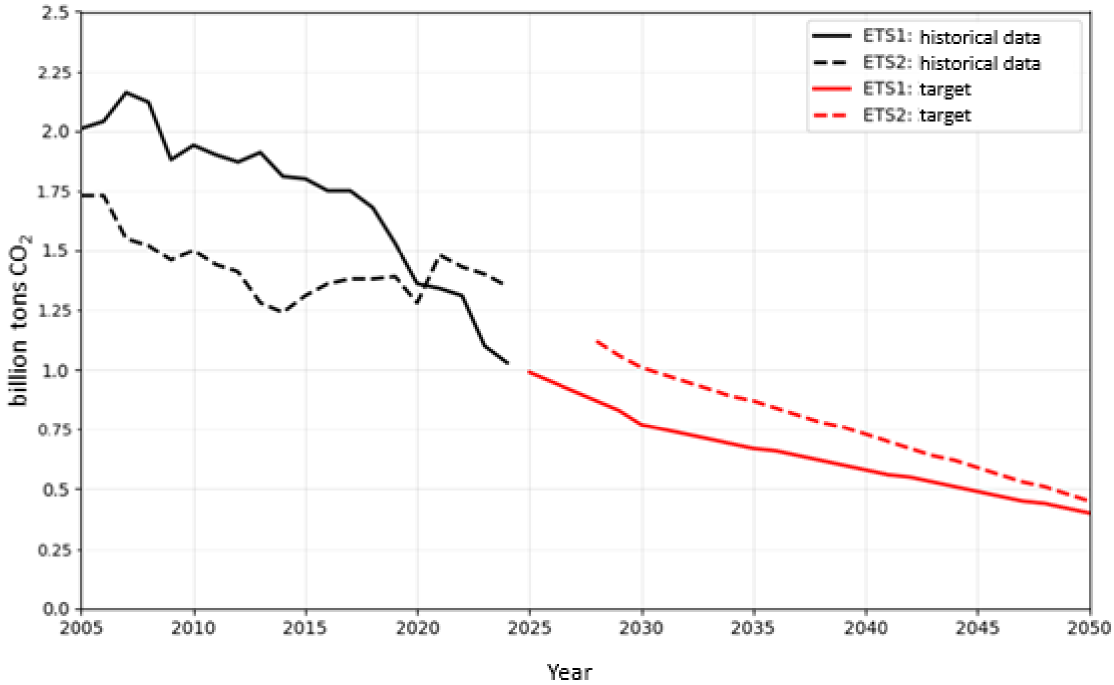

Figure 3: CO_2 emissions in ETS1 and ETS2: Historical development and target paths

4.1 Policy scenarios and methodological approach

Five scenarios are analyzed:

- *No Climate Policy*: A counterfactual benchmark without climate policy—i.e., without explicit or implicit CO_2 pricing, without national ESR emission restrictions (neither directly nor indirectly through national non-market-based measures in buildings/heating and road transport), and without ETS2.
- *Business-as-Usual/weak ETS2:* The status quo of the current EU architecture with ETS1, national ESR targets, and national non-market-based measures in buildings/heating and road transport. This scenario can also be interpreted as ETS1 with a 'weak ETS2': while formally introduced, the ETS2 creates little additional cross-border flexibility because binding national ESR targets persist, no relevant AEA trading occurs to alleviate high abatement costs, and national non-market-based measures further restrict responsiveness to the CO_2 price signal.
- *Strong ETS2, with national measures:* Here, the ETS2 unfolds its intended function as an EU-wide market mechanism—either through greater use of flexibility/AEA trading within the ESR, ensuring that mitigation occurs cross-border where it is most cost-effective, or through institutional decoupling of the ETS2 and ESR, such that ETS2 emissions are no longer 'bound' by national ESR budgets. National non-market-based measures in buildings/heating and road transport remain in place.
- *Strong ETS2, without national measures:* As in the previous scenario; however, national non-market-based measures in buildings/heating and road transport are removed, allowing the CO_2 price signal to operate more freely and further increasing system flexibility.[12]
- *Uniform EU-wide CO_2 price:* A hypothetical long-term perspective involving the full integration of ETS1 and ETS2 into a common EU-wide emissions market (without further national measures).

All climate policy scenarios are based on the same reduction pathways for emissions in the ETS1 and ETS2. These are illustrated in **Figure 3**.[13]

For the quantitative assessments, a newly developed dynamic, empirically calibrated macroeconomic general equilibrium model is utilized. It represents the EU-27 economies as a system of interconnected goods and factor markets, ensuring that production, consumption, and trade decisions, as well as prices and income, are determined consistently from a macroeconomic perspective for each period. The value added compared to partial analyses is

[12] "Without national measures" here refers specifically to the dismantling or restructuring of redundant measures that administratively determine quantities or technologies; complementary measures to address specific market barriers (e.g., financing, information, infrastructure) are conceptually distinct.

[13] The underlying target pathways are based on the projections reported by Member States in 2025: 'with existing measures' (WEM) and 'with additional measures' (WAM). These projections are reported to the EU Commission every two years in accordance with Article 18 of the Governance Regulation.

that climate policy does not only act 'in the energy sector' but influences the entire economy through changes in prices and income as well as sectoral reallocation. The model simulates transformation pathways up to 2050, capturing the EU CO_2 pricing architecture (ETS1/ETS2/ESR), redistribution rules, and non-market-based national measures in the ETS2 sectors. It provides endogenous CO_2 prices, revenues, and effects on welfare, prices, output, and distribution (including between countries). Further details on the model are documented in the appendix.

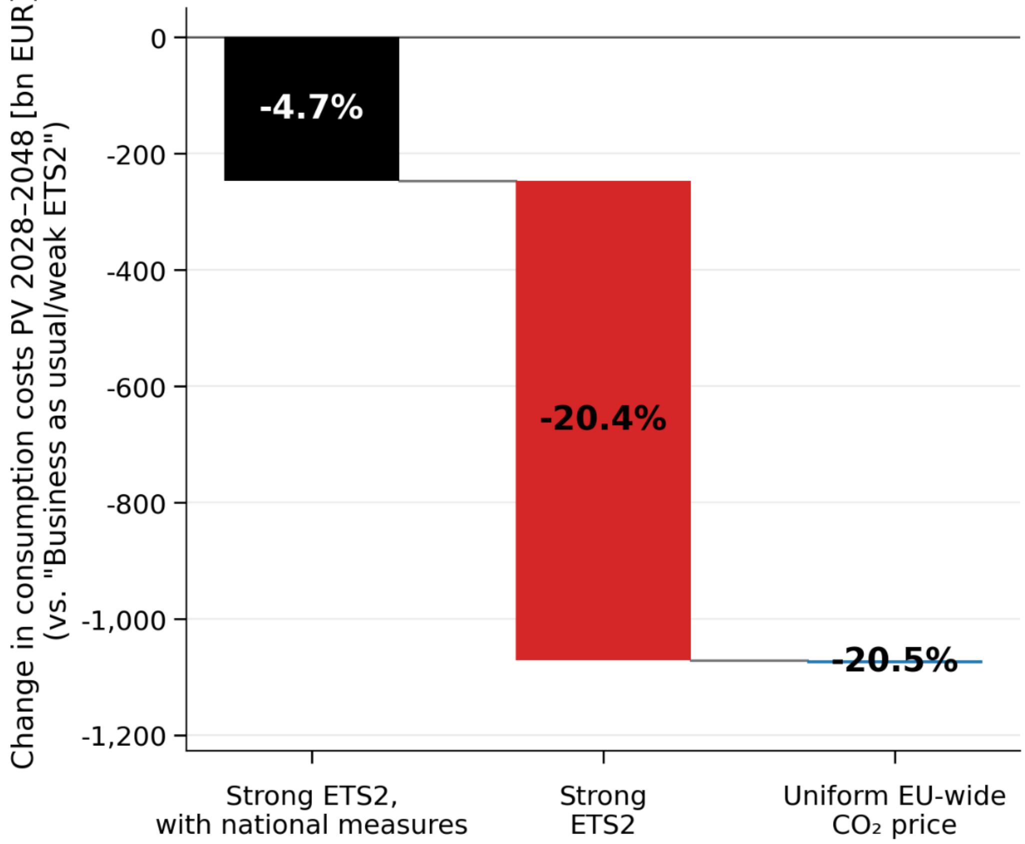

Figure 4: Policy cost reduction (EU-27) through ETS2 and EU-wide CO_2 price harmonization

Notes: Own calculations based on the macroeconomic simulation model. PV: Present value of the change in cumulative consumption costs 2028–2048. Assumption: Discount rate 1.5% p.a. All changes are relative to the "business as usual/weak ETS2" scenario.

4.2 Macroeconomic cost (EU-27) and efficiency gains of introducing ETS2

What macroeconomic costs and efficiency gains relative to the status quo result from the introduction of the ETS2? This chapter focuses on macroeconomic costs, represented by aggregate welfare effects for the EU-27 under identical target achievement. Welfare is measured as the Hicksian equivalent variation of income. This metric captures the direct economic costs of climate policy but excludes monetized benefits from avoided climate damage or other positive externalities (e.g., improved air quality) associated with the reduction of fossil fuel use.

Efficiency potential through overcoming fragmentation. The analysis clarifies: Compared to the current EU climate policy architecture—either a "business-as-usual" (BAU) scenario without ETS2 or a "weak ETS2" rendered ineffective by fragmentation—a "strong ETS2" enables substantial efficiency gains. However, efficiency gains through the ETS2 are not a foregone conclusion. They necessitate overcoming both regulatory fragmentation and the rigid national mix of regulatory and subsidy policies. Figure 4 visualizes these effects as a reduction in policy costs (present value of cumulative consumption costs 2028–2048) relative to the reference scenario.

- *Lever 1: Flexibilization of ESR budgets.* Improved EU-wide usability of national CO_2 budgets (Annual Emission Allocations, AEAs)—for instance, through increased trading or an effective decoupling of the ETS2 from ESR obligations—reduces policy costs by 4.7% ("Strong ETS2 with national measures").

	Relative to *„No Climate Policy"*		Relative to *„Business-as-Usual / Weak ETS2"*			
	Business-as-Usual / Weak ETS2		*Strong ETS2, with National Measures*		*Strong ETS2*	
	%	billion EUR	billion EUR	%	billion EUR	%
2028	-1.0	-93	15	15.8	26	27.3
2033	-1.8	-175	14	8.0	39	22.1
2038	-2.6	-279	13	4.6	58	20.8
2043	-3.6	-406	13	3.2	82	20.1
2048	-4.8	-590	14	2.4	105	17.8
PV 2028-2048[a]		-5.257	247	4.7	824	20.4

Table 1: Overall economic welfare effects (EU-27) of various designs of the ETS2 and EU climate policy

Notes: Own calculations based on the macroeconomic simulation model. The figure shows the change in welfare, measured as Hicksian income equivalence variation, relative to the "no climate policy" scenario and the "business as usual/weak ETS2" scenario. The welfare measure only captures direct economic costs and does not include monetized costs or benefits of avoided climate damage or other externalities associated with the use of fossil fuels.
[a]: Present value of the change in cumulative consumption costs 2028-2048. Assumption: discount rate 1.5% p.a.

- *Lever 2: Removal of non-market-based barriers.* The pivotal finding, however, is that national standards, bans, and subsidy frameworks massively restrict the impact of the ETS2 price signal. Only in the "Strong ETS2 without national measures" scenario do efficiency gains increase significantly: cumulative policy costs decrease by 20.4%. Consequently, a strong ETS2 realizes nearly the entire potential of the theoretical benchmark of a uniform, EU-wide CO_2 price. It prevents the system from being "squeezed" between rigid ESR mandates and national, non-market-based climate policy measures, thereby utilizing previously untapped "where-flexibility."

Absolute cost savings over time. Table 1 substantiates these percentages with absolute figures. The economic costs of the current EU climate policy architecture ("Business-as-usual/weak ETS2") amount to a cumulative total of EUR 5,257 billion for the 2028–2048 period. A strong ETS2 combined with persistent national measures reduces this burden by EUR 247 billion. A strong ETS2 without such constraints, however, generates savings of EUR 824 billion. The dynamics become especially apparent over time: while savings in the scenario with national measures remain moderate, they escalate significantly in the absence of these barriers—rising from a surplus of EUR 26 billion in 2028 to as much as EUR 105 billion by 2048 (relative to the reference scenario).

This highlights that CO_2 pricing, as a market-based instrument for climate protection, leverages its advantages most effectively in the context of ambitious reduction targets. As targets become more stringent, marginal abatement costs increase—making the market's capacity to identify the most cost-efficient mitigation options across sectors and countries through the ETS2

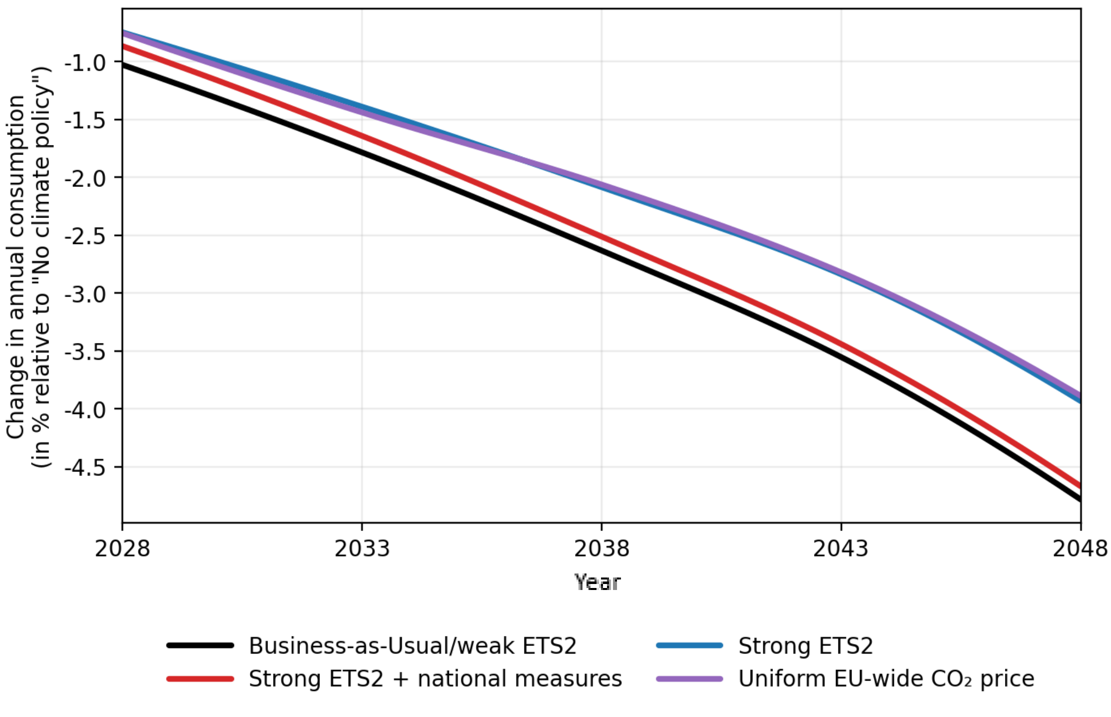

Figure 5: Macroeconomic welfare effects (EU-27) of different designs of the ETS2 and EU climate policy

Notes: Own calculations based on the macroeconomic simulation model. The figure shows the change in welfare, measured as Hicksian equivalence variation in income, relative to the "no climate policy" scenario.

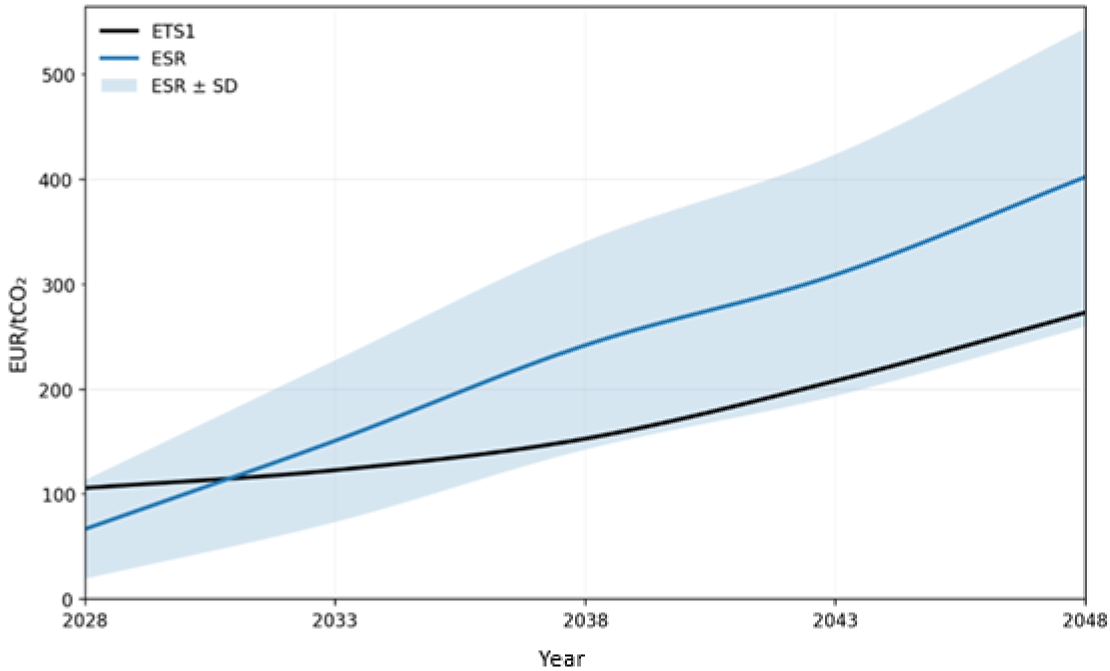

Figure 6: CO_2 prices in ETS1 and ESR (average) in the *"business as usual/weak ETS2"* scenario

Notes: Own calculations based on the macroeconomic simulation model. ESR:EU27-country average of implicit ESR prices. ESR±SD: EU-27-country average plus minus standard deviation.

increasingly vital.

Contextualizing Cost Savings through the ETS2. Figure 5 demonstrates that the ETS2 does not necessarily lead to additional macroeconomic burdens. It illustrates the welfare effects compared to a scenario without any climate policy. It becomes evident that a properly designed ETS2 makes the achievement of climate targets more cost-effective than the current architecture. The decisive lever is the scaling back of national, non-market-based measures and the overcoming of national CO_2 budgets within the ESR in favor of an undistorted ETS2 price signal, which can then function as the central steering instrument.

4.3 Explicit and implicit CO_2 prices: price trends and potential for harmonization

While the preceding analysis focuses on costs at the aggregate EU-27 level, this section elucidates price dynamics and steering signals. The efficiency gains of a reform depend significantly on how successfully the current price fragmentation between sectors and Member States is overcome.

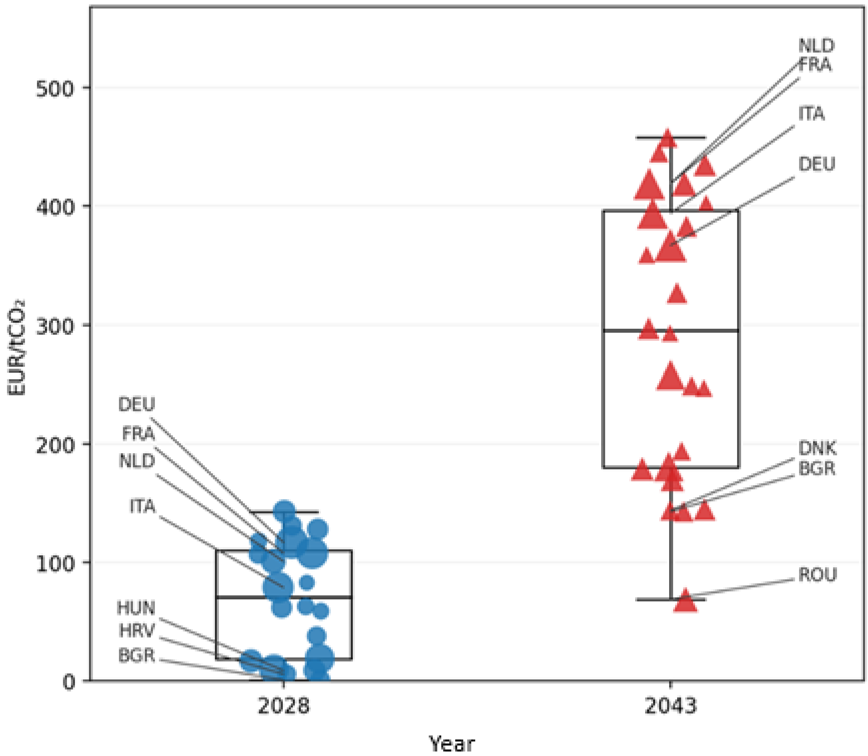

Figure 7: Implicit CO2 prices (marginal abatement costs) in the ESA according to EU-27 country for 2028 and 2043 in the *"business as usual/weak ETS2"* scenario

Notes: Own calculations based on the macroeconomic simulation model. The size of the circles (triangles) indicates the share of CO_2 emissions in a country's ESA in 2028 (2043).

The price gap between ETS1 and ESR. The baseline in the current architecture ("Business-as-usual / Weak ETS2") is characterized by a pronounced price gradient. Figure 6 shows that the explicit CO_2 price in the ETS1 (black line) rises to nearly 180–200 EUR/tCO_2 by 2045, while the average implicit CO_2 prices in the ESR sectors (buildings/heating and road transport)—i.e., the shadow prices or marginal abatement costs for compliance with national budgets—increase to approximately 360 EUR/tCO_2.[14] This price gap is an indicator of inefficiency: with a uniform price signal, part of the avoidance would shift to where it is cheaper. Instead, high marginal avoidance costs remain in the ESR sectors, while more cost-effective options in the ETS1 area are not fully utilized.

National Fragmentation of Abatement Costs. The EU average of ESR shadow prices conceals a significant national dispersion. **Figure 7** illustrates the implicit ESR CO_2 prices per Member State for 2028 and 2043; the symbol size indicates which countries carry particular weight in EU ESR emissions.

[14] ESR prices are implicit prices—they are not observable market prices but rather measure the marginal abatement costs required for each country to comply with its respective national ESR emissions budget.

In the absence of significant trading in Annual Emission Allocations (AEAs), the ESR thus leads to highly divergent marginal abatement costs—and blocks "where-flexibility" between countries: climate protection does not take place where it is most cost-effective EU-wide, but where national budgets and national policy mixes dictate it. The country-specific spread of marginal abatement costs results primarily from the varying stringency of national ESR targets (allocation of AEAs) as well as structural differences in the CO_2 intensity of energy mixes.

Factors such as the baseline level of fossil fuels and the composition of the electricity mix lead to diverging costs for achieving climate targets among Member States. Some countries (e.g., Romania, Bulgaria, Greece, Hungary, Poland) exhibit relatively low implicit prices—due, in part, to comparatively generous ESR CO_2 budgets—while countries such as Germany, France, and Italy (with relatively high per capita income and a tendency toward stricter ESR targets) show significantly higher implicit prices. A comparison between 2028 and 2043 indicates that as policy stringency increases, implicit CO_2 prices rise.

ETS2 as a Harmonization Instrument – and the "Price-Efficiency Trap". The introduction of the ETS2 is the central instrument for establishing a uniform EU-wide price signal in the previously fragmented sectors of buildings and transport. **Figure 8** compares CO_2 price pathways under different policy designs. In the "Strong ETS2" scenario (without restrictive national measures), the modeled allowance price starts at approximately 78 EUR/tCO_2 in 2028 and rises to about 360 EUR/tCO_2 by 2045. It becomes clear that prices between the ETS1 and ETS2 diverge significantly—creating two separate CO_2 markets with distinct scarcities. The long-term benchmark of a "Uniform EU-wide CO_2 Price" further illustrates that under full sectoral integration, an overall lower price pathway would suffice, as mitigation efforts could be systematically shifted to the most cost-effective options EU-wide.

A crucial finding from **Figure 8** concerns the interaction between the ETS2 and national, non-market-based measures. It is shown that the ETS2 price in the "Strong ETS2 + national measures" scenario is noticeably below the level of the scenario without these measures. This can be explained economically as follows. Dampening effect on the market price: National standards, bans (phase-outs), and subsidy regimes already force technological adjustments and emission reductions. This reduces the residual demand for ETS2 allowances, causing the market price to fall. This results in a politically relevant *"price-efficiency trap":* a lower ETS2 allowance price is not a signal of higher climate policy efficiency. On the contrary, the results from Section 3.2 (Figure 4) demonstrate that the macroeconomic efficiency gains in the scenario with national measures significantly lag behind those of the scenario without such measures.[15]

The reason for this discrepancy lies in the lack of flexibility: while non-market-based measures reduce the visible allowance price, they often regulatorily lock in more expensive abatement options and displace price-driven, more cost-effective adjustments. A 'strong ETS2' with

[15] A low ETS2 price can reflect both efficiency and (in the case of binding, price-independent targets) an overlay of the price signal; the decisive factor is whether accompanying measures remove market barriers or administratively determine volumes/technologies.

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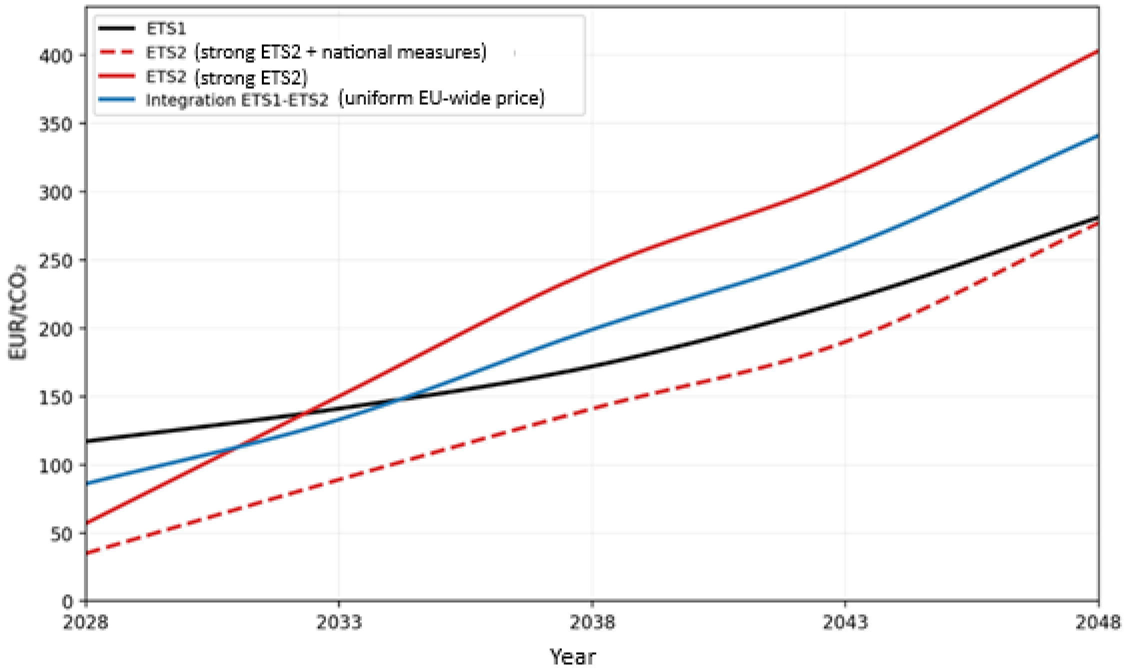


Figure 8: EU CO_2 prices for different configurations of ETS2 and EU climate policy

Notes: Own calculations based on the macroeconomic simulation model.

undistorted price steering thus delivers a higher explicit price but realizes the greatest welfare gains, as it effectively harmonizes marginal abatement costs across the EU.

While Figures 6 and 7 document the fundamental problem of price and cost fragmentation, Figure 8 illustrates the path toward a solution through harmonization within the ETS2. At the same time, the analysis clarifies why the political focus must not rest solely on the 'price level': the decisive factor for the economic viability of the transformation is whether the price signal can actually steer behavior or whether it is structurally overshadowed by national budgets and overlapping regulatory measures, thereby undermining its efficiency

4.4 Distributional effects between EU member states

The introduction of an EU-wide ETS2 leads to a non-negligible redistribution of economic costs and benefits among Member States. While the EU aggregate benefits from efficiency gains, the impacts vary at the national level.

Determinants of Welfare Change. Whether a country gains or loses through the transition to a strong ETS2 is essentially determined by the interplay of three central effects:

- **Efficiency effect (where-flexibility):** A common ETS2 price allows emissions to be mitigated where it is most cost-effective. Countries with high marginal abatement costs (MAC) gain by purchasing more affordable allowances; countries with low MAC gain through the profitable sale of their abatement.

- **Budget effect (relative scarcity):** Welfare depends on the original "generosity" of the national ESR budget. A country transitioning from a system with overallocation to a scarcer system initially experiences a negative effect.
- **Transfer effect (fiscal redistribution):** This includes the distribution of ETS2 revenues (auctioning rights often based on historical emissions, including solidarity shares) as well as funds from the Social Climate Fund (SCF). The latter follows a social progression in which lower-income states receive a disproportionate share of funds.

Grouping of EU Member States

Based on the model-based simulation analysis, countries can be divided into three main groups:

- **Group A** *("Efficiency Winners", Net Sellers)***:** Low domestic MAC that are below the ETS2 CO2 price. They generate revenue by exporting allowances and benefit from fiscal redistribution. Examples: Bulgaria (BGR), Romania (ROU), Poland (POL).
- **Group B** *("Cost-Relieved", Net Buyers)*: Very high domestic MAC that are above the ETS2 CO2 price. They save on domestic abatement costs by replacing expensive national measures with more affordable EU allowances. Examples: Germany (DEU), Austria (AUT), Belgium (BEL).
- **Group C** *("Adjustment Losers")*: Countries that have very "soft" targets in the status quo. The price jump resulting from the introduction of the ETS2 directly burdens consumption, while trade gains often do not fully compensate for this burden. Examples: Greece (GRC), Portugal (PRT), Spain (ESP).

A further factor for the country-specific welfare balance is the interaction between the EU-wide ETS2 market signal and complementary national non-market-based measures. These regulatory interventions force CO_2 reductions regardless of the current allowance price. Consequently, total demand in the ETS2 market falls, triggering a significant price-dampening effect (as previously explained with reference to Figure 8). However, a lower ETS2 price often masks inefficiencies, as domestic actors are forced by national mandates to bear abatement costs far above the market price. While this appears superficially relieving for net importers of allowances, net exporters of abatement (Group A) suffer under this policy mix. For them, the depressed market price directly translates to falling sales revenues for their low-cost savings, which diminishes their potential welfare increase compared to a pure market scenario.

Case Studies on Country-Specific Welfare Effects. The welfare effects for the years 2028 and 2043 illustrated in **Figure 9** clarify how the determinants described above (MAC, budgets, and transfers) interact in practice.

The following case studies illustrate the dynamics for the three country groups:

- *Group A: Example Bulgaria (BGR):* Bulgaria represents those countries in Figure 9 that

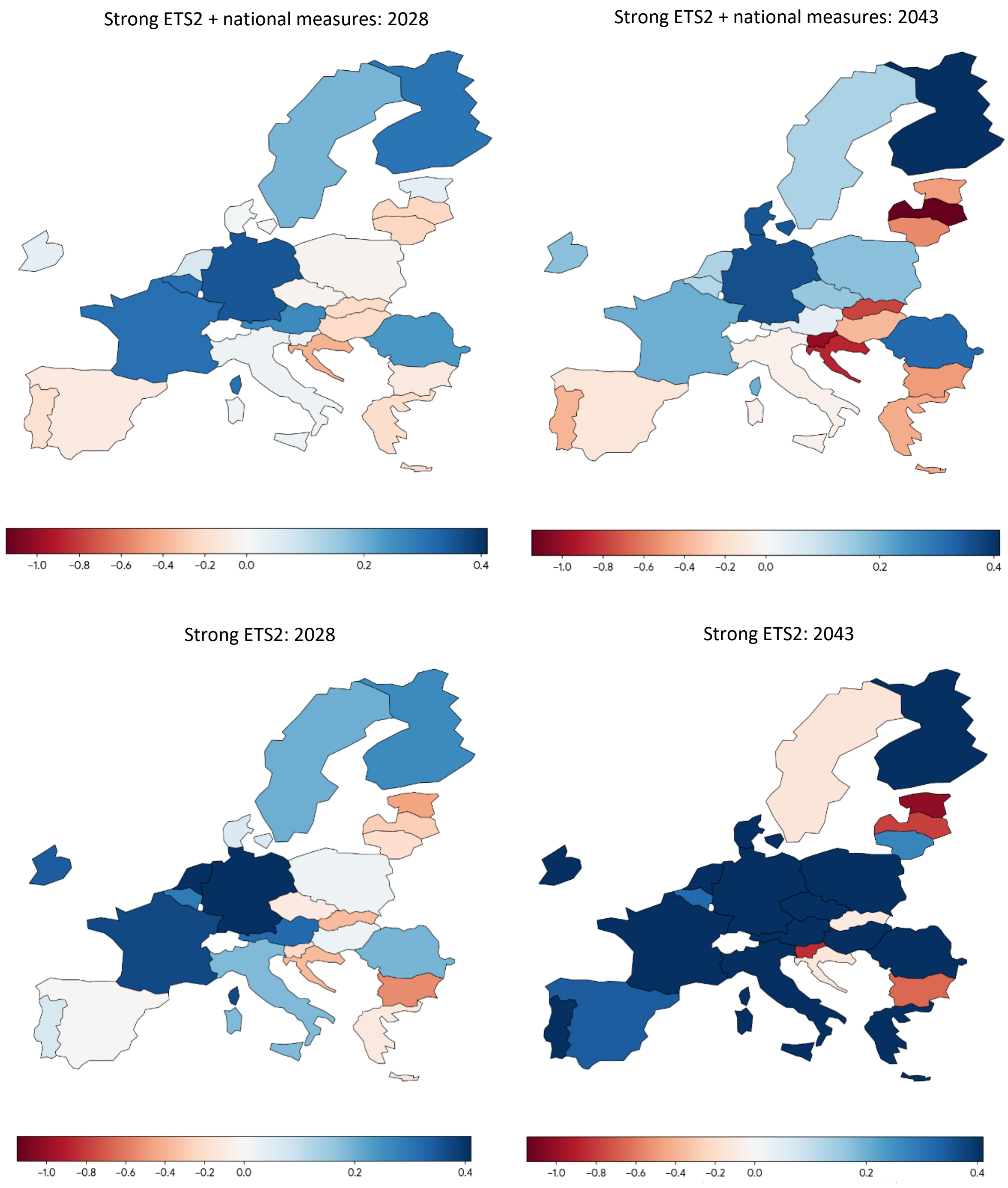


Figure 9: Welfare effects [in %] by EU-27 country in 2028 and 2043 for different ETS2 designs (compared to the *"business as usual/weak ETS2"* scenario)

Notes: Own calculations based on the macroeconomic simulation model.

consistently record positive welfare effects. With very low marginal abatement costs due to generous allocation in the ESR, BGR remains significantly below the ETS2 price path. The map shows a clear welfare gain for BGR. This is because the country fully exploits its "where-flexibility": it abates CO_2 at minimal cost and sells the difference at the high EU market price. Since BGR also receives high redistributions via the Social Climate Fund (SCF) and solidarity shares, the burden on households is more than compensated by the fiscal inflows.

- *Group B: Example Germany (DEU):* Germany shows a relief effect in Figure 9 (particularly compared to the status quo of ESR targets) that increases over time. DEU has high domestic MAC. Without ETS2 trading, the German economy would have to bear these costs in real terms for every ton of CO_2 in the transport and building sectors. The strong ETS2 acts as a "safety valve" for Germany. By purchasing allowances at the market price, the economy saves significantly on abatement costs. In Figure 9, this translates into a positive welfare change relative to the inefficient status quo, as the market's efficiency gains outweigh the net payments into the SCF.
- *Group C: Example Greece (GRC):* Greece illustrates in Figure 9 the risk for countries that come from a very “soft” national budget (ESR). GRC often starts with an implicit CO_2 price of almost zero in the status quo, as previous targets were hardly binding. The transition to a strong ETS2 price scenario means a noticeable increase in costs for Greek consumers. In Figure 9, this leads to negative welfare effects, especially in the short term in 2028, as the level of redistribution is often initially insufficient to immediately compensate for the loss of “free” emission allowances. Looking at the year 2043, the picture for GRC shifts toward a welfare gain. This turnaround can be explained primarily by the enormous importance of “where-flexibility” as climate targets become more stringent. While national GVKs remain comparatively moderate in GRC, they are rising in other parts of the EU. In this late phase, Greece can use its cost-effective avoidance potential as a competitive advantage. The country will become a significant net exporter of CO2 savings; coupled with the cumulative effect of redistribution from the SCF, this means that Greece will be one of the long-term winners of a strong ETS2, as the trading gains will ultimately exceed the initial adjustment costs.

Comparison of time points (2028 vs. 2043). The comparison of the two respective "columns" in Figure 9 shows a convergence of effects. In 2028, the effects are strongly dominated by the original budget distribution and direct price shocks. The distribution is more uneven. In 2043, as stringency and the ETS2 price increase, the efficiency advantages of the common market become more prominent. "Where-flexibility" becomes the decisive factor: countries that organize their transformation efficiently stabilize their welfare, while the importance of historical budget advantages diminishes.

The evaluation of country-specific effects highlights a tension between efficiency and distribution. From a purely economic logic, a strong ETS2 without overlapping national measures represents the most efficient instrument, as it minimizes macroeconomic costs by fully utilizing "where-flexibility." Nevertheless, distributional tensions arise: while market-driven gains flow primarily to countries with low-cost abatement potential—mainly in Eastern Europe—the greatest relative advantage for high-price countries in the West lies in the massive saving of abatement costs.

These results underscore that the introduction of the ETS2 is not a zero-sum game but generates significant efficiency gains for the EU as a whole. While Group A countries generate real export revenues by exporting CO_2 abatement and thus earn "real money," Group B countries gain by being able to "buy themselves out" of economically inefficient and expensive national individual measures. Simultaneously, the temporary welfare losses in Group C signal the urgent need for political action for increased redistribution. In this framework, the combined transfer effect from the targeted distribution of ETS2 auctioning rights and SCF funds acts as an important political cohesive. Through this compensation mechanism, the tensions between necessary economic efficiency and the immediate price burden on households in transition regions can be resolved, securing the long-term acceptance of European climate policy.

5 Conclusion and Outlook

The introduction of the ETS2 offers a historic opportunity to place European climate policy on a new foundation of economic efficiency. The ETS2 is less an "additional CO_2 price" than a strategic pivot for the architecture of European climate policy. It has the potential to make the currently highly fragmented governance in the buildings/heating and road transport sectors significantly more cost-effective—provided, however, that its market-based price signal is not permanently overshadowed by national budgets and overlapping regulations.

Key Findings:

- **Efficiency Potential:** A consistently implemented "strong ETS2" can reduce cumulative policy costs by over 20% (approx. EUR 824 billion) by 2048. This achieves nearly the full efficiency potential of the benchmark of a uniform, EU-wide CO_2 price. This is primarily achieved through the harmonization of marginal abatement costs, which are currently highly fragmented across Member States.
- **The Price-Efficiency Trap:** A lower ETS2 allowance price is not a reliable indicator of more affordable climate policy. National standards, bans/phase-outs, and subsidy frameworks can dampen the visible ETS2 price because they partially "mandate" emission reductions and thus lower the demand for emission allowances—yet, at the same time, they can increase economic costs if they lock in more expensive abatement options and displace flexible, price-driven adjustments. Therefore, the decisive factor is not primarily the price level, but whether the price signal can actually exercise its steering function.
- **Distributional Equity:** Efficiency gains resulting from the introduction of the ETS2 are accompanied by distributional conflicts—though these diminish the more effectively the ETS2 functions as a market mechanism. An EU-wide ETS2 shifts burdens between Member States: countries with previously low implicit ESR shadow prices (due, in part, to generous national budgets) may face short-term burdens, while countries with high marginal abatement costs are relieved through access to more affordable EU-wide mitigation options. The more effectively the ETS2 replaces the current national

patchwork (increased cross-border flexibility, less obligation through national budgets and overlapping national measures), the more marginal abatement costs converge—and the more distributional conflicts decrease over time.

Three areas for action emerge for the further development of EU climate policy:

1. **Institutional Coherence:** The overlap between the ETS2 and ESR must be resolved to ensure the cost-efficiency of the overall system. This requires either an effective activation of flexibility mechanisms (trading of AEAs) or a prospective decoupling of the sectors to make "where-flexibility" highly usable. To realize the efficiency gains of the ETS2, national unilateral actions and redundant measures in the buildings and transport sectors should also be phased out. The ETS2 must not be treated as an additional layer on top but must be understood as an integrative lead instrument.
2. **A Complementary Policy Mix ("Second-Best" Reality):** The economic superiority of CO_2 pricing does not preclude flanking measures. On the contrary: to address multiple market failures such as information deficits, liquidity constraints for low-income households, or the tenant-landlord dilemma, a targeted supporting policy is necessary. However, it is crucial that these measures act complementarily—that is, they must increase the responsiveness of actors to the price signal (e.g., through renovation subsidies or loan programs) instead of replacing the price signal.
3. **Compensation instead of Market Distortion:** Distributional conflicts between Member States should not be resolved through exemptions or price caps within the ETS2, as this destroys the steering effect. Instead, revenues from allowance auctioning (e.g., via the Social Climate Fund) should be used to provide targeted transfer payments, thereby securing political acceptance for the transformation.

The EU faces a choice: either the ETS2 remains within a tight corset of national dirigisme and ESR fragmentation, making the transformation unnecessarily expensive, or it becomes the engine of a cost-effective, cross-border climate strategy. A strong ETS2 is a vital building block for achieving the EU's ambitious 2040 targets while preserving prosperity.

6 Appendix

6.1 Brief explanation: CO_2 pricing as a key instrument of climate policy

In economic logic, CO_2 pricing is considered a lead instrument of efficient climate policy because it addresses the climate problem at its root: scarcity. The central "good" in this context is not coal, oil, or gas, but the limited absorption capacity of the atmosphere—frequently described as the global CO_2 budget.

Even if exact figures fluctuate depending on assumptions and are subject to uncertainties (climate sensitivity, socioeconomic pathways, choice of temperature target), the core statement remains robust: this capacity is finite and, at current high emission levels, will be exhausted within a relatively foreseeable timeframe. Climate policy is therefore, at its core, a problem of managing a scarce resource.

In a market economy, scarce goods are typically coordinated through markets and prices. Prices condense information about scarcity and value, resolve incentive and coordination problems, and steer decentralized decisions: companies invest, households consume, and innovations emerge—without the need for a central authority to prescribe every single technological or behavioral decision. In the case of the climate problem, however, exactly this mechanism is missing: no natural market exists that automatically prices the use of the scarce "CO_2 absorption capacity." Those who cause emissions often bear only their private costs, but not the social costs (climate damage, health consequences, risks of tipping points). In economic terms, this is an externality—and it leads to excessive emissions because the decisive scarcity signal is absent.

CO_2 pricing closes this gap by internalizing the externality: emissions receive a visible price and thus become immediately relevant for the decision-making of firms and households. This can occur via a CO_2 tax (price-based: the state sets the price) or through an emissions trading system (ETS) (quantity-based: the state sets the permissible quantity, and the market forms the price). In both cases, a direct or indirect, but explicit, price signal is created that operates wherever emissions occur: it makes CO_2-intensive options relatively more expensive and low-CO_2 options relatively more favorable. Consequently, emissions are reduced where it is most cost-effective—technologically neutral and across sectors—and a continuous incentive for efficiency, substitution, and innovation is created.

A quantity-based system such as an ETS has a particular strength in this regard: it directly links climate policy with budget logic. When policy sets the total quantity of allowances and reduces it over time, the scarcity of emission rights is systematically increased—and the CO_2 price reflects this scarcity through supply and demand. Thus, climate protection becomes more than just a moral appeal or detailed regulation; it becomes an integral component of economic calculations. This is precisely why CO_2 pricing can be considered a "lead instrument": it creates the missing market and scarcity signal for the scarce resource of the atmosphere and utilizes the coordinating power of prices to achieve climate targets in an efficient, decentralized, and innovation-oriented manner.

6.2 Brief explanation: When do supplementary measures beyond the CO_2 price make sense?

From an economic perspective, CO_2 pricing is a central lead instrument because it translates "external" climate damage into private decisions, thereby triggering cost-effective emission reductions along the entire value chain. However, on its own, it is often insufficient to reduce emissions at the required speed and in a socially sustainable manner. There are several, partly well-documented reasons for this—resulting in a bundle of complementary instruments.

First, a CO_2 price primarily addresses the emission externality, but not other market imperfections that are crucial for the transformation. Of particular importance are innovation and knowledge externalities: companies can only incompletely internalize the social returns from research, development, and early market ramp-up (learning-by-doing, spillovers, network effects). While a pure CO_2 price can provide incentives, it guarantees neither sufficient "knowledge creation" nor the rapid diffusion of new technologies. Therefore, R&D funding, demonstration programs, standards (e.g., efficiency or emission standards), and infrastructure policy (grids, charging infrastructure, heating networks) are complementary: they lower technology and adoption costs, accelerate scale effects, and reduce the risk of the economy becoming trapped in an emission-intensive "path lock-in."

Second, investment and information barriers occur that price signals only partially penetrate: limited access to capital (especially for households and SMEs), high initial investments, split incentives (landlord-tenant), incomplete information, and transaction costs. Particularly in sectors such as building heat and road transport—which are central to the ETS2—a CO_2 price without flanking policies can lead to slow adjustments because short-term price elasticity is low and alternatives (renovation, heat pumps, public transport options) are not immediately available. Complementary instruments such as targeted investment grants, loan programs, consulting, minimum standards, or the acceleration of planning and approval procedures increase responsiveness to the price signal and make the overall package more efficient.

Third, distributional effects are central to acceptance and effectiveness. Depending on consumption profiles, housing situations, and regional alternatives, CO_2 prices can have a regressive effect or at least be perceived as unfair. Without compensation, there is a risk of social hardship and political backlash that could weaken or destabilize the instrument. Therefore, redistribution (e.g., "Klimageld" / climate dividend), targeted relief for vulnerable households, and transformation assistance (e.g., for building renovations for low-income owners or tenants) are sensible not only from a social policy perspective but also economically. Targeted relief and transformation aid can mitigate social hardships and cushion the distributional impacts of CO_2 pricing. This can increase the political viability of higher or more rapidly rising CO_2 prices—and reduce the risk of the price signal remaining permanently too weak for reasons of public acceptance. At the same time, the effect depends heavily on the specific design: depending on the design, trade-offs can arise, for example, through deadweight effects, distortions, or administrative burden.

Fourth, political-economic arguments support a policy mix. In practice, CO_2 prices are not free from uncertainty (price volatility) and political risk (reform pressure, exemptions, caps).

Supplementary instruments can act as insurance: standards and public investment deliver emission reductions even when prices are temporarily low or when price pass-through is incomplete. At the same time, visible co-benefits (better air quality, reduced import dependency, innovation/jobs) can broaden the political coalition for ambitious climate policy. Design is crucial here: flanking measures should address market failures as precisely as possible, limit double regulation and deadweight effects, and complement rather than undermine the price signal.

Fifth, in this context, flanking (green) industrial policy is gaining importance. Its aim is not so much to replace the CO_2 price, but to accompany industrial structural change and provide adjustment assistance. Economically, this can be justified especially where (i) innovation and scaling externalities are strong (e.g., in basic industries, new process technologies, or key components), (ii) coordination problems and complementary investments slow down the market ramp-up (infrastructure, standards, qualifications, permits), or (iii) international competition and risk aspects are relevant (carbon leakage risks, strategic dependencies in supply chains, critical raw materials). Instruments range from "lead market" approaches (e.g., public procurement, quotas/standards, product regulation) and investment and operating cost support for first movers to risk-sharing mechanisms such as (Carbon) Contracts for Difference (CCfDs). At the same time, (green) industrial policy is controversial: it can encourage misallocations ("picking winners"), rent-seeking, high fiscal costs, and trade policy tensions. This results in high design requirements—such as competitive allocation (auctions), clear goal definitions, transparency, time limits (sunset clauses), and evaluation—as well as careful coordination with the CO_2 price signal to ensure it is effectively supplemented rather than hollowed out.

In summary: CO_2 pricing remains the efficient backbone, but an effective and sustainable transformation package combines it with policies for innovation, infrastructure, and the removal of barriers, as well as social compensation. Especially for ETS2 sectors, this bundle increases short-term adaptability, accelerates technological change, and stabilizes the political implementability of ambitious climate targets.

6.3 Further details on the macroeconomic simulation model

The quantitative assessments in this study are based on a dynamic, empirically calibrated macroeconomic general equilibrium model. This class of models represents economies as a system of interconnected goods and factor markets in which production, consumption, trade, income, and prices are determined simultaneously such that all markets clear consistently in each period.

The advantage over partial equilibrium approaches is that climate policy does not only act "in the energy sector" but influences the entire economy through price changes, income effects, and sectoral reallocation. The model is solved in discrete time and maps transformation pathways up to 2050. The starting point is the base year 2017 (based on comprehensive input-output data, bilateral trade data, and energy and emissions data) and a forward calibration up to the starting point of central policy elements (including the ETS2 starting in 2028).

The model combines a detailed representation of energy and emissions with macroeconomic consistency and distributional detail. Firms produce using capital, labor, intermediate inputs, and energy services. The latter are generated from fossil fuels or electricity as well as capital inputs that embody "knowledge." Building on this, the model integrates endogenous innovation via a "Directed Technical Change" approach (Acemoglu, 2002): research and development are directed toward those technologies that become more profitable under changing relative prices (e.g., due to explicit and implicit CO_2 prices); thus, technological pathways and long-term abatement costs become policy-endogenous.

On the policy side, the model can represent various CO_2 pricing architectures of EU climate policy (including ETS1, ETS2, and ESR) with their sectoral coverage, quantity pathways, and redistribution rules. CO_2 prices emerge endogenously from the equilibrium of the respective emissions markets. Thus, the model can consistently quantify key outcome variables such as endogenous CO_2 prices, CO_2 revenues, welfare costs (measured as Hicksian equivalent variation), as well as impacts on consumption/GDP, price and income effects, distributional effects between countries, and changes in sectoral output.

All EU-27 Member States (with the exception of Malta, Luxembourg, and Cyprus, which are assigned to an aggregate for resolution reasons) are represented as individual regions, alongside a "Rest of the World (ROW)" regional aggregate. The macroeconomic structure (input-output, bilateral trade, energy flows, CO_2 emissions) is based on Social Accounting Matrix (SAM) data from GTAP (Global Trade Analysis Project) Version 11. For the electricity sector, country-specific generation structures are supplemented by technology (fossil fuels, nuclear, hydro, wind/solar). Mathematically, the model and the equilibrium problem are formulated as a mixed complementarity problem (MCP) and solved using GAMS/MPSGE and PATH.

The following sectoral and commodity resolution (including final demand categories) is used; ETS1/ETS2 coverage follows the respective regulation or (in the case of "large vs. small" installations) the assignment in the data partitions:

Private and Public Consumption and Investment: **1.** Household consumption (differentiated by non-energy goods and energy services in transport and buildings); **2.** Government consumption; **3.** Investment;

Primary Energy: **4.** Coal; **5.** Crude oil; **6.** Natural gas; **7.** Refined oil products;

Secondary Energy: **8.** Electricity (differentiated by technology/energy source);

Industrial Sectors: **9.** Non-metallic minerals (cement, glass...); **10.** Iron and steel, metals, metal products; **11.** Chemicals, rubber, plastic, paper; **12.** Light industry;

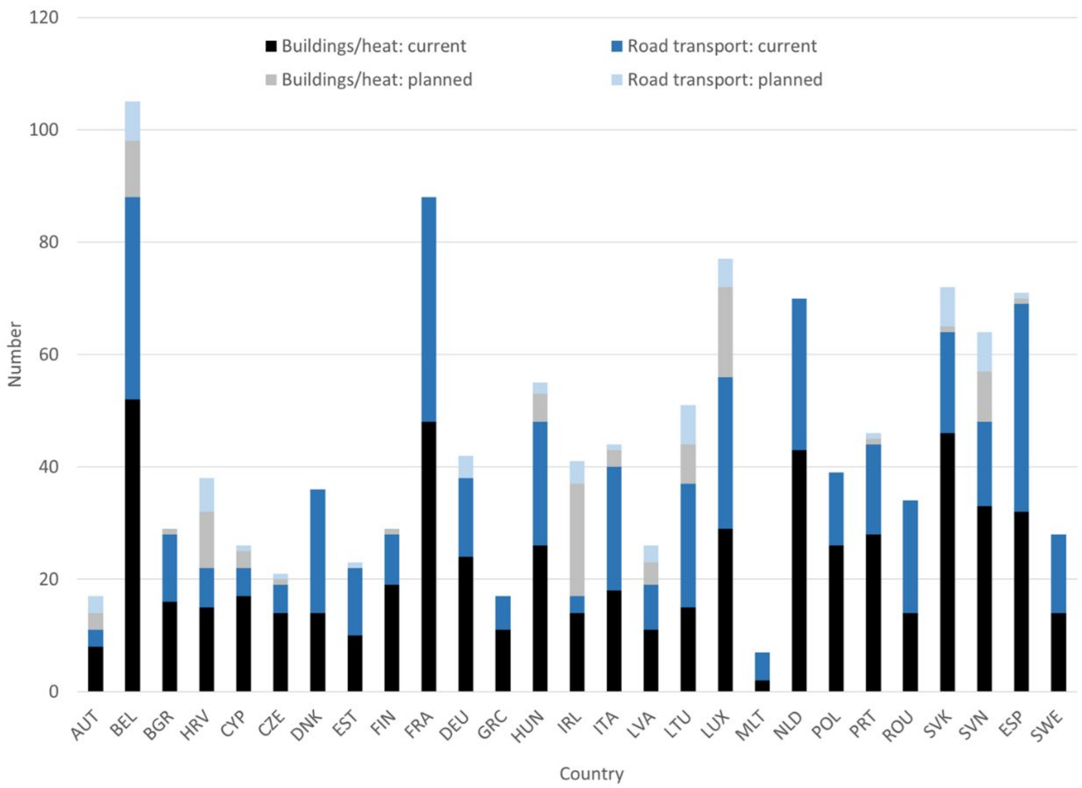
Transport: **13.** Air and water transport; **14.** Road transport (insofar as not covered by household consumption of self-produced energy services in transport);

Other Sectors: **15.** Construction; **16.** Food; **17.** Services; **18.** Agriculture, forestry, and fisheries.

List of EU-27 countries represented in the model (with ISO-3 abbreviations): AUT (Austria), BEL (Belgium), BGR (Bulgaria), HRV (Croatia), CYP (Cyprus), CZE (Czech Republic), DNK (Denmark), EST (Estland), FIN (Finland), FRA (France), DEU (Germany), GRC (Greece), HUN (Hungary), IRL

(Ireland), ITA (Italy), LVA (Latvia), LTU (Lithuania), NLD (Netherlands), POL (Poland), PRT (Portugal), ROU (Romania), SVK (Slovakia), SVN (Slovenia), ESP (Spain), SWE (Sweden).

6.4 Supplementary illustrations



Notes: Own representation. The chart shows the number of nationally reported *Policies and Measures (PaMs)* per EU-27 country in two ETS2-relevant areas: buildings/heating and road transport. Four categories are shown: (i) buildings/heating – existing (status implemented or adopted), (ii) buildings/heating – planned (status planned), (iii) road transport – existing (status implemented or adopted), (iv) road transport – planned (status planned). PaMs entries (measures) are counted, not their budget, stringency, or emission impact. Country labels are ISO 3 codes. Source: European Environment Agency (EEA) / ETC-CM, Policies and Measures (PaMs) database.

Figure 10: Policy mix in ETS2 sectors: Number of existing and planned measures in buildings/heating and road transport (EU-27, by country)