

Research Article

ETS Price Signal in the Power Sector: Evidence on Decarbonisation and Policy Overlap

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We examine whether the EU Emissions Trading System has effectively operated as a direct driver of renewable-energy deployment in the European electricity sector over the period 2013–2024 and investigate the interaction between carbon pricing, renewable investment dynamics and wholesale electricity-price formation within marginal pricing systems. Combining panel econometric analysis on installed renewable capacity across European Member States, a cross-country survey of 120 firms in six EU ETS countries, and an hourly market-based estimation of inframarginal rents on a panel of eight Member States, we find that public support mechanisms emerge as a consistently driver of renewable-capacity expansion. The EU Allowance price does not exhibit significant direct effect on renewable deployment after controlling for structural and market variables. In electricity markets, the ETS primarily operates through mechanisms that shape wholesale electricity prices and carbon-cost pass-through, generating persistent inframarginal revenues for low-carbon technologies through marginal price formation. A comparison between regulatory CO₂ factors used for indirect ETS cost compensation and observed market-based pass-through indicators reveals materially divergent magnitudes across Member States, with regulatory-to-observed ratios ranging from 1.2x in Italy to 46.2x in Sweden. The evidence suggests that, in European electricity markets, the ETS currently operates more directly as a wholesale-price transmission and revenue-redistribution mechanism than as a sufficiently autonomous and stable driver of renewable investment deployment.

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Highlights

- Public support schemes are the dominant driver of renewable-capacity expansion.
- ETS-related inframarginal rents are persistent and structural in European electricity markets.
- Regulatory CO₂ factors used for indirect ETS cost compensation diverge materially from observed market-based pass-through indicators

1. Introduction

Decarbonisation policies increasingly rely on a combination of carbon pricing, regulatory intervention, industrial policy, infrastructure deployment and public support mechanisms intended to accelerate technological transformation and guide long-term investment decisions.

The EU Emissions Trading System (EU ETS) has represented since its introduction one of the most advanced applications of a market-based environmental policy instrument within a large integrated economic area^{[1][2]}. Unfolding its role in the decarbonisation of the power sector is prominent because electricity generation is fully exposed to the carbon price and therefore offers the most direct setting in which to verify whether the ETS has effectively generated observable adjustment dynamics.

In the power sector the carbon price directly affects the marginal cost of fossil-based generation, alters the relative competitiveness of generation technologies, and may therefore influence both short-term dispatch decisions and medium-term investment choices^{[3][4]}. For this reason, the sector provides a natural empirical benchmark for assessing whether the ETS has effectively contributed to decarbonisation of the power sector^{[5][6]}. Recent literature on drivers of renewable energy development suggests that, while both carbon pricing and subsidies matter, targeted subsidies more directly drive renewable energy investment, while ETS works best when revenues or carbon prices are high and well-designed^{[7][8][9]}.

Based on insights from the recent literature, trends in the EU power-sector generation mix, and evidence from market participants, we hypothesised that public support schemes and subsidies play a primary role in driving renewable energy investments, while the ETS carbon price signal primarily serves as a complementary mechanism rather than an autonomous investment driver. This consideration gives rise to the research question underlying this study: to what extent has the EU ETS effectively served as a

direct driver of renewable energy deployment in the European power sector? The idea is that its main impact operates through electricity price formation and complementary policy mechanisms.

We tested our hypotheses by designing a triangulated empirical strategy that combines three complementary perspectives. First, an econometric model is estimated across European Member States for 2013-2024 to test whether the EUA price has a significant direct effect on installed renewable capacity, controlling for subsidies, verified emissions and GDP. Second, an international survey of approximately 120 firms across six EU ETS countries collected evidence from market participants on perceived investment drivers. Third, an hourly market-based methodology was developed to estimate the effective transmission of ETS carbon costs into wholesale electricity prices and the resulting inframarginal rents accruing to low-carbon technologies, applied to a panel of eight Member States over 2021-2024^{[10][11][12]}.

We find that public support mechanisms emerge as a robust driver of renewable-capacity expansion, confirming the central role of subsidies, long-term contractual arrangements and revenue-stabilisation mechanisms in supporting investment decisions and project bankability^{[13][8]}. The carbon price does not display a statistically significant direct effect on renewable deployment. The most economically material effect of the ETS in power markets consists in the generation of persistent inframarginal revenues for low-carbon technologies through marginal price formation, while the comparison between regulatory CO₂ factors used for indirect ETS cost compensation and observed market-based pass-through indicators reveals significant divergences across Member States.

The key message is that, within European electricity markets, the EU ETS currently operates more directly as a wholesale electricity-price transmission and revenue-redistribution mechanism than as a sufficiently autonomous and stable driver of renewable investment deployment. Future reform discussions may therefore increasingly require a more explicit assessment of the interaction between carbon pricing, electricity-market design, renewable-support schemes and long-term investment-bankability conditions^{[14][15]}.

The remainder of the paper is organised as follows. Section 2 presents the research design, including the analytical framework, the survey methodology and the inframarginal-rents identification strategy. Section 3 reports the econometric results, survey evidence, and empirical estimates of ETS-related inframarginal rents and indirect-compensation factors. Section 4 discusses the findings in light of the existing literature and the implications for ETS reform. Section 5 highlights the policy implications, and Section 6 concludes.

2. Research Design

This section outlines the research design underpinning the empirical analysis. Firstly, the section presents the analytical framework used to assess the drivers of renewable capacity development, including the econometric specification of the panel model, the dependent and explanatory variables, the geographical and temporal coverage, and the identification strategy based on two-way fixed effects with clustered standard errors. It then describes the international survey on the drivers of investment in renewable energy and storage systems, outlining its geographical scope, the profile of respondents, the structure of the questionnaire and the use of five-point Likert scales to ensure comparability between investment factors. The section then introduces the identification strategy for pricing technologies and the estimation of the transfer of ETS carbon costs onto wholesale electricity prices. Finally, the methodological scope and limitations are discussed. Figure 1 illustrates the triangulated empirical strategy adopted in the paper, combining panel econometric analysis, survey evidence and market-based estimation of ETS-related inframarginal rents to assess the role of the EU ETS in renewable energy development.

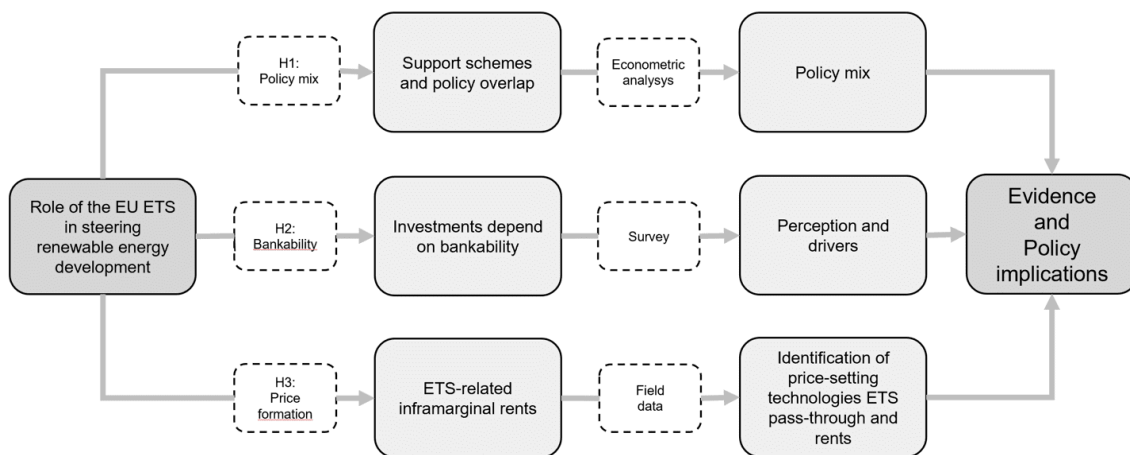


Figure 1. Research framework. Source: the authors. The first investigates the interaction between support schemes, ETS price signals and policy overlap through panel econometric analysis. The second examines the role of investment bankability conditions and perceived investment drivers through an international survey of firms and investors. The third analyses ETS-related inframarginal rents and electricity price formation through the identification of price-setting technologies and market-based pass-through estimation.

2.1. Data Management

The dependent variable is the installed renewable capacity, "i.e.," the installed MW (source: EMBER). The key explanatory variables are: *efsub* that corresponds to incentives (source: EUROSTAT. General government expenditure by function. Sector: General government. COFOG99: Fuel and energy. ESA 2010: Subsidies. Online data code: *gov_10a_exp*. DOI:10.2908/gov_10a_expv). *eua* i.e. the costs of EUA that reflect mainstream idea on the role of carbon price on energy sector decarbonization (Source: EEX), and *efsubxeua* that is the interaction among subsidies and EUA. Control variables include the verified emissions of the energy sector (*energyVE*), which is meant as a decarbonization pressure proxy (source: Emission Trading System Union Registry, "Verified emission 2024") and the gross domestic product (GDP) to control for the economic cycle (Source: EUROSTAT). Table 1 gives the description of the variables used in drivers of renewable capacity development analysis.

Variable	Obs	Mean	Std. dev.	Min	Max
capacity	359	10882.44	22222.85	0.00	165564
efsub	341	2425.46	5930.94	0.00	50744
eua	360	31.64	29.66	4.33	83.66
energy_VE	360	27000	54600	0.00	352000
GDP	359	38145	30733.24	5870.00	185840
euarel	348	2246.21	2191.22	117.88	7168.66
year	402			2013	2024

Table 1. Descriptive statistics

Source: the authors

The survey sample (120 respondents) is balanced across countries: Italy accounts for 25.1% of responses, followed by France (20.5%), Spain (19.9%), Germany (20.3%), Poland (7.1%) and Sweden (7.1%). Medium-sized and large firms dominate the sample, and 37.8% of respondents are C-level executives

The hourly panel covers eight EU Member States—Belgium, France, Germany, Italy, the Netherlands, Poland, Spain and Sweden—and is assembled from the ENTSO-E Transparency Platform^[16]. Four ENTSO-E datasets are used: day-ahead prices (12.1.D), aggregated generation per type (16.1.B/C), actual total load (6.1.A) and physical flows/scheduled commercial exchanges (12.1.F/G). Dataset codes refer to the corresponding articles of Commission Regulation (EU) No 543/2013. Raw data are read with the original tab-separated layout, column names are normalised, and timestamps are coerced to UTC and floored at hourly frequency. Each record is assigned to one of the eight target countries by matching the ENTSO-E map code, area code and area display name. The aggregation rule prefers the exact country row whenever available; otherwise the country value is obtained by summing subzone values for load, generation and cross-border flows—applied in particular to Italy (seven bidding zones) and Sweden (SE1–SE4), with the German–Luxembourg DE-LU price area treated as a single national observation. For multi-zone countries, the national price is computed as the load-weighted average of zonal prices. Generation by technology is reduced to six standardised categories—gas, coal, nuclear, wind, solar and hydro—by string-matching the ENTSO-E production type field. Cross-border physical flows are processed as directional pairs; same-country zone-to-zone flows are excluded to avoid double-counting. Fuel price series (TTF gas and international coal benchmarks) are retrieved from FactSet, and EUA market prices from EEX.

2.2. Empirical Analysis

To address the complexity of industrial decarbonisation under the EU ETS, this paper adopts a triangulation approach that combines multiple methods, datasets, and analytical perspectives in order to provide a more robust and comprehensive interpretation of the empirical evidence. Triangulation means using multiple methods and data sources to study the same phenomenon. In applied economics, it is mainly valued for improving credibility, validity, and causal inference, by reducing bias from any single method. In economics it often means combining quantitative statistical analysis with qualitative evidence to more fully reflect reality enabling combination of different insights^[17]. Triangulation supports empirically based hypothesis construction and theory modification^[18], method innovation^[19] and rebalancing fields dominated by one paradigm by institutionalizing multiple methods to avoid systematic bias^{[17][20]}. Although divergent results may be common, we agree on the fact that it can yield more insightful understanding and new concepts rather than a single approach^[21]. The triangulation strategy adopted in this work allows for a better understanding of the interaction between

the carbon price signal, technological maturity, infrastructure constraints, and investment behavior in different manufacturing sectors.

2.2.1. Drivers of renewable development

In order to assess whether the EU ETS carbon price has operated as an implicit economic signal supporting the decarbonisation of the European power sector, the empirical strategy is organised to investigate whether the same price signal may have contributed to renewable investment dynamics, proxied by installed renewable capacity. From a theoretical perspective, the ETS price is expected to influence renewable investments indirectly, by increasing wholesale electricity prices and improving the competitiveness of low-carbon technologies. However, this transmission may be partial or uncertain due to market design, regulatory interventions and price volatility^{[22][23]}. By contrast, renewable subsidies act more directly on investment decisions by improving expected returns and reducing financing constraints^{[24][25]}. The empirical framework allows the testing of three key hypotheses: whether renewable subsidies are a significant and robust driver of installed capacity; whether the EUA price has an independent effect on renewable investment; and whether the interaction between the two instruments suggests complementarity or substitution effects. The analysis is based on a panel covering European Member States over the period 2013–2024.

$$\begin{aligned} \ln(\text{capacity}_{it}) = & \beta_1 \ln(\text{efsub}_{i,t-1}) + \beta_2 \ln(\text{eua}_{i,t-1}) \\ & + \beta_3 \left[\ln(\text{efsub}_{i,t-1}) \times \ln(\text{eua}_{i,t-1}) \right] + \beta_4 \ln(\text{energyVE}_{it}) \\ & + \beta_5 \ln(\text{GDP}_{it}) + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (1)$$

The model is estimated as a two-way fixed-effects panel with country fixed effects (α_i) and year fixed effects (γ_t), with standard errors clustered at the country level to account for heteroskedasticity and serial correlation^[26]. This framework is particularly relevant in the European context, where multiple policy instruments coexist and may generate overlapping or interacting incentives. The model investigates the main determinants of renewable energy capacity development across countries, focusing on the role of EUA price and incentives. This relates to a broader issue: whether different climate policy tools act as complements or substitutes in fostering the energy transition.

2.2.2. Survey on renewable energy investment drivers

An international survey was commissioned across six European countries (Italy, France, Spain, Germany, Poland and Sweden), focusing on the main EU economies participating in the ETS. The survey targeted

companies operating in the energy sector as well as financial intermediaries specialised in investments in green technologies, with the objective of collecting 120 responses. Respondents were selected among energy utilities and project developers active in renewable energy generation and storage, financial intermediaries and investors specialised in green and low-carbon technologies. The questionnaire is divided into an introductory section on demographic and professional characteristics, a section on route-to-market strategies and revenue structures, a central section on factors incentivising investment in renewable energy and storage, and a section on market, regulatory and financial constraints. Most questions use five-point Likert scales, allowing comparable measurement of the degree of importance attributed by respondents to the various factors considered.

2.2.3. Identification of price-setting technologies and ETS pass-through

The estimation of ETS-related inframarginal rents is grounded in a set of simplifying but economically consistent assumptions regarding the functioning of wholesale electricity markets. The analysis builds on the marginal pricing framework, according to which electricity prices are determined on an hourly basis by the marginal unit, defined as the last generation technology dispatched to meet demand^{[27][28]}. Under this assumption, the observed day-ahead market price is interpreted as a proxy for the marginal cost of the price-setting technology.

The empirical implementation combines hourly electricity market data with daily fuel price series and EUA prices. Day-ahead electricity prices and hourly generation by technology are matched with daily observations of fuel prices (TTF for gas and international coal benchmarks). Within this framework, the marginal cost of fossil technologies is constructed by explicitly accounting for plant efficiency and emission intensity. Fuel prices are converted into electricity-equivalent marginal costs by dividing them by the assumed conversion efficiency of the relevant technology, while the carbon cost component is added by multiplying the EUA price by the corresponding emission factor per unit of electricity produced:

$$MC_{gas} = \frac{Gas}{\eta_{gas}} + EUA \times EF_{gas} \quad (2)$$

And

$$MC_{coal} = \frac{Coal}{\eta_{coal}} + EUA \times EF_{coal} \quad (3)$$

Baseline assumptions are $\eta_{gas} = 0.55$ for combined-cycle gas turbines, $\eta_{coal} = 0.38$ for coal-fired generation, $EF_{gas} = 0.37$ tCO₂/MWh and $EF_{coal} = 0.90$ tCO₂/MWh, consistent with standard engineering

values reported by the International Energy Agency^[29], Intergovernmental Panel on Climate Change^[30] and the European Commission Joint Research Centre^[31]. A prudential residual-load threshold of 0.20 (residual load over total load) is introduced to exclude hours characterised by very low residual demand conditions, where standard merit-order dynamics may be less representative of actual price formation.

The identification of the marginal technology follows a rule-based classification operationalising the merit-order logic. For each hour, observed electricity prices are compared with the estimated marginal costs of gas and coal. When the observed price is compatible with the estimated marginal cost of gas and gas-fired generation is active, the hour is classified as “Gas”; when the observed price is compatible with the estimated marginal cost of coal and coal generation is active, the hour is classified as “Coal”; remaining observations are assigned to a residual category. On this basis, an effective ETS transmission factor is constructed by assigning to each hour the emission factor of the identified marginal technology and aggregating over time. Inframarginal rents are then estimated by isolating the ETS-related component of electricity prices and attributing it to infra-marginal generation (wind, solar and hydro), which does not bear equivalent carbon costs but receives the market price set by fossil units.

2.3. Methodological Limitations

The approach should be interpreted as a stylised representation of market dynamics rather than a full reconstruction of price formation. In particular, it does not explicitly account for cross-border electricity flows and their impact on marginal pricing, network constraints and congestion effects, or situations in which non-fossil technologies—such as hydro, nuclear or storage—set the marginal price. Strategic bidding behaviour and other market imperfections are not modelled. As a result, the estimated marginal technologies and the associated ETS pass-through should be regarded as representative indicators of underlying market conditions rather than exact hour-by-hour reconstructions. The analysis relies on publicly accessible market and generation data; more granular assessments could potentially be developed by National Regulatory Authorities and ACER within the broader REMIT market-monitoring framework established by Regulation (EU) No 1227/2011^[32].

3. Results

The results are organised around four subsections that progressively move from the determinants of renewable-capacity expansion to the transmission of carbon costs into wholesale electricity prices. First

comes the econometric evidence on the drivers of renewable capacity development, testing the relative roles of public subsidies, the EUA price and their interaction within a two-way fixed-effects framework. Second comes the survey evidence on investment drivers, summarising how senior decision-makers in the six surveyed countries rank the relative importance of subsidies, regulatory stability, long-term support schemes, procurement mechanisms and the EUA price for both renewable generation and energy storage projects. Third comes the quantification of ETS-related inframarginal rents across the eight Member States analysed over 2021–2024, isolating the carbon-cost component embedded in wholesale electricity prices and estimating its magnitude in each country and year. Finally comes the comparison of the regulatory CO₂ factors used within the EU State aid framework for indirect ETS cost compensation with the observed market-based factors derived from the empirical methodology, highlighting the divergence between structural and market-based pass-through indicators across Member States.

3.1. Drivers of Renewable Capacity Development

Evidence in Table 2 indicates that renewable energy investment decisions are policy-driven, and that the carbon price signal alone is not sufficient^{[25][33]}. A 1% increase in public subsidies is associated with a 0.28% increase in renewable capacity, and the effect remains statistically significant after clustering standard errors at country level, confirming the role of public support schemes. In contrast, the EUA price does not exhibit a statistically significant direct effect on installed renewable capacity once country and year fixed effects and relevant controls are included. This suggests that carbon pricing alone is insufficient to drive renewable investment in Europe over the period considered. The interaction term between subsidies and EUA price is negative and weakly significant, suggesting that the effectiveness of subsidies declines as the carbon price increases—a result consistent with partial overlap effects within the broader policy mix^[3].

Renewable development	M1 (EU 27)	M2 (Rel. EUA)	M3 (EU27+NO)
L.ln_efsub	0.284** (0.125)	0.414 (0.257)	0.258** (0.122)
L.ln_eua	0.767 (0.985)	—	0.611 (0.999)
L.ln_efsub × L.ln_eua	-0.053* (0.030)	—	-0.046 (0.029)
ln_energy_VE	-0.037 (0.042)	-0.001 (0.032)	0.002 (0.031)
ln_GDP	0.118 (0.340)	0.357 (0.375)	0.286 (0.359)
L.ln_euarel		-0.166 (0.700)	
L.ln_efsub × L.ln_euarel		-0.041 (0.031)	
Constant	5.336 (3.620)	4.617 (4.652)	3.337 (3.597)
Observations	306	295	295
R-squared	0.805	0.812	0.813
Country FE / Year FE / Clustered SE	Yes	Yes	Yes

Table 2. Regression analysis of drivers of renewable capacity development

Source: Authors' elaboration. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. M1: EUA price, EU27; M2: relative EUA price (EUA × fossil share); M3: EU27 + NO.

3.2. Survey Evidence: Investment Drivers

For renewable energy generation projects, natural gas prices emerge as the most influential driver (average score 4.16 out of 5), followed by long-term public support schemes with durations exceeding 10 years (4.14), regulatory stability and policy certainty (4.10), public subsidies and incentives (4.09) and structured procurement mechanisms such as Contracts for Difference (4.08). The EUA price records a comparatively lower average score of 3.89. For energy storage systems, regulatory stability and policy certainty emerge as the most important factor (4.18), followed by capital expenditure (4.11), public subsidies and incentives (4.10) and development costs (4.09); the EUA price records an average value of 3.98. Across both segments (Tables 3 and 4), respondents consistently attribute higher importance to subsidies, long-term support schemes and regulatory stability than to the EUA price alone, confirming that market participants view public intervention and risk-reduction mechanisms as more decisive than carbon pricing alone^{[13][34]}.

Factor	Average score (1-5)
Natural gas price	4.16
Long-term public support (e.g. CfD >10y)	4.14
Regulatory stability and policy certainty	4.10
Public subsidies/incentives	4.09
Procurement (e.g. CfD)	4.08
Development costs	4.03
Capital expenditure	4.00
Power Purchase Agreements	3.94
EUA price	3.89
Exposure to spot markets	3.88

Table 3. Importance of factors in triggering investment in renewable energy generation projects

Source: Authors' elaboration based on survey responses (international survey of 180 firms across six EU ETS countries).

Factor	Average score (1-5)
Regulatory stability and policy certainty	4.18
Capital expenditure	4.11
Public subsidies/incentives	4.10
Development costs	4.09
Natural gas price	4.06
Procurement (e.g. CfD)	3.98
EUA price	3.98

Table 4. Importance of factors in triggering investment in energy storage systems

Source: Authors' elaboration based on survey responses (international survey of 180 firms across six EU ETS countries).

3.3. ETS-Related Inframarginal Rents Across EU Markets

The application of the methodological framework confirms the existence of substantial inframarginal rents across all countries analysed^{[35][36]}. The magnitude of estimated rents varies significantly: in 2022, Germany recorded €5.76 bn, France €3.29 bn, Italy €2.47 bn, Spain €2.14 bn, Poland €1.64 bn, the Netherlands €0.89 bn and Belgium €0.38 bn; by 2024, values had moderated to €2.10 bn (Italy), €1.48 bn (Germany), €0.96 bn (Spain), €0.88 bn (Poland), €0.86 bn (France), €0.40 bn (the Netherlands) and €0.13 bn (Belgium). Two elements are particularly relevant (Table 5). First, the magnitude of inframarginal rents appears closely linked to the frequency with which gas-fired generation acts as the marginal technology, rather than to the absolute level of the carbon price alone^[27]. Second, the persistence of these rents over time indicates that the ETS-related component of electricity prices is not limited to temporary market conditions or exceptional scarcity episodes but represents a structural feature of electricity markets in which fossil technologies continue to play a central role in price formation^{[28][37]}. Taken

together, these results support the interpretation that one of the main observable effects of the ETS in the power sector operates through the price-formation channel and the associated generation of persistent inframarginal rents.

Country	2021	2022	2023	2024
Italy	1.66	2.47	2.28	2.10
Spain	1.99	2.14	1.43	0.96
France	1.71	3.29	1.78	0.86
Belgium	0.19	0.38	0.24	0.13
Germany	2.46	5.76	2.27	1.48
Poland	0.77	1.64	1.28	0.88
Netherlands	0.44	0.89	0.53	0.40

Table 5. Estimated ETS-related inframarginal rents by country and year (€ billion, 2021-2024)

Source: Authors' elaboration based on hourly ENTSO-E^[16] data, FactSet fuel prices (TTF gas and international coal benchmarks) and EEX EUA prices.

3.4. Regulatory CO₂ Factors Versus Observed Market-Based Factors

A comparison between the maximum regional CO₂ emission factors defined in Annex III of Commission Communication C/2026/196^[38]—used within the State aid framework for indirect ETS cost compensation—and the observed market-based factors derived from the empirical methodology reveals materially divergent magnitudes (Table 6). Average observed market-based factors over 2021–2024 are 0.36 tCO₂/MWh for Italy (against a regulatory factor of 0.44, ratio 1.2x), 0.23 for France (0.43, ratio 1.9x), 0.21 for Spain (0.47, ratio 2.2x), 0.25 for Germany (0.73, ratio 2.9x), 0.17 for Belgium (0.37, ratio 2.2x), 0.27 for the Netherlands (0.44, ratio 1.6x), 0.27 for Poland (0.78, ratio 2.9x) and 0.01 for Sweden (0.60, ratio 46.2x). The Swedish case is particularly illustrative: despite a very limited observed frequency of fossil-fuel marginal price-setting conditions during the period analysed, the standardised regulatory CO₂ factor remains comparatively elevated. The divergence does not reflect statistical inconsistency but rather the

fundamental distinction between two different conceptual approaches: regulatory parameters rely on structural characteristics of electricity systems (weighted average CO₂ intensity of fossil-based generation within predefined geographical areas), whereas market-based indicators measure the effective transmission of carbon costs into wholesale electricity prices through observed marginal price-setting conditions.

Country	EU CO ₂ factor (tCO ₂ /MWh)	Observed market-based factor	Reg./obs. ratio
Italy	0.44	0.36	1.2×
France	0.43	0.23	1.9×
Spain	0.47	0.21	2.2×
Germany	0.73	0.25	2.9×
Belgium	0.37	0.17	2.2×
Netherlands	0.44	0.27	1.6×
Poland	0.78	0.27	2.9×
Sweden	0.60	0.01	46.2×

Table 6. Comparison between EU CO₂ factors and observed market-based factors (2021-2024)

Source: Authors' elaboration based on hourly ENTSO-E^[16] data, FactSet fuel prices, EEX EUA prices, and Annex III of Commission Communication C/2026/196^[38].

The four results indicate that the EU ETS operates in the European electricity sector primarily as a wholesale-price transmission and inframarginal-rent generation mechanism rather than as an autonomous driver of renewable investment. Subsidies and long-term contracts remain the dominant drivers of capacity expansion, ETS-related inframarginal rents are substantial across the eight Member States, and regulatory CO₂ factors diverge materially from market-based indicators.

4. Discussion

Our results contribute to a long-standing strand of literature on the role of carbon pricing in driving low-carbon investment. Previous studies have produced mixed conclusions. Some have argued that, in specific market and intermittency conditions, carbon taxes alone can reduce renewable investment incentives or be less effective than dedicated subsidies^[39]. Others have shown that an ETS without recycling revenues into renewables may reduce renewable generation by cutting overall demand and raising renewable costs, while using most ETS revenue to support all renewables can make the ETS “the spring” of renewable generation^[9]. For the EU specifically, higher carbon prices have been shown to reduce the differences between subsidy types, though subsidies remain important alongside the ETS^[24]. A regression study has found that higher permit volumes (looser caps) are associated with a lower share of renewables^[40], and recent reviews stress that policy mixes combining subsidies, carbon pricing, green bonds and other fiscal instruments are typically used in practice, with subsidies/FITs crucial for early deployment and carbon pricing increasingly important as markets mature^{[34][41][7]}.

Our findings contribute to this literature in three ways. First, the panel evidence on 2013–2024 confirms, with a longer and updated time horizon, that public support remains the dominant statistically significant driver of renewable-capacity expansion and that the EUA price does not exhibit an independent effect on installed renewable capacity. This result is consistent with Wang et al.^[25] and Lecuyer and Quirion^[33], who find that renewable subsidies outperform other approaches and that feed-in tariffs can be welfare-improving as a “safety net” when permits are overallocated. The added value lies in the triangulation between econometric, survey and market-based evidence: the survey results corroborate the econometric finding from the perspective of market participants, while the inframarginal rents estimation provides a quantitative measure of the alternative channel through which the ETS operates in practice. Second, the estimation of ETS-related inframarginal rents extends the analytical framework first developed by Keppler and Cruciani^[35] and Sijm et al.^[10] to a more recent period (2021–2024) and to a broader panel of eight Member States, exploiting the granularity of ENTSO-E hourly data. The estimates confirm the structural and persistent nature of the price-formation channel, in line with recent evidence on gas as marginal price-setter^[28] and on the role of carbon-cost pass-through in Italy^[36]. The contribution is methodological: by directly attributing price-setting conditions to fossil technologies whenever observed prices are compatible with their estimated marginal costs, the framework preserves the actual market pricing structure rather than imposing scarcity filters or

exogenous adjustments, thereby providing a transparent and replicable empirical approximation that could be further refined through access to REMIT regulatory market-surveillance datasets. Third, the comparison between regulatory CO₂ factors and observed market-based factors highlights an issue that has received limited empirical attention in the literature on indirect ETS cost compensation. While the State aid framework for indirect compensation has been the subject of significant policy debate, the empirical extent of the divergence between structural and market-based indicators has rarely been systematically documented. The evidence developed here suggests that, in several Member States, the effective carbon-cost pass-through embedded in wholesale electricity prices may be materially lower than the maximum structural CO₂ factors used to define the compensation envelope. This finding has direct implications for the proportionality and consistency of compensation schemes within the EU internal market: a mechanism originally designed to mitigate distortions associated with carbon-leakage risks could, under certain conditions, contribute to new forms of asymmetry within the internal market itself if standardised structural parameters progressively diverge from observed market-based pass-through dynamics as electricity systems continue to decarbonise.

Thus, the role of the ETS in the electricity sector should be assessed by distinguishing between different transmission channels. The ETS may operate simultaneously as a carbon-cost internalisation mechanism for fossil generation, as a wholesale electricity-price transmission mechanism, and as an implicit revenue-transfer mechanism generating persistent inframarginal revenues for low-carbon generation technologies not directly exposed to equivalent carbon costs. The coexistence of explicit renewable-support mechanisms financed through public resources and persistent ETS-related inframarginal revenues may generate cumulative remuneration effects not fully captured within conventional assessments of ETS effectiveness and renewable-support efficiency. The growing development of long-term contractual arrangements such as Contracts for Difference (CfDs) and Power Purchase Agreements (PPAs), together with the broader evolution of the European electricity-market design framework under Regulation (EU) 2024/1747^[42], reflects this structural transition toward a more differentiated relationship between short-term electricity-price formation and long-term low-carbon investment remuneration^[7].

4.1. Policy Implications

The evidence developed here has direct implications for the design of the EU ETS in the electricity sector during the next reform cycle.

The econometric finding that public support mechanisms emerge as a robust driver of renewable-capacity expansion, while the EUA price does not exhibit an independent effect on installed renewable capacity over 2013-2024, indicates that carbon pricing alone is not sufficient to steer investment decisions and that subsidies, long-term contracts and regulatory stability remain essential to support project bankability.

The survey evidence further supports the econometric results by showing that investors and energy utilities perceive public subsidies, long-term support schemes, and regulatory stability as the main drivers of renewable energy investments, while the ETS carbon-price signal is considered comparatively less influential. In particular, respondents consistently assign higher importance to direct support mechanisms and bankability conditions than to the EUA price itself, suggesting that carbon pricing alone is not perceived as a sufficiently stable or predictable incentive to trigger large-scale renewable deployment.

With regards to the inframarginal analysis, the complementary finding that ETS-related inframarginal rents accruing to non-fossil generation are substantial and structurally persistent across the eight Member States analysed over 2021-2024, ranging from around EUR 0.13 billion to EUR 5.76 billion per country per year, indicates that the ETS now operates predominantly through a price-formation and revenue-redistribution channel rather than as a primary investment-orienting mechanism. The coexistence of explicit renewable-support schemes financed through public resources and persistent ETS-related inframarginal revenues calls for a more explicit assessment of cumulative remuneration effects, in line with the broader evolution of the European electricity-market design framework under Regulation (EU) 2024/1747, which progressively encourages long-term contractual arrangements such as Contracts for Difference and Power Purchase Agreements as instruments capable of stabilising investor revenues without relying solely on short-term wholesale-price signals. The substantial divergence between the regulatory CO₂ factors defined in Annex III of Commission Communication C/2026/196 and the observed market-based factors derived from the empirical methodology, with ratios ranging from 1.2× in Italy to 46.2× in Sweden, has direct implications for the design of the State aid framework for indirect ETS cost compensation. In several Member States, the effective carbon-cost pass-through embedded in wholesale electricity prices may be materially lower than the maximum structural CO₂ factors used to define the compensation envelope, which means that compensation schemes calibrated on structural averages could progressively diverge from observed market dynamics as electricity systems continue to decarbonise.

A future revision of the framework should therefore consider a more explicit anchoring of the regulatory pass-through parameters to empirical, market-based indicators, alongside the existing structural approach, in order to preserve the proportionality and consistency of the compensation mechanism across the EU internal market. Taken together, these implications indicate that the effectiveness of the ETS in the electricity sector should be assessed by distinguishing between three transmission channels — carbon-cost internalisation in fossil generation, wholesale electricity-price transmission, and implicit revenue redistribution to low-carbon technologies — and that the next phase of ETS reform should be assessed jointly with the calibration of complementary support schemes and indirect-compensation rules, recognising that the carbon-price signal transmitted to industrial and electricity consumers reflects the interaction between regulatory scarcity, electricity-market design and the broader architecture of public-support instruments.

5. Conclusion

We have assessed whether the carbon price has effectively operated as a direct driver of renewable-energy deployment in the European electricity sector over the period 2013-2024 by combining econometric analysis, an international survey, and a market-based estimation of inframarginal rents over 2021-2024. We conclude reporting that (i) public support mechanisms is the dominant driver of renewable-capacity expansion, (ii) investors consider direct incentives rather than indirect role of ETS price and (iii) the ETS in power markets operates through wholesale price formation and the generation of inframarginal rents, and the regulatory CO₂ factors used for indirect ETS cost compensation diverge from observed market-based pass-through indicators. The key message is that, within European electricity markets, the EU ETS currently operates more directly as a wholesale-price transmission and revenue-redistribution mechanism than as an autonomous and stable driver of renewable investment. Our policy advice is that future reform increasingly require a more explicit assessment of the interactions among carbon pricing, electricity-market design, renewable-support schemes, and long-term investment bankability conditions.

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