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How Does Energy Transition Progress Affect the Reciprocal Relationships Between Environmental and Financial Performance in the EU Chemical, Rubber and Plastics Industries?

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Abstract

EU environmental regulations place a heavy burden on chemical-sector companies, complicating efforts to balance environmental responsibility and profitability. Understanding how financial and environmental performance evolve is essential for identifying the best policy combinations and for developing industrial strategies that incorporate the principles of sustainable development. This paper examines the bidirectional links between financial performance (FP) and environmental performance (EP) in the EU chemical (C20) and rubber and plastics (C22) industries, and assesses how a country's energy transition progress affects this relationship. Unlike most prior studies, we use dynamic panel models to capture the temporal cross-lagged dependencies between EP and FP, highlighting the importance of dual dynamics in the EP–FP relationship over time. We estimate linear and nonlinear (U-shaped and inverted U-shaped) relationships at the industry level. Results show reciprocal linear links between EP and FP in both industries, supporting the virtuous-circle perspective: each may reinforce the other. However, the proposed nonlinear relationships are not supported. Moreover, greater readiness for energy transformation at the country level, as measured by the ETI, is associated with better environmental performance in the chemical industry, reflected in lower energy consumption and greenhouse gas emission intensity. At the same time, it is negatively associated with financial results. These findings underscore the need for proactive, sector-specific policies that help industries advance the energy transition and climate neutrality without undermining financial performance.

Keywords: financial performance; energy intensity; environmental strategy; sustainable development; chemical industry; rubber and plastics industry; energy transition

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1. Introduction

The chemical sector is vital to many industries; however, its production primarily depends on oil and other fossil resources, making it a major source of environmental pollution [1–3]. Therefore, EU policymakers have begun imposing increasingly stringent pollution control requirements on chemical companies to promote greener practices, leading to a transition in the chemical industry. Among the measures implemented was the REACH Regulation (Registration, Evaluation, Authorization, and Restriction of Chemical Substances), which mandates chemical companies to disclose more information about

the environmental and human health risks of their products, and also offers registration exemptions for processes supporting new, sustainable innovations for five years [4]. Furthermore, since 2013, the scope of the European Emissions Trading System (EU ETS) has been expanded to include certain chemical installations as part of a new carbon-pricing policy that aims to encourage companies to adopt low-emission technologies by partially offsetting the higher investment costs associated with meeting climate and energy transition goals. This expansion underscores the urgent need to transform chemical manufacturing toward low-carbon modernization, which means much more than reducing emissions and also requires the structural modernization of technological processes, with production systems, energy sources, feedstocks, and innovation strategies redesigned to operate with minimal lifecycle carbon emissions while remaining economically competitive (Net-zero industry act, 2024) [5]. Still, investing in pollution control and environmental protection is expensive, creating a dilemma for the chemical industry, which must balance socially and environmentally responsible strategies with the goal of making profits [6].

Implementing such strategies may affect companies in the chemical sector by creating both opportunities and threats that can impact their financial and environmental performance (FP and EP), especially when companies gain more or less stakeholders' trust due to higher or lower compliance with regulatory requirements, respectively. Some companies prioritize the green transition, going beyond compliance by investing in environmental initiatives that decrease resource waste and increase profits from green products, offsetting compliance costs [7]. Conversely, strict regulations can add costs, lowering profitability and investment. This constrains opportunities to enhance financial performance through advanced environmental strategies, especially in sectors heavily regulated for environmental issues. Although the positive effect of environmental institutional regulations promoting the energy transition on corporate environmental progress is undeniable, its influence on the EP–FP relationship is contested [8–10]. Therefore, in this study, we examine whether energy transition strategies (including both energy system performance and transition readiness dimensions) influence how the chemical sector reconciles environmental responsibility and strategy with financial goals.

In the literature, debate persists over whether a firm's financial performance is the result of or the driver of environmental activities. Although numerous studies examine the causal direction from EP to FP, research on reverse causality between EP and FP remains scarce [11–13]. The rationale for reverse causality is that companies' engagement in environmentally friendly activities varies with the level of financial slack, so financially successful companies are expected to operate at a higher sustainability level according to their stakeholders [14]. This pattern holds for the sector as a whole. Such activity suggests a possible non-linear relationship between EP and FP [13]. Therefore, it is necessary to investigate the EP–FP linkages in more detail to identify possible reciprocal and non-linear relationships between environmental and financial performance. We address this research gap in the context of the sector level in this paper.

It was highlighted that a firm's industry affiliation greatly affects the EP–FP relationship, as responses to enhanced environmental management strategies can vary with technological capabilities and market conditions [11,15]. Research on the effect of EP on FP within specific industries is limited, mainly focusing on energy sector firms [16,17], with scant studies on the chemical industry [18]. Given the lack of research on how energy transition strategies at the country level influence the financial and environmental performance of the EU chemical sector, which faces uniform regulations on decarbonisation, energy efficiency, and environmental impact reduction, this study addresses this gap in the literature.

This study aims to identify and assess the bidirectional links between financial and environmental performance across EU chemical sectors C20 (chemical) and C22 (rubber and plastics), differentiated by energy and emissions intensity, and to examine how countries' progress in balancing energy equity, security, and sustainability (Energy Transition Index) influences these relationships, highlighting similarities and differences in vulnerability to changes in the energy transition across these sectors.

It advances the literature by offering insights into EP–FP interactions using both linear and nonlinear models and by demonstrating how changes in energy transition affect the chemical sector's ability to balance environmental and financial priorities. Unlike many prior studies that rely on static models, our approach uses dynamic models to accurately capture interactions among energy transition measures, financial outcomes, and environmental performance. Following Liu [11], we apply the temporal cross-lagged model to highlight the importance of dual dynamism in EP–FP relationships over time, enabling a more dynamic analysis and reducing endogeneity concerns. Ultimately, the study discusses the economic and environmental impacts of changes in countries' energy transition on EU chemical sectors, which face challenges given their role in European economic growth and climate neutrality goals.

The rest of the paper is organized as follows: Section 2 reviews the relevant literature; Section 3 outlines the research methodology; Section 4 describes the data used; Section 5 reports and discusses the empirical results, including robustness checks; Section 6 concludes by highlighting the main findings and policy implications.

2. Theoretical Foundations

Theoretical discussions on the link between environmental performance (EP) and financial performance (FP) reveal various perspectives explaining both positive and negative relationships across manufacturing firms, guiding the development of linear and nonlinear models. According to neoclassical theory (Friedman's hypothesis), strict environmental regulations compel companies to allocate extra resources to minimize environmental harm, which can increase costs and reduce profits. For example, chemical firms that adopt clean production, water treatment, carbon capture, and recycling technologies improve environmental performance [18]. If many companies within a chemical sector implement these approaches, aggregate environmental performance may lead to higher sector productivity, greater innovation intensity, stronger competitiveness, and improved long-run financial performance (transition pathway for the chemical industry, single-market-economy.ec.europa.eu). However, these firms may also experience profit declines due to higher compliance costs [18], high energy costs, or increased global competition (single-market-economy.ec.europa.eu). As a result, a sector may suffer declining profitability while simultaneously achieving substantial reductions in emissions and waste, especially in the chemical sector.

Porter [19] argues that stricter environmental regulations can prompt companies to adopt innovative production methods, potentially improving their profitability and competitiveness over time. This positive view of environmental performance (EP) benefiting financial performance (FP) is supported by resource-based theory [20], which suggests environmental advances lead to new skills and cleaner production technologies, enhancing financial results. At the sector level, in the case of the chemical industry, resource-based theory helps explain why this sector is generally characterized by high R&D intensity, specialized scientific knowledge, and advanced production technologies.

Most of the literature explains how EP affects FP; only a few studies examine the reverse direction, i.e., how FP influences EP [21]. Evidence shows that better FP can improve EP, supporting slack resource theory, which suggests financially successful firms

have resources to invest in environmental and social efforts [22,23]. The same applies at the sectoral level, i.e., sectors with stronger aggregate financial performance generate greater collective slack resources, enabling companies within the sector to invest more heavily in environmental improvements, especially for chemical companies, to invest in low-carbon technologies, to finance recycling and circular-economy projects, and to implement cleaner production processes. However, some studies find a negative effect, indicating that more financial slack can make firms less responsive to social pressure to improve environmental performance [24]. At the sectoral level, this might indicate that a given sector is collectively less sensitive to external demands for environmental improvement, and that its financial strength serves as a buffer against the pressure resulting from environmental regulations that require costly investments in environmental protection, especially in the case of the chemical sector. Research on the bidirectional relationship between EP and FP is limited both at a firm and sector level. This study aims to fill that gap.

The inconsistent evidence on the relationship between EP and FP suggests the possibility of a non-linear relationship, shaped like an inverted U or U, questioning whether FP is a result or driver of EP [13]. As environmental efficiency improves, companies' sales and profits initially rise, but only up to a certain point. Beyond this threshold, greater involvement in environmental activities—especially among innovative producers and technology leaders—may hurt financial performance, as the costs of environmental investments outweigh the profits they generate, creating an inverted U-shaped relationship. This aligns with the "too-much-of-a-good-thing effect" (TMGT) [25,26], which suggests that better environmental performance can have negative effects (FP) if gains in EP exceed a certain threshold, leading to costs that outweigh benefits. Additionally, there is a "too-little-of-a-good-thing" (TLGT) effect, which explains how early improvements in EP can be costly due to the long payback period of environmental investments and the necessary shift from low-cost "end-of-pipe" solutions to more expensive clean technologies [26]. Once the threshold point (TP) is crossed, further investments in clean technologies and innovations improve financial outcomes, following a U-shaped curve. The same holds at the sector level, i.e., insufficient environmental commitment across the entire sector leads to its technological backwardness and a decline in competitiveness (TLGT), and too restrictive environmental standards imposed too quickly across an entire sector result in the TMGT effect, when compliance costs cripple profitability, leading to a decline in its economic performance.

Regarding FP's impact on EP, relationships may be either inverted U-shaped or U-shaped. In the inverted U-shape, companies with limited slack resources (below the FP threshold) are forced to comply with strict environmental regulations, boosting environmental efficiency. Meanwhile, firms with ample financial slack tend to invest less in environmental efforts, resulting in decreased performance (aligned with slack resource theory) [27,28]. The U-shaped relationship indicates that lower-performing companies focus more on expanding production, which increases environmental impact; conversely, firms with higher financial performance reduce environmental harm because resource availability encourages eco-friendly projects (consistent with resource-based views) [21,29]. This pattern of relationship also applies at the sector level.

The relationship between EP and FP is shaped by institutional theory, which highlights companies' and the entire sector's compliance with environmental regulations. The EU's climate goals and rules create a strong institutional framework that encourages sustainability initiatives. Institutional pressures often influence the EP–FP link, as strict regulations motivate firms to assume environmental responsibility, increase pro-environmental activities, and find opportunities to boost competitive advantage and financial outcomes [30]. However, commitment to the Sustainable Development Goals (SDGs) can also lead to reduced financial returns. At the sectoral level, institutional theory suggests that the EP–FP

relationship varies with the institutional environment, including regulatory quality, policy commitment, enforcement, the financial system, and societal expectations. Although all EU countries operate under EU legislation, they differ in enforcement intensity, administrative quality, stakeholder pressure, and policy stability. Therefore, the EP–FP relationship may vary across national institutional environments. Across EU countries, stronger institutions provide regulatory support, financial resources, innovation capacity, and policy certainty. These conditions improve environmental performance and support the energy transition, increasing the likelihood that such improvements are rewarded through enhanced financial performance. This is the rationale for examining how these multidimensional conditions affect the EP–FP relationship across chemical industries that are heavily affected by EU environmental and climate policies, though to varying degrees depending on their energy and emissions intensity.

3. Research Methodology

Neglecting the reciprocal relationship between firms' and sectors' financial and environmental performance may cause a simultaneity problem [31]. The same problem may arise from an incorrect dynamic structure of the model describing the EP–FP relationship, which is why Liu [11] proposed a cross-lagged temporal model that includes lagged independent variables and an autoregressive term. This approach highlights the dual dynamics of EP–FP, as financial responses to improved environmental performance were often delayed, and the financial performance tended to be persistent [32,33]. Moreover, in modelling the EP–FP relationship, a one-period-lagged variable related to progress in energy transition is included because its effects on profitability or on reducing environmental degradation are only visible after some time [34]. The following econometric model is proposed, which describes the impact of EP on FP in Equation (1) and FP on EP in Equation (2) with the stimulating role of energy transition progress, addressing the issue of dual dynamism among financial and environmental variables, as well as the non-linear nature of these relationships:

$$FP_{i,t} = \alpha_0 + \alpha_1 FP_{i,t-1} + \alpha_2 EP_{i,t-1} + \alpha_3 EP^2_{i,t-1} + \alpha_4 ETI_{i,t-1} + \alpha_5 Size_{i,t} + \delta_i + \varepsilon_{i,t} \quad (1)$$

$$EP_{i,t} = \beta_0 + \beta_1 EP_{i,t-1} + \beta_2 FP_{i,t-1} + \beta_3 FP^2_{i,t-1} + \beta_4 ETI_{i,t-1} + \beta_5 Size_{i,t} + \gamma_i + \epsilon_{i,t} \quad (2)$$

where $FP_{i,t}$ and $FP_{i,t-1}$—current and lagged financial performance of industries representing i-th country in year t (i = 1, 2, …, N; t = 1, 2, …, T), $EP_{i,t}$ and $EP_{i,t-1}$—current and lagged environmental performance of industries, $ETI_{i,t-1}$—lagged indicator describing the energy transition progress in the i-th country, $Size_{i,t}$—the industry's size in the i-th country, α_j and β_j (j = 0, 1, …, 5)—estimated coefficients, δ_i and γ_i—cross-sectional specific effects of industries on FP and EP respectively, $\varepsilon_{i,t}$ and $\epsilon_{i,t}$—error terms in Equations (1) and (2).

In the case of a nonlinear relationship between EP and FP (a U-shaped: $\alpha_2 < 0$, $\alpha_3 > 0$ or $\beta_2 < 0$, $\beta_3 > 0$; an inverted U-shaped: $\alpha_2 > 0$, $\alpha_3 < 0$ or $\beta_2 > 0$, $\beta_3 < 0$), the estimated value of the turning point (TPEP or TPFP) should be compared with the empirical range of the independent variable:

$$TP_{EP} = \frac{-\alpha_2}{2\alpha_3} \; or \; TP_{FP} = \frac{-\beta_2}{2\beta_3} \quad (3)$$

The assessment of the turning point (TPEP) identifies the maximum (inverted U-shaped) or minimum (U-shaped) level at which proactive environmental practices might be beneficial [35]. TPFP estimates indicate the optimal level of financial performance for improving sustainable environmental practices.

The Generalized Method of Moments (GMM) dynamic panel estimation enables addressing some econometric problems related to endogeneity and serial correlation is-

sues [36–40]. Following Kapuria and Singh [41], who estimated dynamic models on a panel sample of similar size (N = 19, T = 7), the parameters of Equations (1) and (2) are estimated by means of the difference generalized methods of moments (GMM) technique to control potential endogeneity problems. The two primary sources of endogeneity are unobserved heterogeneity and simultaneity. The first problem may result from the omission of variables in the regression equation that reflect time-invariant characteristics of each industry. The second problem of simultaneity (or reverse causality) may occur when the financial performance of the two studied industries: chemical and rubber and plastics industries and their environmental activities impact variables affect each other and have reciprocal feedback [41]. Moreover, the existence of a potential dynamic link between current values of environmental performance variables and past realizations of financial performance variable may introduce the dynamic endogeneity bias. The presence of lagged dependent variable among the explanatory variables can be referred to as dynamic endogeneity bias, as such a lagged variable could be correlated with the error term and lead to the serial correlation problem [33]. According to Arellano and Bond (1991), the first difference GMM panel data estimator solves the aforementioned endogeneity problems, but its limitation is the reduction in the number of observations and it may lead to the creation of relatively weak instruments [33]. The lagged dependent and independent variables have been introduced as instrumental variables [41,42]. To keep the number of instruments below the number of cross-sectional units—thereby mitigating the risk of instrument proliferation—this study restricts the lag range used for instrument construction, rather than employing the full set of available lags, consistent with the approach of [43,44]. The Arellano–Bond 2-step estimator is chosen, which allows the calculation of white period robust standard errors [45]. To verify the validity of GMM estimation, the Hansen test for instrument reliability and the Arellano–Bond test for autocorrelation are used [40]. If the disturbances $\varepsilon_{i,t}$ and $\epsilon_{i,t}$ are not serially correlated, one expects to find evidence of negative first-order serial correlation and no evidence of second-order serial correlation in the differential residuals. Therefore, the first-order (AR(1)) and second-order (AR(2)) serial correlation statistics should be significant and insignificant, respectively [46]. The Hansen test of overidentifying restrictions verifies the validity of instrument subsets, with the null hypothesis positing no correlation between the instrumental variables and the residuals [40,41,46].

Therefore, implementing the GMM approach allows for obtaining more robust estimation results and, consequently, drawing more reliable conclusions regarding the identification of the EP–FP relationship and the impact of environmental policy stringency on it, compared to static panel models [40].

4. Data Description

The financial performance (FP) of the C20 and C22 sectors is approximated by the standard indicator used in the Structural Business Statistics (SBS) conducted by Eurostat, which determines the share of gross operating surplus in value added at factor costs [%]. According to Eurostat, "the profit share of non-financial corporations is the gross operating surplus divided by gross value added" (Business—statistics on profits and investment. Statistics Explained, November 2025) [47]. This variable is defined as the ratio of value added at factor costs minus personnel costs to the gross income from operating activities, adjusted for operating subsidies and indirect taxes. In other words, the numerator of FP indicates the portion of economic output available for saving after accounting for taxes on income and wealth and for remuneration of capital (dividends or reinvested earnings), which may be used, for example, for investments, other capital transactions, or loans (Eurostat, 2025) [47]. In turn, the denominator of FP reflects the value generated by the production account, showing the value added to products or services beyond raw

materials, so value added can be useful for formulating an industry's development strategy or for industry comparisons. We selected this indicator because it is methodologically consistent with Eurostat-recommended environmental performance measures, such as energy intensity or greenhouse gas emission intensity.

Environmental performance (EP) is assessed based on two indicators aligned with the EU's climate goals and the Green Deal Industrial Plan: improving energy efficiency and reducing air pollutant emissions. The first is the Energy Intensity (EI), which measures net energy consumption per unit of value added at factor costs [kilowatt-hours per euro]. A lower EI indicates higher energy efficiency in production, as less energy is needed to generate each unit of value added [48]. The second is the Greenhouse Gas Emissions Intensity (GHGI), representing the proportion of greenhouse gas emissions from chemical production relative to value added at factor cost [kilograms per euro]. The lower the GHGI, the cheaper it is to remove pollutants and comply with environmental regulations, thereby improving chemical sectors' environmental performance [49]. This approach to measuring environmental performance is recommended by official statistical and institutional guidelines (Eurostat, OECD, IEA). It also enables consistent calculation and compilation of results across industries within individual countries [50]. Researchers use these two indicators as official measures of sustainable development for European Union countries [51] and treat them as operational measures of energy efficiency, arguing that reducing them is necessary to decouple economic growth from energy consumption [52].

The Energy Transition Index (ETI) was included as a variable measuring the progress in energy transition in EU countries. A country's ETI is a weighted composite of scores on two sub-indices: the system performance index, assessed across dimensions of economic development and growth, environmental sustainability, and energy access and security; and the transformation readiness index, estimated based on dimensions of regulations and political commitments, institutions and governance, capital and investments, infrastructure and innovative business environment, human capital and consumer participation, and energy system structure (World Economic Forum, 2025) [53]. The multidimensionality of the ETI makes this variable useful for assessing the efficiency of a country's energy system and for better understanding the current state of the country's energy transition [54]. It is worth emphasizing that the ETI indicator may reflect whether the legal and political environment in a given country creates appropriate conditions for progress in energy transformation. Singh et al. [54] point out that the ETI incorporates institutional, social, and geopolitical factors into its Transition Readiness sub-index, which accounts for 50% of the total score. These factors are measured through the "Regulation and Political Commitment" pillar (covering policy stability, regulatory indicators for sustainable energy—RISE—and international commitments) and the "institutions and governance" pillar (covering rule of law and transparency). Qazi [55] indicates that poor performance in the area of "Regulation and Political Commitment" lowers a country's overall ETI score. Countries that perform well in the energy transition are characterized by a strong rule of law, high scores on the RISE (energy efficiency and renewable energy sources) index, and a clear commitment to climate neutrality.

Moreover, we use Size as a control variable, which may explain potential differences across countries in the chemical industry regarding access to financial resources or "green" financing necessary to cover the high costs associated with sustainable development [8], as well as the possibility of obtaining additional support for implementing energy transformation programs, accessing technological innovations, or adopting pro-environmental strategies [26]. Due to data availability, information on the number of employees and active chemical enterprises is used to assess the average employment level in the C20 and C22 sectors. Based on this, the control variable—Size 1—is defined as a dummy variable that

takes the value 1 for countries with an employment indicator above the median and 0 otherwise. This variable captures the employment-scale effect, indicating whether the chemical industry is more or less important to a country's economy. To conduct robustness checks, we also included the continuous variable Size 2, which reports the average employment in the chemical industry across countries.

All variables related to the environmental and financial results of sectors producing chemicals and chemical products (NACE C20) and rubber and plastics products (NACE C22) are calculated using data from the Eurostat Structural Business Statistics and Eurostat databases (see Table A1). Due to data availability, the final sample comprises sectors C20 and C22 in the following EU countries: Austria, Belgium, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. Econometric analyses cover the period 2014–2022 because EU climate and energy policy rules changed significantly during these years. These changes may have influenced progress in the country's energy transition and the chemical industry's environmental performance. The sample starts in 2014 due to data availability and because key events and policy decisions from that period were particularly relevant to the industries studied (the adoption of the 2030 Climate and Energy Policy Framework, the implementation and enforcement of Phase III EU Emissions Trading System regulations, the Energy Security Strategy and the foundation of the Energy Union, and the new Energy Efficiency Directive and support policies for electro-intensive industries).

Following Refs. [56,57], variables are winsorized at the 5th and 95th percentiles to reduce the influence of outliers on the parameter estimates in Equations (1) and (2). Setting this wider threshold—in line with the method proposed by [57], which uses the 5th and 95th percentiles rather than the 1st and 99th—dampens extreme object-specific values, including those arising from COVID-19, without imposing a uniform pandemic effect, as the C20 and C22 sectors may have been affected by the pandemic in different ways. Nonetheless, we examined whether the COVID-19 period (2020–2021) was associated with a disproportionate share of winsorized observations. For each variable winsorized at the 5th/95th percentiles, we compared the proportion of adjusted sector-year observations in the pandemic years with that in the remaining years using a two-proportion *t*-test (see Table A2). The proportion of adjusted observations in 2020–2021 does not differ significantly from that in other years ($p > 0.40$), suggesting that our winsorization approach adequately addresses COVID-related extreme values.

Descriptive statistics are used to examine the basic characteristics of the data (Table 1). We use EViews 14 software for empirical analyses.

Table 1. Descriptive statistics and unit root test.

Statistics/Test	FP		EI		GHGI		ETI
	C20	C22	C20	C22	C20	C22	
Minimum	34.6169	24.3110	2.9270	0.0971	0.1426	0.0277	53.79
Mean	53.0338	41.5189	16.3779	1.1458	2.0470	0.1444	62.37
Median	51.7753	41.5056	12.8221	1.0479	1.4739	0.0867	61.80
Maximum	73.6979	57.5392	40.6943	2.8036	6.8907	0.6113	72.58
Variation Coefficient	20.16%	23.19%	69.49%	61.26%	91.74%	113.71%	8.21%
Stationarity test							
LLC test	−13.4157 ***	−3.2553 ***	−3.0923 ***	−6.8206 ***	−14.7995 ***	−2.0811 **	−8.2543 ***
p-value	0.0000	0.0006	0.0010	0.0000	0.0000	0.0187	0.0000

Note: ***, **, indicate the significance at the 1%, 5% levels, respectively; Modified Schwarz Information Criterion (MSIC) is used for lag selection; T = 9, N = 23. LLC test—the Levin, Lin, and Chu test for unit root.

Comparing the minimum, mean, median, and maximum values of the financial performance indicator, it is evident that the share of gross operating profit in value added is higher in companies producing chemicals and chemical products compared to those producing rubber and plastics products. The variability of financial results remains similar for C20 and C22 companies, at 20% and 23%, respectively. However, significant differences in environmental performance are observed, with the mean and median energy intensity and greenhouse gas emission intensity higher for C20 companies than for C22 companies. The surveyed groups of companies are not homogeneous in terms of the negative environmental impact of their production processes, with coefficients of variation for EI above 60% and for GHGI over 90%. The chemical industry (C20) produces bulk chemicals—including ammonia, fertilizers, petrochemicals, basic organic chemicals, industrial gases, chlorine, and alkali products—using large amounts of electricity and fossil fuels. By contrast, C22 converts existing polymers (plastics and rubber) into final products through energy-intensive processes such as extrusion, injection molding, blow molding, and thermoforming, but uses much less energy than C20. As a result, C20 has higher energy intensity than C22. Similarly, C20 has a higher GHGI because it generates process emissions directly from chemical reactions, in addition to emissions from fuel combustion. By contrast, C22 mainly involves material transformation, with emissions primarily linked to energy use rather than chemical reactions. Greater variability across countries is also expected for C20, as national chemical industries differ in their product mix. [58,59]. Analysis of the descriptive statistics for the Energy Transition Index shows that EU countries are most similar to one another in the functioning of their energy systems and in the current state of their energy transition, with a coefficient of variation of 8%. Following the panel data modelling procedure outlined by [41], the Levin, Lin, and Chu (LLC) test is conducted to assess the stationarity of the variables. The null hypothesis of unit roots in the panel variables is rejected at the 5% level, confirming that all variables are stationary.

5. Empirical Results and Discussion

5.1. Impact of EP on FP in the Chemical, Rubber, and Plastics Sectors

To assess whether transition energy (ETI) influences the effect of environmental performance on financial results, the parameters of Equation (1) were estimated for NACE C20 and C22 (Table 2).

To justify the choice of the dynamic specification of model (1), it is helpful to evaluate the significance of the autoregressive coefficient (α_1), which measures the impact of the previous year's financial results on their current value. All autoregressive coefficients are positive and statistically significant at the 1% level (Table 2); however, in the case of the C20 sector, their relatively low values suggest low persistence of financial results over time (Table 2), while in the C22 sector, their relatively higher values compared to the C20 sector indicate that the share of gross operating surplus in value added is more persistent and more susceptible to the influence of its past values. Therefore, it is evident that the financial results of the C22 industry exhibit greater stability over time than those in the C20 industry. This can be explained by the fact that C20 sector is more vulnerable to environmental risks than C22 sector, due to their second-largest share in the EU economy's net energy consumption (around 8.1%) in 2022 (Eurostat, Net domestic energy use by economic activities of the European Union (EU-27), 2022) [60] and due to different energy intensity (C20 is one of the most energy-intensive manufacturing sectors, and C22 is much less energy-intensive than C20). In the context of decarbonizing the EU industry, this may lead to lower persistence of their financial outcomes. Similar results at the company level have been found by [11], who modeled the relationship between EP–FP and highlighted the

high stability of companies' financial results over time. Vashisht et al. [29] also showed that the autoregressive coefficients estimated for profitability indicators of brown companies are lower than those for green companies, but in both groups, they are positive and significant.

Table 2. Results of panel regression estimation (1).

Parameter	Dependent Variable: FP			
	C20		C22	
	Linear	Nonlinear	Linear	Nonlinear
$\alpha_1(FP_{t-1})$	0.1403 *** (3.339)	0.3011 *** (4.6033)	0.3061 *** (5.8968)	0.4710 *** (5.0517)
$\alpha_2\ (EI_{t-1})$	−0.9038 *** (−6.7158)	−1.0957 *** (−15.964)	−6.8729 *** (−5.9344)	−24.115 *** (−3.9977)
$\alpha_3\left(EI_{t-1}^2\right)$	-	0.0103 *** (5.1793)	-	5.5839 *** (3.9904)
$\alpha_4(ETI_{t-1})$	−0.8422 ** (−2.4677)	−0.7232 *** (−4.1483)	−0.4673 ** (−2.6152)	−0.6229 ** (−2.0858)
$\alpha_5(Size1_t)$	−8.4254 (−1.1270)	−3.6729 (−1.1916)	−0.5373 (−0.6782)	−0.4808 (−0.5606)
TPEP	-	53.166	-	2.159
Diagnostic tests				
Number of instruments	21	22	17	18
Hansen test	20.4646 [0.2512]	20.996 [0.2265]	13.959 [0.3767]	14.449 [0.3429]
AR(1) test	−2.4977 [0.0125]	−2.8885 [0.0039]	−2.7419 [0.0061]	−2.6265 [0.0086]
AR(2) test	−0.4777 [0.6328]	−0.5951 [0.5518]	−1.1344 [0.2566]	−0.2725 [0.7852]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, **, indicate the significance at the 1%, 5% levels, respectively. Size 1 is a dummy variable.

Analysis of the estimation results in Table 2 shows that the parameters of the linear models for the EI variable (α_2) are negative and statistically significant at the 1% level. This indicates that reducing the energy intensity of production processes in both sectors (NACE C20 and C22) this year will lead to improved financial outcomes in the following year. The direction of the EP–FP relationship, as indicated by the linear models, can be explained by the natural resource-based view. Higher energy intensity in the chemical industry, as well as in the rubber and plastics industry, may signal cost-driven production processes, reflecting compliance costs and exposure to regulatory risk, which may negatively impact financial performance. In turn, lower energy intensity may suggest that the chemical industry has built a development strategy based on resource-efficient technologies, and that innovations in production technologies have been offset by the gradual realization of profits from compensation.

Considering the nonlinear models (Table 2) and the signs and significance of the parameters ($\alpha_3 > 0$, $\alpha_2 < 0$), a U-shaped relationship could be identified between energy intensity (EI) observed a year earlier and the current share of gross operating surplus in value added (FP) in the chemical sector (C20) and the rubber and plastics sector (C22). This would indicate the existence of two groups of the chemical industries in EU countries which are characterized by higher profitability: one with the worst environmental performance

and the other with the best results. In the most harmful group (EI > TPEP), reducing energy intensity in the current year would result in worse financial outcomes the following year. Conversely, in the more environmentally friendly group (EI < TPEP), improving EI would lead to better financial results in the following year. However, comparing the energy intensity turning points (TPEP) in the C20 and C22 industries (53.166 kWh/EUR and 2.159 kWh/EUR) with their empirical ranges shows that they are above or near their maximum EI values (40.6943 kWh/EUR and 2.8036 kWh/EUR—see Table 1). This means that the chemical industries in most countries maintain energy intensity below the thresholds, which supports the idea that improved environmental performance positively impacts financial results and is consistent with linear model findings. Consequently, the results from nonlinear models do not provide convincing evidence of a U-shaped relationship between EP and FP in the C20 and C22 sectors, as the threshold point (TP) is above or near the maximum EI values.

Nevertheless, several company-level studies show a U-shaped or an inverted U-shaped relationship between environmental and financial performance (EP–FP), reflecting its dependence on environmental strategies and business models, compliance costs, and stakeholder perceptions [17,26,30,57,61,62]. On the other hand, some researchers use only linear models to evaluate the EP–FP relationship. Liu [11] found a positive effect of EP on FP based on estimation results of linear model explaining that the increase in a company's environmental performance can improve its financial performance in the next period. Vashisht et al. [29] did not confirm the significant impact of environmental scores on financial performance for brown firms, by assessing the estimation results of linear models, which varied depending on the model specification, estimation methods, and FP and EP measures. The estimated linear models for C20 and C22 chemical sectors indicate the same direction of the impact of EP on FP as in the empirical study presented by Liu [11] at the firm level; a similar lag structure in the response of financial performance to improved environmental performance was also observed.

Analysis of the coefficients assigned to the variable ETI, which represents the impact of progress in the EU energy transition (linear models, −0.8422 ** and −0.4673 **, Table 2), shows that all are negative and significant at the 5% level. This suggests that advancing the EU energy transition, as reflected in a higher ETI scores this year, may reduce the share of gross operating surplus in value added in the C20 and C22 industries next year. The chemical industries in highly regulated countries that perform well in energy efficiency and have favorable conditions for an effective energy transition might face higher compliance costs under new environmental regulations tied to the country's energy transition programs, which could affect their financial performance in the short term. This is particularly important because key industry stakeholders, such as customers, regulatory agencies or governing bodies, can directly influence the activities of the chemical industry by imposing specific environmental requirements or standards that must be met [8]. Martín-Tapia and Llamas-Sánchez [10] confirmed that in a company-level study, i.e., companies in countries with strict regulations and advanced environmental progress, realized fewer profits from unique environmental actions due to institutional pressures for uniformity.

For the control variable Size, all coefficients (α_5) are negative for the C20 and C22 sectors, but in both linear and nonlinear specifications, they are insignificant (Table 2). The negative impact of size on the chemical industry might suggest that FP is lower in areas with a larger employment-based economic impact of the chemical industry. Li et al. [30], referring to this correlation, explained that highly employment-intensive companies tend to avoid environmental irresponsibility due to greater public and government pressure. This pattern may also dominate the entire chemical industry, especially the C20 sector.

The validity of GMM estimation is assessed using two post-estimation tests: the autocorrelation test and the instrument reliability test, presented in Table 2 (Ref. [63]). Under the dynamic model assumptions, there is evidence of negative first-order serial correlation (Arellano–Bond AR(1) statistics are negative and statistically significant at the 5% level) and no evidence of second-order serial correlation (Arellano–Bond AR(2) statistics are insignificant at the 10% level) in the differential residuals of model (1). The Hansen test of overidentifying restrictions confirms the validity of the instruments in linear and nonlinear models [41,44].

5.2. Impact of FP on EP in the Chemical, Rubber, and Plastics Sectors

To assess the impact of FP on EP, with the energy transition (ETI) acting as a stimulus, dynamic panel models (2) were estimated for NACE C20 and C22 (Table 3).

Table 3. Results of panel regression estimation (2).

Parameter	Dependent Variable: EI			
	C20		C22	
	Linear	Nonlinear	Linear	Nonlinear
$\beta_1(EI_{t-1})$	0.3522 *** (9.0703)	0.8443 *** (28.226)	0.2519 *** (37.507)	0.2751 *** (4.1467)
$\beta_2\ (FP_{t-1})$	−0.3365 *** (−14.007)	0.3465 *** (14.779)	−0.0123 *** (−4.4457)	0.1366 ** (2.9480)
$\beta_3\left(FP_{t-1}^2\right)$	-	−0.0039 *** (−9.6261)	-	−0.0013 *** (−2.8795)
$\beta_4(ETI_{t-1})$	−1.5819 *** (−13.009)	−0.3587 *** (−2.3789)	−0.0508 *** (−15.276)	−0.0773 *** (−5.965)
$\beta_5(Size1_t)$	−1.4875 (−0.4412)	−0.9441 (−0.3679)	−0.0043 (−0.1498)	−0.2589 ** (−2.3033)
TPFP	-	44.433	-	52.538
Diagnostic tests				
Number of instruments	19	21	17	21
Hansen test	17.327 [0.2997]	21.251 [0.1691]	17.784 [0.4026]	10.785 [0.5474]
AR(1) test	−2.8901 [0.0038]	−2.8852 [0.0039]	−2.3599 [0.0183]	−1.8597 [0.0629]
AR(2) test	−1.1915 [0.2334]	−0.9449 [0.3447]	−0.2105 [0.8333]	−0.4352 [0.6634]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, ** indicate the significance at the 1%, 5% levels, respectively. Size 1—a dummy variable.

The autoregressive coefficients (β_1) are positive and significant at the 1% level (linear and nonlinear models), indicating that sectors' energy intensity from the previous year can carry over into the current year, thereby confirming the dynamic specification in Equation (2). These findings align with other empirical studies at the company level showing high stability in companies' environmental performance over time [32].

The negative and statistically significant estimates of the β_2 coefficient (p-value < 0.01) in linear models (Table 3) indicate that higher financial results (FP) in the previous year for the C20 and C22 sectors are associated with lower energy intensity in their current operations. According to the slack resources theory, improving the financial performance

of the chemical sectors can lead to greater environmental performance the following year. Slack resources, indicated by high profitability, may motivate companies and entire sectors to invest in new technologies or environmental initiatives that reduce their negative environmental impact [20,26]. As the gross operating surplus in value added increases, the share of economic production savings available for use, e.g., for investments supporting innovative, pro-ecological projects, also rises, allowing the chemical industry to act more effectively in environmental protection. This suggests that improving sectors' financial performance can lead to better environmental efficiency the following year. In particular, the different responses of the C20 and C22 sectors to financial slack may reflect their structural differences. Compared with the rubber and plastics sector (C22), the chemical sector (C20) is more capital-intensive, spends more on R&D, faces stricter environmental regulation, and consumes more energy [64]. Chemical production is also dominated by large, integrated firms subject to substantial environmental and safety requirements, while rubber and plastics manufacturing is more fragmented and includes a larger share of SMEs. As a result, additional financial resources are more likely to fund environmental investments and process innovations in C20 than in C22, producing a stronger effect of slack resources on environmental performance (cefic.org, Chemical trends report) [65].

Empirical studies at the company level also confirmed that companies with better financial health can enhance environmental performance. This positive correlation is explained by the fact that more profitable enterprises have additional funding to develop environmental projects and can enhance environmental performance by reducing emissions, incurring environmental protection expenses, or implementing new environmental management practices [11,29]. In turn, Lu and Taylor [66] observed a negative relationship between FP and EP, suggesting that financially successful firms are less likely to achieve strong environmental performance. Similarly, Alexopoulos et al. [67] found that avoiding investment in environmental improvements is associated with better financial performance, as only resourceful firms are willing to adopt "greener" production technologies.

For the nonlinear models estimated for the variable (EI), the signs of the estimated parameters ($\beta_3 < 0$, $\beta_2 > 0$) and their significance (Table 3) could indicate an inverted U-shaped relationship between the share of gross operating surplus in value added (FP) and current energy intensity (EI) in the C20 and C22 sectors. However, these results should be treated with caution, given that the turning points are near the limits of the empirical range of the financial performance variable for both industries studied.

Notably, the estimated turning point (TPFP = 44.433%) for the C20 sector lies close to the lower bound of the empirical range, whereas for the C22 sector, the threshold (TPFP = 52.538%) is near the maximum value. The results indicate that the C20 and C22 sectors differ in their environmental responses as financial performance improves. As financial performance rises, most chemical industries in EU countries (FP > TPFP) reduce their energy intensity, while most rubber and plastics industries in EU countries (FP < TPFP) consume more energy during production. These differences have been partially explained earlier, with reference to the specific nature of operations in both sectors and the theory of slack resources. Investigating the non-linear relationship within the chemical sectors requires in-depth analysis and may point to an interesting direction for future research.

Considering the impact of the energy transition (ETI) on the EI variable in linear models (Table 3), the coefficients assigned to ETI are negative and significant at the 1% level, indicating that strengthening the energy transition in the previous year reduces energy intensity in the chemical sector (C20) and the rubber and plastics sector (C22) in the current year. The C20 and C22 industries face high, uniform environmental standards across the EU, which can lead to differences in ETI levels between countries, motivating sectors to enhance their environmental strategies, and thereby increasing competitive pressure [10].

This supports research linking energy transition regulations to higher renewable energy use [32] and to lower pollutant emissions through carbon regulations [68]. Such regulations prompt the development of environmental programs aligned with policy aims, thereby boosting environmental and financial performance [30].

The Size coefficient (β_5) is negative in the linear model for the C20 and C22 sectors, but it is statistically insignificant in both cases. This pattern might indicate that energy intensity is lower in countries where the chemical, rubber, and plastics industries have a greater impact on the economy through employment, compared with countries where these industries have less of an impact. The Hansen test and the Arellano–Bond (2) test yield *p*-values above 0.1 for both sector groups, confirming the validity of the GMM estimation in model (2).

Empirical results confirm a reciprocal relationship between financial and environmental performance and underscore the importance of the dual dynamics in the EP–FP relationship for the C20 and C22 sectors. According to the temporal cross-lagged model, EU sectors (C20 and C22) exhibit persistence in both environmental and financial performance over time, delayed changes in environmental performance following increases in financial performance, and delayed financial responses to improvements in environmental strategies [11]. Additionally, a country's energy system efficiency and readiness for the energy transition shape both the financial outcomes and the energy intensity of the EU chemical, rubber, and plastics sectors.

5.3. Robustness Checking

This study uses an alternative measure of environmental performance to assess the robustness of empirical findings for the C20 and C22 sectors. The greenhouse gas emission intensity (GHGI) serves as a proxy for EP, and models (1)–(2) are re-estimated to examine how the energy transition affects the EP–FP relationship (Tables 4 and 5).

As shown in Table 4, together with the signs and significance of the parameters associated with a linear term ($\alpha_2 < 0$) and a quadratic term ($\alpha_3 > 0$) of the GHGI, indicate that the impact of emission intensity on financial results in the C20 and C22 sectors cannot be described by a U-shaped curve. Comparing the turning points (TPEP: 6.7572 kg/EUR and 0.5655 kg/EUR) with the empirical GHGI ranges for the C20 and C22 sectors, it is observed that they are near the maximum GHGI values. These results confirm those presented in Table 2. Nevertheless, reducing greenhouse gas emissions intensity more often leads to improved financial performance (companies meeting the condition: GHGI < TPEP) than to worse financial outcomes (companies meeting the condition: GHGI > TPEP).

However, the location of turning points near the upper limit of the empirical range of greenhouse gas emission intensity clearly indicates that linear models are a better choice for describing the relationship between FP and EP for the chemical, rubber, and plastics industries. As with the estimation results presented in Table 2, the parameters of the linear models for the GHGI variables (α_2) (Table 4) are negative and statistically significant at the 1% level. This means that an increase in the intensity of greenhouse gas emissions related to the activities of the chemical industry (C20 and C22) in a given year may result in worse financial performance in the following year. These results confirm those presented in Table 2, both in terms of the choice of a linear model to describe the impact of environmental performance (EP) on financial performance (FP) and in terms of the identified direction of this relationship, which is justified by the resource-based view theory.

The C20 and C22 sectors also respond similarly to the energy transition requirements, as the share of gross operating surplus in value added (FP) decreases with a one-year delay following an increase in the Energy Transition Index (for both linear and nonlinear models). Therefore, the shape of the EP–FP relationship remains unchanged, and the impact of ETI

on sectors' financial results is preserved when greenhouse gas emission intensity is used as a proxy for the environmental performance of the C20 and C22 sectors.

Table 4. Robustness test for panel regression (1).

Parameter	Dependent variable: FP			
	C20		C22	
	Linear	Nonlinear	Linear	Nonlinear
$\alpha_1(FP_{t-1})$	0.0782 *** (3.4645)	0.1807 *** (6.6695)	0.1907 *** (8.4323)	0.4462 *** (9.8693)
$\alpha_2\ (GHGI_{t-1})$	−4.9147 *** (−11.0296)	−8.2900 *** (−28.215)	−35.091 *** (−9.8660)	−99.935 *** (−6.0713)
$\alpha_3\left(GHGI_{t-1}^2\right)$	-	0.6134 *** (12.2016)	-	88.512 *** (3.990)
$\alpha_4(ETI_{t-1})$	−0.9728 *** (−8.3589)	−1.3126 *** (−5.1628)	−0.7568 *** (−19.517)	−0.7453 *** (−4.4605)
$\alpha_5(Size1_t)$	−3.1747 (−1.1124)	−4.0089 (−1.364)	−7.1324 ** (−2.1154)	−0.9509 (−1.4263)
TPEP	-	6.7572	-	0.5645
Diagnostic tests				
Number of instruments	21	22	18	21
Hansen test	17.8734 [0.4640]	20.8758 [0.2319]	19.066 [0.3247]	16.635 [0.2165]
AR(1) test	−2.3439 [0.0191]	−2.4782 [0.0132]	−2.7898 [0.0053]	−1.7873 [0.0739]
AR(2) test	−1.1786 [0.2386]	−1.1264 [0.2600]	−0.9492 [−0.3425]	−0.6145 [−0.5889]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, ** indicate the significance at the 1%, 5% levels, respectively.

The negative and statistically significant estimates of the β_2 coefficient in the linear models suggest that improved financial performance in both the C20 and C22 sectors may lead to a decrease in greenhouse gas emission intensity in the following year. This confirms previous observations regarding the EI variable and is consistent with the slack resources theory. In turn, based on the estimates for the linear ($\beta_2 > 0$) and quadratic FP terms ($\beta_3 < 0$), as well as the threshold value (TPFP = 37.1%) close to the minimum of the FP empirical range, most C20 sectors (FP > TPFP) that improve their financial performance in one year can reduce their greenhouse gas emission intensity the following year (Table 5). While the estimated parameters for the C20 sector indicate an inverted U-shaped effect of FP on GHGI, echoing the pattern observed when EI proxies EP, the location of the turning point casts doubt on this conclusion. For the C22 sector, a U-shaped relationship between financial performance and greenhouse gas emission intensity is possible (TPFP = 40.43% near the median of FP), meaning that the initial improvement in financial performance is accompanied by a decrease in emission intensity (FP < TPFP), while an increase in GHGI is observed after exceeding the threshold of 40.43%. The empirical results indicate that progress in the energy transition in the previous year can positively impact the decarbonization of both C20 and C22 sectors' production in the current year, as all estimates of parameter β_4 for C20 and C22 sectors are negative and

statistically significant at the 1% level. Nevertheless, these tentative conclusions require rigorous diagnostic testing, pointing to an intriguing direction for future research.

Table 5. Robustness test for panel regression (2).

Parameter	Dependent Variable: GHGI			
	C20		C22	
	Linear	Nonlinear	Linear	Nonlinear
$\beta_1(GHGI_{t-1})$	0.7568 *** (23.052)	0.9432 *** (27.307)	0.9167 *** (44.424)	0.9613 *** (51.043)
$\beta_2\ (FP_{t-1})$	−0.0577 *** (−20.427)	0.0371 *** (15.447)	−0.0011 *** (−6.3013)	−0.0049 ** (−2.4092)
$\beta_3\left(FP_{t-1}^2\right)$	-	−0.0005 *** (−20.864)	-	6.06E−5 *** (3.0348)
$\beta_4(ETI_{t-1})$	−0.1345 *** (−5.8865)	−0.1248 *** (−10.125)	−0.0044 *** (−7.9529)	−0.002 *** (−2.8295)
$\beta_5(Size1_t)$	−0.0704 (−0.9226)	−0.1715 (−1.5178)	−0.0267 ** (−2.7839)	−0.0125 *** (−3.8198)
TPEP	-	37.10	-	40.43
Diagnostic tests				
Number of instruments	21	22	21	22
Hansen test	19.628 [0.3535]	19.199 [0.3172]	18.067 [0.3846]	17.508 [0.4204]
AR(1) test	−2.329 [0.0199]	−2.5131 [0.0120]	−2.7583 [0.0058]	−2.3448 [0.019]
AR(2) test	−0.2899 [0.7719]	−0.4155 [0.6778]	−1.3464 [0.1782]	−1.0182 [0.32086]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, ** indicate the significance at the 1%, 5% levels, respectively.

The empirical results indicate that progress in the energy transition in the previous year can positively affect the decarbonization of production in both the C20 and C22 sectors in the current year, as all estimates of parameter β_4 for the C20 and C22 sectors are negative and statistically significant at the 1% level.

Because all autoregressive coefficients (α_1 and β_1) are positive and statistically significant at the 1% level (Tables 4 and 5), and the Arellano–Bond and Hansen tests confirm the reliability of the GMM estimation, the choice of the dynamic specification for panel models, in the case of GHGI used to approximate the EP, is justified. It should be noted that most of the empirical findings presented in Tables 4 and 5 on modeling the EP–FP relationship, with the ETI variable playing a stimulating role, are consistent with the results presented in Tables 2 and 3, confirming the robustness of the modeling results.

To test the robustness of the estimated models (1)–(2)—which describe the dynamic, reciprocal relationship between EP and FP and the impact of energy transformation progress on the environmental and financial performance of the C20 and C22 sectors—additional estimations were carried out without the control variable Size 1. We also assessed the robustness of the EP–FP relationships with respect to the impact of average employment in the sector, represented by the continuous variable Size 2. The results presented in Tables A3–A6 support the findings on the direction of impact in the reciprocal relationship between EP and FP for both sectors (C20 and C22) across both linear and nonlinear models,

regardless of whether the Size 2 variable is omitted or included. Similarly, the impact of progress in energy transformation on the environmental and financial performance of the chemical industry and the rubber and plastics sectors in EU countries has been confirmed.

6. Conclusions

The goal of this paper is to analyze the relationship between financial and environmental performance across the chemical (C20) and rubber and plastics (C22) sectors in EU countries, accounting for reciprocal causality and the stimulating role of development in energy transition, proxied by the Energy Transition Index. To achieve this, we use dynamic panel models, with financial performance proxied by the share of gross operating profit in value added, and environmental performance proxied by energy intensity (EI). As a robustness check, we also evaluate environmental performance using greenhouse gas emission intensity (GHGI).

Our research findings show that causality between environmental and financial performance in EU for C20 and C22 sectors operates in both directions. Within the framework of linear models, this means that efforts to enhance sectors' environmentally friendly practices are shown to be profitable. Conversely, financially successful companies have sufficient resources and are better positioned to invest in environmental initiatives.

However, our results do not provide sufficient evidence to support a U-shaped or inverted U-shaped trajectory in the EP–FP relationship. Exploring the nonlinear relationship between financial and environmental performance may yield interesting findings and is a promising direction as more data become available.

When it comes to energy transition, as reflected in the growing ETI, our results show both positive and negative effects. This means that the progress in energy transition significantly influences sectors' environmental progress, resulting in lower energy and greenhouse gas emission intensities in chemical production processes. This may suggest the idea that the chemical industry engages in environmentally friendly activities primarily due to multidimensional processes (investment in new technologies and innovation, energy security, sustainability, regulations on energy transition policies). However, given EP's impact on FP, institutional pressure related to environmental protection contributes to a decline in financial outcomes due to potentially higher compliance costs with environmental regulations and energy transition. In such cases, this pressure may be counterproductive for profit-driven companies, and as a result, the entire sector in the short term. Across EU countries, stronger institutions support the energy transition by providing regulatory backing, financial resources, innovation capacity, and policy certainty. These conditions help sectors such as C20 and C22 improve their environmental performance and make it more likely that these improvements will be rewarded with stronger long-term financial performance. Because the C20 (chemical industry) and C22 (rubber and plastics industry) respond differently to financial slack due to structural differences (especially, the C20 sector is more capital- and energy-intensive and more exposed to environmental risk), extra resources are more likely to support environmental investments and process innovation in C20, thereby strengthening the slack's effect on environmental performance. Thus, the energy transition is a key mechanism through which institutional factors influence the relationship between EP and FP across industrial sectors in EU countries, particularly in the chemical sector.

This direction has been taken by the 2024 Antwerp Declaration and the Draghi report, which calls for urgent, concrete measures to create a business environment that helps companies build on their strengths while advancing the EU's green transition and climate-neutrality goals. Achieving net-zero GHG emissions by 2050 is estimated to require investment 37–51% above business-as-usual levels [3,69]. Public funding can accelerate

the deployment of green technologies and decarbonization—many of which are already available or nearing maturity—and strengthen the sector's competitiveness.

The findings have several policy implications. Given chemistry's importance to the economy, policymakers must consider sector-specific capabilities, balance environmental requirements with profitability, and support the green and digital energy transition. Next, as EU border enforcement remains inconsistent and industrial policy is more complex and unpredictable than elsewhere, policymakers should aim to make European policy appear more regulatory than incentive-driven.

To qualify these conclusions, we acknowledge several limitations in our study. First, we analyze the EP–FP relationship only for the C20 and C22 chemical sectors, not for the entire chemical industry, due to data availability constraints. For the same reason, our sample covers the period up to 2022, excluding the recent period marked by a substantial slowdown in EU chemical industries. The small cross-sectional dimension of our panel, remaining risks of reverse causality and unobserved common shocks are other limitations of the study. Our measure of the energy transition, represented by the Energy Transition Index, could also be seen as a limitation. Therefore, it is worth examining the EP–FP relationship using alternative indicators of the energy transition and the latest available data. This line of research remains on the agenda for future studies. Furthermore, a particularly promising direction for future research is to assess how changes in EU climate and energy policy shape the relationship between environmental performance (EP) and financial performance (FP) in the broadly defined chemical industry, using the event study approach. Transferring these considerations to the microeconomic level, while accounting for diverse institutional conditions, provides a valuable perspective for further research.

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Abbreviations

The following abbreviations are used in this manuscript:

EP	Environmental performance
FP	Financial performance
EI	Energy use intensity
GHGI	Greenhouse gas emission intensity
ETI	Energy Transition Index

REACH	Registration, Evaluation, Authorization, and Restriction of Chemical Substance
EU ETS	EU Emissions Trading System
TLGT	"too-little-of-a-good-thing" effect
TMGT	"too-much-of-a-good-thing" effect
GMM	Generalized Methods of Moments
TP	Turning point

Appendix A

Table A1. Input data collected for analysis purposes.

Variable	Input Data	Source of Data and Dataset Availability
ETI	Energy Transition Index	World Economic Forum: https://www.weforum.org/publications/series/energy-transition-index/ accessed on 15 June 2025
EI	Energy use	Energy supply and use by NACE Rev. 2 activity, [env_ac_pefasu]; Structural Business Statistics (SBS database)—Eurostat https://doi.org/10.2908/ENV_AC_PEFASU accessed on 12 May 2025
GHGI	Greenhouse gas emissions	Air emissions accounts by NACE Rev. 2 activity; Structural business statistics (SBS)—Eurostat https://doi.org/10.2908/ENV_AC_AINAH_R2 accessed on 12 May 2025
FP	Gross operating surplus, Value added at factor cost	Structural Business Statistics (SBS database)—Eurostat https://doi.org/10.2908/SBS_NA_SCA_R2, https://doi.org/10.2908/SBS_SC_OVW accessed on 28 April 2025
Size	Number of employees, number of active enterprises	Structural Business Statistics (SBS database)—Eurostat https://doi.org/10.2908/SBS_NA_SCA_R2, https://doi.org/10.2908/SBS_SC_OVW accessed on 4 May 2025

Appendix B

Table A2. Significance test for the proportion of adjusted observations during the pandemic and the period outside the pandemic.

Winzored Variable	Chemical Industry (C20)			Rubber and Plastics Industry (C22)		
	Non-Pandemic	Pandemic	*p*-Value	Non-Pandemic	Pandemic	*p*-Value
FP	0.099379	0.108696	[0.8026]	0.111801	0.043478	[0.1682]
GHGI	0.099379	0.086957	[0.8014]	0.093168	0.101449	[0.4628]
EI	0.099379	0.086957	[0.8014]	0.111801	0.065217	[0.3585]
ETI	0.099379			0.086957		[0.8014]

Note: non-pandemic—means percentage of adjusted observations outside the pandemic period; pandemic—means percentage of adjusted observations outside the pandemic period.

Appendix C

Table A3. Robustness check for models in Table 2—chemical sector (C20).

Parameter	Dependent Variable: FP			
	C20		C20	
	Linear	Linear	Nonlinear	Nonlinear
$\alpha_1(FP_{t-1})$	0.1968 *** (9.9299)	0.2380 *** (7.3367)	0.3022 *** (4.1699)	0.3146 *** (3.8991)
$\alpha_2\ (EI_{t-1})$	−0.6205 *** (−4.5829)	−0.7537 *** (−5.8584)	−0.9703 *** (−10.379)	−0.9583 *** (−11.413)
$\alpha_3\left(EI^2_{t-1}\right)$	-	-	0.0096 *** (3.9854)	0.006 ** (2.1051)
$\alpha_4(ETI_{t-1})$	−0.6092** (−2.5812)	−1.7912 *** (−4.1554)	−0.2785 *** (−1.8971)	−1.7842 *** (−5.0348)
$\alpha_5(Size2_t)$	-	−0.5912 * (−1.9612)	-	−0.6995 *** (−3.1458)
TPEP	-	-	50.536	79.858
Diagnostic tests				
Number of instruments	20	21	21	22
Hansen test	16.684 [0.5449]	18.379 [0.3653]	18.239 [0.3739]	19.663 [0.2918]
AR(1) test	−2.5687 [0.0102]	−2.3719 [0.0177]	−3.0048 [0.0027]	−2.4016 [0.0163]
AR(2) test	−1.0095 [0.3127]	−0.6812 [0.4958]	−0.7109 [0.4771]	−0.5086 [0.6110]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, **, * indicate the significance at the 1%, 5% and 10% levels, respectively, Size 2—average employment in a sector.

Table A4. Robustness check for models in Table 3—chemical sector (C20).

Parameter	Dependent Variable: EI			
	C20		C20	
	Linear	Linear	Nonlinear	Nonlinear
$\beta_1(EI_{t-1})$	0.3568 *** (10.069)	0.4520 *** (5.8841)	0.8518 *** (40.181)	0.6034 *** (3.6433)
$\beta_2\ (FP_{t-1})$	−0.3192 *** (−14.801)	−0.5078 *** (−9.8411)	0.3457 *** (17.886)	0.3544 *** (6.6678)
$\beta_3\left(FP^2_{t-1}\right)$	-	-	−0.0038 *** (−10.761)	−0.0031 *** (−5.0629)
$\beta_4(ETI_{t-1})$	−1.7234 ** (−17.241)	−0.1837 (−0.5256)	−0.3499 *** (−3.2268)	−0.8072 (−1.1899)
$\beta_5(Size2_t)$	-	−0.3478 (−1.0333)	-	−0.2432 (−0.6819)
TPEP	-	-	45.487	57.161
Diagnostic tests				
Number of instruments	19	16	21	20
Hansen test	18.553 [0.2925]	13.001 [0.3689]	21.102 [0.2217]	14.3225 [0.5012]
AR(1) test	−2.6434 [0.0082]	−1.6688 [0.0952]	−2.8165 [0.0049]	−2.4511 [0.0065]
AR(2) test	−1.3386 [0.1807]	−1.5938 [0.1110]	−0.9355 [0.3495]	−0.0834 [0.9335]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, ** indicate the significance at the 1%, 5% levels, respectively, Size 2—average employment in a sector.

Table A5. Robustness check for models in Table 2—rubber and plastics sector (C22).

Parameter	Dependent Variable: FP			
	C22		C22	
	Linear	Linear	Nonlinear	Nonlinear
$\alpha_1(FP_{t-1})$	0.3017 *** (5.5610)	0.3052 *** (5.7071)	0.4714 *** (5.1321)	0.4371 *** (4.5874)
$\alpha_2\ (EI_{t-1})$	−6.6225 *** (−5.8762)	−6.6387 *** (−5.7988)	−24.3109 *** (−4.0997)	−25.1033 *** (−4.1606)
$\alpha_3\left(EI^2_{t-1}\right)$	-	-	5.6263 *** (4.0757)	5.7619 *** (4.1269)
$\alpha_4(ETI_{t-1})$	−0.4746 ** (−2.6366)	−0.4597 ** (−2.1486)	−0.6417 ** (−2.2726)	−0.6423 ** (−2.3689)
$\alpha_5(Size2_t)$	-	−0.0292 (−0.1669)	-	−0.1807 (−1.2729)
TPEP	-	-	2.160	2.1784
Diagnostic tests				
Number of instruments	16	16	17	17
Hansen test	13.6167 [0.4014]	13.6104 [0.3263]	14.3796 [0.3477]	13.3364 [0.3045]
AR(1) test	−2.7423 [0.0061]	−2.7705 [0.0056]	−2.5846 [0.0098]	−2.4052 [0.0162]
AR(2) test	−1.2062 [0.2277]	−1.2499 [0.2113]	−0.2310 [0.8173]	−0.0513 [0.9591]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, ** indicate the significance at the 1%, 5% levels, respectively, Size 2—average employment in a sector.

Table A6. Robustness check for models in Table 3—rubber and plastics sector (C22).

Parameter	Dependent Variable: EI			
	C22		C22	
	Linear	Linear	Nonlinear	Nonlinear
$\boldsymbol{\beta_1(EI_{t-1})}$	0.2587 *** (56.311)	0.305 *** (18.2635)	0.2307 *** (5.6257)	0.2713 *** (9.4077)
$\boldsymbol{\beta_2\ (FP_{t-1})}$	−0.0121 *** (−8.8891)	−0.0145 *** (−5.6181)	0.1241 *** (3.2349)	0.0165 *** (3.8598)
$\boldsymbol{\beta_3\left(FP^2_{t-1}\right)}$	-	-	−0.0011 *** (−3.0317)	−0.0002 *** (−3.1345)
$\boldsymbol{\beta_4(ETI_{t-1})}$	−0.0501 *** (−24.796)	−0.0567 *** (−8.7884)	−0.0554 *** (−5.1116)	−0.0491 *** (−6.5930)
$\boldsymbol{\beta_5(Size2_t)}$	-	−0.0418 *** (−6.9580)	-	−0.0099 * (−1.8757)
TPEP	-	-	56.409	41.250
Diagnostic tests				
Number of instruments	17	18	21	21
Hansen test	13.263 [0.4277]	13.107 [0.4396]	19.664 [0.3520]	14.8434 [0.6068]
AR(1) test	−1.6550 [0.0979]	−10.5541 [0.0000]	−1.6439 [0.1002]	−1.38081 [0.1673]
AR(2) test	−0.5755 [0.5649]	−0.6682 [0.504]	−0.4358 [0.6630]	−0.3054 [0.760]

Note: *t*-statistic in parentheses, *p*-value in brackets; ***, * indicate the significance at the 1% and 10% levels, respectively, Size 2—average employment in a sector.

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