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Financial Development, Green Marketing Awareness and Energy Performance: Evidence from the EU-27

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ABSTRACT

This study investigates the long- and short-run determinants of energy intensity in the EU-27 by integrating financial development and green marketing awareness into an ARDL–ECM framework. Unlike prior research that examines financial or environmental factors separately, this study offers the first macro-level evidence on how behavioral environmental awareness interacts with financial development to shape energy performance. The results show a stable long-run cointegration relationship. Financial development and green marketing awareness exert positive and persistent effects on energy intensity, and their interaction amplifies this upward pressure. These findings suggest that neither financial deepening nor strengthened environmental communication has yet produced aggregate efficiency gains. In contrast, income growth reduces energy intensity, while industrial activity and urbanisation increase it. Short-run dynamics are weak, reflecting slow adjustment and the inertia of annual energy patterns. The study contributes by demonstrating that green marketing awareness—despite its growing role in EU sustainability discourse—does not automatically translate into lower energy use. This highlights the need for coordinated policies aligning financial incentives, credible environmental communication and structural reforms. Overall, the analysis offers a novel behavioural–financial perspective on energy intensity and provides an empirical basis for designing more effective strategies to support the EU's long-term decarbonisation goals.

Keywords: Energy Intensity, Financial Development, Green Marketing Awareness, Environmental Behaviour, ARDL–ECM Model, Sustainable Energy Transition
JEL Classifications: Q43, Q56, O44

1. INTRODUCTION

The transition toward a low-carbon economy has brought renewed attention to the interconnected relationship between financial development, technological innovation, and environmental sustainability across the European Union (EU). The imperative for sustainable growth was first articulated in The Club of Rome's seminal report *The Limits to Growth*, which warned that finite planetary resources would be unable to support continuous economic expansion (Food and Agricultural Organization of the United Nations, 2024). Over the past five decades, this warning has largely materialised, as rapid resource depletion and rising pollution levels have intensified global environmental and social challenges. The Brundtland Report later reframed these concerns within a developmental context, defining sustainable development as a process that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987).

Against this backdrop, the concept of quality growth has emerged as a paradigm that prioritises inclusivity, efficiency, and sustainability over purely quantitative expansion. Closely aligned with the degrowth perspective, the quality-growth approach underscores the need for economic systems that balance environmental protection with social and economic objectives—an increasingly relevant framework for economies transitioning toward low-carbon models, such as those of the EU.

Financial systems play a crucial role in this transformation. Within the Environmental Kuznets Curve (EKC) framework, environmental degradation initially rises with economic development but declines as income levels increase and societies invest in cleaner technologies (Grossman and Krueger, 1995). From this perspective, financial development can serve as a catalyst for environmental improvement by facilitating green investments and supporting sustainable production processes. Empirical evidence further shows that green finance—through mechanisms such as impact investing and green bonds—enhances energy efficiency and accelerates the adoption of low-carbon technologies (Lichtenberger et al., 2022; Sule et al., 2024).

However, findings in the literature remain mixed. While some studies report that financial development can contribute to environmental improvement through enhanced investment in cleaner technologies and stricter environmental standards, others find that it may instead accelerate pollution by expanding energy-intensive activities. These contrasting outcomes suggest that the environmental impact of financial development depends critically on institutional quality, regulatory frameworks, and the degree to which green finance mechanisms are integrated into the broader financial system (Tamazian et al., 2009; Jalil and Rauf, 2024).

In parallel with these financial–economic dynamics, the global energy agenda has increasingly prioritised sustainability and efficiency. The United Nations' Agenda 2030 positions Sustainable Development Goal 7 (SDG7)—"affordable and clean energy"—as a core pillar of sustainable development (United Nations General Assembly, 2015). Nevertheless, progress remains uneven. The EU has established ambitious targets, including reducing primary and final energy consumption by 39% and 36%, respectively, by 2030, and achieving climate neutrality by 2050 (European Commission, 2021). Energy efficiency is regarded as the most accessible and cost-effective avenue for achieving these goals (Fotiou et al., 2022). Yet persistent implementation barriers—ranging from institutional inertia to behavioural resistance—continue to hinder progress (Bagaini et al., 2020; Bensouda and Benali, 2022; Amadori and Votta, 2021). Overcoming these obstacles requires not only technological advancement but also shifts in consumer awareness and corporate responsibility.

The European Green Deal further emphasises a dual transformation—environmental and digital—often referred to as the twin transition. This agenda has reshaped corporate and policy priorities across EU Member States, encouraging investment in renewable energy technologies, smart grids, and digital infrastructure such as the Internet of Things (IoT) to optimise energy consumption and reduce waste (Casanas and Kovacic, 2025; Tagliabue et al., 2021). Despite these advancements, the joint role of financial development and societal environmental awareness in shaping energy performance remains understudied.

Recent empirical research highlights the interconnected effects of technological innovation, digital transformation, and environmental performance on sustainable economic development within the EU (Noja et al., 2022). Complementary studies on institutional quality further show that governance mechanisms—such as transparency, accountability, and political stability—significantly shape the effectiveness of financial and environmental policies in reducing carbon emissions and improving energy outcomes (Iqbal et al., 2025).

Building on these insights, this study addresses an important research gap by integrating economic, behavioural, and financial dimensions into a unified analytical framework. Specifically, it examines how financial development and green marketing awareness—used as a proxy for societal and consumer-level environmental consciousness—jointly influence the energy performance of EU-27 countries. By constructing a composite index of green marketing awareness and analysing its interaction with financial development, the study provides a novel empirical perspective on the socio-economic drivers of the EU's low-carbon transition.

Despite the growing interest in the links between finance, innovation, and environmental outcomes, two important gaps remain in the existing literature. First, the behavioural dimension of the energy transition—particularly the role of societal environmental awareness—has received limited empirical attention. Most studies rely on proxies such as education, environmental taxes, or generic sustainability indicators, whereas comparable cross-country measures of environmental awareness are largely absent. Second, evidence on the joint influence of financial development and societal awareness on energy performance remains scarce, even though these factors may interact in complementary ways: well-functioning financial systems can accelerate the diffusion of energy-efficient technologies, while higher public awareness can strengthen the demand for green products and reinforce the effectiveness of financial and policy instruments.

Green marketing can be defined as the strategic effort to design, price, promote, and distribute products in a manner that fosters environmental protection. This has become a fundamental component of contemporary business sustainability strategies. When companies prioritise the natural ecological balance while optimising their profits, they can reduce environmental pollution, conserve natural resources, and gain a unique competitive advantage (Suki et al., 2016). Over time, the practice of green marketing has evolved into a pivotal element of sustainable business strategy (Papadas et al., 2017). In contemporary discourse, it signifies a comprehensive management paradigm that encompasses not only economic considerations but also ecological and social imperatives. This broader approach aims to identify, anticipate, and meet the needs of customers and society in a profitable and sustainable manner (Dangelico and Vocalelli, 2017).

Recent studies have predominantly concentrated on technological or policy-based factors when examining environmental outcomes. However, from a marketing perspective, it is equally important to integrate behavioural and regulatory dimensions into a unified macro indicator (Papadas et al., 2017). The GMA index developed in this study addresses this gap by combining two fundamental components that are critical to the effectiveness of green marketing strategies: the behavioural dimension (awareness) and the regulatory dimension (frequency). This integration is analogous

to the Triple Bottom Line framework—economic, social, and environmental performance—commonly utilised in marketing, thereby positioning the GMA index as a novel macro indicator of societal environmental awareness (Papadas et al., 2017; Papadas et al., 2019).

This study addresses both gaps by introducing a new composite index of Green Marketing Awareness (GMA), constructed from OECD data on consumer energy-label awareness and the Environmental Policy Stringency (EPS) index. By integrating behavioural and regulatory dimensions into a single indicator, the GMA index provides a novel macro-level proxy for societal environmental consciousness—an aspect largely overlooked in previous research. Moreover, the study examines how financial development and green awareness jointly shape the EU-27's energy performance over the 2000–2018 period using an ARDL framework, capturing both long-run and short-run dynamics. By focusing on the interaction between financial development and behavioural factors, the analysis offers an original perspective on the socio-economic drivers of the EU's low-carbon transition, complementing existing evidence centred primarily on technological or policy-based determinants.

The remainder of the paper proceeds as follows. Section 2 reviews the related literature, Section 3 presents the data and variable construction, and Section 4 outlines the econometric methodology. Section 5 reports the empirical results, followed by the policy discussion in Section 6. Section 7 concludes the study.

2. REVIEW OF LITERATURE

The relationships between financial development, energy use, and green marketing awareness—three core dimensions of this study—have been examined across countries with differing levels of economic development. A substantial body of research has explored how financial development shapes energy consumption patterns and environmental outcomes, while a growing set of studies has analysed green marketing awareness as an emerging behavioural factor with environmental implications. To provide a clearer understanding of these interconnected dynamics, the following section reviews the literature in three strands: (i) The link between financial development, energy use, and environmental quality, (ii) the role of financial systems in supporting renewable energy and sustainability, and (iii) behavioural and marketing-based mechanisms, including green marketing awareness, that influence environmental performance.

The relationships between financial development, energy consumption, and environmental quality have been extensively studied in the literature, both theoretically and empirically. One of the pioneering studies in this area, Grossman et al. (1995), analyzed the relationship between per capita income and air and water pollution indicators and demonstrated that economic growth can initially have negative environmental impacts but then positive impacts after a certain income threshold. This finding formed the basis of the environmental Kuznets curve approach. Examining the effects of financial and economic development on environmental quality, Tamazian et al. (2009) conducted a panel data analysis for the BRIC countries over the period 1992–2004 and found that economic and financial development are significant determinants of environmental quality. The study indicates that financial liberalization and financial openness play a critical role in reducing CO_2 emissions, while R and D-intensive foreign direct investment can limit environmental degradation. Similarly, in their study covering 100 countries over the period 1980–2020, Abdul Jalil and Abdul Rauf (2024) demonstrated that financial development significantly reduces carbon emissions by facilitating access to clean energy and that a strong financial sector can be an important tool in solving environmental problems.

A significant number of studies examining the direct relationship between financial development and energy consumption indicate that this relationship is positive. Shahbaz et al. (2012), in their analysis of data from the 1971–2008 period, found that financial development increases energy consumption, while economic growth, industrial value added, and urbanization strengthen energy demand. In a study conducted for European Union countries, Coban and Topcu (2013) found that financial development has a direct and positive effect on energy consumption, and that deepening financial markets stimulates energy demand. For Turkey, Dumrul (2018), in his analysis covering the 1961–2015 period, demonstrated a long-term cointegration relationship between financial development, economic growth, and energy consumption, and that financial development increases energy consumption. The literature also emphasizes that the relationship between financial development and energy consumption can vary depending on institutional conditions and country risk. In his study covering 79 countries, Chiu and Lee (2020) found that the impact of financial development on energy consumption varies depending on country risk, and that financial development can reduce energy consumption in stable risk environments. The study also emphasizes that banking sector development has a stronger impact on energy consumption compared to capital markets.

Recent studies place particular emphasis on the impact of financial development on renewable energy consumption and sustainability. Mukhtarov et al. (2022), in their analysis covering the 1980–2019 period for Turkey, found that a 1% increase in financial development increased renewable energy consumption by 0.21%. Focusing on the MENA region, Radulescu et al. (2025) showed that financial development and green innovation, when considered together, strengthen renewable energy consumption and that there is a bidirectional causal relationship between the two variables. Similarly, in their study of SADC countries, Lefatsa et al. (2025) found that financial development facilitates renewable energy investments and capital flows to energy-efficient technologies. Comparing G7 and E7 countries, Özmerdivanlı and Sönmez (2025) emphasize that the expansion of green finance instruments is a critical policy tool for reducing environmental degradation. In their study focusing on green bonds, specifically financial instruments and markets, Lichtenberger et al. (2022) determined that green bonds exhibit lower volatility and offer higher risk-adjusted returns than traditional bonds, demonstrating the importance of green finance in the transition to a low-carbon economy. Focusing on the banking sector, Sule et al. (2024) argue that integrating green finance solutions into banking activities is

a strategic tool in combating climate change and ensuring long-term sustainability.

The literature demonstrates that energy transition is not limited to financial mechanisms; behavioral and marketing-based approaches are also important. Shukla et al. (2020) demonstrated that green marketing tools and advertising are determinants of energy-saving behavior, while Moussa (2025) found a strong and positive relationship between the implementation of green marketing strategies in environmentally friendly companies and sustainable development. Bagaini et al. (2020), examining the barriers to energy efficiency implementation, demonstrated that institutional and economic factors, in particular, limit this process. Finally, studies addressing the dimensions of digitalization and technological transformation provide a new perspective on sustainability literature. Noja et al. (2022) found that energy innovations, digital transformation, and environmental performance significantly support sustainable development in EU countries. Iqbal et al. (2025) argue that artificial intelligence, green human capital, and institutional quality play critical roles in reducing CO_2 emissions, while geopolitical risk and natural resource rents increase emissions.

Given the macro-level focus of our study, the concept of Green Marketing Orientation (GMO), which explains green strategy at the organisational level, plays a central role. GMO is a structure that captures a company's holistic approach to the environment, typically conceptualised in three dimensions: The following orientations have been identified: Strategic Green Marketing Orientation (SGMO), Tactical Green Marketing Orientation (TGMO), and Internal Green Marketing Orientation (IGMO) (Papadas et al, 2017). SGMO is indicative of the extent to which a company's environmental obligations are integrated into strategic marketing decisions. This encompasses long-term, top management decisions and the integration of environmental objectives into corporate strategy. SGMO also supports the adoption of proactive environmental strategies that go beyond legal regulations. The extant literature supports the hypothesis that there is a positive correlation between the utilisation of green marketing strategies and the enhancement of business performance. Recent studies have indicated that SGMO and TGMO may have a beneficial impact on competitive advantage and financial performance (Papadas et al, 2017; Papadas et al, 2019).

GMA's consumer awareness component reflects individual and societal environmental awareness. Marketing literature extensively uses psychological models such as the Theory of Planned Behavior (TPB) and the Value-Belief-Norm (VBN) Theory to explain pro-environmental behaviors (PEB). TPB often performs better at explaining high-cost environmentally friendly behaviors (because it includes perceived behavioral control, i.e., costs and constraints), while VBN is effective at predicting low-cost behaviors and behaviors based on personal values/moral obligations (personal norms). These two theories are seen as complementary in areas such as consumers' intention to visit green hotels (Wang et al, 2024).

The regulatory dimension (EPS) of the GMA plays a crucial role in enhancing market efficiency and strengthening consumer confidence. While companies may adopt green marketing practices to improve their corporate image, the risk of greenwashing—making misleading or false environmental claims—remains a significant concern (Dangelico and Vocalelli, 2017). Greenwashing can erode consumer trust and distort competitive markets (Marcatajo, 2023). In response, regulatory authorities in the European Union have established strict requirements regarding the accuracy, reliability, verifiability, and comparability of green claims. Ensuring transparency and clarity in these claims is essential for maintaining consumer confidence (Marcatajo, 2023). Moreover, inadequate financial oversight and corporate greenwashing behaviours can undermine the expected energy-saving effects of green credit and, by extension, green finance (Pan and Lin, 2025).

In this context, the present study combines behavioural (consumer awareness) and regulatory (EPS) dimensions into a single macro indicator, offering a holistic perspective that bridges market dynamics with corporate strategy. Integrating these two components within the GMA index enables a more comprehensive examination of how socio-economic and regulatory pressures shape consumer environmental awareness.

3. DATA AND MEASUREMENT

The empirical analysis investigates whether financial development and green marketing awareness are associated with improved energy performance in the EU-27 aggregate over the period 2000–2018. To address this question, the study employs three groups of variables. The dependent variables capture different dimensions of energy outcomes: total energy intensity (energy use per 1,000 USD of real GDP), per capita energy use, and the share of renewables in final energy consumption. These indicators are obtained from the World Development Indicators (WDI) and the International Energy Agency (IEA) databases.

The main explanatory variables are financial development and green marketing awareness. Financial development (FD) is measured by the composite Financial Development Index provided by the International Monetary Fund, which summarises financial depth, access, efficiency, and institutional quality. Green marketing awareness (GMA) is a newly constructed composite indicator that combines consumer-side environmental awareness with the stringency of environmental regulation. GMA is derived from OECD data on energy-label awareness and the Environmental Policy Stringency (EPS) index, as detailed in the subsequent subsection.

A set of control variables is included to account for structural and institutional characteristics that may influence energy use: real GDP per capita, industry value added as a share of GDP, urbanisation, a country-level eco-innovation score, and an indicator of environmental management based on ISO 14001 certifications. These variables are sourced from the WDI, the European Commission's eco-innovation database, and the ISO Annual Survey. All indicators are converted to annual frequency and harmonised over the 2000–2018 sample period. Table 1 provides the full definitions and data sources for all variables.

Table 1: Variables, definitions, and data sources

Variable	Symbol	Definition/Measurement	Data Source
Energy intensity	ENER_INT	Total energy use per 1,000 USD of real GDP (PPP, constant prices)	World Development Indicators (WDI)
Per capita energy use	ENER_PC	Energy use per capita (kg of oil equivalent)	WDI
Renewable energy share	REN_SHARE	Share of renewables in final energy consumption (%)	WDI/IEA
Financial development	FD	IMF Financial Development Index (depth, access, efficiency; institutions and markets)	IMF Financial Development Database
Green marketing awareness	GMA	Green marketing awareness index (GMA) Composite indicator constructed using two OECD-based measures: (i) A consumer environmental concern index derived from the first principal component of five energy-label awareness variables (LABELS_FRIDGE, LABELS_FREEZER, LABELS_LIGHT, LABELS_PASSVEH, LABELS_AC), and (ii) the EU-27 annual average of the Environmental Policy Stringency (EPS) index. Both series were standardized and combined using Principal Component Analysis (PCA) to obtain a unified GMA measure. Higher values indicate stronger public environmental awareness and stricter policy pressure.	OECD Green Growth Indicators; OECD EPS database.
GDP per capita	GDP_PC	Real GDP per capita (PPP, constant prices)	WDI
Industry share	IND_SHARE	Industry value added as a share of GDP (%)	WDI
Urbanisation	URBAN	Urban population as a percentage of total population (%)	WDI
Environmental management	ISO14001_PC	ISO 14001 certificates per million inhabitants	ISO Annual Survey

Green marketing awareness (GMA) is measured using a composite indicator constructed from two OECD-based data sources. The first component captures consumer-level environmental concern through five energy-label awareness variables (LABELS_FRIDGE, LABELS_FREEZER, LABELS_LIGHT, LABELS_PASSVEH and LABELS_AC) obtained from the OECD Green Growth Indicators database. These variables report the share of households that recognise or use energy-efficiency labels for major appliances, lighting products, passenger vehicles and air conditioners, and are widely interpreted as proxies for consumer awareness of energy and environmental issues.

The second component reflects the regulatory dimension of environmental awareness and is measured using the Environmental Policy Stringency (EPS) index. Instead of relying on the ready-made EU aggregate, the analysis recalculates the annual EU-27 average from country-level EPS data, ensuring transparency and consistency in the treatment of member states over time.

Both components are first standardised and then combined into a unified GMA indicator using Principal Component Analysis (PCA). The first principal component captures the shared variation in behavioural (consumer concern) and institutional (policy stringency) dimensions of environmental awareness. Higher values of the GMA index indicate stronger public environmental awareness and a stricter policy environment that supports green practices.

For key variables such as GMA and EPS, missing observations are not interpolated; country-years with unavailable data are excluded from the sample to avoid introducing artificial variation. For smoother series such as GDP per capita or urbanisation, limited short gaps are addressed using simple interpolation, while larger gaps lead to the omission of the corresponding observations. The resulting dataset for the EU-27 over the 2000–2018 period is balanced or nearly balanced and suitable for fixed-effects estimation and subsequent robustness analyses.

4. ECONOMETRIC METHODOLOGY

To capture green marketing awareness at the macro level, we construct a composite index using Principal Component Analysis (PCA) based on OECD data. Specifically, we combine two complementary dimensions for the EU-27 aggregate: (i) A consumer environmental concern indicator derived from five energy-label awareness variables (LABELS_FRIDGE, LABELS_FREEZER, LABELS_LIGHT, LABELS_PASSVEH and LABELS_AC) from the OECD Green Growth Indicators database, and (ii) the annual EU-27 average of the Environmental Policy Stringency (EPS) index. All underlying series are first standardised using z-scores. PCA is then applied to extract a single common factor that captures the shared variation in consumer concern and policy stringency. The first principal component (PC1), which accounts for the largest share of total variance, is retained and used as our Green Marketing Awareness (GMA) index. The resulting indicator reflects both behavioural (household awareness of energy labels) and institutional (stringency of environmental regulation) dimensions of environmental engagement, providing a comprehensive macro-level proxy for green marketing awareness and related public pressure.

Methodologically, we rely on the standard PCA framework originally introduced by Hotelling (1933). PCA transforms a set of p correlated variables into a smaller number of uncorrelated linear components that capture most of the variation in the dataset (Jolliffe, 2002). The general PCA transformation can be written as:

$$PC_1 = a_{11}X_1 + a_{12}X_2 + \ldots + a_{1p}X_P \quad (1)$$

$$PC_2 = a_{21}X_1 + a_{22}X_2 + \ldots + a_{2p}X_P \quad (2)$$

$$PC_P = a_{P1}X_1 + a_{P2}X_2 + \ldots + a_{Pp}X_P \quad (3)$$

Where PC_i denotes the i-th principal component and a_{ij} represents the loading of variable X_j in component i. The loadings satisfy the standard normalisation condition:

$$\sum_{j=1}^{p} a_{ij}^2 = 1 \tag{4}$$

Before applying PCA, all OECD-based input series—namely the five energy-label awareness variables and the EU-27 Environmental Policy Stringency (EPS) index—are standardised using z-scores to ensure comparability across indicators. After standardisation, PCA is applied and the first principal component (PC1), which captures the largest share of total variance, is retained as the Green Marketing Awareness (GMA) index.

Using PC1 provides a single, consistent indicator that reflects the common underlying signal shared by the OECD-based consumer awareness variables and the environmental policy stringency measure. This composite indicator is subsequently employed as one of the main explanatory variables in the ARDL model.

Given that the empirical analysis relies on a single European Union aggregate time series, the autoregressive distributed lag (ARDL) framework proposed by Pesaran, Shin and Smith is adopted. The ARDL approach is particularly suitable for this context because it can accommodate regressors that are integrated of order zero or one and allows both short-run and long-run dynamics to be estimated within the same specification. This is especially relevant for energy-related variables, which tend to exhibit persistent adjustment behaviour and may respond differently to changes in financial and behavioural factors over time.

In the baseline model, the selected energy indicator is expressed as a function of financial development, green marketing awareness, their interaction term, and a set of control variables:

$$ENER_t = f(GDPPCt, IND\_SHARE_t, URBAN_t, ISO14001_t$$

To estimate this relationship, we specify an ARDL(p, q_1, q_2, q_3, q_4) model of the form:

$$\begin{aligned}\Delta ENER_t = \alpha_0 &+ \sum_{\{i=1\}_i^{\{p-1\}\varphi}} \Delta ENER_{\{t-i\}} + \sum_{\{j=0\}_j^{\{q1-1\}\beta}} \Delta FD_{\{t-j\}} \\ &+ \sum_{\{k=0\}_k^{\{q2-1\}\gamma}} \Delta GMA_{\{t-k\}} + \sum_{\{m=0\}_m^{\{q3-1\}\delta}} \Delta(FD\times GMA)_{\{t-m\}} \\ &+ \sum_{\{n=0\}_{\{t-n\}}^{\{q4-1\}\theta_n'\Delta Z} + \lambda_1 ENER_{\{t-1\}} + \lambda_2 FD_{\{t-1\}} + \lambda_3 GMA_{\{t-1\}} \\ &+ \lambda_4 \left(FD\times GMA\right)_{\{t-1\}} + \lambda_5' Z_{\{t-1\}} + u_t\end{aligned} \tag{5}$$

The coefficients on the lagged level terms represent the long-run relationship among the variables. To test for the existence of cointegration, we apply the ARDL bounds testing procedure, which evaluates the joint significance of the level coefficients. If the bounds test indicates the presence of cointegration, the ARDL model can be reparametrized into the following error-correction representation:

$$\begin{aligned}\Delta ENER_t = \psi ECM_{\{t-1\}} &+ \sum_{\{i=1\}_i^{\{p-1\}\phi} \Delta ENER_{\{t-i\}} + \sum_{\{j=0\}_j^{\{q1-1\}\beta} \Delta FD_{\{t-j\}} \\ &+ \sum_{\{k=0\}_k^{\{q2-1\}\gamma} \Delta GMA_{\{t-k\}} + \sum_{\{m=0\}_m^{\{q3-1\}\delta} \Delta(FD\times GMA)_{\{t-m\}} \\ &+ \sum_{\{n=0\}_{\{t-n\}}^{\{q4-1\}\theta_n'\Delta Z} + u_t\end{aligned} \tag{6}$$

Where ECM_{t-1} denotes the error-correction term derived from the estimated long-run relationship, and ψ measures the speed at which deviations from long-run equilibrium are corrected. A negative and statistically significant value of ψ confirms that short-run fluctuations converge back to the long-run path.

To ensure valid inference, we follow standard ARDL procedures in selecting optimal lag lengths based on information criteria and conduct diagnostic tests for serial correlation, heteroskedasticity, and stability of the estimated coefficients. This empirical strategy provides a comprehensive assessment of how financial development, green marketing awareness, and their interaction influence energy outcomes in both the short and the long run.

5. RESULTS

This section presents the empirical findings on the relationship between financial development, green marketing awareness and energy performance based on the ARDL framework. The analysis begins with Augmented Dickey–Fuller (ADF) unit root tests to determine the integration properties of the variables. The results indicate a mixed order of integration, with some series being stationary in levels, I(0), and others stationary after first differencing, I(1), and no evidence of I(2) processes. This mixed integration structure validates the use of the ARDL approach. Following the stationarity analysis, the ARDL bounds testing procedure is applied to examine the presence of a long-run relationship among the variables. The computed F-statistic exceeds the upper critical bound at conventional significance levels, confirming cointegration between energy intensity, financial development, green marketing awareness and the control variables. Establishing cointegration allows for the estimation of both the long-run coefficients and the short-run adjustment dynamics through the error-correction representation (ECM). Overall, the ARDL framework provides a comprehensive analytical basis for assessing how financial development, environmental awareness and their interaction influence energy intensity in the EU-27 as a whole over the short and long run. The ADF unit root test results are reported in Table 2 .

The presence of a long-run relationship among the variables is examined using the ARDL bounds testing procedure of Pesaran et al. (2001). The computed F-statistic (F = 4.367) exceeds the upper critical value at the 1% significance level, indicating that the null hypothesis of no cointegration can be rejected.

This finding confirms the existence of a long-run equilibrium relationship between energy intensity, financial development, green marketing awareness and the set of control variables. Establishing cointegration allows for the estimation of both the long-run coefficients and the short-run adjustment dynamics through the error-correction representation, where the error-correction term captures the speed at which deviations from the long-run equilibrium are corrected over time.

The F-statistic exceeds the upper critical value at the 1% level, confirming the presence of cointegration among energy intensity, financial development, green marketing awareness and the control variables. This result establishes a long-run equilibrium relationship and justifies the estimation of long-run parameters within the ARDL framework. Table 3 reports the bounds testing results, while Table 4 presents the estimated long-run coefficients and their statistical significance, offering insights into the structural determinants of energy performance.

The long-run coefficients obtained from the ARDL model point to substantial and directionally consistent effects of the key explanatory variables on energy intensity. Financial development carries a positive long-run coefficient (26.68), suggesting that improvements in financial depth and access have been associated with higher levels of energy use relative to economic output across the EU-27 during the sample period. One interpretation is that expanded financial resources may have supported energy-intensive consumption and production rather than systematically fostering low-carbon investments.

Table 2: ADF unit root test results

Variable	ADF statistic	P-value	Integration order	Decision
lENER_INT	1.231	0.996	I (1)	Non-stationary at level
lFD	–4.019	0.001	I (0)	Stationary at 1%
GMA	–4.048	0.001	I (0)	Stationary at 1%
FD_GMA	–4.325	0.0004	I (0)	Stationary at 1%
lGDP_PC	–0.777	0.826	I (1)	Non-stationary at level
lIND_SHARE	–1.613	0.476	I (1)	Non-stationary at level
lURBAN	–4.805	0.00005	I (0)	Stationary at 1%
lISO14001_PC	–2.589	0.095	I (1)	Weakly non-stationary at level

No variable is I (2), validating the ARDL approach

Table 3: ARDL bounds testing results

Test statistic	Value
F-statistic	4.367
Lower Bound P-value	0.00007
Upper Bound P-value	0.00499

Table 4: Long-Run ARDL coefficient estimates

Variable	Long-run coefficient
lFD	26.68
GMA	35.57
FD_GMA	44.64
lGDP_PC	–118.59
lIND_SHARE	14.97
lURBAN	290.85
lISO14001_PC	–1.41

Green marketing awareness also exerts a sizeable positive long-run effect (35.57), indicating that the rise in environmental consciousness has not yet translated into measurable improvements in aggregate energy efficiency. This may reflect a mismatch between environmental attitudes and behavioural or technological change, or alternatively, that "green" product demand has grown alongside overall consumption.

The interaction term (FD_GMA) displays an even larger positive long-run coefficient (44.64), implying that the simultaneous expansion of financial systems and environmental awareness amplifies upward pressure on energy intensity. In other words, when financial development and environmental awareness increase together, the net effect is a rise in energy intensity—possibly due to stronger scale effects in investment and consumption.

Among the control variables, GDP per capita bears a negative long-run coefficient (–118.59), consistent with the argument that higher income levels are associated with technological upgrading and efficiency improvements. By contrast, industrial value added (14.97) and urbanisation (290.85) contribute to higher long-run energy intensity, reflecting structural and demographic drivers that elevate energy demand. Environmental management capacity, proxied by ISO 14001 certifications per capita, shows a small negative coefficient (–1.41), suggesting a modest contribution to efficiency improvements.

Overall, the long-run estimates indicate that the EU's structural and behavioural dynamics over 2000–2018 have not fully converged toward a sustained reduction in energy intensity. While income growth and environmental management practices exert downward pressure, these effects appear to be offset by the combined influence of financial development, environmental awareness, industrial structure and urbanisation.

5.1. Long-Run ARDL Results

Following the confirmation of cointegration, the long-run ARDL estimates (Table 4) reveal clear and economically meaningful relationships between the explanatory variables and energy intensity. Financial development exhibits a positive and statistically significant coefficient, indicating that deeper and more accessible financial systems have been associated with higher energy use relative to economic output in the EU-27. Green marketing awareness also shows a positive long-run effect, suggesting that the rise in environmental consciousness has not yet translated into aggregate efficiency gains at the macro level.

The interaction term between financial development and green awareness has an even larger positive coefficient, implying that the simultaneous expansion of financial systems and public environmental awareness reinforces upward pressure on energy intensity rather than mitigating it. This may indicate that behavioural awareness, in the absence of strong structural or technological shifts, amplifies consumption and investment patterns that remain energy intensive.

Among the control variables, per capita income has the expected negative long-run effect, consistent with efficiency-enhancing technological progress at higher income levels. By contrast, industrial activity and urbanisation exert upward pressure on energy intensity, reflecting well-known structural and demographic drivers of energy demand. Environmental management capacity, proxied by ISO 14001 certifications per capita, displays a small negative coefficient, indicating a modest contribution to efficiency improvements.

Overall, the long-run findings suggest that the EU's structural and behavioural dynamics during 2000–2018 have not fully converged toward lowering energy intensity. Despite improvements in income levels and environmental management systems, these effects appear to be offset by financial deepening, rising environmental awareness and the region's industrial and demographic profile.

5.2. Short-Run Dynamics and ECM Results

Short-run dynamics, assessed through the error-correction representation, show that the lagged ECM term is negative—consistent with convergence toward the long-run equilibrium—but statistically insignificant. This is a common outcome in ARDL models estimated on relatively short annual macroeconomic samples, and suggests that adjustment toward equilibrium operates slowly.

Consistent with this, none of the first-difference variables exhibit statistically significant short-run effects. Annual changes in financial development, green marketing awareness or macroeconomic conditions do not produce immediate adjustments in energy intensity. Instead, the influence of these variables appears to materialise gradually through long-run channels such as technological upgrading, structural shifts and evolving consumption patterns.

Taken together, the ECM results reinforce the conclusion that while a stable long-run relationship exists, short-run responses are limited. This implies that policy interventions targeting financial development or public environmental awareness are likely to influence energy performance primarily through long-term mechanisms rather than rapid short-term adjustments.

After estimating the long-run parameters, the short-run dynamics are examined through the error-correction representation of the ARDL model. Table 5 reports the short-run coefficients, including first-differenced explanatory variables and the lagged error-correction term (ECM), which captures the speed of adjustment toward the long-run equilibrium.

Table 5: ECM–ARDL short-run estimates

Variable	Coefficient	Standard error	t-statistic	P-value
ΔlFD	0.2055	0.3319	0.6192	0.5989
ΔGMA	0.2658	0.2028	1.3107	0.3202
ΔFD_GMA	0.3358	0.2386	1.4077	0.2945
ΔlGDP_PC	–1.5509	2.8611	–0.5421	0.6421
ΔlIND_SHARE	0.6997	2.9047	0.2409	0.8321
ΔlURBAN	173.6682	129.9973	1.3359	0.3133
ΔlISO14001_PC	–0.0137	0.0524	–0.2618	0.8180
ECM(_{t-1}) (≡ lENER_INT.L1)	–1.0158	0.9905	–1.0256	0.4129

5.3. Diagnostic Tests

The diagnostic checks provide mixed but overall acceptable evidence regarding the adequacy of the estimated ARDL–ECM specification. The Ljung–Box Q-statistic at lag 1 indicates the presence of first-order serial correlation in the residuals (Ljung and Box, 1978), which is not unusual given the small sample size and the dynamic nature of the model. In contrast, the Jarque–Bera test fails to reject the null hypothesis of normally distributed residuals (Jarque and Bera, 1980), and the White test suggests that heteroskedasticity is not a concern (White, 1980).

Moreover, the stability diagnostics based on the CUSUM and CUSUMSQ tests do not reveal any structural instability over the sample period (Brown et al., 1975). Taken together, while the presence of low-order serial correlation warrants some caution when interpreting the short-run coefficients, the combination of residual normality, homoskedasticity and parameter stability supports the overall reliability of both the long-run estimates and the ECM specification. Similar diagnostic patterns are commonly reported in ARDL applications employing relatively small annual macroeconomic samples (Narayan, 2005; Jordan and Philips, 2018). The diagnostic test results are presented in Table 6 .

5.4. Diagnostic Tests – Interpretation

The diagnostic tests provide an overall assessment of the adequacy of the estimated ARDL–ECM model. The Ljung–Box Q-statistic indicates some evidence of first-order serial correlation in the residuals—a result that is not uncommon in small-sample macroeconomic settings (Narayan, 2005). In contrast, the Jarque–Bera test fails to reject the null hypothesis of normality (Jarque and Bera, 1980), and the White LM test suggests that heteroskedasticity is not a concern (White, 1980).

Furthermore, stability diagnostics based on the CUSUM and CUSUMSQ statistics reveal no structural instability over the sample period, indicating that the estimated parameters remain stable throughout (Brown et al., 1975; Pesaran et al., 2001). Taken together, these results suggest that although the presence of low-order serial correlation warrants some caution when interpreting

Table 6: Diagnostic test results

Diagnostic test	Statistic	P-value	Conclusion
Ljung–Box Q (lag 1)	8.2886	0.003989	Evidence of first-order serial correlation
Jarque–Bera Normality	0.7511	0.6869	Residuals are normally distributed
White Test (LM)	18.0000	0.3888	No heteroskedasticity detected
White Test (F)	–	–	Not applicable in small sample

(1) The Ljung–Box test is applied at lag 1 based on the small sample size and the ARDL (1,1,1,1,1,1,1) structure. (2) White's F-statistic is not reported due to small-sample rank limitations; the LM version provides the relevant inference

short-run coefficients, the combination of residual normality, homoskedasticity and parameter stability lends credibility to the overall ARDL–ECM specification. This diagnostic pattern aligns with findings reported in empirical ARDL applications using short annual macroeconomic samples (Shin et al., 2014).

5.5. Overall Synthesis of Empirical Findings

he empirical results consistently point to a stable long-run relationship among energy intensity, financial development and green marketing awareness across the EU-27 countries. The long-run coefficients indicate that structural and behavioural forces associated with financial deepening and rising environmental awareness exert persistent upward pressure on energy intensity. These findings echo earlier evidence suggesting that financial development and environmental consciousness may stimulate economic expansion and consumption patterns that remain energy intensive, at least until certain technological or institutional thresholds are reached (Tamazian and Rao, 2010; Sadorsky, 2010).

In contrast, economic development—captured by per capita income—contributes to long-run improvements in energy efficiency, consistent with the view that higher income levels facilitate technological upgrading, stricter regulation and cleaner production processes.

Short-run dynamics, however, are relatively weak. Although the error-correction term is negative, its lack of statistical significance suggests slow and imprecise adjustment toward the long-run equilibrium. This is consistent with the inertia of annual energy indicators and the long time horizon required for structural adjustments, capital-stock renewal and behavioural changes to materialise. Consequently, year-to-year fluctuations in financial development, environmental awareness and macroeconomic conditions do not translate into immediate changes in aggregate energy intensity.

Despite the weak short-run effects, the combined evidence of significant long-run coefficients, confirmed cointegration and broadly satisfactory diagnostic properties provides a coherent and internally consistent empirical foundation for the policy discussion that follows. The results imply that financial development and environmental awareness exert their primary influence through long-term structural channels rather than through short-term fluctuations—highlighting the importance of sustained policy engagement, institutional strengthening and technological transformation.

The study also demonstrates that environmentally friendly products—eco-labelled goods—are predominantly developed and consumed in wealthier markets, which are characterised by higher overall resource use. This pattern aligns with the finding that behavioural forces linked to financial development (wealth) and green marketing awareness may reinforce rather than diminish energy intensity. The current implementation of eco-labelling is therefore closely associated with higher, rather than lower, levels of resource consumption (Barkemeyer et al., 2023).

Furthermore, greater environmental awareness and the integration of green marketing practices within commercial enterprises can activate behavioural mechanisms that offset expected environmental gains. Concepts such as moral licensing, conspicuous consumption and innovation-seeking behaviour have been proposed as explanations for this phenomenon. For example, eco-labelled products—frequently marketed as premium or luxury goods—may be perceived by affluent consumers as both environmentally superior and socially desirable, thus functioning as a form of moral licensing for other high-impact activities (Barkemeyer et al., 2023). Alternatively, the purchase of eco-products may be motivated more by novelty-seeking tendencies than by genuine environmental responsibility (Zhao et al., 2025).

6. POLICY DISCUSSION

The empirical findings of this study offer several important policy insights for the EU-27, particularly in the context of the bloc's long-term sustainability and decarbonisation goals. The results indicate that financial development and green marketing awareness exert strong and persistent long-run effects on energy intensity, while short-run adjustments remain weak due to the slow and statistically insignificant error-correction mechanism. These patterns suggest that policy interventions must be designed with a long-term structural perspective rather than expecting rapid improvements in energy performance.

A first implication concerns the role of the financial system. The positive long-run effect of financial development on energy intensity suggests that, over the sample period, financial resources were not systematically channelled toward low-carbon sectors, energy-efficient technologies or environmentally responsible investments. Instead, financial deepening appears to have supported broader economic expansion, including activities that remain energy-intensive. This highlights the need for stronger green financial regulations, including taxonomies that classify sustainable activities, mandatory climate-related disclosures, preferential financing for energy-efficient technologies and targeted credit schemes to reduce the cost of capital for renewable energy and efficiency-enhancing investments. Without such structural incentives, financial development alone may continue to reinforce energy demand rather than promoting decarbonisation (Bayar et al., 2020; Uddin et al., 2021; Hodžić et al., 2023).

The second implication relates to green marketing awareness. Although environmental awareness has increased notably across Europe, the positive coefficient implies that this awareness has not yet translated into lower energy intensity at the aggregate level. A plausible explanation is that green marketing has often been oriented toward symbolic communication or product differentiation rather than driving substantive behavioural change, technological upgrading or energy-efficient consumption patterns (Rawal and Aryal, 2024; Shukla et al., 2020). This underscores the importance of strengthening regulatory oversight of environmental claims, supporting consumer education programs on energy-efficient practices and ensuring that green communication strategies are aligned with measurable environmental improvements. Policies that integrate behavioural nudges, labelling schemes and digital tools that provide real-time energy consumption feedback may

help convert awareness into actual energy-saving behaviour (Cuc et al., 2022).

The positive and sizeable coefficient of the interaction term between financial development and green marketing awareness further reinforces the idea that neither financial expansion nor rising environmental concern, on their own, have been sufficient to shift the EU's energy trajectory onto a lower-intensity path. Instead, their combined effect appears to amplify energy use, potentially because both forces stimulate overall economic activity. This finding suggests the need for coordinated policy frameworks that simultaneously reshape financial incentives and behavioural dynamics. Examples include green bond standards tied explicitly to energy-efficiency outcomes, financial support for firms adopting ISO 50001 or other energy management systems and integrated policy packages combining sustainable finance with mandatory energy-efficiency targets for industries and households.

Turning to the control variables, the negative long-run coefficient of per capita income indicates that economic development supports energy efficiency, likely through technological progress, cleaner production methods and stronger regulatory frameworks (Tallini and Cedola, 2016). This implies that targeted support for low-income EU members, particularly in Central and Eastern Europe, may accelerate convergence toward a low-energy-intensity growth path. Conversely, the positive effects of industrial activity and urbanisation highlight persistent structural sources of energy demand. Policies focused on industrial restructuring, energy-efficient urban planning, the electrification of transport systems and the deployment of smart grids become essential for managing rising energy needs in growing urban areas and industrial centres.

Finally, the small negative coefficient associated with ISO 14001 certifications suggests that voluntary environmental management systems contribute to energy efficiency, albeit modestly. This finding supports policies that incentivise environmental management adoption in SMEs—such as certification subsidies, technical support programmes and the integration of ISO-based practices into broader sectoral sustainability strategies (Laskurain et al., 2017).

Overall, the policy implications derived from the ARDL–ECM results point to a clear conclusion: meaningful reductions in energy intensity will require long-term, multi-dimensional and coordinated interventions. These interventions must align financial development, environmental awareness, industrial strategy and urban planning with the EU's decarbonisation objectives. Short-term measures alone are unlikely to deliver substantial improvements given the structural nature of the drivers identified in this study.

The finding that financial growth and environmental awareness exert their primary influence through long-term structural channels indicates that companies should prioritise substantive and persistent corporate actions, avoiding short-term showmanship (Salovaara and Hagolani-Albov, 2025). From a marketing perspective, the following steps may be taken during this process (Li et al., 2024).

It is imperative for organisations to refrain from symbolic environmental actions that fail to yield meaningful results or that are purely superficial, as such behaviour can undermine corporate credibility. Symbolic actions often reflect only superficial alignment with sustainability goals, serving primarily to create an appearance of compliance. However, in competitive environments where information demand is high (e.g., among industry stakeholders), such actions may damage corporate reputation and raise doubts about genuine commitment. Corporate credibility is better supported through substantive environmental actions that require deeper organisational change, greater resource allocation and long-term investment—such as developing environmental innovations. The higher cost of such actions makes them more difficult to imitate, thereby sending stronger and more credible signals about a firm's competence and commitment. Technological transformation and corporate empowerment, which are critical for long-term impact, are also directly tied to fulfilling Environmental, Social and Governance (ESG) responsibilities.

In conclusion, as emphasised throughout this article, sustained policy engagement and institutional strengthening are essential to prevent sustainability from being reduced to merely "optimising day-to-day operations" within prevailing market logic. Genuine transformation requires corporate strategies that interrogate underlying structures and invest in fundamental innovation, rather than relying on individualised solutions centred solely on consumers purchasing "green products."

7. CONCLUSION

This study examined the long-run and short-run determinants of energy intensity in the EU-27 by integrating financial development and green marketing awareness into an ARDL–ECM framework. The motivation behind the analysis stems from the increasing recognition that financial structures, environmental awareness and behavioural dynamics jointly shape countries' progress toward energy efficiency and decarbonisation. While prior studies have tended to examine financial or environmental dimensions in isolation, this research provides one of the first empirical assessments of how green marketing awareness—an emerging behavioural and informational mechanism—interacts with financial development to influence energy intensity at the macro level.

The results reveal a clear long-run cointegration relationship among the variables. Financial development and green marketing awareness both exert positive and persistent effects on energy intensity, and their interaction further amplifies this upward pressure. These findings indicate that neither financial deepening nor strengthened environmental communication has yet translated into substantial reductions in energy intensity across the EU-27. Instead, rising environmental awareness and expanding financial capacity appear to coexist with production and consumption structures that remain fundamentally energy-intensive. By contrast, higher income levels contribute to long-run improvements in energy efficiency, whereas industry structure and urbanisation increase energy use relative to economic output. Short-run dynamics are weak, reflecting a slow and statistically

insignificant adjustment mechanism and the high inertia of annual energy consumption patterns.

The study's main contribution lies in demonstrating that green marketing awareness, despite its prominence in policy agendas and corporate communication, does not automatically lead to improved energy efficiency at the aggregate level (Cuc et al., 2022; Pillai et al., 2024). By incorporating this behavioural dimension into a macro-econometric framework, the analysis uncovers a critical gap between environmental signalling and actual energy performance. This insight complements traditional economic and technological explanations of energy intensity and underscores the importance of aligning environmental communication with substantive efficiency-enhancing investments and structural transformations. The interaction effect further suggests that financial and behavioural mechanisms can reinforce each other in ways that are not necessarily conducive to sustainability.

From a policy perspective, the findings imply that energy intensity in the EU-27 cannot be reduced by financial development or environmental awareness alone. Effective progress requires coordinated strategies that channel financial resources into genuinely low-carbon technologies, strengthen the credibility and regulation of green marketing practices, and address structural drivers such as industrial composition and urbanisation (Hodžić et al., 2023). Without such alignment, both finance and environmental messaging risk remaining symbolic rather than transformative (Pyka and Pyka, 2023).

Despite its contributions, this study is subject to certain limitations. The analysis relies on aggregate annual data, which may mask within-country heterogeneity in consumer behaviour, firm-level practices or local financial structures. Additionally, green marketing awareness is measured indirectly, and future research could benefit from more granular indicators capturing communications intensity, consumer responses or firm-level environmental claims. Extending the framework to a panel ARDL or nonlinear specification may also uncover asymmetries and country-specific dynamics that are not observable in aggregate time-series analysis (Kwiliński et al., 2023; Celic and Lenz, 2022).

Overall, the study advances the understanding of how financial and behavioural factors interact in shaping energy performance and provides a novel empirical foundation for integrating green marketing into macro-level sustainability research. Its findings highlight the need for policies that bridge the gap between rising environmental awareness and real improvements in energy efficiency, supporting a more coherent transition toward the EU's long-term decarbonisation objectives.

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