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Innovation, Energy Transition, and Sustainable Economic Development in the European Union: Evidence from a System GMM Approach

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Abstract

The economic dimension of sustainable development has become a central objective of European policies aimed at balancing economic prosperity, social inclusion, and environmental sustainability. This study investigates the contribution of innovation and energy transition to the economic dimension of sustainable development in the European Union. Using a balanced panel dataset covering the 27 European Union Member States over the period 2010–2024, the effects of research and development expenditure, employment rate, energy productivity, and renewable energy share on GDP per capita, employed as a proxy for the economic dimension of sustainable development, are analysed using a two-step System Generalized Method of Moments (System GMM) estimator. The results indicate that employment and energy productivity have positive and statistically significant effects, whereas research and development expenditure and renewable energy share are not statistically significant. The findings suggest that labour market performance and efficient energy use contribute positively to the economic dimension of sustainable development, whereas the effects of innovation and renewable energy deployment may materialise only over longer time horizons. The study provides empirical evidence supporting integrated policies that strengthen economic competitiveness and long-term sustainability within the European Union.

Keywords: economic dimension of sustainable development; energy transition; innovation; renewable energy; energy productivity

1. Introduction

Sustainable economic development has become a central objective of contemporary public policies, particularly in the context of growing environmental challenges, climate change, resource scarcity, and increasing socioeconomic inequalities. The adoption of the United Nations Sustainable Development Goals (SDGs) and the implementation of the European Green Deal have reinforced the need for development models capable of balancing economic prosperity, social inclusion, and environmental protection. As a result, policymakers and researchers have increasingly focused on identifying the factors that can simultaneously support economic growth and sustainability objectives [1–3].

Within this context, the concept of energy transition has gained significant importance in both academic research and policy debates. The transition from conventional fossil fuel-based systems toward cleaner and more efficient energy structures is widely regarded as a prerequisite for achieving long-term sustainability. European Union Member States



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have intensified their efforts to promote renewable energy deployment, improve energy efficiency, and stimulate technological innovation as part of broader strategies aimed at fostering sustainable development. These initiatives are expected not only to reduce environmental pressures but also to enhance economic competitiveness, resilience, and long-term prosperity [4–7].

Innovation represents another fundamental pillar of sustainable economic development. Investments in research and development (R&D) contribute to technological progress, productivity improvements, and the creation of new economic opportunities. At the same time, innovation facilitates the development of cleaner production processes, energy-efficient technologies, and renewable energy solutions that support the transition toward a more sustainable economy. Consequently, the interaction between innovation and energy transition has attracted increasing attention in the sustainability literature [8,9].

Employment also plays a crucial role in achieving sustainable economic development. Beyond its direct contribution to economic output, higher employment levels support social cohesion, reduce poverty risks, and enhance living standards. The social dimension of sustainability emphasises the importance of inclusive labour markets capable of generating quality employment opportunities while ensuring long-term economic resilience. In the European context, employment policies have become increasingly integrated with broader sustainability strategies, reflecting the recognition that economic and environmental transitions must be accompanied by positive social outcomes.

Similarly, energy productivity has emerged as a key indicator of sustainable development. By measuring the economic value generated per unit of energy consumed, energy productivity reflects the efficiency with which economies utilise available resources. Improvements in energy productivity contribute to reducing energy dependence, lowering production costs, and decreasing environmental pressures. Consequently, energy efficiency policies have become an essential component of European sustainability initiatives, supporting both economic competitiveness and climate objectives [10,11].

Existing empirical research has extensively examined the relationships between innovation, renewable energy, employment, energy efficiency, and economic performance. Numerous studies report a positive association between research and development activities and economic growth, highlighting the role of innovation in enhancing productivity and competitiveness. Other contributions emphasise the beneficial effects of renewable energy adoption and energy efficiency improvements on sustainable development outcomes. Likewise, labour market performance has been identified as an important determinant of long-term economic prosperity. However, the empirical evidence remains fragmented, as many studies focus on individual determinants while overlooking the potential interactions among innovation, employment, and energy transition variables [6,12].

Furthermore, previous investigations often rely on static estimation techniques that may not adequately address endogeneity, reverse causality, and the dynamic nature of economic development processes. Given that current levels of economic development are strongly influenced by past performance, dynamic panel approaches offer a more appropriate framework for analysing the determinants of sustainable economic development. Despite the growing interest in sustainability-related research, relatively limited evidence exists regarding the combined effects of innovation, employment, energy productivity, and renewable energy deployment within a unified dynamic framework covering all European Union Member States.

Despite the growing body of literature on sustainable economic development, several important research gaps remain. First, most empirical studies examine innovation, renewable energy, employment, or energy efficiency separately, providing only a partial understanding of the complex interactions among these determinants. Second, previous

research has predominantly focused either on economic growth or on environmental sustainability, while relatively limited attention has been devoted to assessing how innovation and energy transition jointly influence the economic dimension of sustainable development within an integrated analytical framework. Third, existing empirical evidence remains inconclusive regarding the effectiveness of research and development expenditure and renewable energy deployment in promoting economic prosperity, with previous studies reporting mixed and sometimes contradictory findings. Finally, relatively few studies investigate these relationships using a dynamic panel framework that simultaneously addresses persistence in economic development, endogeneity concerns, and country-specific heterogeneity across all 27 European Union Member States. These limitations highlight the need for further empirical evidence capable of providing a more comprehensive understanding of the drivers of sustainable economic development in the European Union.

Building upon the research gaps identified above, the present study makes several important contributions to the literature on sustainable economic development. First, it develops an integrated analytical framework that simultaneously examines the roles of innovation, employment, energy productivity, and renewable energy deployment, thereby providing a more comprehensive perspective on the economic dimension of sustainable development than studies focusing on these determinants in isolation. Second, by analysing all 27 European Union Member States over the period 2010–2024, the study offers updated empirical evidence for a policy context characterised by the accelerated implementation of the European Green Deal and the Sustainable Development Goals. Third, the study contributes to the ongoing debate on the effectiveness of innovation- and energy transition-related policies by evaluating whether investments in research and development and renewable energy deployment translate into measurable improvements in economic performance. Finally, by employing a dynamic panel framework capable of addressing persistence, endogeneity, and unobserved heterogeneity, the analysis provides robust empirical evidence that contributes to a better understanding of the factors that support the economic dimension of sustainable development in the European Union. The findings are expected to enrich the existing literature while offering useful insights for policymakers seeking to design more effective strategies for achieving sustainable and resilient economic growth.

In light of the research gaps identified and the contributions outlined above, the primary objective of this study is to examine the extent to which innovation and energy transition contribute to the economic dimension of sustainable development in the European Union. To achieve this objective, the study investigates the effects of research and development expenditure, employment rate, energy productivity, and renewable energy share on GDP per capita across the 27 EU Member States during the period 2010–2024. Despite the growing body of literature on innovation, energy transition, and sustainable development, important research gaps remain. Existing studies generally examine these relationships separately, focus on a limited set of determinants, or rely on static econometric approaches that do not fully account for the dynamic nature of economic development. Moreover, comprehensive evidence covering all 27 European Union Member States over the post-2010 period remains limited, particularly in the context of recent policy initiatives such as the European Green Deal and the accelerating energy transition. To address these gaps, this study develops an integrated dynamic framework that simultaneously examines the effects of research and development expenditure, employment, energy productivity, and renewable energy share on sustainable economic development using a two-step System GMM estimator. The study contributes to the literature in three ways. First, it provides a comprehensive assessment of innovation and energy transition within a unified analytical framework. Second, it applies a dynamic estimation strategy that explicitly addresses endogeneity, country heterogeneity, and the persistence of economic development. Third,

it offers updated empirical evidence for all EU Member States over the period 2010–2024, contributing to a better understanding of the factors supporting sustainable economic development in the contemporary European policy context. Given the multidimensional nature of sustainable development, the present study focuses specifically on its economic dimension. Accordingly, the study seeks to answer the following research question: To what extent do innovation- and energy transition-related factors influence the economic dimension of sustainable development in the European Union? To address this question, the study employs a dynamic panel framework that captures the interactions among innovation, labour market performance, energy productivity, and renewable energy deployment over time. By integrating these determinants within a unified framework, the study provides empirical evidence on how innovation, labour market performance, and energy transition jointly influence the economic dimension of sustainable development across the European Union.

Given the multidimensional nature of sustainable development, the empirical analysis focuses on its economic dimension. Accordingly, GDP per capita is employed as a proxy for economic performance. Although this indicator does not fully capture the environmental and social dimensions of sustainable development, it is widely used in empirical macroeconomic research as a reliable measure of long-term economic prosperity and economic performance. Consequently, the results should be interpreted as reflecting the economic dimension of sustainable development rather than sustainable development in its broader multidimensional sense.

The remainder of this paper is organised as follows. Section 2 critically reviews the relevant literature and develops the research hypotheses. Section 3 describes the data, variables, and econometric methodology employed in the empirical analysis. Section 4 presents the empirical findings, while Section 5 discusses the results in relation to the existing literature, highlighting their theoretical and policy implications. Finally, Section 6 summarises the main conclusions, outlines the study's limitations, and suggests directions for future research.

2. Literature Review

2.1. Innovation and Sustainable Economic Development

Innovation is widely recognised as one of the most important drivers of long-term economic development and sustainability. Within the framework of endogenous growth theory, investments in research and development (R&D) generate technological progress, enhance productivity, and improve the capacity of economies to create and absorb new knowledge. Consequently, innovation contributes not only to economic expansion but also to the achievement of broader sustainability objectives by facilitating the development of cleaner technologies, more efficient production processes, and environmentally friendly business models [13–16].

In recent years, the relationship between innovation and sustainable development has attracted increasing attention from both researchers and policymakers. The transition towards low-carbon and resource-efficient economies requires substantial technological advances capable of reducing environmental pressures while maintaining economic competitiveness. In this context, innovation is considered a key enabler of energy transition, supporting the diffusion of renewable energy technologies, improvements in energy efficiency, and the development of sustainable industrial systems. Studies focusing on green growth and sustainability transitions emphasise that technological innovation and knowledge creation play a fundamental role in strengthening economic resilience and supporting sustainable development pathways [17–19].

Although a substantial body of empirical research reports a positive relationship between research and development expenditure and economic performance, the evidence is not entirely conclusive. While several studies identify significant positive effects of innovation on productivity, competitiveness, and long-term economic growth, other contributions suggest that the economic benefits of R&D investment may depend on factors such as institutional quality, innovation efficiency, absorptive capacity, or the time required for innovation outcomes to materialise. Consequently, on the economic dimension of sustainable development remains context-dependent, justifying further empirical investigation, particularly within the European Union [18–21].

Within the European Union, innovation occupies a central position in sustainability-oriented policy frameworks. Initiatives such as the European Green Deal and various research and innovation programmes emphasise the importance of technological development in achieving climate neutrality, enhancing resource efficiency, and fostering sustainable economic development. As European economies continue to pursue ambitious sustainability objectives, investments in research and development are expected to generate both direct economic benefits and indirect gains through improved environmental performance and energy system transformation [21,22]. Nevertheless, despite these ambitious policy initiatives, empirical evidence remains inconclusive regarding the extent to which higher R&D expenditure translates into measurable improvements in economic performance across EU Member States.

Based on the theoretical arguments and empirical evidence discussed above, innovation is expected to positively influence the economic dimension of sustainable development. Higher levels of research and development expenditure enhance knowledge creation, stimulate productivity growth, support energy transition processes, and strengthen the capacity of economies to achieve sustainable development objectives. Despite the predominance of positive findings in the literature, the mixed empirical evidence suggests that the strength and significance of this relationship may vary across countries and periods. Therefore, further empirical investigation remains necessary to assess whether innovation consistently contributes to the economic dimension of sustainable development within the European Union.

H1. *Research and development expenditure has a positive effect on the economic dimension of sustainable development in the European Union.*

2.2. Employment and Sustainable Economic Development

Employment constitutes a fundamental pillar of sustainable economic development, contributing not only to economic performance but also to social cohesion, poverty reduction, and overall societal well-being. The sustainability paradigm emphasises the importance of balancing economic, social, and environmental objectives, placing labour market performance at the centre of inclusive development strategies. In this context, higher employment levels are generally associated with increased household income, improved living standards, and stronger economic resilience [23–25].

From a theoretical perspective, employment contributes directly to economic development through the utilisation of human capital and the expansion of productive capacity. Labour represents a key production factor, and higher employment rates generally support economic output and productivity growth. Moreover, employment enhances social inclusion by facilitating participation in economic activities, reducing inequality, and strengthening the capacity of individuals and communities to adapt to economic and environmental transitions. Consequently, labour market performance is increasingly regarded as an essential component of sustainable development frameworks [24,26].

Although a substantial body of empirical research reports a positive association between employment and the economic dimension of sustainable development, the empirical

evidence is not entirely uniform. While many studies conclude that higher employment rates stimulate economic growth, social cohesion, and living standards, other contributions suggest that the quality of employment, labour productivity, labour market flexibility, and institutional conditions may be more important than employment levels alone. Moreover, some studies argue that structural changes associated with digitalization, automation, and the green transition may generate short-term labour market adjustments, limiting the immediate contribution of employment to sustainable economic development. These contrasting findings indicate that the relationship remains complex and deserves further empirical investigation [27–29].

Within the European Union, employment policies have become closely linked to sustainability objectives. European strategies increasingly emphasise the creation of quality jobs capable of supporting both economic growth and social inclusion while facilitating the transition towards greener and more resource-efficient economies. The concept of a “just transition” further underlines the necessity of ensuring that sustainability-oriented transformations generate positive labour market outcomes and do not exacerbate existing social disparities. Consequently, maintaining high employment levels remains a critical prerequisite for achieving sustainable economic development across EU Member States [23,25,30]. Nevertheless, considerable differences in labour market structures, institutional arrangements, and economic development across EU Member States suggest that the impact of employment on the economic dimension of sustainable development may not be uniform throughout the European Union.

Considering the theoretical arguments and empirical evidence discussed above, employment is expected to positively influence the economic dimension of sustainable development. Higher employment rates enhance economic activity, strengthen social cohesion, and support the adaptive capacity of economies undergoing sustainability and energy transition processes. Despite the predominance of positive theoretical arguments, the heterogeneous empirical evidence indicates that the contribution of employment to sustainable economic development may differ across institutional and economic contexts. Accordingly, further empirical investigation is required to assess this relationship within the European Union.

H2. *Employment rate has a positive effect on the economic dimension of sustainable development in the European Union.*

2.3. Energy Productivity and Sustainable Development

Energy productivity has emerged as a key indicator of sustainable development, reflecting the efficiency with which economies transform energy inputs into economic output. As concerns regarding climate change, resource depletion, and energy security continue to intensify, improving energy productivity has become a central objective of sustainability-oriented policies worldwide. By generating greater economic value from a given amount of energy consumption, economies can simultaneously enhance competitiveness, reduce environmental pressures, and support long-term sustainable development [31–33].

Theoretical perspectives suggest that improvements in energy productivity contribute to economic development through several mechanisms. Higher energy efficiency reduces production costs, improves resource allocation, and increases the competitiveness of firms and industries. Moreover, efficient energy utilisation decreases dependence on external energy sources and strengthens economic resilience against fluctuations in energy prices and supply disruptions. Consequently, energy productivity is increasingly viewed as a strategic factor supporting both economic performance and environmental sustainability [34,35].

The relationship between energy productivity and sustainable development has received considerable attention in recent empirical research. Although a large body of empirical research reports a positive relationship between energy productivity and the eco-

economic dimension of sustainable development, the evidence is not entirely consistent. While numerous studies conclude that improvements in energy efficiency enhance economic performance and environmental sustainability, other contributions argue that these effects may vary according to countries' technological capabilities, industrial structure, energy mix, and institutional quality. Furthermore, some authors suggest that the economic benefits of higher energy productivity may materialise only over longer time horizons or may be influenced by complementary innovation and energy policies. These contrasting findings indicate that the relationship remains context-dependent and warrants further empirical investigation. A growing body of evidence further suggests that economies characterised by higher levels of energy efficiency tend to achieve stronger economic performance while simultaneously reducing environmental impacts. Improvements in energy productivity facilitate the decoupling of economic growth from energy consumption, enabling countries to expand economic activity without proportionally increasing resource use. This decoupling process represents a fundamental component of sustainable development strategies and is frequently associated with technological progress, innovation, and structural transformation [34–37].

Within the European Union, energy productivity occupies a prominent position in policy frameworks aimed at achieving climate neutrality and enhancing economic competitiveness. The European Green Deal, together with various energy efficiency initiatives, emphasises the importance of reducing energy intensity and promoting more efficient patterns of energy use across economic sectors. By improving energy productivity, EU Member States can simultaneously support economic growth, strengthen energy security, and advance environmental sustainability objectives [33,36,38]. Nevertheless, substantial differences in energy systems, technological development, and energy policy implementation across EU Member States suggest that the impact of energy productivity on the economic dimension of sustainable development may not be uniform throughout the European Union.

In the present study, energy productivity is measured using the Eurostat indicator, which expresses the ratio between gross domestic product and gross available energy. Although this indicator incorporates an economic output component in its construction, it is widely adopted within the European policy framework as a benchmark for assessing improvements in energy efficiency and resource utilisation. Accordingly, the indicator is interpreted in this study as a proxy for the efficiency with which economies transform available energy into economic value rather than as an alternative measure of economic performance itself. Nevertheless, the potential methodological implication arising from the inclusion of an output component is explicitly acknowledged and is further discussed in the Conclusions section when interpreting the empirical results.

Given the theoretical foundations and empirical evidence presented above, higher energy productivity is expected to be positively associated with the economic dimension of sustainable development while supporting broader sustainable development objectives through more efficient energy utilisation. Despite the generally positive theoretical expectations, the heterogeneous empirical evidence suggests that the magnitude and significance of the relationship between energy productivity and sustainable economic development may differ across countries and over time. Therefore, further empirical investigation is required to assess this relationship within the European Union.

H3. *Energy productivity has a positive effect on the economic dimension of sustainable development in the European Union.*

2.4. Renewable Energy and Sustainable Economic Development

The expansion of renewable energy has become one of the most significant components of contemporary sustainability strategies. Growing concerns regarding climate change, environmental degradation, and energy security have accelerated the transition from fossil fuel-based energy systems towards cleaner and more sustainable energy sources. As a result, renewable energy deployment has emerged as a central pillar of national and international policies aimed at fostering sustainable development and supporting long-term economic resilience [39–41].

From a theoretical perspective, renewable energy contributes to sustainable economic development through multiple channels. First, the increased use of renewable energy reduces dependence on finite fossil fuel resources and enhances energy security. Second, investments in renewable energy infrastructure stimulate economic activity by creating new industries, generating employment opportunities, and encouraging technological innovation. Third, renewable energy supports environmental sustainability by reducing greenhouse gas emissions and mitigating the adverse effects of climate change. Consequently, the transition towards renewable energy is increasingly viewed as a mechanism capable of simultaneously generating economic, social, and environmental benefits [42–44].

The empirical literature generally reports a positive relationship between renewable energy development and economic performance. Numerous studies indicate that greater renewable energy adoption contributes to economic growth by promoting investment, enhancing energy diversification, and supporting technological advancement. In addition, renewable energy expansion is frequently associated with improvements in environmental quality and resource efficiency, reinforcing its role within broader sustainable development frameworks. Nevertheless, empirical findings are not always unanimous, as the magnitude and direction of the relationship may vary depending on the level of economic development, energy market structures, and institutional conditions [42–47]. Some studies argue that the positive economic effects of renewable energy deployment may only materialise over longer time horizons because the transition requires substantial upfront investments, technological adaptation, and structural adjustments. Other contributions suggest that the effectiveness of renewable energy policies depends on complementary factors such as energy productivity, innovation capacity, institutional quality, and the overall regulatory environment. Consequently, the economic impact of renewable energy remains context-specific and continues to be the subject of empirical debate.

Within the European Union, renewable energy occupies a strategic position in sustainability and climate policies. The European Green Deal and related policy initiatives have established ambitious targets aimed at increasing the share of renewable energy in final energy consumption and accelerating the transition towards climate neutrality. These efforts reflect the recognition that renewable energy deployment can simultaneously support environmental objectives, strengthen energy independence, and contribute to sustainable economic development. Consequently, understanding the economic implications of renewable energy expansion remains highly relevant for both policymakers and researchers [39,40,48]. However, considerable differences in renewable energy penetration, national energy mixes, and policy implementation across EU Member States suggest that the economic effects of renewable energy deployment may vary across countries.

Based on the theoretical arguments and empirical evidence discussed above, renewable energy is expected to positively influence the economic dimension of sustainable development. A higher share of renewable energy contributes to cleaner economic growth, supports energy transition processes, and enhances the long-term sustainability of economic systems. Although theoretical arguments largely support a positive contribution of renewable energy to the economic dimension of sustainable development, the hetero-

geneous empirical evidence indicates that the magnitude and timing of these effects may differ across countries and institutional settings. Therefore, further empirical investigation is necessary to evaluate the role of renewable energy deployment in promoting the economic dimension of sustainable development within the European Union.

H4. *Renewable energy share has a positive effect on the economic dimension of sustainable development in the European Union.*

Overall, the reviewed literature suggests that innovation, labour market performance, and energy transition are important determinants of the economic dimension of sustainable development. However, previous empirical evidence remains fragmented, as studies frequently analyse these determinants in isolation, report mixed findings, or focus on individual countries and limited time periods. Moreover, the existing literature provides mixed evidence regarding the magnitude and statistical significance of these relationships, highlighting the need for further empirical investigation within a unified analytical framework. Furthermore, relatively limited attention has been devoted to examining their joint effects within a dynamic framework encompassing all European Union Member States. These limitations motivate the present study, which seeks to provide an integrated assessment of these relationships using a two-step System GMM estimator and updated data for the period 2010–2024.

3. Materials and Methods

3.1. Data and Variables

This study investigates the determinants of sustainable economic development in the European Union using a balanced panel dataset covering the 27 EU Member States over the period 2010–2024. The selected period captures important economic, social, and environmental transformations, including post-financial crisis recovery, the implementation of sustainability-oriented policies, the acceleration of energy transition initiatives, and the adoption of the European Green Deal.

All data were obtained from Eurostat, ensuring consistency and comparability across countries and over time. In this study, GDP per capita is employed as a proxy for the economic dimension of sustainable development. Although sustainable development is inherently multidimensional, encompassing economic, social, and environmental dimensions, GDP per capita remains one of the most widely used indicators of long-term economic prosperity and widely employed in cross-country macroeconomic analyses. Therefore, the empirical results should be interpreted as reflecting the economic dimension of sustainable development rather than sustainability in its broader sense. Nevertheless, the authors acknowledge that this indicator does not fully reflect the environmental and social dimensions of sustainable development, representing a limitation of the present study and an important avenue for future research.

The explanatory variables were selected based on theoretical considerations and previous empirical research. Innovation is measured through research and development expenditure as a percentage of GDP (RD). Labour market performance is represented by the employment rate of the population aged 20–64 years (EMP). Energy efficiency is captured through energy productivity (ENEPD), which reflects the economic value generated per unit of energy consumed. Finally, the energy transition dimension is represented by the share of renewable energy in gross final energy consumption (REN).

Table 1 summarises the variables included in the analysis.

To reduce potential heteroscedasticity, improve the distributional properties of the variables, and facilitate the interpretation of the estimated coefficients, GDP per capita and

energy productivity are transformed into natural logarithms. Consequently, the empirical analysis employs $\ln\text{GDPPC}$ and $\ln\text{ENEPROD}$ in econometric estimations.

Table 1. Description of Variables Used in the Empirical Analysis.

Variable	Description	Measurement
GDPPC	GDP per capita	Euro per capita
RD	Research and development expenditure	% of GDP
EMP	Employment rate (20–64 years)	%
ENEPROD	Energy productivity	Euro per kilogram of oil equivalent
REN	Renewable energy share	% of gross final energy consumption

3.2. Model Specification

To examine the determinants of the economic dimension of sustainable development in the European Union, this study specifies a dynamic panel data model in which current GDP per capita depends on both its past values and a set of explanatory variables associated with innovation, labour market performance, and energy transition. The dynamic specification is particularly appropriate because GDP per capita exhibits persistence over time, implying that current economic conditions are influenced by previous development trajectories.

The baseline empirical model is specified as follows:

$$\ln(\text{GDPPC})_{it} = \alpha \ln(\text{GDPPC})_{it-1} + \beta_1 \text{RD}_{it} + \beta_2 \text{EMP}_{it} + \beta_3 \ln(\text{ENEPROD})_{it} + \beta_4 \text{REN}_{it} + \mu_i + \varepsilon_{it}, \quad (1)$$

where

$\ln(\text{GDPPC})_{it}$ represents the natural logarithm of GDP per capita in country (i) at time (t);

$\ln(\text{GDPPC})_{it-1}$ denotes the lagged dependent variable;

RD_{it} represents research and development expenditure as a percentage of GDP;

EMP_{it} denotes the employment rate of the population aged 20–64 years;

$\ln(\text{ENEPROD})_{it}$ represents the natural logarithm of energy productivity;

REN_{it} denotes the share of renewable energy in gross final energy consumption;

μ_i captures country-specific unobserved effects;

ε_{it} represents the idiosyncratic error term.

The dynamic nature of the economic dimension of sustainable development, together with the potential presence of endogeneity, reverse causality, and unobserved country-specific heterogeneity, justifies the use of a dynamic panel data approach. Moreover, explanatory variables such as research and development expenditure, employment, energy productivity, and renewable energy deployment may be simultaneously influenced by economic development, giving rise to potential endogeneity concerns. Ignoring these issues could result in biased and inconsistent parameter estimates. Therefore, a dynamic specification including the lagged dependent variable is adopted to better capture the adjustment process of the economic dimension of sustainable development across European Union Member States.

Preliminary panel diagnostics were conducted before estimating the dynamic model. The Im–Pesaran–Shin panel unit root test indicates that most variables are non-stationary in levels but become stationary after first differencing, while RD appears stationary in levels. These results support the use of a dynamic panel framework based on transformed variables and internal instruments. In addition, the Pesaran cross-sectional dependence test indicates significant cross-sectional dependence among EU Member States, reflecting the presence of common shocks and structural interdependencies within the European Union. Therefore, the empirical strategy relies on a dynamic System GMM estimator with robust diagnostic testing to address persistence, endogeneity, and panel-specific effects.

The inclusion of the lagged dependent variable reflects the dynamic nature of the economic dimension of sustainable development and captures persistence effects over time. Research and development expenditure is expected to positively influence the economic dimension of sustainable development through technological progress, productivity enhancement, and innovation-driven growth. Employment rate is included to capture the social dimension of sustainability and its contribution to economic performance. Energy productivity reflects the efficiency with which energy resources are transformed into economic output, while renewable energy share captures the degree of energy transition and the adoption of sustainable energy systems.

Based on the theoretical framework and empirical evidence discussed in Section 2, positive coefficients are expected for all explanatory variables. Higher levels of innovation, employment, energy productivity, and renewable energy deployment are anticipated to contribute to the economic dimension of sustainable development across European Union Member States.

3.3. Estimation Method

The estimation of dynamic panel data models presents several econometric challenges, including unobserved heterogeneity, endogeneity, and potential reverse causality between economic development and its determinants. In the present study, these issues are particularly relevant because variables such as research and development expenditure, employment rate, energy productivity, and renewable energy deployment may be simultaneously influenced by the level of economic development. Furthermore, the inclusion of a lagged dependent variable generates correlation between the explanatory variables and the error term, leading to biased and inconsistent estimates when conventional estimation techniques are applied.

Traditional estimation approaches, such as Ordinary Least Squares (OLS), Fixed Effects (FE), and Random Effects (RE), are not fully appropriate in this context. OLS estimators are biased due to the presence of country-specific effects, while fixed effects estimators suffer from the well-known dynamic panel bias resulting from the inclusion of the lagged dependent variable. Consequently, more advanced estimation techniques are required to obtain consistent parameter estimates.

To address these issues, this study employs the System Generalized Method of Moments (System GMM) estimator developed by [49]. The System GMM approach combines equations in first differences with equations in levels, using internal instruments derived from lagged values of the variables. Compared with the Difference GMM estimator proposed by [50], System GMM generally provides more efficient and reliable estimates, particularly when the variables exhibit a high degree of persistence over time.

The choice of the System GMM estimator is primarily motivated by the dynamic specification of the model and the potential endogeneity of the explanatory variables rather than by the relative dimensions of the panel alone. The sample comprises 27 European Union Member States observed over 15 years, representing a moderate cross-sectional dimension and a relatively short time horizon. In this context, conventional fixed-effects estimation may remain biased because the lagged dependent variable is correlated with the transformed error term. Moreover, reverse causality may arise because more economically developed countries can invest more in research and development, energy efficiency, renewable energy infrastructure, and labour-market policies, while these factors may simultaneously influence economic development. System GMM addresses these concerns by combining equations in first differences and levels and by using lagged values of the variables as internal instruments. Given the moderate number of cross-sectional units, the instrument set was deliberately restricted to avoid instrument proliferation and overfitting.

Consequently, the estimates are interpreted cautiously and evaluated together with the Arellano–Bond serial-correlation tests and the Hansen test of instrument validity.

In the empirical specification, the lagged dependent variable together with research and development expenditure, employment rate, energy productivity, and renewable energy share are treated as potentially endogenous, reflecting the possibility of simultaneous interactions between these variables and the economic dimension of sustainable development.

To construct the instrument matrix, lagged values of the endogenous variables were employed as internal instruments within the System GMM framework. In particular, instruments were generated from sufficiently lagged observations in order to minimise contemporaneous correlation with the error term while preserving instrument relevance. The number of instruments was deliberately restricted to avoid instrument proliferation and to maintain the reliability of the Hansen test. This instrumentation strategy follows the recommendations of Blundell and Bond (1998) and Roodman (2009) for dynamic panel data models [49,51]. The instrument matrix collapsed following the recommendations of Roodman (2009) in order to further limit the number of instruments, reduce the risk of instrument proliferation, and preserve the reliability of the Hansen test [51].

To improve the reliability of the estimates, the two-step System GMM estimator with Windmeijer (2005)-corrected robust standard errors is employed [52]. The validity of the model specification is assessed using several diagnostic tests. First, the Arellano–Bond tests for first-order [AR(1)] and second-order [AR(2)] serial correlation are performed. While the presence of first-order serial correlation is expected in differenced residuals, the absence of second-order serial correlation is required for model validity. Second, the Hansen test of overidentifying restrictions is used to evaluate the overall validity of the instruments. A non-significant Hansen statistic indicates that the selected instruments are appropriate and exogenous.

Prior to estimating the dynamic model, preliminary panel diagnostics were conducted. Stationarity was assessed using the Im–Pesaran–Shin (IPS) panel unit root test, while cross-sectional dependence was examined using the Pesaran CD test. The results, reported in Appendix B, indicate that most variables become stationary after first differencing, whereas the Pesaran CD test reveals significant cross-sectional dependence among EU Member States. These preliminary diagnostics provide additional support for the application of the dynamic System GMM estimator.

Finally, to preserve the reliability of the Hansen test, the number of instruments is deliberately maintained below the number of cross-sectional units, following widely accepted recommendations in the dynamic panel data literature [49,51,53].

Overall, the application of the two-step System GMM estimator provides a robust econometric framework for analysing the dynamic determinants of the economic dimension of sustainable development in the European Union. The interpretation of the empirical findings is based not only on the statistical significance of the estimated coefficients but also on the diagnostic tests confirming the validity and robustness of the estimated model.

4. Results

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics for the variables included in the empirical analysis. The sample consists of 405 observations covering the 27 Member States of the European Union over the period 2010–2024.

The descriptive statistics indicate substantial cross-country heterogeneity in terms of economic development, innovation performance, labour market conditions, and energy transition indicators across the European Union.

Table 2. Summary Statistics of the Study Variables.

Variable	Mean	Median	Std. Dev.	Min	Max
lnGDPPC	10.148	10.065	0.607	8.862	11.586
RD	1.646	1.390	0.895	0.380	3.710
EMP	71.761	72.800	6.667	52.500	83.500
lnENEPD	1.882	1.895	0.471	0.708	3.296
REN	21.727	18.898	12.163	0.979	66.393

The data also reveal considerable variation in employment rates, energy productivity, and renewable energy deployment across Member States, reflecting differences in labour market conditions, energy efficiency, technological development, and the progress of the energy transition. These patterns provide preliminary evidence of structural heterogeneity characterising the European Union.

Overall, the descriptive statistics confirm the existence of sufficient cross-sectional variability to support the application of panel data techniques. Moreover, the observed heterogeneity across European Union Member States provides additional support for investigating the dynamic relationships between innovation, employment, energy productivity, renewable energy deployment, and the economic dimension of sustainable development.

The descriptive statistics reveal substantial heterogeneity among European Union Member States regarding innovation performance, labour market conditions, and energy transition indicators. The average employment rate reached 71.76%, indicating relatively strong labour market participation across the sample period. Research and development expenditure averaged 1.65% of GDP, although considerable variation exists between countries, reflecting differences in innovation capacities and technological development. Renewable energy share exhibited the highest variability among the explanatory variables, suggesting significant disparities in the pace of energy transition across EU Member States. Energy productivity also displayed notable variation, highlighting differences in energy efficiency and resource utilisation. These descriptive differences suggest that European Union Member States are characterised by diverse economic structures, innovation capacities, labour market conditions, and energy transition pathways. Such heterogeneity provides a strong rationale for employing a dynamic panel framework capable of accounting for country-specific characteristics in the subsequent econometric analysis.

The descriptive statistics and pairwise correlations provide useful preliminary insights into the characteristics of the dataset. However, these descriptive measures do not account for dynamic persistence, endogeneity, reverse causality, or unobserved country-specific heterogeneity. Therefore, to obtain consistent estimates of the relationships between the explanatory variables and the economic dimension of sustainable development, the empirical analysis proceeds with the estimation of the two-step System GMM model.

4.2. Correlation Analysis

Prior to the econometric estimation, a correlation analysis was conducted to examine the relationships among the variables and assess potential multicollinearity issues. Table 3 presents the Pearson correlation coefficients for all variables included in the empirical model. The correlation matrix provides preliminary evidence regarding the direction and strength of the bivariate relationships among the economic dimension of sustainable development, innovation, labour market performance, energy productivity, and renewable energy deployment.

The correlation matrix indicates that all explanatory variables exhibit positive bivariate associations with the economic dimension of sustainable development, as proxied by GDP per capita. The strongest correlation is observed between lnGDPPC and lnENEPD

($r = 0.780$), suggesting that higher levels of energy productivity are associated with higher levels of GDP per capita. This finding provides preliminary evidence that more efficient energy utilisation is associated with higher levels of economic development. Nevertheless, correlation analysis does not imply causality, and the magnitude and direction of these relationships require further investigation within the dynamic econometric framework.

Table 3. Pearson Correlation Matrix of the Variables.

Variable	lnGDPPC	RD	EMP	lnENEPD	REN
lnGDPPC	1	0.592	0.421	0.780	0.002
RD	0.592	1	0.449	0.407	0.417
EMP	0.421	0.449	1	0.190	0.333
lnENEPD	0.78	0.407	0.190	1	0.064
REN	0.002	0.417	0.333	0.064	1

Research and development expenditure also displays a moderately strong positive correlation with lnGDPPC ($r = 0.592$), supporting the argument that innovation plays an important role in enhancing the economic dimension of sustainable development. Similarly, the employment rate is positively correlated with GDP per capita ($r = 0.421$), indicating that stronger labour market performance is associated with higher levels of GDP per capita.

Among the explanatory variables, the highest correlation is observed between RD and EMP ($r = 0.449$), while the remaining coefficients remain at moderate levels. Importantly, none of the pairwise correlations among the explanatory variables exceeds the commonly accepted threshold of 0.80, suggesting the absence of severe multicollinearity problems. Consequently, the correlation analysis provides preliminary support for the inclusion of all selected variables in the subsequent System GMM estimations, where their individual effects are evaluated while controlling for dynamic relationships, endogeneity, and unobserved heterogeneity.

The relatively weak correlation between renewable energy share and GDP per capita ($r = 0.002$) suggests that the relationship between renewable energy deployment and the economic dimension of sustainable development may be more complex than simple pairwise associations indicate. This result may reflect, according to previous empirical studies, differences in the timing of the economic benefits associated with the energy transition, as well as substantial heterogeneity among European Union Member States regarding renewable energy penetration, institutional frameworks, and energy policies. Therefore, a multivariate dynamic framework is required to properly assess the contribution of renewable energy while simultaneously accounting for innovation, labour market performance, and energy productivity.

4.3. System GMM Estimation Results

Table 4 reports the estimation results obtained using the two-step System Generalized Method of Moments (System GMM) estimator. The dynamic specification allows the simultaneous assessment of persistence in GDP per capita together with the effects of innovation, employment, energy productivity, and renewable energy deployment on the economic dimension of sustainable development across the European Union. The validity and robustness of the estimated model are subsequently evaluated using the diagnostic tests reported in Table 5.

As a robustness check, an additional System GMM specification was estimated by replacing energy productivity with household final energy consumption per capita (HFEC_PC), an energy-related indicator that does not directly include GDP in its construction. This additional specification was estimated to assess whether the baseline findings

remain robust when using an alternative measure of energy use. The results are reported in Table 6.

Table 4. Dynamic Panel Estimation Results Using the System GMM Estimator.

Variable	Coefficient	<i>p</i> -Value	Interpretation
L.lnGDPPC	0.715	0.000	positive, significant
RD	0.003	0.738	positive, not significant
EMP	0.006	0.000	positive, significant
lnENEPROD	0.147	0.033	positive, significant
REN	−0.0001	0.071	negative, weakly significant

Table 5. Diagnostic Tests for the System GMM Estimator.

Test	Value
AR(1) <i>p</i> -value	0.000
AR(2) <i>p</i> -value	0.855
Hansen <i>p</i> -value	0.867
Instruments	6

Table 6. Sensitivity Analysis Using an Alternative Energy Indicator.

Variable	Coefficient	Std. Error	z-Statistic	<i>p</i> -Value
L.lnGDPPC	0.9814	0.6051	1.6218	0.1049
RD	−0.0935	0.1082	−0.8639	0.3877
EMP	0.0055	0.0150	0.3694	0.7119
lnHFEC_PC	0.0051	0.7826	0.0066	0.9948
REN	−0.0032	0.0107	−0.2981	0.7657
Diagnostic Test			Value	
Arellano–Bond AR(1), <i>p</i> -value			0.0000	
Arellano–Bond AR(2), <i>p</i> -value			0.7280	
Hansen test, <i>p</i> -value			0.8810	
Number of instruments			6	
Number of countries/groups			27	

Note: The alternative specification replaces the energy productivity variable (lnENEPROD) with the natural logarithm of household final energy consumption per capita (lnHFEC_PC). Because lnHFEC_PC reflects residential energy consumption rather than economy-wide energy efficiency, the results should be interpreted as a sensitivity analysis. AR(1) and AR(2) denote the *p*-values of the Arellano–Bond tests for first- and second-order serial correlation, respectively. The Hansen test reports the *p*-value for the joint validity of the instruments.

The relatively large standard error associated with lnHFEC_PC should be interpreted with caution. Unlike energy productivity, household final energy consumption per capita captures only one dimension of energy use and does not fully reflect the efficiency with which energy contributes to economic output across the entire economy. Consequently, the estimated coefficient is less precise, resulting in a larger standard error and reduced statistical significance. This outcome is more likely attributable to the limited suitability of the proxy representing economy-wide energy performance than to econometric issues such as multicollinearity, as the diagnostic statistics do not indicate model misspecification.

The diagnostic tests support the econometric validity of the alternative System GMM specification. The Arellano–Bond tests indicate the expected first-order serial correlation and the absence of second-order serial correlation, while the Hansen test does not reject the overall validity of the instrument set. The restricted number of instruments relative to the number of country groups further reduces the risk of instrument proliferation.

Compared with the baseline specification, the alternative model using household final energy consumption per capita produces substantially weaker empirical results. None

of the explanatory variables, including the lagged dependent variable and employment, remains statistically significant. Moreover, the estimated coefficient of $\ln HFEC_PC$ is close to zero and is associated with a comparatively large standard error. These findings indicate that the estimated relationships are sensitive to the choice of the energy-related indicator and should therefore be interpreted as a sensitivity analysis rather than as direct confirmation of the baseline results.

This outcome may reflect the different concepts captured by the two energy indicators. While energy productivity measures the economic value generated per unit of energy use, household final energy consumption per capita primarily reflects the level of residential energy consumption and does not constitute a direct measure of economy-wide energy efficiency. Consequently, the alternative specification provides complementary evidence regarding the sensitivity of the estimated relationships rather than a direct robustness confirmation of the baseline model.

Table 4 presents the results of the dynamic panel estimations obtained using the System Generalized Method of Moments (System GMM) estimator. The findings confirm the dynamic nature of the economic dimension of sustainable development, as evidenced by the positive and statistically significant coefficient of the lagged dependent variable. This result indicates that current levels of GDP per capita are strongly influenced by previous development trajectories, highlighting the persistence of economic development processes across European Union Member States. The strong persistence effect also suggests that improvements in sustainable economic development are cumulative rather than instantaneous, implying that current policy interventions are likely to generate their full economic benefits only over longer time horizons.

Employment rate exhibits a positive and statistically significant effect on the economic dimension of sustainable development. This finding supports Hypothesis 2 and suggests that stronger labour market performance contributes to higher levels of economic prosperity. This outcome is consistent with the theoretical framework emphasising the importance of employment for income generation, social inclusion, and economic resilience. Higher employment rates increase productive capacity and strengthen the foundations of sustainable development. From a policy perspective, this finding indicates that labour market policies promoting higher employment rates may generate benefits that extend beyond income creation, contributing to greater economic resilience and supporting the economic dimension of sustainable development.

Energy productivity also exhibits a positive and statistically significant relationship with GDP per capita, supporting Hypothesis 3. This finding indicates that economies capable of generating greater economic value from energy consumption tend to achieve higher levels of economic development. This result is broadly consistent with previous empirical studies reporting that improvements in energy efficiency constitute one of the most effective channels through which advanced economies simultaneously enhance economic competitiveness and sustainability outcomes. Consequently, improvements in energy productivity appear to represent an important mechanism through which sustainability objectives can be aligned with economic performance. The positive effect of energy productivity is particularly important in the context of the European Union's sustainability agenda. As energy efficiency remains a central objective of European climate and energy policies, the findings suggest that improving the efficiency with which energy resources are utilised can simultaneously support economic growth and environmental sustainability. This result reinforces the view that energy productivity represents a key mechanism for supporting the economic dimension of sustainable development while reducing resource pressures and enhancing economic resilience.

Research and development expenditure displays a positive coefficient, although its effect is not statistically significant. While the sign of the coefficient is consistent with Hypothesis 1 and the broader innovation literature, the absence of statistical significance suggests that the contribution of innovation to the economic dimension of sustainable development may materialise over longer time horizons. Research and development expenditures often generate indirect rather than immediate economic effects because the commercialization of innovations, the diffusion of new technologies, and productivity gains require considerable time. Moreover, differences in absorptive capacity, institutional quality, and the efficiency of national innovation systems may limit the short-term contribution of R&D expenditure to economic performance, even in highly developed economies such as those of the European Union. Furthermore, differences in innovation capacity, institutional quality, and technology transfer mechanisms across EU Member States may influence the effectiveness of research and development investments.

The results for renewable energy share reveal a negative coefficient with limited statistical significance. Therefore, Hypothesis 4 is not supported by empirical evidence. One possible explanation is that the economic benefits associated with renewable energy deployment require substantial investments and adjustment costs that may not immediately translate into higher levels of GDP per capita. In addition, the effects of renewable energy expansion may vary considerably across countries depending on their energy mix, institutional framework, and stage of energy transition. Importantly, the estimated coefficient should not be interpreted as evidence that renewable energy deployment hinders sustainable economic development. Rather, it suggests that, during the analysed period, the short-term economic benefits of the energy transition may have been partially offset by substantial investment requirements, infrastructure adaptation costs, and structural adjustments associated with the expansion of renewable energy systems. Previous empirical evidence suggests that, over longer time horizons, however, these investments are expected to generate broader economic, environmental, and social benefits that may not yet be fully captured within the study period.

Overall, the empirical findings suggest that the economic dimension of sustainable development in the European Union is primarily supported by strong labour market performance and improvements in energy productivity. By contrast, the effects of research and development expenditure and renewable energy deployment appear to be more complex and are likely to materialise through indirect or longer-term channels. These findings contribute to the existing literature by indicating that strengthening the economic dimension of sustainable development requires not only investments in innovation and the energy transition but also complementary institutional and labour market conditions capable of transforming these investments into measurable economic outcomes.

5. Discussion

The empirical findings provide important insights into the economic dimension of sustainable development in the European Union and contribute to the ongoing debate regarding the roles of innovation, labour market performance, and the energy transition in supporting long-term economic prosperity. The results indicate that the analysed determinants differ not only in their statistical significance but also in the economic mechanisms through which they influence GDP per capita, employed in this study as a proxy for the economic dimension of sustainable development. Rather than confirming that all sustainability-related factors exert an immediate positive influence, the findings reveal a more nuanced pattern. Employment and energy productivity emerge as significant determinants of the economic dimension of sustainable development, whereas the effects of research and development expenditure and renewable energy deployment appear to

be more complex. One possible explanation is that their economic effects may require longer adjustment periods or depend on complementary institutional and structural conditions. However, these mechanisms were not directly examined in the present analysis and therefore should be interpreted with caution. These findings suggest that strengthening the economic dimension of sustainable development requires not only investments in innovation and the energy transition but also complementary economic and institutional conditions capable of transforming such investments into measurable economic outcomes. Furthermore, the significant coefficient of the lagged dependent variable confirms the dynamic nature of GDP per capita, indicating that current economic performance remains strongly influenced by previous development trajectories, consistent with the theoretical foundations of endogenous growth theory.

5.1. The Role of Employment in Sustainable Economic Development

Among the explanatory variables, employment emerges as one of the most relevant determinants of the economic dimension of sustainable development. The positive relationship identified in the empirical analysis supports the view that labour market performance constitutes a fundamental pillar of sustainable development. Higher employment rates contribute not only to economic output but also to social cohesion, income generation, and overall societal well-being. These findings are consistent with previous studies highlighting the importance of inclusive labour markets in promoting long-term economic resilience and sustainable growth. From an economic perspective, higher employment rates expand the productive capacity of the economy by increasing labour utilisation, household income, and aggregate demand. At the same time, stronger labour market participation enhances the diffusion of knowledge and skills, facilitating technological adoption, and improving firms' adaptability to structural economic changes. Consequently, employment not only stimulates current economic activity but also strengthens the long-term resilience of economies undergoing sustainability and energy transition processes.

The result is particularly relevant in the context of the European Union, where sustainability strategies increasingly incorporate social objectives alongside environmental and economic goals. Policies aimed at increasing labour market participation, reducing unemployment, and improving workforce skills may therefore generate positive effects that extend beyond economic performance and contribute to broader sustainability outcomes. These findings also suggest that labour market policies should be considered an integral component of sustainable development strategies, complementing innovation and energy transition policies in achieving balanced and resilient economic growth across the European Union.

5.2. The Contribution of Innovation to Sustainable Economic Development

The results indicate a positive, although statistically insignificant relationship between research and development expenditure and the economic dimension of sustainable development. The positive sign is consistent with the theoretical literature [17] and supports the view that innovation contributes to long-term economic prosperity through technological progress, productivity improvements, and knowledge creation. However, the absence of statistical significance may indicate that the economic effects of research and development expenditure are more complex than expected. One possible explanation is that these effects may require longer periods to become observable or may depend on the effectiveness of national innovation systems, institutional quality, and technology transfer mechanisms. Since these mechanisms were not directly examined in the present study, they should be interpreted as plausible explanations rather than conclusions supported by the empirical results. This finding also suggests that increasing research and development expenditure alone

may not be sufficient to stimulate sustainable economic performance. The effectiveness of innovation policies depends on the ability of national economies to transform research investments into commercially successful innovations, productivity improvements, and broader economic value creation.

Several plausible explanations may account for this outcome, although they were not directly examined in the empirical analysis. First, previous empirical studies suggest that investments in research and development often generate benefits over longer time horizons, implying that their effects may not be immediately reflected in economic development indicators. Second, the effectiveness of innovation expenditures depends on the capacity of economies to transform research investments into commercially viable technologies and productivity gains. Moreover, research and development expenditure does not automatically translate into productivity gains or economic growth. Its effectiveness depends on firms' absorptive capacity, the quality of human capital, and the efficiency with which research outcomes are commercialised and diffused throughout the economy. Third, significant differences among EU Member States regarding innovation systems, institutional quality, and technological capabilities may influence the observed relationship [18]. These considerations are particularly relevant within the European Union, where substantial disparities persist regarding innovation performance, research intensity, and the capacity to commercialise scientific knowledge. Consequently, identical levels of research and development expenditure may generate different economic outcomes across Member States.

Consequently, the findings of the present study do not provide evidence of a statistically significant contemporaneous effect of research and development expenditure on the economic dimension of sustainable development. Nevertheless, together with previous empirical evidence, they are consistent with the view that innovation may represent a long-term strategic investment. Future research could examine whether longer time horizons, institutional quality, or innovation diffusion mechanisms explain this relationship more fully.

5.3. Energy Productivity as a Driver of Sustainable Economic Development

Energy productivity represents one of the most important dimensions linking economic performance and environmental sustainability. The empirical findings confirm the positive and statistically significant contribution of energy productivity to the economic dimension of sustainable development in the European Union. This result suggests that economies capable of generating greater economic value from energy consumption tend to achieve higher levels of GDP per capita, supporting the argument that energy efficiency constitutes a fundamental pillar of sustainable growth. Unlike research and development expenditure, whose economic effects may require longer periods to materialise, improvements in energy productivity generate more immediate economic benefits by reducing production costs, increasing resource efficiency, and enhancing firms' competitiveness. This distinction helps explain why energy productivity emerges as a statistically significant determinant of the economic dimension of sustainable development during the analysed period.

The sensitivity analysis reported in Table 6 indicates that the estimated relationship depends on the energy-related indicator employed. While energy productivity exhibits a positive and statistically significant association with the economic outcomes of sustainable development in the baseline specification, household final energy consumption per capita does not produce comparable results. This difference should be interpreted cautiously, as the two indicators capture different dimensions of energy use rather than equivalent measures of energy efficiency.

Higher energy productivity enables firms to allocate financial resources more efficiently by lowering energy expenditures and releasing additional resources for productive investment, technological upgrading, and business expansion. At the macroeconomic level, these efficiency gains improve overall productivity, strengthen industrial competitiveness, and increase economic resilience against energy price volatility.

The findings are consistent with previous studies emphasising the role of energy efficiency in enhancing competitiveness, improving resource allocation, and reducing production costs [54]. By increasing the economic output generated per unit of energy consumed, higher energy productivity allows countries to strengthen their economic performance while simultaneously reducing pressure on natural resources and energy systems. Consequently, energy productivity contributes to the decoupling of economic growth from resource consumption, which represents a central objective of sustainable development strategies. Overall, the baseline results suggest that energy productivity is positively associated with the economic dimension of sustainable development. However, the sensitivity analysis indicates that the estimated relationship depends on the choice of the energy-related indicator. Consequently, these findings should be interpreted with appropriate caution and verified in future research using alternative measures of energy efficiency.

The positive effect identified in the empirical analysis is particularly relevant in the context of the European Union, where energy efficiency occupies a central position within sustainability and climate policies [55]. Initiatives associated with the European Green Deal, energy efficiency directives, and broader decarbonization strategies increasingly emphasise the importance of improving energy productivity as a mechanism for achieving climate neutrality while maintaining economic competitiveness.

From a policy perspective, the results suggest that investments aimed at improving energy efficiency can generate both economic and environmental benefits. Measures supporting technological modernization, energy-efficient production processes, and innovation in resource management may therefore play an important role in strengthening the economic dimension of sustainable development across EU Member States. Consequently, the results suggest that energy productivity should be viewed not merely as an indicator of environmental performance, but as a strategic policy lever capable of simultaneously fostering economic growth, strengthening industrial competitiveness, enhancing energy security, and facilitating the transition towards climate-neutral and sustainable economies.

5.4. Renewable Energy Deployment and Sustainable Economic Development

The empirical evidence suggests that the contribution of renewable energy deployment to the economic dimension of sustainable development is more nuanced than often suggested in the literature. Although renewable energy constitutes a fundamental pillar of the European Union's sustainability agenda, its direct impact on economic development appears to depend on the pace of the energy transition, country-specific structural characteristics, and the complementary investments required to fully exploit renewable energy technologies [56].

These findings differ from several previous empirical studies reporting a positive contribution of renewable energy consumption to economic growth. For example, Oliveira et al. [57] found that both conventional and renewable energy consumption positively influence economic growth, with renewable energy exerting a stronger long-term effect. The difference between these findings and the present study may be explained by differences in the geographical scope, economic structure, the stage of the energy transition, and the indicators used to measure renewable energy performance. Within the European Union, where renewable energy deployment has reached relatively advanced levels in many Member States, the short-term economic effects may also reflect differences in adjust-

ment costs, infrastructure requirements, and institutional heterogeneity. However, these mechanisms were not directly examined in the present analysis and therefore represent plausible interpretations rather than conclusions supported by the empirical model.

This divergence also illustrates that the economic consequences of renewable energy deployment are highly context-dependent and may vary according to the stage of the energy transition, the structure of national energy systems, and the institutional environment.

One possible explanation, supported by previous empirical studies, is that renewable energy deployment is frequently associated with substantial upfront capital investments, infrastructure modernisation, and structural adjustments that may temporarily reduce economic efficiency before generating long-term benefits. During the early stages of the transition, substantial financial resources are redirected towards energy infrastructure, grid adaptation, and technology deployment. Although these investments improve long-term sustainability, they may temporarily reduce the resources available for other productive activities, thereby moderating their immediate contribution to economic growth. Furthermore, the economic returns of renewable energy investments are likely to depend on complementary factors such as energy storage capacity, electricity market integration, technological maturity, and the effectiveness of national energy policies.

This finding contrasts with the positive and statistically significant effect identified for energy productivity. While improvements in energy productivity generate relatively immediate efficiency gains by reducing production costs and increasing resource efficiency, previous empirical studies have suggested that the economic benefits of renewable energy deployment may emerge over longer time horizons. However, the present study does not directly examine the timing of these effects. Their effectiveness depends on complementary investments in electricity grids, energy storage systems, technological learning, and supportive institutional frameworks. Consequently, the contribution of renewable energy to the economic dimension of sustainable development may become more pronounced as the energy transition advances across European Union Member States, although this hypothesis requires further empirical investigation.

The estimated coefficient should therefore not be interpreted as evidence that renewable energy hinders the economic dimension of sustainable development. Rather, the results indicate that the present specification does not identify a statistically significant positive association during the analysed period. Although previous studies suggest that adjustment costs and structural changes may influence this relationship, these mechanisms were not directly examined in the present analysis and therefore require further empirical investigation.

Nevertheless, the strategic importance of renewable energy should not be underestimated. In this respect, the findings of the present study, together with previous empirical evidence, are consistent with the view that renewable energy may represent a long-term structural investment rather than a short-term determinant of economic performance. Future research should further investigate how institutional quality, technological maturity, and different stages of the energy transition influence this relationship across European Union Member States. Potential benefits may extend beyond immediate economic returns by enhancing energy independence, reducing exposure to fossil fuel price volatility, strengthening climate resilience, and supporting the transition towards a low-carbon economy. From a policy perspective, these findings imply that renewable energy policies should be complemented by measures supporting technological innovation, grid modernisation, energy storage systems, and institutional capacity in order to maximise their long-term economic benefits. Consequently, the transition towards renewable energy may be viewed as a long-term strategic investment capable of strengthening economic resilience, accelerat-

ing decarbonisation, and supporting the long-term objectives of sustainable development across the European Union.

5.5. Policy Implications

The empirical findings provide several important implications for policymakers seeking to strengthen the economic dimension of sustainable development while supporting the European Union's long-term sustainability objectives. A successful transition towards sustainable development requires not only environmental improvements but also the creation of quality employment opportunities capable of supporting social inclusion and economic resilience. These findings indicate that labour market policies should not be considered solely as social instruments but also as important determinants of the economic dimension of sustainable development.

Second, policymakers should maintain strong support for research and development activities while recognising that innovation outcomes may require longer periods to materialise. The empirical evidence does not identify a statistically significant contemporaneous effect of research and development expenditure on the economic dimension of sustainable development. One possible interpretation is that increasing research and development expenditure alone may be insufficient to generate immediate economic benefits unless accompanied by effective innovation ecosystems capable of transforming scientific knowledge into commercial applications. However, this mechanism was not directly examined in the present study. Strengthening innovation ecosystems, promoting technology transfer, and enhancing cooperation between research institutions and industry may improve the effectiveness of innovation investments.

Third, the results emphasise the importance of energy efficiency policies. Measures aimed at increasing energy productivity can improve economic competitiveness, reduce resource consumption, and facilitate the achievement of sustainability objectives. The significant effect identified in the empirical analysis suggests that improving energy productivity represents one of the most effective policy instruments for simultaneously enhancing economic competitiveness and advancing sustainability objectives.

Renewable energy policies should therefore be implemented within a broader framework of policy coherence, combining investments in infrastructure, energy storage, smart grids, technological innovation, and regulatory stability. These results further suggest that renewable energy policies should be evaluated from a long-term perspective, recognising that short-term adjustment costs may precede substantial economic and environmental gains.

Overall, the findings suggest that sustainable economic development in the European Union cannot be achieved through isolated policy measures. Instead, the empirical evidence supports an integrated policy approach in which labour market performance, energy productivity, innovation, and renewable energy deployment interact in complementary ways. While employment and energy productivity generate more immediate economic benefits, innovation and renewable energy are likely to produce stronger effects over longer time horizons and under favourable institutional and technological conditions, as suggested by previous empirical studies. Consequently, policymakers should adopt coordinated strategies capable of simultaneously strengthening economic competitiveness, social inclusion, and environmental sustainability. Such an integrated approach would not only improve the effectiveness of individual policy measures but also strengthen the synergies between economic growth, social cohesion, and environmental protection. In this respect, sustainable development should be understood as the outcome of coordinated policies capable of simultaneously addressing economic, social, and environmental objectives.

6. Conclusions

This study examined the economic dimension of sustainable development in the European Union by investigating the roles of innovation, labour market performance, energy productivity, and renewable energy deployment using a two-step System Generalized Method of Moments (System GMM) estimator applied to a balanced panel of the 27 European Union Member States over the period 2010–2024. Given the multidimensional nature of sustainable development, the analysis focused specifically on its economic dimension, employing GDP per capita as a proxy for long-term economic prosperity. By integrating innovation- and energy transition-related variables within a dynamic panel framework, the study provides updated empirical evidence on the factors shaping the economic dimension of sustainable development across the European Union.

The empirical findings indicate that the analysed determinants differ substantially in both their statistical significance and the mechanisms through which they influence economic performance. Employment and energy productivity emerge as the most significant determinants of the economic dimension of sustainable development, suggesting that stronger labour market performance and more efficient energy use contribute directly to higher levels of economic prosperity. In contrast, research and development expenditure exhibits a positive but statistically insignificant coefficient, while renewable energy deployment does not exert a significant positive contemporaneous effect during the analysed period. These results indicate that research and development expenditure and renewable energy deployment do not exhibit statistically significant contemporaneous effects within the estimated specification. One possible interpretation is that their economic contribution may depend on longer adjustment periods and complementary institutional, technological, and structural conditions. However, these mechanisms were not directly examined in the present study and therefore require further empirical investigation.

From a theoretical perspective, the study contributes to the literature by providing an integrated assessment of innovation, labour market performance, and energy transition within a unified dynamic framework. Unlike many previous studies that analyse these determinants separately, the present research suggests that the economic dimension of sustainable development reflects the complementary interaction of labour market conditions, innovation capacity, energy productivity, and renewable energy policies. The findings further suggest that isolated policy interventions are unlikely to achieve the desired sustainability outcomes unless they are implemented within coherent and mutually reinforcing policy frameworks. Accordingly, policymakers should continue to support employment creation, improvements in energy efficiency, innovation ecosystems, and renewable energy investments while recognising that these policy areas may generate economic benefits over different time horizons.

The study is subject to several limitations that should be considered when interpreting the findings. First, the analysis focuses exclusively on the European Union and therefore the results may not be directly generalizable to other regions with different institutional and economic characteristics. Second, GDP per capita is employed as a proxy for the economic dimension of sustainable development and, although widely used in empirical macroeconomic research, it does not fully capture the environmental and social pillars of sustainability. Third, although the sample includes all 27 European Union Member States, the estimated coefficients represent average effects and may conceal important cross-country heterogeneity arising from differences in economic structure, institutional quality, innovation capacity, and energy systems. Finally, while the two-step System GMM estimator is appropriate for addressing the dynamic nature of the model and potential endogeneity, the moderate cross-sectional dimension of the panel suggests that the estimated relationships should be interpreted with appropriate caution despite the satisfactory

diagnostic tests and the parsimonious instrument strategy adopted. Fourth, the sensitivity analysis indicates that the estimated relationships involving energy-related variables depend on the choice of the energy indicator employed. Consequently, the findings concerning energy-related variables should be interpreted with appropriate caution and verified in future research using alternative measures of energy efficiency and energy transition.

Future research could extend the present analysis by employing multidimensional sustainability indicators that simultaneously capture the economic, environmental, and social dimensions of sustainable development. Additional research may also investigate heterogeneous effects across different groups of European Union Member States, examine potential nonlinear relationships, and incorporate additional determinants related to institutional quality, digitalisation, environmental performance, and green innovation. Furthermore, future studies could compare the results obtained using alternative dynamic panel estimation techniques and assess whether the relationships identified in the present study vary across alternative energy indicators, longer observation periods, and different institutional settings.

Overall, the findings suggest that strengthening the economic dimension of sustainable development in the European Union requires coordinated policies that simultaneously promote labour market performance, improve energy productivity, foster innovation, and support the gradual expansion of renewable energy. Although these factors differ in their estimated contemporaneous associations with the economic dimension of sustainable development, previous empirical evidence suggests that their broader contribution may vary according to institutional conditions, technological development, and the stage of the energy transition. These relationships, however, warrant further empirical investigation.

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Appendix A

Table A1. Data Sources and Variable Definitions.

Variable	Eurostat Code	Unit
GDPPC	nama_10_pc	euro per capita
RD	rd_e_gerdtot	% GDP
EMP	tipslm100	%
ENEPROD	sdg_07_30	EUR/kg oil equivalent
REN	sdg_07_40	%

Appendix B

Table A2. Preliminary Panel Data Diagnostics.

Variable	IPS Test, Levels	<i>p</i> -Value	IPS Test, First Differences	<i>p</i> -Value	Pesaran CD	<i>p</i> -Value
lnGDPPC	−0.783	1.000	−4.015	0.001	58.023	0.000
RD	−1.893	0.038	−4.401	0.001	12.060	0.000
EMP	−0.760	1.000	−2.922	0.001	64.409	0.000
lnENEPROD	−0.057	1.000	−3.929	0.001	67.666	0.000
REN	−0.405	1.000	−3.881	0.001	59.653	0.000

References

- United Nations. *Transforming Our World: The 2030 Agenda for Sustainable Development*; United Nations: New York, NY, USA, 2015.
- Sachs, J.D.; Schmidt-Traub, G.; Mazzucato, M.; Messner, D.; Nakicenovic, N.; Rockström, J. Six Transformations to Achieve the Sustainable Development Goals. *Nat. Sustain.* **2019**, *2*, 805–814. [\[CrossRef\]](#)
- Barbier, E.B.; Burgess, J.C. The Sustainable Development Goals and the Systems Approach to Sustainability. *Economics* **2017**, *11*, 20170028. [\[CrossRef\]](#)
- European Commission. *The European Green Deal*; European Commission: Brussels, Belgium, 2019.
- International Energy Agency (IEA). *World Energy Outlook 2023*; IEA: Paris, France, 2023.
- Organisation for Economic Co-operation and Development (OECD). *Green Growth Indicators 2017*; OECD Publishing: Paris, France, 2017.
- European Commission. *Energy Efficiency First Principle*; European Commission: Brussels, Belgium, 2021.
- Romer, P.M. Endogenous Technological Change. *J. Political Econ.* **1990**, *98*, S71–S102. [\[CrossRef\]](#) [\[PubMed\]](#)
- Aghion, P.; Howitt, P. A Model of Growth through Creative Destruction. *Econometrica* **1992**, *60*, 323–351. [\[CrossRef\]](#)
- International Labour Organization (ILO). *World Employment and Social Outlook: Greening with Jobs*; ILO: Geneva, Switzerland, 2018.
- Stiglitz, J.E.; Sen, A.; Fitoussi, J.P. *Report by the Commission on the Measurement of Economic Performance and Social Progress*; Commission on the Measurement of Economic Performance and Social Progress: Paris, France, 2009.
- Organisation for Economic Co-operation and Development (OECD). *The Innovation Imperative: Contributing to Productivity, Growth and Well-Being*; OECD Publishing: Paris, France, 2015.
- Schumpeter, J.A. *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*; Harvard University Press: Cambridge, MA, USA, 1934.
- Grossman, G.M.; Helpman, E. *Innovation and Growth in the Global Economy*; MIT Press: Cambridge, MA, USA, 1991.
- Hall, B.H.; Rosenberg, N. (Eds.) *Handbook of the Economics of Innovation*; Elsevier: Amsterdam, The Netherlands, 2010.
- Porter, M.E.; van der Linde, C. Toward a New Conception of the Environment–Competitiveness Relationship. *J. Econ. Perspect.* **1995**, *9*, 97–118. [\[CrossRef\]](#)
- D’Amato, D.; Droste, N.; Allen, B.; Kettunen, M.; Lähinen, K.; Korhonen, J.; Leskinen, P.; Matthies, B.D.; Toppinen, A. Green, Circular, Bio Economy: A Comparative Analysis of Sustainability Avenues. *J. Clean. Prod.* **2017**, *168*, 716–734. [\[CrossRef\]](#)
- Carayannis, E.G.; Grigoroudis, E.; Campbell, D.F.J.; Meissner, D.; Stamati, D. The Ecosystem as Helix: An Exploratory Theory-Building Study of Regional Competitive Entrepreneurial Ecosystems as Quadruple/Quintuple Helix Innovation Models. *R&D Manag.* **2018**, *48*, 148–162.
- Cainelli, G.; De Marchi, V.; Grandinetti, R. Does the Development of Environmental Innovation Require Different Resources? Evidence from Spanish Manufacturing Firms. *J. Clean. Prod.* **2015**, *94*, 211–220. [\[CrossRef\]](#)
- Horbach, J.; Rammer, C.; Rennings, K. Determinants of Eco-Innovations by Type of Environmental Impact—The Role of Regulatory Push/Pull, Technology Push and Market Pull. *Ecol. Econ.* **2012**, *78*, 112–122. [\[CrossRef\]](#)
- European Commission. *Horizon Europe Strategic Plan 2021–2024*; European Commission: Brussels, Belgium, 2021.
- European Commission. *Research and Innovation Supporting the European Green Deal*; European Commission: Brussels, Belgium, 2020.
- Eurofound. *Employment and Social Developments in Europe 2021*; Publications Office of the European Union: Luxembourg, 2021.
- Organisation for Economic Co-operation and Development (OECD). *Job Creation and Local Economic Development 2020: Rebuilding Better*; OECD Publishing: Paris, France, 2020.
- Rodríguez-Pose, A.; Tselios, V. Education and Income Inequality in the Regions of the European Union. *J. Reg. Sci.* **2010**, *50*, 411–437.
- Kluve, J. The Effectiveness of European Active Labour Market Programs. *Labour Econ.* **2010**, *17*, 904–918. [\[CrossRef\]](#)
- European Commission. *Employment and Social Developments in Europe: Annual Review 2023*; European Commission: Brussels, Belgium, 2023.
- International Labour Organization (ILO). *World Employment and Social Outlook: Trends 2024*; ILO: Geneva, Switzerland, 2024.
- OECD. *Employment Outlook 2023: Artificial Intelligence and the Labour Market*; OECD Publishing: Paris, France, 2023.
- European Commission. *The European Pillar of Social Rights Action Plan*; European Commission: Brussels, Belgium, 2021.
- Ang, B.W. Monitoring Changes in Economy-Wide Energy Efficiency: From Energy–GDP Ratio to Composite Efficiency Indexes. *Energy Policy* **2006**, *34*, 574–582. [\[CrossRef\]](#)
- Stern, D.I. The Role of Energy in Economic Growth. *Ann. N. Y. Acad. Sci.* **2011**, *1219*, 26–51. [\[CrossRef\]](#) [\[PubMed\]](#)
- European Commission. *Fit for 55: Delivering the EU’s 2030 Climate Target on the Way to Climate Neutrality*; European Commission: Brussels, Belgium, 2021.
- Odyssee-Mure. *Energy Efficiency Trends and Policies in Europe*; European Commission Project Report; Odyssee-Mure: Montrouge, France, 2022.
- International Energy Agency (IEA). *Energy Efficiency 2022*; IEA: Paris, France, 2022.

36. European Environment Agency (EEA). *Trends and Projections in Europe 2023: Tracking Progress Towards Europe's Climate and Energy Targets*; EEA: Copenhagen, Denmark, 2023.
37. European Commission. *Energy Union Progress Report 2023*; European Commission: Brussels, Belgium, 2023.
38. Patterson, M.G. What Is Energy Efficiency? Concepts, Indicators and Methodological Issues. *Energy Policy* **1996**, *24*, 377–390.
39. European Commission. *REPowerEU Plan*; European Commission: Brussels, Belgium, 2022.
40. International Energy Agency (IEA). *Renewables 2023*; IEA: Paris, France, 2023.
41. International Renewable Energy Agency (IRENA). *World Energy Transitions Outlook 2023*; IRENA: Abu Dhabi, United Arab Emirates, 2023.
42. Apergis, N.; Payne, J.E. Renewable Energy Consumption and Economic Growth: Evidence from a Panel of OECD Countries. *Energy Policy* **2010**, *38*, 656–660. [[CrossRef](#)]
43. Bhattacharya, M.; Paramati, S.R.; Ozturk, I.; Bhattacharya, S. The Effect of Renewable Energy Consumption on Economic Growth: Evidence from Top 38 Countries. *Appl. Energy* **2016**, *162*, 733–741. [[CrossRef](#)]
44. Marques, A.C.; Fuinhas, J.A. Is Renewable Energy Effective in Promoting Growth? Evidence from European Countries. *Energy Policy* **2012**, *45*, 434–442.
45. Pata, U.K. Renewable and Non-Renewable Energy Consumption, Economic Growth, and CO₂ Emissions in Turkey: Testing EKC Hypothesis with Structural Breaks. *J. Clean. Prod.* **2018**, *187*, 770–779.
46. Destek, M.A.; Aslan, A. Renewable and Non-Renewable Energy Consumption and Economic Growth in Emerging Economies: Evidence from Bootstrap Panel Causality. *Renew. Energy* **2017**, *111*, 757–763. [[CrossRef](#)]
47. European Environment Agency (EEA). *Renewable Energy in Europe 2023: Recent Growth and Knock-On Effects*; EEA: Copenhagen, Denmark, 2023.
48. European Commission. *EU Solar Energy Strategy*; European Commission: Brussels, Belgium, 2022.
49. Blundell, R.; Bond, S. Initial Conditions and Moment Restrictions in Dynamic Panel Data Models. *J. Econom.* **1998**, *87*, 115–143. [[CrossRef](#)]
50. Arellano, M.; Bond, S. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *Rev. Econ. Stud.* **1991**, *58*, 277–297. [[CrossRef](#)]
51. Roodman, D. How to Do xtabond2: An Introduction to Difference and System GMM in Stata. *Stata J.* **2009**, *9*, 86–136. [[CrossRef](#)]
52. Windmeijer, F. A Finite Sample Correction for the Variance of Linear Efficient Two-Step GMM Estimators. *J. Econom.* **2005**, *126*, 25–51. [[CrossRef](#)]
53. Arellano, M.; Bover, O. Another Look at the Instrumental Variable Estimation of Error-Components Models. *J. Econom.* **1995**, *68*, 29–51. [[CrossRef](#)]
54. European Environment Agency (EEA). *Energy Efficiency and Energy Consumption in Europe 2023*; EEA: Copenhagen, Denmark, 2023.
55. United Nations Economic Commission for Europe (UNECE). *Pathways to Sustainable Energy Systems in Europe*; United Nations: Geneva, Switzerland, 2022.
56. International Renewable Energy Agency (IRENA). *Renewable Capacity Statistics 2024*; IRENA: Abu Dhabi, United Arab Emirates, 2024.
57. Oliveira, J.C.; Nogueira, M.C.; Madaleno, M. Do the Reduction of Traditional Energy Consumption and the Acceleration of the Energy Transition Bring Economic Benefits to South America? *Energies* **2023**, *16*, 5527. [[CrossRef](#)]

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