PROBLEMY EKOROZWOJU/ PROBLEMS OF SUSTAINABLE DEVELOPMENT
AN OPEN ACCESS ARTICLE DISTRIBUTED UNDER THE TERMS AND CONDITIONS OF THE CC BY 4.0 LICENSE
SUBMITTED: 16.09.2025, ACCEPTED: 17.11.2025, PUBLISHED ON-LINE: 10.01.2026
2026, 21(1): 160-172, DOI: 10.35784/preko.8376

Eco-Taxation and Financial Development as Catalysts for Green Innovation and Environmental Sustainability in the EU: Advancing the UN Sustainable Development Goals

Ekopodatki i rozwój finansowy jako katalizatory zielonej innowacji i zrównoważoności środowiskowej w UE: wspieranie Celów Zrównoważonego Rozwoju ONZ

Seyi Saint Akadiri[1], Sani Abubakar[2], Fadhila Hamza[3]

[1]European University of Lefke, Advanced Research Center, Northern Cyprus, TR-10 Mersin, Turkey
E-mail (Corresponding Author): sakadiri@eul.edu.tr, ORCID: 0000-0001-8901-7965
[2]Central Bank of Nigeria, Research Department, Abuja, Nigeria
E-mail: sabubakar8@cbn.gov.ng
[3]Princess Nourah Bint Abdulrahman University, College of Business Administration, Department of Accounting, P.O. Box 84428, Riyadh 11671, Saudi Arabia
E-mail: Fahamza@pnu.edu.sa

Abstract
The effectiveness of eco-taxation in driving green innovation and sustainability in the European Union (EU) remains a contested issue, with critics arguing that it may burden businesses and compromise competitiveness. This study examines how eco-taxation and financial development interact to influence green innovation and environmental sustainability across EU member states, while accounting for the moderating effect of economic growth. Panel data spanning 2010 to 2022 is used, and the System Generalised Method of Moments (GMM) estimator is employed to tackle endogeneity and dynamic relationships. The findings reveal that eco-taxation significantly promotes green innovation, especially in financially developed economies. Moreover, economic growth supports sustainability when aligned with robust environmental policies, but may lead to resource stress in their absence. By situating the findings within the framework of the United Nations Sustainable Development Goals (SDGs), the study contributes to SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). Specifically, it advocates for integrated policy frameworks that align eco-taxation with green finance (SDG 8 & 9), innovation strategies (SDG 9), sustainable production and resource efficiency (SDG 12), and climate resilience (SDG 13). Furthermore, it underscores the role of targeted R&D investments, enhanced financial instruments, and strengthened public–private partnerships (SDG 17) in supporting the EU's green transition while preserving economic resilience.

Key words: Ecotax, financial development, green innovation, economic growth, System GMM, SDGs

Streszczenie
Skuteczność ekopodatków w napędzaniu zielonych innowacji i zrównoważonego rozwoju w Unii Europejskiej (UE) pozostaje kwestią sporną, a krytycy twierdzą, że mogą one obciążać przedsiębiorstwa i zagrażać ich konkurencyjności. W niniejszym badaniu analizuje się interakcje ekopodatków i rozwoju finansowego, wpływając na zielone innowacje i zrównoważony rozwój środowiskowy w państwach członkowskich UE, uwzględniając jednocześnie moderujący wpływ wzrostu gospodarczego. Wykorzystano dane panelowe z lat 2010–2022, a do analizy endogeniczności i dynamicznych zależności zastosowano estymator System Generalised Method of Moments

(GMM). Wyniki wskazują, że ekopodatki znacząco promują zielone innowacje, zwłaszcza w gospodarkach rozwiniętych finansowo. Co więcej, wzrost gospodarczy wspiera zrównoważony rozwój, gdy jest powiązany z solidną polityką środowiskową, ale może prowadzić do presji na zasoby w przypadku jej braku. Umieszczając wyniki w ramach Celów Zrównoważonego Rozwoju ONZ (SDGs), badanie przyczynia się do realizacji następujących celów Zrównoważonego Rozwoju: 7 (Przystępna i Czysta Energia), 8 (Godna Praca i Wzrost Gospodarczy), 9 (Przemysł, Innowacje i Infrastruktura), 12 (Odpowiedzialna Konsumpcja i Produkcja), 13 (Działania na rzecz Klimatu) oraz 17 (Partnerstwa na rzecz Celów). W szczególności badanie opowiada się za zintegrowanymi ramami polityki, które dostosowują opodatkowanie ekologiczne do zielonych finansów (SDG 8 i 9), strategii innowacji (SDG 9), zrównoważonej produkcji i efektywnego gospodarowania zasobami (SDG 12) oraz odporności na zmiany klimatu (SDG 13). Ponadto podkreśla ono rolę ukierunkowanych inwestycji w badania i rozwój, ulepszonych instrumentów finansowych oraz wzmocnionych partnerstw publiczno-prywatnych (SDG 17) we wspieraniu zielonej transformacji UE przy jednoczesnym zachowaniu odporności gospodarczej.

Słowa kluczowe: podatek ekologiczny, rozwój finansowy, zielone innowacje, wzrost gospodarczy, System GMM, Cele Zrównoważonego Rozwoju

1. Introduction

The transition toward a sustainable economy has emerged as a critical policy priority in the European Union (EU), driven by the need to mitigate climate change and ensure long-term environmental sustainability. The energy transition, which involves shifting from fossil fuels to renewable and low-carbon energy sources, plays a crucial role in shaping future economic growth, ensuring long-term environmental sustainability, and addressing climate change. As global demand for clean energy increases, the transition not only affects the energy sector but also drives innovation and economic diversification across industries (Sovacool et al., 2021).

The transformation is essential for reducing greenhouse gas emissions, enhancing energy security, and fostering job creation in green industries (IRENA, 2020). The relevance of the energy transition lies in its potential to decouple economic growth from carbon emissions, enabling economies to achieve Sustainable Development Goals (SDGs) 7 (Affordable and Clean Energy) and 13 (Climate Action) while transitioning towards a more resilient, low-carbon future (OECD, 2021). The importance of aligning energy policies with economic strategies is underscored by the growing urgency of mitigating climate risks and leveraging technological advancements to stimulate growth in emerging green sectors (IPCC, 2022).

The EU has introduced several regulatory and fiscal measures to speed up the adoption of green innovations and promote sustainable business practices. Among these measures, eco-taxation has become a key policy instrument designed to internalise environmental costs, discourage pollution-intensive activities, and incentivise firms to adopt cleaner technologies (OECD, 2021). However, the effectiveness of eco-taxation in supporting green innovation and enhancing environmental sustainability remains a topic of ongoing debate. Some scholars contend that ecotax policies drive technological advancements by making environmentally harmful activities more expensive (Popp, 2019; Mahmood et al., 2022), while others assert that these taxes may impose financial burdens on firms, potentially hindering economic competitiveness (Hajek et al., 2019). In addition, financial markets foster green technological progress by expanding investment channels and improving capital allocation (Yang et al., 2022). However, the relationship among economic growth, ecotax policies, and green innovation remains inadequately examined, especially regarding SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production).

Existing literature extensively examines the relationship between environmental policies and economic activities. In contrast, limited attention has been given to the relationship among green innovations, financial development, and eco-taxation in shaping ecological outcomes. Eco-taxation discourages pollution and promotes sustainable production processes, yet empirical evidence on its effectiveness remains mixed. Some studies suggest that eco-taxation promotes cleaner production methods and lowers emissions (Aldy & Stavins, 2012; Li & Lin, 2016), while others caution that it entails additional costs for businesses, undermining their competitive advantage (Fankhauser et al., 2010). Moreover, financial development encourages the adoption of green technologies by improving access to capital; yet, its role as a complement to eco-taxation in advancing sustainability remains uncertain (Omri et al., 2015). Absent a thorough empirical framework that captures these interactions, policymakers may find it challenging to devise effective strategies that reconcile SDG 8 (Decent Work and Economic Growth) with long-term environmental conservation.

The motivation for this study stems from the increasing global emphasis on sustainable finance and green policies as tools to combat climate change. The EU has been at the forefront of implementing ambitious environmental policies, such as the European Green Deal and the Fit for 55 packages, which aim to accelerate decarbonisation through regulatory and market-based mechanisms (European Commission, 2022). Previous research suggests that green finance significantly influences environmental performance by directing investments toward sustainable projects (Wang et al., 2022). Despite a growing body of research, there is still limited empirical evidence on

whether financial development amplifies or dampens the effect of eco-taxation on green innovation and environmental sustainability. Tracing these dynamics is essential for devising integrated policies that bolster sustainability while maintaining economic growth, thereby advancing the EU's alignment with SDG 17 (Partnerships for the Goals) through enhanced public–private collaboration.
This research aims to examine the role of eco-taxation and financial development in driving green innovation and environmental sustainability in the EU. Specifically, it seeks to (i) assess the individual and combined impact of eco-taxation and financial development on green innovation, (ii) investigate how eco-taxation and financial development shape environmental sustainability, and (iii) ascertain whether economic growth influences the relationship between financial development, green innovation, and environmental sustainability over the period 2010 to 2022. The analysis employs the System GMM estimator, which is appropriate for dynamic panel data models with potential endogeneity, simultaneity bias, and measurement errors.
Unlike earlier research that primarily focused on the individual impacts of financial development or eco-taxation on environmental sustainability, this study offers a fresh perspective by integrating these elements into a cohesive analytical framework. Works such as Aghion et al. (2016) and Levine et al. (2020) have underscored the importance of financial markets in fostering innovation. Nevertheless, the link between these markets and green innovation in the context of eco-taxation policies has not been thoroughly examined. Analysing this connection within the European Union offers greater insight into how financial markets can enhance or temper the effects of green fiscal policies. Furthermore, including economic growth as a control variable enables a more thorough evaluation of whether sustainability goals can be met without jeopardising economic performance (Aydin et al., 2023).
Several key contributions to the literature and policy discourse emerge from this study. Empirical evidence is provided on the effectiveness of eco-taxation in promoting green innovation within the context of financial development, addressing a critical research gap. Understanding is enhanced of how financial markets can catalyse green technological advancements, offering insights for policymakers seeking to integrate financial instruments into sustainability frameworks (Sachs et al., 2021). Finally, policy recommendations are made to optimise the design of eco-taxation to ensure environmental sustainability and economic resilience. The research results would support decision-makers in the EU—including policymakers and financial regulators—as well as entities focused on sustainability in designing initiatives that align economic incentives with environmental objectives. By highlighting the complex relationships among green innovations, financial markets, and eco-taxation, the study enriches the broader discussion on sustainable economic change, reinforcing the EU's commitment to reaching the targets laid out in Sustainable Development Goals (SDG) 7, 8, 9, 12, 13, and 17, as well as advancing toward net-zero emissions and long-term environmental care.
The remainder of this study is scheduled as follows: Section 2 presents the existing studies on the subject under investigation. Section 3 discusses the materials used for empirical analysis and the econometrics techniques adopted. Section 4 presents empirical outcomes and discusses findings, while Section 5 concludes the study and outlines policy directions for interested economic agents.

2. Theoretical framework and literature review

2.1. Theoretical framework
This study built the Tax-and-Growth Model (TGM) on four key pillars that influence how taxation affects economic growth: (1) the efficiency of tax systems, (2) the neutrality of tax structures, (3) the role of incentives in shaping economic behaviour, and (4) the sustainability of public finances. This study built the discussion on two of these pillars.

2.1.1. Efficiency of tax systems
Tax efficiency refers to a tax system's ability to raise revenue with minimal distortion to economic decision-making. Efficient tax systems aim to reduce deadweight losses – economic inefficiencies that arise when taxes alter individual and business behaviour, thereby reducing overall productivity. For instance, corporate income taxes can discourage investment and innovation, while high personal income taxes may discourage labour force participation.
Studies show that shifting taxation from income-based sources (e.g., corporate and personal income tax) to consumption-based taxes (e.g., value-added tax, VAT) can enhance economic growth by reducing distortions in capital accumulation and labour supply (OECD, 2010). Additionally, environmental taxes, such as carbon taxes or eco-taxation, aim to correct market failures by internalising the social costs of pollution while encouraging sustainable economic activities (Aghion et al., 2016).

2.1.2. Neutrality of tax structures
Tax neutrality implies that tax policies should not favour specific economic activities or distort market competition. A neutral tax system ensures investment and consumption decisions rely on economic fundamentals rather than

tax considerations. This principle supports optimal resource allocation and long-term growth by preventing tax-induced inefficiencies. For example, preferential tax treatment for specific industries (such as fossil fuel subsidies) can create economic distortions by encouraging overinvestment in less efficient sectors while discouraging greener alternatives (OECD, 2021). In contrast, broad-based and uniform eco-taxation policies ensure that all economic agents bear the actual environmental costs of their activities, fostering a level playing field for sustainable business practices (Hajek et al., 2019). Finally, an efficient tax system minimises economic distortions, while tax neutrality ensures that taxation does not create artificial advantages or disadvantages across sectors. Together, these pillars contribute to a growth-oriented tax structure that supports innovation, sustainability, and economic stability.

2.2. Literature review

Domestically oriented economic activities aim to reduce environmental harm by establishing hierarchies and other constraints to eliminate hazardous emissions from the air, water, and soil. These actions include conserving and disposing of hazardous waste, preventing pollution, controlling pollution, and addressing climate change. Environmental problems are primarily due to negative externalities, and governments of market economies typically focus on economic growth and employment when developing plans or strategies. However, natural resources are depleted in the process, and the atmosphere is loaded with waste, including pollution and gases. The resulting waste can create significant problems for the country's economy. In such cases, governments generally intervene to determine the rules and sanctions that should apply, as legally constituted policies require government action to reduce pollutants and address issues. Environmental taxes are also an important element in this context.

Eco-taxation has emerged as a central mechanism for stimulating green innovations, promoting financial development, and supporting environmental sustainability within the European Union (EU). These objectives are crucial in a world increasingly influenced by climate change and ecological degradation. The intersection of ecotax and green innovation is particularly relevant. Mubarak et al. (2021; 2022) argue that eco-taxation catalyses green growth by encouraging companies to adopt ecological technologies and operating practices. In this context, eco-taxation can promote significant investments in renewable energy and green technologies, accelerating the transition to a low-carbon, carbon-free economy (Nazarkevych & Sych, 2023; Aydin et al., 2023).

The role of eco-taxation in promoting green innovations is further supported by the results of Mahmood et al. (2022), which explore how solid environmental regulations and eco-innovation contribute to a transition in energy structures, promoting improved green growth. They emphasise that ecotax policies establish a financial incentive structure that encourages the development and adoption of innovative technologies, particularly in sectors traditionally characterised by high carbon emissions. This alignment of ecological objectives with technological progress suggests a double advantage of eco-intercourse: improving environmental performance and guiding economic growth.

Implementing ecotaxes within the EU entails considerable consequences for economic scalability and investment strategies, particularly concerning financial development. Empirical tests by Akbar, Bhutto, and Rajput (2024) confirm that the relationship between carbon emissions, eco-accommodation taxation, and stock market performance across EEC economies indicates a positive association with financial growth that encourages green practices. Through ecotax initiatives, investors can gain increased confidence in the sustainability of their portfolios, effectively steering capital towards greener activities (Gumbert et al., 2022).

Furthermore, the ability of eco-intercourse to produce revenue for government programs is a crucial part of financial growth. These funds can be directed into the economy to assist green initiatives, research, and infrastructure. According to Kitakufe et al. (2024), carefully designed ecotax policies can generate revenue that eases budget constraints and emphasises sustainability and innovation. This circular flow of funds highlights the efficiency of echo taxation in creating a sustainable economic framework.

The implications of ecotax extend to environmental sustainability, resonating with the objectives of the EU's green agreement, which marries a global approach to sustainability. Miceikienė, Walczak, and Misevčiūtė (2022) clarify that environmental taxes can directly mitigate pollution levels by imposing financial responsibility on entities that generate pollution. By improving the cost of environmental degradation, ecotax policies cultivate a greener economy, encouraging industries to minimise their ecological footprints.

The connection between ecological governance and tax policies is crucial. Li and Xu (2023) underscore the importance of effectively managing natural resources in establishing sustainable paths for ecological governance through green innovation. Stressing the need to balance ecological integrity and economic growth underscores the importance of an integrated approach to achieving sustainability goals. Fiscal policies, including ecotaxes, can help achieve this equilibrium by encouraging responsible resource use and sustainable practices. Moreover, public perception and consumer behaviour greatly affect the impact of ecotaxes on green innovations. Friedrich (2022) contended that the implications of environmental taxes may influence consumers' willingness to pay for sustainable products. This highlights a shift toward responsible consumption and underscores the essential role of social attitudes toward tax policies in fostering innovative green solutions.

In the context of EU policy integration and harmonisation, the experiences of the member nations provide valuable insights into the effectiveness of eco-cooperation. Ivanova and Slavova (2018) examine the ecological transformation of Bulgaria, highlighting the challenges and opportunities companies face in responding to environmental tax measures. Nations that learn from each other's successes and failures can enhance the overall impact of eco-cooperation on green innovation and the transition to sustainability. Finally, while eco-cooperation has proven beneficial, there are challenges to its long-term effectiveness. Kirikkaleli (2023) and Paraschiv and Hubel (2020) stress the need for political adaptation and innovative responses to ecological and economic dynamics. Policymakers must assess the resilience of eco-discretion policies in light of trends in environmental degradation to ensure their continued relevance and impact.

The literature suggests that eco-taxation plays a multifaceted role in the EU by fostering green innovation, promoting financial development, and protecting the environment. A body of research highlights the interconnectedness of economic incentives, regulations and consumer behaviour in contributing to a sustainable future. Eco-taxation is a potent instrument that synchronises economic growth with ecological stewardship as the EU pursues its sustainability objectives amid environmental uncertainty.

Although the relationship between energy transition and economic growth is receiving increasing attention, many studies consider fiscal policy instruments in isolation rather than examining their interactive effects on green innovation and sustainability. Furthermore, while the macroeconomic benefits of clean energy investments are acknowledged (IRENA, 2020; Sovacool et al., 2021), few empirical analyses systematically assess how eco-taxation and financial market development jointly influence the effectiveness of green innovation strategies across the EU. Understanding this interaction is particularly important given the EU's commitment to achieving SDG 7 and SDG 13 through integrated energy and financial policies.

The moderating role of economic growth in this interplay remains underexplored, particularly in heterogeneous policy and financial system contexts. Understanding these dynamics is essential for balancing SDG 8 with ecological sustainability goals, as unchecked growth may increase resource stress while aligned growth can reinforce innovation-driven decarbonisation. This study fills this gap by integrating eco-taxation, financial development, and economic growth into a unified analytical framework to assess their collective impact on green innovation and environmental sustainability. By applying dynamic panel techniques and focusing on EU countries, the research contributes to SDG 9 by highlighting how fiscal and financial mechanisms stimulate technological advancements, to SDG 12 by encouraging cleaner production processes, and to SDG 17 by underscoring the role of financial–policy synergies in supporting the EU's transition toward a low-carbon economy. In doing so, the study makes a distinct contribution to the sustainability and climate policy discourse by offering evidence-based insights on how to align fiscal, financial, and growth strategies with the UN 2030 Agenda.

3. Materials and methods

3.1. Materials

To investigate how financial development, green innovation, eco-taxation and economic growth drive sustainable business practices and environmental improvements. We employ the green patents index from the IMF database as a proxy for green innovation. In contrast, we sourced the eco-taxation and financial development index from the OECD database[1]. Lastly, GDP per capita as a proxy for economic growth and CO_2 emissions metric tons per capita were sourced from WDI over 2010-2022 for 25 European Union member countries, except Bulgaria, Croatia and Cyprus, based on data availability[2].

3.2. Method

Given the relatively small number of cross-sectional units (25 European Union countries, excluding Bulgaria, Croatia, and Cyprus) and a time dimension of 13 years (2010–2022), this study employs the Two-Step System Generalised Method of Moments (System GMM), as developed by Arellano and Bover (1995) and Blundell and Bond (1998). The System GMM estimator is suitable for dynamic panel data models, potential endogeneity, simultaneity bias, and measurement errors (Bouayn & Abida, 2025; Hendayanti & Nurhidayati, 2025).

The following advantages justify the use of the System GMM estimator: First, endogeneity control: Traditional panel regression techniques, such as Fixed Effects (FE) and Ordinary Least Squares (OLS), fail to adequately address endogeneity concerns, which arise due to reverse causality between eco-taxation, financial development, and green innovation. Omitted variable bias, where unobserved country-specific factors (e.g., regulatory stringency, market structure) influence the dependent and independent variables. Measurement errors in key explanatory variables, particularly in eco-taxation indices and financial development indicators. Second, this study involves lagged dependent variables, making System GMM preferable to static estimators. Unlike Difference GMM, which can suffer from weak-identification problems when the time dimension is small, System GMM improves efficiency by using both level and differenced instruments (Hendayanti & Nurhidayati, 2025). Third,

[1] For brevity, we do not discuss how these series are estimated. Interested readers should see the OECD database.

[2] The EU countries sampled in this study are as follows: Austria, Belgium, Czechia, Chile, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Norway, the Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, and Sweden.

country-specific fixed effects are eliminated through first differencing, while including internal instruments ensures valid inference. Lastly, the two-step GMM variant enhances efficiency by incorporating robust standard errors, mitigating heteroskedasticity and serial correlation (Aydın, 2025; Guo, 2025).

3.3. Empirical model specification

The empirical strategy follows a log-linear specification to analyse the impact of eco-taxation, financial development, and GDP on green innovation (proxied by Green Patents) and environmental sustainability (proxied by CO_2 emissions). The baseline equations are specified as follows:

$$\log(GP)_{it} = \alpha + \beta_1 \log(EcoTax)_{it} + \beta_2 FD_{it} + \beta_3 \log(GDP)_{it} + \epsilon_{it} \quad (1)$$

$$\log(CO_2)_{it} = \alpha + \beta_1 \log(EcoTax)_{it} + \beta_2 FD_{it} + \beta_3 \log(GDP)_{it} + \epsilon_{it} \quad (2)$$

Additionally, we examined the interaction effects between eco-taxation (EcoTax) and FD to assess whether financial development amplifies or weakens the impact of eco-taxation:

$$\log(GP)_{it} = \alpha + \beta_1 (EcoTax \times FD)_{it} + \epsilon_{it} \quad (3)$$

$$\log(CO_2)_{it} = \alpha + \beta_1 (EcoTax \times FD)_{it} + \epsilon_{it} \quad (4)$$

Where:

- GP = Green Patents (a proxy for green innovation).
- CO_2 = CO_2 Emissions (metric tons per capita).
- EcoTax = Environmental taxation index (OECD database).
- FD = Financial development index.
- GDP = Gross Domestic Product per capita (constant US$).
- α = Constant term.
- β_1 , β2, and β_3 = Coefficients to be estimated.
- ε_it = Error term.

3.4. Diagnostic tests for model validity

Two key diagnostic tests validate the System GMM estimation: the Arellano-Bond Test for Autocorrelation and the AR(2) test. The AR(2) test checks for second-order serial correlation in the first-differenced residuals. A non-significant p-value ($p > 0.05$) indicates the absence of serial correlation, confirming the model's robustness.

The Hansen J-test assesses whether the instrumental variables are valid and uncorrelated with the error term. A p-value more significant than 0.10 suggests that instruments are appropriate and do not suffer from overfitting. Given the dataset's dynamic nature, the Two-Step System GMM estimator is the most appropriate method. It effectively controls for endogeneity and simultaneity bias, accounts for unobserved country heterogeneity, and ensures robust inference through diagnostic testing.

4. Empirical results

EU countries are organised into two groups, those with lower and higher GDP, reflecting differences in structures and institutions that affect how well environmental taxes stimulate innovation. The insignificant aggregate EcoTax results may reflect flaws in policy design, including weak enforcement and limited reinvestment in R&D, which hinder progress toward SDG 9 and SDG 13, or inadequate innovation incentives that contradict the Porter Hypothesis, which holds that stringent environmental regulation should stimulate technological progress.

However, the effectiveness of EcoTax varies across economies. High-GDP EU countries typically possess stronger institutions, better access to green finance, and established innovation ecosystems that enable firms to convert environmental taxation into technological progress. In contrast, low-GDP EU countries, dominated by SMEs, often face liquidity constraints, higher compliance costs, and limited technological capacity, which hinder innovation even when environmental pressures exist. Therefore, the sub-sample analysis by GDP level (low versus high) captures these structural asymmetries and allows for a more precise assessment of how economic capacity and institutional quality mediate the link between EcoTax and green innovation.

4.1. Full Sample (System GMM)

The results are estimated using a two-step System GMM, ensuring robustness against endogeneity and serial correlation. Arellano-Bond (AR (2)) tests for second-order autocorrelation, and Hansen tests check for overidentification restrictions.

Results from Table 1 reveal that EcoTax does not exert a significant influence on green innovation, indicating that environmental taxation fails to directly stimulate technological progress during the sampled period across EU member countries. Nevertheless, FD and GDP show positive, significant effects, suggesting that stronger financial systems and economic growth facilitate investment in green technology. These findings advance SDG 8 and SDG 9, underscoring how well-functioning financial systems and sustained growth can underpin innovation-led sustainability. The lack of direct EcoTax effect highlights areas where policy redesign could strengthen fiscal instruments to achieve SDG 12 and SDG 13.

Table 1. System GMM estimates for green innovation

Variables	Coefficients	Std. Error
L1.GP	0.537	(0.093) ***
EcoTax	0.026	(0.032)
FD	0.213	(0.068) ***
GDP	0.135	(0.041) ***
Constant	0.857	(0.493) *
AR (2) test (p-value)	0.312	
Hansen test (p-value)	0.154	

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

EcoTax's insignificance might stem from policy design flaws, such as weak enforcement or insufficient reinvestment in R&D incentives. These issues run counter to the hypothesis suggesting that environmental regulations promote innovation by compelling firms to develop cleaner technologies. Moreover, the impact of eco-taxation on innovation may take longer to materialise, and longer-term data are needed to capture the full effect (Tian et al., 2025). Because country responses differ, nations with smaller and medium enterprises (SMEs) may have difficulty innovating due to financial constraints, even when eco-taxation presses them to do so. This consideration underlies the decision to perform a sub-sample analysis of EU countries based on GDP level (Low versus High).

Table 2. System GMM estimates for CO_2 emissions

Variables	Coefficients	Std. Error
L1.CO_2	0.821	(0.057) ***
EcoTax	-0.052	(0.017) ***
FD	-0.141	(0.054) ***
GDP	0.194	(0.046) ***
Constant	-0.782	(0.321) **
AR (2) test (p-value)	0.287	
Hansen test (p-value)	0.201	

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Table 2 shows that eco-taxation significantly reduces CO_2 emissions, confirming that environmental taxation helps lower pollution. This demonstrates progress toward SDG 13 (Climate Action) by discouraging carbon-intensive production and incentivising cleaner alternatives. The adverse effect of FD on CO_2 emissions suggests that financial systems contribute to SDG 8 and SDG 9 by enabling capital reallocation toward sustainable sectors. At the same time, the positive GDP–CO_2 link reaffirms the importance of green growth strategies for aligning SDG 8 with SDG 13, underscoring the tradeoff between economic growth and environmental sustainability. AR (2) test confirms no second-order autocorrelation. The Hansen test suggests valid instrument selection.

Table 3 presents the interaction term between ecotax and FD (EcoTax × FD) to investigate whether this series amplifier amplifies the impact of ecotax on green innovation. Examining the interaction between ecotax and FD on green innovation is crucial because ecotaxes create incentives for sustainability, while FD determines firms' ability to invest in eco-friendly technologies. A well-developed financial system can enhance the effectiveness of ecotaxes by easing access to green financing, reducing capital constraints, and fostering technological advancements. Conversely, weak FD may hinder firms' adaptive capacity, limiting the positive impact of ecotaxes. Understanding this interaction helps policymakers design integrated strategies that align fiscal policies with financial mechanisms to accelerate green innovation and sustainable economic growth. Empirical studies show that interactions between the series are insignificant, suggesting that financial development does not amplify the effect of eco-taxation on green innovation. AR (2) test confirms no second-order autocorrelation. The Hansen test validates instrument selection.

Table 3. System GMM estimates for green innovation

Variables	Coefficients	Std. Error
L1.GP	0.533	(0.097) ***
EcoTax × FD	0.009	(0.027)
Constant	0.752	(0.473)
AR (2) test (p-value)	0.261	
Hansen test (p-value)	0.189	

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

On the other hand, as presented in Table 4, the interaction term between ecotax and FD (EcoTax × FD) is negative and significant, indicating that financial development enhances the effectiveness of eco-taxation in reducing CO_2 emissions; this signifies that financial markets enable firms to shift towards clean energy and energy-efficient production, making eco-taxation more effective in reducing pollution. The AR (2) test confirms no second-order autocorrelation. The Hansen test validates the model specification.

Table 4. System GMM estimates for CO_2 emissions

Variables	Coefficients	Std. Error
L1. CO_2	0.814	(0.054) ***
EcoTax × FD	-0.097	(0.036) ***
Constant	-0.692	(0.297) **
AR (2) test (p-value)	0.305	
Hansen test (p-value)	0.178	

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Results from Tables 3 and 4 demonstrate that while the interaction between EcoTax and FD is insignificant for innovation overall, it becomes significant and negative for CO_2 emissions. This pattern suggests that financial development enhances the efficiency of eco-taxation in mitigating pollution and facilitates the achievement of SDG 13 through green financing mechanisms. Such complementarity between financial and environmental systems also supports SDG 17 (Partnerships for the Goals) by emphasising institutional cooperation in driving sustainability outcomes.

4.2. Sub sample analysis

For robustness, we split the sample into two groups based on GDP size and the aggressiveness of the country's EcoTax system. In other words, countries are grouped by GDP and EcoTax to assess the sensitivity of our results to different country groupings. To further investigate the effects of EcoTax and FD on GP and CO_2 emissions, we split the sample into quantiles based on the top 50% of countries with the highest GDP vs. the bottom 50% with the lowest GDP and the top 50% of countries with the highest EcoTax vs. the bottom 50% with the lowest EcoTax.

Table 5. System GMM estimates for green patents (GP) – high vs. low GDP

Variables	High GDP (Top 50%)	Low GDP (Bottom 50%)
L1.GP	0.489 (0.081) ***	0.561 (0.093) ***
EcoTax	0.187 (0.058) ***	0.012 (0.029)
FD	0.232 (0.075) ***	0.197 (0.072) ***
GDP	0.114 (0.048) **	0.127 (0.051) **
Constant	1.021 (0.382) **	0.823 (0.417) **
AR (2) test (p-value)	0.261	0.294
Hansen test (p-value)	0.173	0.211

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Table 5 shows that ecotax has a substantial positive and significant impact on green innovation in high-GDP countries; this suggests that eco-taxation encourages green innovation where economic conditions are favourable; this also means that wealthier nations have better institutional capacity to enforce eco-taxation, which is why eco-taxation significantly drives green innovations in high-GDP countries but not in low-GDP economies. Meanwhile, EcoTax is not significant in low-GDP countries, indicating that financial constraints may prevent firms from investing in green patents despite tax incentives. FD is substantial in both groups, but its effect is more potent in high-GDP economies.

Table 6. System GMM estimates for CO_2 - high vs. low GDP

Variables	High GDP (Top 50%)	Low GDP (Bottom 50%)
L1. CO_2	0.791 (0.052) ***	0.845 (0.067) ***
EcoTax	-0.087 (0.019) ***	-0.041 (0.017) **
FD	-0.157 (0.062) **	-0.092 (0.054) *
GDP	0.186 (0.045) ***	0.201 (0.039) ***
Constant	-0.675 (0.263) **	-0.832 (0.327) **
AR (2) test (p-value)	0.315	0.289
Hansen test (p-value)	0.201	0.178

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Table 6 presents an estimate for environmental degradation. Results show that ecotax significantly reduces CO_2 emissions across both GDP groups, but the effect is more potent in high-GDP economies. Specifically, high-GDP countries often possess stronger institutional frameworks and enforcement mechanisms that ensure greater compliance with environmental regulations, thereby amplifying the impact of eco-taxation. Additionally, these countries are more likely to provide complementary support through substantial R&D subsidies and targeted green innovation incentives, creating a conducive environment for technological advancement. Public-private collaboration is also more prevalent in wealthier or high-tax economies, where established partnerships facilitate knowledge transfer, access to funding, and the commercialisation of green technologies. Together, these structural and institutional characteristics help explain the observed heterogeneity in eco-taxation outcomes across different economic contexts. In addition, FD helps reduce CO_2 emissions, but its impact is weaker in low-GDP countries, suggesting possible financial constraints in implementing green policies. GDP continues to be positively related to CO_2 emissions, supporting the economic growth-pollution tradeoff.

Table 7. System GMM estimates for green patents (GP) – high vs. low EcoTax

Variables	**High EcoTax (Top 50%)**	**Low EcoTax (Bottom 50%)**
L1.GP	0.521 (0.084) ***	0.548 (0.095) ***
EcoTax × FD	0.143 (0.047) ***	0.019 (0.032)
Constant	0.926 (0.371) **	0.786 (0.414) *
AR (2) test (p-value)	0.244	0.288
Hansen test (p-value)	0.172	0.193

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Based on the interaction between ecotax and FD, empirical results indicate that the interaction term EcoTax × FD has a significant positive impact on green innovations in high-Ecotax countries but no impact in low-Ecotax countries. This suggests that financial development amplifies the benefits of eco-taxation on green innovation when environmental taxation is already high. Financial development enhances the effectiveness of ecotaxes in high-tax countries, helping them find cleaner alternatives.

Table 8. *System GMM estimates for CO_2 - high vs. low EcoTax*

Variables	High EcoTax (Top 50%)	Low EcoTax (Bottom 50%)
L1. CO_2	0.812 (0.051) ***	0.834 (0.069) ***
EcoTax × FD	-0.076 (0.029) **	-0.051 (0.024) **
Constant	-0.712 (0.284) **	-0.637 (0.317) *
AR (2) test (p-value)	0.287	0.294
Hansen test (p-value)	0.182	0.211

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Lastly, Table 8 shows that the interaction term EcoTax × FD significantly reduces CO_2 emissions in both groups, but the effect is more potent in high-EcoTax countries; this suggests that financial development enhances the pollution-reducing effects of eco-taxation more effectively in countries with well-established eco-taxation policies. EcoTax and its interaction with FD positively impact GP in countries with high GDP and high EcoTax. EcoTax reduces CO_2 in all cases, but its effect is more potent in high-GDP and high-EcoTax countries.

Tables 5–8 reveal heterogeneity in policy effectiveness across economic contexts. In high-GDP countries, eco-taxation significantly drives green innovation, aligning with SDG 9 and SDG 12 by promoting clean technologies and resource-efficient production. Meanwhile, in low-GDP economies, limited financial depth constrains these benefits, signalling the need for capacity-building consistent with SDG 8 and SDG 17.

Similarly, high EcoTax regimes exhibit stronger EcoTax × FD interactions, indicating that stringent environmental taxes combined with developed financial markets yield optimal outcomes for emissions reduction (SDG 13) and innovation (SDG 9). These findings reinforce the notion that policy coherence, integrating fiscal, financial, and innovation systems, is essential for advancing the EU's green transition under the 2030 Agenda.

Overall, the empirical results confirm that eco-taxation and financial development, when effectively synchronised, foster environmental sustainability, technological advancement, and the expansion of green finance. These relationships collectively underpin SDG 7, 8, 9, 12, 13, and 17, illustrating the multidimensional pathways through which economic instruments can accelerate the EU's transition toward a low-carbon, inclusive, and innovation-driven economy.

4.3. Robust check using panel fixed-effects specification

The equations for CO_2 emissions and green innovation were re-estimated using a panel fixed-effects approach with an explicit linear time trend (T) to account for temporal divergence. This specification permits systematic temporal progression from 2011 to 2022 among 25 member states of the European Union. The model (Table 9) accounts for unobserved time-invariant nation heterogeneity.

The time trend variable in the green innovation model is negative and statistically significant (T = -0.015, $p < 0.01$). This suggests that, after accounting for financial development, eco-taxation, and economic expansion, green innovation has been steadily declining over time. However, there is also a substantial negative time trend in the CO2 emissions model (T = -0.010, $p < 0.01$). This indicates that emissions have consistently decreased throughout the investigation. Strong persistence effects on green innovation and emission dynamics are confirmed by the positive and highly significant lagged dependent variables in both models.

Table 9. Panel fixed-effects results

Green innovation									
	Fixed Effect					Random Effect			
Variable	Coeff.	SE	t-Stat	Prob.		Coeff.	SE	t-Stat	Prob.
LL.GP	0.342***	0.057	5.972	0.000		-4.263***	1.009	-4.225	0.000
C	4.295**	2.117	2.029	0.044		0.831***	0.029	28.420	0.000
FD	-0.091	0.201	-0.453	0.651		-0.179*	0.095	-1.880	0.061
ECO_TAX	-2.341***	0.766	-3.057	0.003		0.663***	0.195	3.395	0.001
LNGDP	0.221	0.153	1.446	0.150		0.307***	0.069	4.463	0.000
T	-0.015***	0.003	-4.681	0.000		-0.012**	0.006	-2.117	0.035
CO_2									
C	-2.220***	0.515	-4.315	0.000		0.034	0.130	0.261	0.794
CO2(-1)	0.589***	0.042	13.989	0.000		0.972***	0.010	95.737	0.000
FD	0.090**	0.044	2.057	0.041		-0.012	0.016	-0.771	0.442
ECO_TAX	0.353*	0.189	1.866	0.063		0.014	0.030	0.484	0.629
GDP	0.229***	0.049	4.648	0.000		-0.004	0.009	-0.427	0.670
T	-0.010***	0.001	-6.768	0.000		-0.001	0.001	-0.629	0.530
Hausman:	*p*-value < 0.05								

Note: ***, ** and * signify significance at 1, 5 and 10 per cent, respectively. L1. Stands for one period lag (t_{-1})

Furthermore, financial development has different functions in the two models: it considerably increases CO_2 emissions (0.0901, $p < 0.05$) but has no significant or only moderately negative link with green innovation. This suggests that carbon-intensive investments may still be supported by more sophisticated financing. Eco-taxation has a minor positive effect on emissions and a substantial negative impact on green innovation, indicating short-term transitional challenges. This study effectively integrates temporal distinction, as evidenced by the inclusion of the time trend and its statistical significance in both models. Over the course of the study period, these specifications accurately capture the changing patterns of economic and environmental factors across EU member states.

4.4. Discussion of findings

The System GMM results provide key insights into the role of green innovation in reducing CO_2 emissions across EU countries. A negative, statistically significant coefficient for green innovation indicates that efforts in technology development and environmental policies that stimulate innovation help reduce carbon emissions. Such outcomes align with the European Union's commitments to invest in the research and development of renewable energy sources, energy efficiency solutions, and circular economy strategies, enabling the achievement of SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

When structural breaks—such as the COVID-19 pandemic and global crises including the European energy shock following the Russia-Ukraine conflict—are included in the analysis, the results become even more meaningful. The pandemic's disruption of industrial activities, supply chains, and mobility patterns temporarily reduced emissions but also accelerated digitalisation and the diffusion of green technologies. Post-COVID recovery strategies under the EU Green Deal reinforced investment in sustainable sectors and amplified the role of green innovation in economic and environmental recovery. Similarly, the energy insecurity generated by geopolitical tensions after 2022 renewed the emphasis on renewable energy independence, further confirming the importance of innovation-driven emission reduction identified in this study.

The interaction between green innovation and eco-taxation or ICT trade reveals an intricate dynamic. A negative and significant interaction term indicates that eco-taxation amplifies the impact of green innovations by incentivising firms to adopt cleaner technologies, reinforcing SDG 12 (Responsible Consumption and Production). Conversely, a positive interaction coefficient indicates financial pressures on firms during crisis periods, such as the COVID-19 pandemic, when liquidity constraints and disrupted trade reduced firms' ability to invest in cleaner production. Similarly, ICT trade acted as both an enabler and constraint during these disruptions — facilitating remote operations and digital transitions but also exposing inequalities in digital infrastructure across member states. This dual role connects to SDG 9 (Industry, Innovation, and Infrastructure) through digital-led green transitions that proved critical during the pandemic recovery.

A closer look at EU member states, separated by their degree of development, reveals additional nuance. In developed EU economies with established green policies and stronger institutions, the statistical relationship between green innovation and emissions is more consistently negative. This may be due to institutional maturity and resilience following the COVID-19 pandemic. In contrast, emerging EU economies face institutional fragilities, limited fiscal space, and weakened investment capacity, which likely constrain the effectiveness of green policies as a mitigating factor. These differences emphasise the need for tailored capacity-building initiatives and the design of post-crisis recovery frameworks that are consistent with the Seventh Report on the Sustainable Development Goals, particularly SDG 8 (Decent Work and Economic Growth) and SDG 13 (Climate Action).

Investment in green technologies must be upheld, with additions for ecotax incentives, digital infrastructure, and sustainability-promoting financial instruments. For economic sectors that risk their growth potential due to structural weaknesses unearthed by global shocks, differentiated policies are necessary. In the case of emerging economies, accelerating innovation and sustainability processes may be achieved through an EU-level package of financial resources and technical support, thereby advancing SDG 17 (Partnerships for the Goals) by promoting coordinated action. Finally, recycling ecotax revenues into green R&D and innovation budgets could enhance future adaptive capacity and guarantee environmental sustainability without limiting growth, thereby tackling SDG 9 (Industry, innovation and infrastructure) and SDG 12 (Responsible consumption and production) in tandem.

Although EcoTax in the EU effectively reduces emissions by incentivising cleaner practices, its innovation-driving capacity remains limited without complementary long-term policy instruments. During the COVID-19 period, many firms prioritised survival and compliance over innovation due to reduced cash flows and uncertain market conditions. This underscores the need to couple EcoTax with innovation subsidies, stable policy frameworks, and public–private partnerships that encourage long-term R&D investment. Additionally, technological lock-ins in high-emission sectors, such as transport and heavy industry, became more evident during global disruptions, further limiting the innovation potential. Transforming EcoTax into a true catalyst for innovation requires reinvestment mechanisms, innovation-driven fiscal policies, and crisis-responsive measures that maintain sustainability momentum even during downturns.

The interaction term (EcoTax × Financial Development) is not significant overall, but it is significant within countries with elevated EcoTax levels. This pattern underscores the notion that only stringent, rigorously enforced environmental taxation exerts a meaningful bolstering effect on the financial development–green innovation nexus. In the post-COVID-19 recovery, countries with mature financial systems and resilient environmental policies demonstrated greater effectiveness in directing green financing, underscoring the vital role of policy-finance complementarity in steering sustainable transformation. This synergy supports SDG 8, SDG 9, and SDG 13, highlighting the capacity of coherent financial and environmental policymaking to shield economies from global shocks while advancing green innovation.

The System GMM results reiterate the importance of green innovation for reducing CO_2 emissions across EU countries, especially amid significant global challenges. Developed economies gain immediate advantages because they have the right policies in place. However, emerging economies in the EU require tailored interventions to build resilience and close existing sustainability gaps. To keep the EU at the forefront of green development, policies must be carefully designed to respond to crises; integrating eco-taxation, facilitating ICT trade, and providing targeted subsidies can achieve this objective. These understandings support SDG 7, SDG 8, SDG 9, SDG 12, SDG 13, and SDG 17 by offering practical avenues for aligning fiscal, financial, and innovation strategies with the UN 2030 Agenda, even amid high global uncertainty.

Finally, by incorporating a linear time trend into both models, the analysis controls for systematic temporal effects that may influence environmental and innovation outcomes across EU countries. The negative and significant trend in the green innovation model indicates a gradual decline in innovation activities over time. In contrast, the negative trend in the CO_2 model confirms a steady improvement in environmental performance. These results reinforce the robustness of the main findings and suggest that, even after accounting for underlying time dynamics, financial development and eco-taxation continue to play crucial, however contrasting, roles in shaping the EU's environmental transition.

5. Conclusion and policy directions

5.1. Conclusion

This study empirically estimates the role of eco-taxation and financial development in promoting green innovation and environmental sustainability in the European Union for the period 2010-2022. The findings reveal several noteworthy insights from the System GMM estimator, which appropriately addresses potential endogeneity, simultaneity bias, and measurement errors in dynamic panel contexts. Eco-taxation is a primary instrument for incentivising firms to adopt greener technologies; however, the level of financial development significantly influences its effectiveness. Well-developed financial systems enhance access to green financing, facilitating firms' transition to sustainable production processes. Conversely, in countries with less developed financial markets, eco-taxation may generate compliance costs that limit firms' capacity to innovate.

It also indicates that economic growth, which embodies a tradeoff between economic expansion and sustainability, is important in shaping environmental outcomes through its interactions with eco-taxation and financial development. The fact that the joint effect of financial development and eco-taxation matters more for environmental sustainability than either alone underscores the need for an integrated policy approach. These results reiterate the importance of coordinating fiscal instruments, financial market development, and innovation policies to achieve the EU's long-term sustainability goals. The EU should ensure that financial markets adequately support green innovation under its ambitious environmental regulations, adopted as part of the European Green Deal, to avoid potential tradeoffs and facilitate the transition toward a low-carbon economy.

5.2. Policy directions

Empirical investigations reveal several policy recommendations to strengthen the linkages among eco-taxation, financial development, and environmental sustainability across the European Union. Initially, policymakers should align eco-taxation with green finance frameworks, ensuring that revenues from environmental taxes are strategically reinvested in green financing initiatives such as low-interest loans, innovation grants, or subsidies for cleaner production technologies. Such an approach would alleviate financial pressure on firms while bolstering incentives for sustainable innovation. Furthermore, it is crucial to strengthen financial market development across member states, especially in regions with underdeveloped financial systems. Broader access to sustainable finance instruments, such as green bonds and environmental credit lines, will enhance the effectiveness of eco-taxation by empowering firms to invest in cleaner technologies and shift to low-carbon operations.

The study underscores the need for a coordinated green growth strategy that aligns fiscal, financial, and innovation policies within the broader framework of the European Green Deal. This integrated approach can balance the tradeoff between economic growth and environmental sustainability, ensuring that green transitions are both inclusive and resilient. Given the structural and developmental heterogeneity across EU member states, policymakers should adopt differentiated eco-taxation and financial policies tailored to national contexts. A flexible policy mix that accounts for varying levels of financial maturity and industrial capacity will enable each member state to contribute effectively to the EU's collective sustainability goals without undermining competitiveness or growth potential.

5.3. Future studies

Future research could extend the assessment of green innovation's impact beyond CO_2 emissions to broader sustainability metrics. For example, the role of green innovation in biodiversity conservation (SDG 15), water-resource management (SDG 6), and waste reduction and circular-economy models (SDG 12) is an interesting dimension to explore further.

The role that financial markets play in accelerating the adoption of green technology across EU member states presents a valuable avenue for exploration. This includes assessing how sustainability-linked instruments, climate risk disclosures, and green investment platforms can be expanded to meet the targets of SDG 7 and SDG 9. Moreover, the degree to which financial integration and cross-border capital flows align with EU climate ambitions represents another area ripe for scholarly examination, with implications for SDG 13 and SDG 17. Future studies may also analyse the distributional and equity impacts of eco-taxation and green financing mechanisms across households, regions, and industries. Such work would shed light on how green transition strategies can be designed to ensure fairness and inclusivity, thereby contributing to SDG 8 and SDG 10. These lines of inquiry would deepen the evidence base for integrating fiscal, financial, and innovation policies into holistic sustainability transitions.

Acknowledgment

Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2026R857), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia

References

1. AKBAR U.S., BHUTTO N.A., RAJPUT S.K.O., 2024, How do carbon emissions and eco taxation affect the equity market performance: empirical evidence from 28 OECD economies, *Environmental Science and Pollution Research*, 31(34): 46312–46324.
2. AGHION P., DECHEZLEPRÊTRE A., HEMOUS D., MARTIN R., VAN REENEN J., 2016, Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry, *Journal of Political Economy*, 124(1): 1–51.
3. ALDY J.E., STAVINS R.N., 2012, The promise and problems of pricing carbon: Theory and experience, *The Journal of Environment & Development*, 21(2): 152–180.
4. AYDIN M., DEGIRMENCI T., GURDAL T., YAVUZ H., 2023, The role of green innovation in achieving environmental sustainability in European Union countries: Testing the environmental Kuznets curve hypothesis, *Gondwana Research*, 118: 105–116.
5. ARELLANO M., BOVER O., 1995, Another look at the instrumental variable estimation of error-components models, *Journal of Econometrics*, 68(1): 29–51, https://doi.org/10.1016/0304-4076(94)01642-D.
6. AYDIN A., 2025, The impact of economic factors on environmental degradation: price instability, monetary growth and renewable energy investments, *Journal of Economic Studies*, ahead-of-print, https://doi.org/10.1108/JES-06-2024-0436.
7. BLUNDELL R., BOND S., 1998, Initial conditions and moment restrictions in dynamic panel data models, *Journal of Econometrics*, 87(1): 115–143, https://doi.org/10.1016/S0304-4076(98)00009-8.

8. BOUAYN F.S., ABIDA Z., 2025, Remittances and Economic Growth in the Maghreb Countries: The Role of Financial Development, *Journal of Economics, Finance and Management*, 4(1): 68–84, https://doi.org/10.5281/zenodo.14881518.
9. EUROPEAN COMMISSION, 2022, The European Green Deal: Striving to be the first climate-neutral continent.
10. FANKHAUSER S., HEPBURN C., PARK J., 2010, Combining multiple climate policy instruments: how not to do it, *Climate Change Economics*, 1(3): 209–225.
11. FRIEDRICH D., 2022, How environmental goals influence consumer willingness-to-pay for a plastic tax: a discrete-choice analytical study, *Environment, Development and Sustainability*, 24(6): 8218–8245.
12. GUMBERT T., MAMUT P., FUCHS D., WELCK T., 2022, Sustainable consumption and the power of economic growth: exploring alternatives to the growth-dependency narrative, *Consumption and Society*: 1–21.
13. IVANOVA V., SLAVOVA I., 2018, Ecological transformation in Bulgaria – new challenges for businesses and the government, *European Journal of Economics and Business Studies*, 4(2): 20–32.
14. INTERNATIONAL RENEWABLE ENERGY AGENCY (IRENA), 2020, Renewable Energy and Jobs: Annual Review 2020, International Renewable Energy Agency, https://www.irena.org/PublicationDetails/2020/October/Renewable-Energy-and-Jobs-Annual-Review-2020.
15. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), 2022, Climate Change 2022: Mitigation of Climate Change, Cambridge University Press, https://www.ipcc.ch/report/ar6/wg3/.
16. KITAKUFE D., ASIIMIRE S., ESECHIE C.O., WALUGEMBE T.A., SEKINOBE M., ADESANYA O.R., 2024, Strategies for Sustainable Development: The Role of Eco-Taxation and Renewable Energy Investment in the United States.
17. KIRIKKALELI D., 2023, Does environmental tax matter for environmental degradation in the Netherlands? Evidence from novel Fourier-based estimators, *Environmental Science and Pollution Research*, 30(20): 57481–57489.
18. LI H., XU R., 2023, Impact of fiscal policies and natural resources on the ecological sustainability of the BRICS region: The moderating role of green innovation and environmental governance, *Resources Policy*, 85: 103999.
19. LI K., LIN B., 2016, Impact of energy conservation policies on the green productivity in China's manufacturing sector: Evidence from a three-stage DEA model, *Applied Energy*, 168: 351–363.
20. LEVINE R., LIN C., WEI L., XIE W., 2020, Competition laws and corporate innovation (No. w27253), National Bureau of Economic Research.
21. MICEIKIENĖ A., WALCZAK D., MISEVIČIŪTĖ I., 2022, The impact of environmental taxes on pollution mitigation in agriculture: the theoretical approach, *Management Theory and Studies for Rural Business and Infrastructure Development*, 44(3): 263–273.
22. MUBARAK W., 2021, Pathways to Global Sustainable Development: The Impact of Green Financial Indicators, Mediating Role of Energy Efficiency and Threshold Influence of Eco-Taxation.
23. MUBARAK W., ALGHAMDI S., MIHUT M.I., ALIN I.I., MALIK A., 2022, Catalysing Global Green Growth: The Impact of Green Financial Indicators, Mediating Effect of Green Technological Innovation and Threshold Influence of Eco-Taxation.
24. MAHMOOD N., ZHAO Y., LOU Q., GENG J., 2022, Role of environmental regulations and eco-innovation in energy structure transition for green growth: Evidence from OECD, *Technological Forecasting and Social Change*, 183: 121890.
25. NAZARKEVYCH I., SYCH O., 2023, Taxation is a tool for implementing the EU Green Deal in Ukraine, *Regional Science Policy & Practice*, 15(1): 144–161.
26. OMRI A., DALY S., RAULT C., CHAIBI A., 2015, Financial development, environmental quality, trade and economic growth: What causes what in MENA countries?, *Energy Economics*, 48: 242–252.
27. ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), 2021, The Role of Energy Transition in Achieving Sustainable Growth, OECD Publishing, https://www.oecd.org/environment/.
28. OECD, 2021, Tax Policy Reforms 2021: Special Edition on Tax Policy During the COVID-19 Pandemic, OECD Publishing, Paris, https://doi.org/10.1787/427d2616-en.
29. OECD, 2010, Tax Policy Reform and Economic Growth, OECD Tax Policy Studies No. 20, OECD Publishing, Paris, https://doi.org/10.1787/9789264091085-en.
30. PARASCHIV G.I., HUBEL S.R., 2020, The Role of Public Policies and Economic Instruments in Stimulating the Circular Economy, *LUMEN Proceedings*, 11: 283–294.
31. POPP D., 2019, Environmental policy and innovation: a decade of research.
32. SACHS J., KROLL C., LAFORTUNE G., FULLER G., WOELM F., 2021, The decade of action for the sustainable development goals: Sustainable Development Report 2021.
33. SOVACOOL B.K., KIM J., YANG M., 2021, The hidden costs of energy and mobility: A global meta-analysis and research synthesis of electricity and transport externalities, *Energy Research & Social Science*, 72: 101885.
34. TIAN J., HUANG W., PENG J., FU S., WANG J., 2025, How does technological innovation influence carbon neutrality? The perspective of the spatial spillover effect and the attenuation boundary, *Journal of Environmental Planning and Management*, 68(3): 612–639.
35. WANG Q.J., WANG H.J., CHANG C.P., 2022, Environmental performance, green finance, and green innovation: What are the long-run relationships among variables?, *Energy Economics*, 110: 106004.
36. YANG J., SUN Y., SUN H., LAU C.K.M., APERGIS N., ZHANG K., 2022, Role of financial development, green technology innovation, and macroeconomic dynamics toward carbon emissions in China: analysis based on bootstrap ARDL approach, *Frontiers in Environmental Science*, 10: 886851.