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Assessing the Impact of Sustainability Initiatives on Greenhouse Gas Emissions in Sweden and Finland

[1]Aleeza Batool, [2]Amjad Ali, [3]Marc Audi

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Aleeza Batool
Lahore School of Accountancy and Finance, University of Lahore, Pakistan
Amjad Ali
Lahore School of Accountancy and Finance, University of Lahore, Pakistan
Marc Audi
Abu Dhabi School of Management, Abu Dhabi, United Arab Emirates

ABSTRACT

Climate change has become a central concern in global policy discourse over the past two decades, motivating nations to adopt a wide range of sustainability initiatives. Analyzing the specific measures implemented and their effectiveness in promoting environmental sustainability is therefore critical. This study aims to evaluate the contribution of various sustainability actions to environmental preservation by focusing on Sweden and Finland, recognized for their leadership in sustainable development. Employing panel least squares and generalized method of moments methodologies using 2010-2020 data, the research rigorously assesses the impact of sustainability initiatives on environmental performance, with a particular focus on greenhouse gas emissions as the primary indicator. The empirical findings reveal that the expansion of renewable energy sources delivers the most prompt and significant reductions in greenhouse gas emissions among the interventions examined. Additionally, investments in green technologies and the issuance of green bonds are shown to enhance environmental quality, with their benefits projected to increase over time. These results highlight the necessity of prioritizing renewable energy development in national climate strategies. Building on these insights, the study presents targeted policy recommendations for Sweden and Finland. It advocates for a strategic shift from compliance-oriented environmental reporting towards the adoption of actionable policies that produce measurable emission reductions. Recommended policy measures include the promotion of sector-specific emission abatement, accelerated development of renewable energy infrastructure, and the encouragement of clean technology innovation through public investment and fiscal incentives. By comparing two Nordic sustainability leaders, Sweden and Finland, this study clarifies which targeted environmental measures are most effective within advanced institutional contexts.

INTRODUCTION

In contemporary society, safeguarding the environment is imperative for the continued survival of life on Earth. Since the early twenty-first century, climate change has increasingly disrupted human societies and destabilized weather patterns worldwide. According to the National Aeronautics and Space Administration, global climate change now constitutes an imminent threat, with observable impacts on ecosystems, meteorological systems, and sea levels across many regions (NASA, 2024). The Intergovernmental Panel on Climate Change, in its Sixth Assessment Report, concluded that anthropogenic emissions have already warmed the planet by approximately 1.1 degrees Celsius above pre-industrial levels, and projected that global temperatures may reach or surpass 1.5 degrees Celsius in the coming decades (IPCC, 2021). The World Health Organization estimates that, by 2050, climate change could cause an additional 250,000 deaths annually, while joint assessments by the World Health Organization and the World Bank forecast the displacement of over 140 million people as a result of climate-induced factors (WHO, 2023; World Bank, 2022). The severity of future climate impacts will be determined by present-day choices: higher emissions will lead to increasingly severe consequences, whereas substantial reductions could avert the most catastrophic outcomes (NASA, 2024). Consequently, urgent action is required to reduce emissions and mitigate environmental harm that has already occurred.

Globally, nations have developed and enacted comprehensive sustainability strategies aimed at environmental protection. Organizations such as the Climate Bonds Initiative, the Organisation for Economic Co-operation and Development, and the International Renewable Energy Agency are pivotal in mobilizing international capital for climate projects, shaping sustainable development policy, and supporting the transition to renewable energy (Climate Bonds Initiative, 2023; OECD, 2022; IRENA, 2023). The United Nations' 2030 Agenda for Sustainable Development, adopted in 2015, encompasses 17 Sustainable Development Goals (SDGs) that aim to eradicate poverty, foster prosperity, and address climate change (United Nations, 2015). These goals emphasize the integration of climate action into national policy frameworks and promote public awareness and education to address climate risks. Additionally, frameworks such as the Global Reporting Initiative and the Carbon Disclosure Project support organizations in embedding sustainability within operational practices (GRI, 2021; CDP, 2022). Such coordinated action is essential for ecological balance and represents a critical component in confronting the global climate crisis, exemplifying the value of international cooperation and shared governance frameworks.

The impact of these global efforts is reflected in measurable progress toward the Sustainable Development Goals in many countries. According to the Sustainable Development Solutions Network and Bertelsmann Stiftung (2024), Finland and Sweden are leaders in sustainability, with scores of 86.35 and 85.70, respectively. This leadership is underscored by ambitious national targets: Finland aims for carbon neutrality by 2035 (International Energy Agency, 2023), and Sweden by 2045 (Government Offices of Sweden, 2021). Both nations have embedded sustainability into governance structures, industrial sectors, and daily life, as evidenced by their high international rankings. At the local level, Nordic municipalities have also demonstrated broad engagement with the 2030 Agenda. Surveys show that over 95 percent of municipalities in Norway and Sweden, and significant proportions in Denmark, Finland, and Iceland, are actively implementing sustainable development principles (Nordregio, 2024). This institutional commitment supports the selection of Sweden and Finland as optimal case studies for examining the effectiveness of national sustainability initiatives. Accordingly, the present study analyzes the strategies pursued by these two countries over the past decade, evaluating their environmental impacts to guide other nations aiming to achieve long-term sustainability objectives.

This research focuses on six key sustainability initiatives that have been actively implemented in Finland and Sweden during the last decade. First, both countries have significantly expanded their use of renewable energy, investing heavily in wind and solar power. Sweden, for instance, has set targets for 65 percent of electricity to come from renewables by 2030, to reach 100 percent by 2040 (Energy Connects, 2022). Second, the adoption of electric vehicles has accelerated, facilitated by government incentives and extensive charging infrastructure. In 2022, electric and hybrid vehicles accounted for 50 percent of new car registrations in Finland and 56 percent in Sweden (Scopes Data, 2024; EVS38, 2025). Third, green bonds have been used to finance climate projects and expand resources for sustainability, with Sweden's municipal Green Loan program supporting hundreds of projects and Finland's Municipality Finance Plc. Funding 154 initiatives to advance public-sector climate goals (Kommuninvest, 2024; Municipality Finance Plc., 2024). Fourth, both countries' industrial sectors have increased investment in environmental innovation, spurred by regulation and targeted incentives. Notable Swedish projects include fossil-free steel production by H2 Green Steel and SSAB, and clean water solutions developed by Solvatten (Tech.EU, 2025). In Finland, initiatives like the P2X Solutions green hydrogen plant and digital water management technologies exemplify ongoing sustainable innovation (Reuters, 2025). Lastly, stringent regulatory frameworks have been established in both countries to ensure compliance with sustainability standards and emission limits. This research fills an important gap by systematically comparing the effectiveness of individual sustainability initiatives in Sweden and Finland. It aims to identify which interventions deliver the most significant emission reductions in high-capacity, advanced economies, information that is currently limited in the literature

LITERATURE REVIEW

Over the past decade, the global adoption of clean energy sources such as hydropower and solar energy has grown substantially, playing a pivotal role in advancing environmental sustainability. For instance, Nathaniel et al. (2024) examined the interplay between clean energy use, globalization, financial development, and the ecological footprint in Bangladesh. Applying advanced autoregressive distributed lag simulation techniques, they established that clean energy and financial development contribute to reducing the ecological footprint, whereas economic growth can intensify environmental degradation. The study calls for a strategic transition toward clean energy, enhanced government investment in green initiatives, and broader adoption of eco-friendly technologies, while acknowledging the contextual limitations of their findings in Bangladesh.

Complementary insights emerge from Yadav et al. (2024), who investigated the influence of green finance and governance effectiveness on renewable energy investment and carbon dioxide emissions across the BRICS economies using panel data spanning 2000 to 2021. Their results indicate that increased renewable energy usage and the development of green finance, alongside robust governance, produce significant reductions in emissions. The authors recommend strengthening governance frameworks, implementing effective renewable energy policies, and ensuring strong enforcement mechanisms to sustain progress.

China's commitment to sustainability, notably through its dual-carbon targets and the expansion of new energy vehicles powered by renewables, offers another perspective. Chen et al. (2023) assessed the emission reduction potential of new energy vehicles in China, using scenario analysis and the generalized Bass model. They found that, although current policies and technologies enable notable emission reductions, further technological innovation and expanded policy support are necessary for achieving carbon neutrality.

In the context of the circular economy, Knable et al. (2022) demonstrated, using panel data from 25 European countries, that circular practices such as recycling, reuse, and remanufacturing significantly foster sustainable development by raising gross domestic product, lowering greenhouse gas emissions, and reducing unemployment. Their work underscores the importance of policies promoting circular economy adoption by both firms and consumers and highlights the need for more research in developing regions.

Green energy investment is also emerging as a central sustainability strategy. Křístková et al. (2025), using the Modular Applied General Equilibrium Tool model, revealed that investments in green energy can reduce emissions by as much as 22 percent, with carbon taxes further amplifying these benefits, although with varying economic effects across regions. They advocate for regulated green bond markets and the careful implementation of carbon taxes, while noting the need for research on the financial stability of these instruments. Borrallo et al. (2024) explored the role of management attention in environmental performance concerning green bond issuance, analyzing data from diverse industries and countries. Their results indicate that green bond issuance enhances environmental performance primarily in expanding firms and that the scale of bond issuance is directly correlated with positive outcomes, explaining the importance of tailoring green bond policies to firm characteristics.

Technological advancements, especially within the financial sector, have further contributed to sustainability. Bonsu et al. (2025) found, through their study of manufacturing firms in China and India, that financial technology (Fintech) bolsters green innovation and environmental investments, streamlines industrial structures, and enables firms to integrate eco-friendly products and practices. Their findings support prioritizing Fintech and green innovation, although the authors call for expanded research in less developed settings. Charfeddine et al. (2024) provided additional insights by investigating the roles of information and communication technology, digitalization, renewable energy, and financial development on environmental sustainability in the most polluted countries. Their analysis, using panel vector autoregression, revealed that renewable energy consistently reduces the ecological footprint, while unchecked financial development can increase it. The mixed effects of digitalization explain that policies must target resource management and innovation support in pollution-intensive sectors. Li et al. (2024) assessed the impact of renewable energy, green taxes, and trade openness on carbon neutrality within BRICS countries. Utilizing robust econometric methods, they established that renewable energy and green taxes are substantial drivers of carbon neutrality, advocating for the prioritization of green energy adoption and the implementation of environmental tax measures.
Jiang et al. (2024) extended this analysis to the G7 countries, employing advanced econometric

techniques to demonstrate that renewable energy and environmental innovation are effective in reducing both carbon dioxide emissions and particulate matter pollution. Their findings reinforce the value of eco-innovation and public-private collaboration, while emphasizing the importance of environmental taxes as a tool for carbon reduction. Research by Ghosh (2024) on newly industrialized countries highlighted the significant roles played by renewable energy and high-technology industries in decreasing carbon dioxide emissions and ecological footprints. The study's panel econometric approach indicated that investment in renewable energy and technological complexity should be key priorities for policymakers aiming to advance sustainability objectives.

Examining the context of Pakistan, Ansari et al. (2024) demonstrated that renewable energy and financial inclusion significantly improve environmental sustainability, especially when supported by strong institutional quality and digital finance. Their results explain that tax policies discouraging fossil fuel use, alongside investments in digital finance and renewables, are essential for progress. Subhani et al. (2025) focused on BRICS countries, revealing that while environmental, social, and governance initiatives require considerable capital and face financing barriers, robust financial sector development can enhance access to debt for sustainable projects. They recommend legislative reforms and fiscal incentives to promote environmental, social, and governance adoption. Zhang (2024) examined the intersection of green finance, green bonds, public-private partnerships, and technological innovation, showing that such partnerships have facilitated environmentally friendly investment and improved energy efficiency, though economic growth may complicate the attainment of carbon neutrality in some contexts.

The effect of digital finance on emission intensity was scrutinized by Jiang et al. (2024), who used provincial Chinese data to demonstrate that digital inclusive finance is associated with reduced carbon emissions and enhanced green technology innovation. Their work illustrates the complex relationship between innovation types and environmental outcomes, calling for balanced investment in both digital and green technologies. Alofaysan et al. (2024) evaluated eco-friendly and financial technologies in 38 emerging economies, uncovering a U-shaped relationship between economic development and green energy adoption, and recommending supportive legal frameworks and international collaboration to foster green technology deployment despite potential economic constraints.

The relationship between sustainability initiatives and corporate carbon performance was the focus of Haque and Ntim (2022), whose longitudinal study of European firms indicated that sustainability programs lead to lower emission intensities, particularly in polluting sectors, and emphasized the need for policies that move beyond disclosure toward comprehensive frameworks that actively promote emissions reduction and innovation. Liao et al. (2025) investigated the interplay between green finance, technological innovation, and carbon emissions in mineral-rich economies along the Belt and Road Initiative, concluding that strong institutions and digital governance are essential for reducing emissions and advancing environmental goals, though technological advancement may have nuanced effects depending on national income levels. Liu et al. (2025) addressed sustainable financing and energy justice transformation in Asian developing countries, finding that sustainable finance is instrumental in advancing energy justice, particularly where governance quality is high. Their policy recommendations include establishing specialized agencies and reinforcing regulatory frameworks for sustainable finance. Rahman and Hossain (2024) examined stakeholder awareness as a driver in the relationship among green technologies, governance, sustainable finance, and progress on Sustainable Development Goal 12 in Bangladesh's pharmaceutical sector. Their findings highlighted sustainable finance as a primary catalyst for responsible production and consumption, explaining that broad stakeholder education and access to finance are vital for the widespread adoption of green practices.

While there is considerable evidence that renewable energy, green finance, technological innovation, and robust governance frameworks contribute to environmental sustainability and emissions reduction across diverse regions, the existing literature reveals several critical gaps concerning the effectiveness of specific policy measures and financial instruments within highly developed economies. Much of the empirical research, such as Nathaniel et al. (2024), Yadav et al. (2024), and Bonsu et al. (2025), has focused on developing or emerging markets, or broader regions like the BRICS, G7, or Asian countries, often overlooking how targeted sustainability initiatives perform in advanced contexts with established environmental regulations. Moreover, prior studies frequently aggregate sustainability actions, rather than disentangling the relative impacts of interventions such as renewable energy expansion, electric vehicle incentives, green bonds, and digital finance (Hussain & Khan, 2022; Ross, 2023; Charfeddine et al., 2024; Jamel & Zhan, 2024' Zhang, 2024; Jiang et al., 2024). Limited research has systematically compared the combined and individual effects of these initiatives within countries that have consistently ranked at the forefront of global sustainability, like Sweden and Finland. This leaves unresolved questions about which specific policy levers are most effective and scalable in achieving rapid and lasting greenhouse gas emissions reductions in mature, institutionalized settings (Ahmad, 2018; Emodi, 2019; Mustapha, 2022; Haque & Ntim, 2022; Ibrahim & Simian, 2023; Singh & Kumar, 2023; Křístková et al., 2025; Audi, 2024; Borrallo et al., 2024; Ito & Zhang, 2025; Khalid & Abdul, 2025). Therefore, by conducting a focused empirical analysis on Sweden and Finland, nations recognized for their ambitious sustainability agendas and advanced policy environments, this study addresses the pressing need to clarify the real-world outcomes of distinct environmental initiatives in advanced economies, filling a notable gap in both policy and academic discourse. While evidence on emerging economies and aggregated sustainability actions is extensive, there remains a lack of disaggregated, cross-initiative analysis in mature economies. This study directly addresses this by focusing on targeted interventions in Sweden and Finland.

EMPIRICAL METHODOLOGY

Greenhouse gas emissions are widely regarded as a key indicator of environmental health and climate change, and serve as a benchmark for evaluating the success of sustainability policies (Stern, 2007). The reduction of these emissions remains a central objective in the Nordic region, with Sweden and Finland both being signatories to the Paris Agreement and recognized for their stringent environmental policy frameworks (OECD, 2022). The analytical model developed in this study draws on prior research, which underscores the importance of renewable energy deployment, advancement in green technologies, increased mobilization of green finance (such as green bond issuances), and robust regulatory enforcement in reducing emissions (Ali & Audi, 2016; Weber, 2022; Khan et al., 2023; Calin & Horodnic, 2023; Marc et al., 2024; Gielen et al., 2019; Taghizadeh-Hesary & Yoshino, 2020; Stein, 2025; Hanvoravongchai & Paweenawat, 2025). This research is based on the Environmental Kuznets Curve (EKC) theory, which posits an inverted U-shaped relationship between environmental degradation and economic development. According to the EKC, environmental impacts such as greenhouse gas emissions initially intensify with economic growth but ultimately decline as societies embrace cleaner technologies and enforce more rigorous environmental policies (Grossman & Krueger, 1995). Building on this theoretical basis, the present study assesses the effectiveness of sustainable environmental initiatives in Sweden and Finland by analyzing how specific policy interventions affect greenhouse gas emissions.

In this context, greenhouse gas emissions are employed as the dependent variable, representing aggregate environmental outcomes. The principal explanatory variables reflect both policy- and market-driven sustainability initiatives. Environmental policy stringency is included as a proxy for regulatory ambition and enforcement, consistent with literature highlighting its role in emissions mitigation (Botta & Kozluk, 2014; Ali et al., 2021; Lopez & Peters, 2025; Audi et al., 2025). The proportions of electric vehicles and renewable energy usage serve as indicators of technological transition and decarbonization efforts, aligning with evidence from research on green technology adoption (Sorrell, 2018). The share of environmental patents provides a measure of innovation in environmental technology, which is vital for decoupling economic growth from environmental harm (Popp, 2019; Audi et al., 2025; Wang & Zaman, 2025). The issuance of green bonds is considered to capture the role of sustainable finance in supporting climate-related investments, a mechanism increasingly emphasized in recent studies (Flammer, 2021; Marc, 2025). Finally, industry expenditures on environmental protection are used to represent direct investments in pollution abatement and resource preservation (Sterpu et al., 2018). The model can be specified as follows:

$$GHG = \alpha + \beta 1EPSI_{t-1} + \beta 2EV_{t-1} + \beta 3REN_{t-1} + \beta 4PATENT_{t-1} + \beta 5BOND_{t-1} + \beta 6ENV\_EXP_{t-1} + \varepsilon$$

Where:

- GHG emissions are the dependent variable representing the amount of greenhouse gas emissions in Sweden and Finland
- EPSI measures the level of environmental policy stringency.
- EV Share represents the proportion of electric vehicles in total vehicles.
- REN indicates the share of renewable energy in total final energy consumption.
- PAT indicates environmental patents as a percentage of total patents
- BONDS indicate green bonds issued (billions USD)
- ENV_EXP Environmental protection expenditures by industries in Sweden and Finland (SEK millions)
- β_0 is the intercept (baseline GHG emissions when all independent variables are zero).
- β_1-β_6 represent the coefficients of each predictor, measuring the marginal impact of each variable on emissions.
- t-1 denotes the one-period lag of the respective independent variables
- ε is the error term capturing unobserved factors that may influence GHG emission

TABLE 1: MEASUREMENTS OF VARIABLES

Variables	Symbols	Data Source
Greenhouse Gas Emissions	GHG	MacroTrends, Statistics Finland
Environmental Policy Stringency Index	EPSI	OECD Environmental Policy Stringency Index
Share of new electric cars	EV	International Energy Agency. Global EV Outlook 2024. – processed by Our World in Data
Renewable energy consumption (% of total final energy consumption)	REN	IEA, IRENA, UNSD, World Bank, WHO. 2023. Tracking SDG 7: The Energy Progress Report. World Bank
Patents on environment technologies (% of all technologies)	PATENTS	OECD Data Explorer
Green bonds issuance (Billions US dollars)	BONDS	Refinitiv, Country authorities, and IMF staff calculations.
Total Environmental Protection Expenditure by Industries (SEK Millions)	ENV_EXP	Statistics Finland, Statistics Sweden

To analyze the relationship between sustainability initiatives and greenhouse gas emissions in Sweden and Finland from 2010 to 2020, this study employs both panel least squares estimation and the generalized method of moments methodology. The panel least squares estimator is widely used for evaluating baseline relationships within panel datasets, as it accommodates unobserved heterogeneity across entities and provides consistent estimates of policy impacts (Steigerwald et al., 2021). Nevertheless, to address issues of endogeneity, simultaneity bias, and the inherently dynamic nature of greenhouse gas emissions, the generalized method of moments estimator is also utilized. This technique mitigates endogeneity by employing lagged variables as instruments and effectively accounts for both autocorrelation and heteroskedasticity within the data (Wooldridge, 2001). The combined application of these two estimation methods enhances the robustness and credibility of the results, allowing for a more comprehensive and reliable assessment of the dynamic interactions between sustainability initiatives and greenhouse gas emissions. Panel GMM estimation is used alongside least squares to mitigate potential endogeneity and simultaneity bias, ensuring more reliable inference. All models are checked for serial correlation and heteroskedasticity to verify robustness

EMPIRICAL RESULTS AND DISCUSSIONS

This section of the study presents the results and discussion of the findings. Table 1 displays the descriptive statistics for the variables under investigation. Greenhouse gas emissions have a mean value of 54,538.05 and a standard deviation of 5,847.98, reflecting variability among observations. Environmental expenditure records a mean of 24,326.48 and a relatively high standard deviation of 16,507.22, indicating considerable dispersion within the data. The mean values for bond issuance, environmental, social, and governance performance, electric vehicle adoption, patent counts, and renewable energy utilization are 2.47, 3.69, 4.70, 14.31, and 46.27, respectively. Analysis of skewness and kurtosis reveals that certain variables, particularly bond issuance and electric vehicle adoption, exhibit non-normal distribution patterns. This assessment is corroborated by the Jarque-Bera test, which rejects the null hypothesis of normality for both electric vehicle adoption and bond issuance at the one percent significance level. The application of descriptive statistics, along with measures of skewness, kurtosis, and the Jarque-Bera test, is essential for understanding data variability, detecting outliers, and assessing the suitability of variables for econometric modeling (Gujarati & Porter, 2020; Wooldridge, 2020). Overall, the descriptive statistics indicate substantial heterogeneity across the dataset, thereby supporting the use of further econometric analysis (Baltagi, 2021; Hair et al., 2022).

TABLE 2: DESCRIPTIVE STATISTICS

	GHG	BONDS	ENV_EXP	EPSI	EV	PATENTS	REN
Mean	54538.05	2.47	24326.48	3.69	4.7	14.31	46.27
Median	54382.48	1	15449	3.67	1.4	14.36	45.4
Maximum	67940	14.02	50218.72	4.11	32	16.6	57.8
Minimum	45458.82	0	9340.22	3.39	0	12.04	35.1
Std. Dev.	5847.98	4.02	16507.22	0.17	7.71	1.29	5.5
Skewness	0.46	1.98	0.65	0.42	2.47	-0.31	-0.03
Kurtosis	2.62	5.85	1.58	3.16	8.82	2.52	2.66
Jarque-Bera	0.87	20.78	3.26	0.65	51.06	0.53	0.1
Probability	0.65	0	0.2	0.72	0	0.77	0.95
Sum	1145299	51.84	510856.2	77.58	98.61	300.58	971.6
Sum Sq. Dev.	6.84E+08	322.59	5.45E+09	0.57	1187.88	33.26	605.01

The correlation matrix presented in Table 3 provides valuable insights into the associations between greenhouse gas emissions and the principal explanatory variables considered in this sustainability-oriented analysis. A pronounced negative correlation is observed between greenhouse gas emissions and renewable energy consumption, with a coefficient of 0.9202, indicating that higher shares of renewable energy within total energy consumption are closely linked to notable reductions in emissions. This strong inverse relationship is consistent with established empirical evidence that identifies renewable energy expansion as a fundamental strategy for curbing environmental degradation, as also shown by Sadorsky (2009), who found substantial reductions in carbon intensity resulting from renewable energy investments in high-income economies. Similarly, there is a robust negative correlation between greenhouse gas emissions and the issuance of green bonds, reflected by a coefficient of 0.7023. This explains that increased activity in green bond markets is generally associated with lower emissions, supporting the view that sustainable finance can channel resources into projects with direct emission-reducing outcomes, in line with the findings of Flammer (2021).

The share of electric vehicles among new vehicle registrations is also negatively correlated with greenhouse gas emissions, as indicated by a coefficient of 0.6556. This underscores the environmental benefits of adopting electric vehicles as a replacement for traditional combustion engine vehicles, contributing to lower fuel use and reduced tailpipe emissions. This association aligns with the work of Li et al. (2016), who documented significant emission reductions attributable to widespread electric vehicle infrastructure in advanced economies. The environmental policy stringency index demonstrates an inverse, though smaller, correlation with greenhouse gas emissions (negative 0.0987), implying that greater policy stringency provides incremental gains in emission control. This observation supports the conclusions of Botta and Koźluk (2014), who acknowledged the effectiveness of stringent policies but also highlighted the challenges posed by uneven enforcement and regional variations in implementation.

Expenditure on environmental protection by industries shows a weak and statistically insignificant negative correlation with greenhouse gas emissions (negative 0.1325), explaining that while financial commitments to environmental protection are made, immediate emission reductions are not always realized. This may result from inefficiencies, time lags, or misallocation of resources, an outcome that resonates with Borghesi et al. (2015), who stressed the importance of targeting environmental investments toward measurable results. Conversely, the positive correlation between greenhouse gas emissions and the share of environmental patents (0.2213) is notable. This relationship may be attributed to the tendency of higher-emitting economies to intensify investment in environmental innovation, a pattern described by Popp (2006), who noted that such innovation often accelerates in response to heightened pollution challenges.

Additionally, the correlation between green bond issuance and the share of electric vehicles is notably high (0.822), pointing to a strong synergy between sustainable finance and green technology diffusion. This result explains that funds raised through green bonds are frequently allocated to transformative infrastructure and clean energy projects, including transportation electrification. This finding is consistent with Tang and Zhang (2020), who reported that green bond financing is often directed toward sectors such as renewable energy and clean transport, thereby advancing large-scale decarbonization objectives.

TABLE 3: CORRELATION MATRIX

	GHG	BONDS	ENV_EXP	EPSI	EV	PATENTS	REN
GHG	1						
BONDS	-0.7023	1					
ENV_EXP	-0.1325	-0.0667	1				
EPSI	-0.0987	0.128	0.7826	1			
EV	-0.6556	0.822	0.1871	0.4601	1		
PATENTS	0.2213	0.1243	0.0468	0.2386	0.088	1	
REN	-0.9202	0.7369	-0.1347	-0.1225	0.6261	-0.2482	1

The Augmented Dickey-Fuller test results, summarized in Table 3, indicate that most variables in the empirical analysis are non-stationary in their original form but achieve stationarity after first differencing. For example, greenhouse gas emissions display non-stationarity at the level, with a probability value of 0.1012, yet become stationary following first differencing, as shown by a probability value of 0.0308. This pattern explains that greenhouse gas emissions follow a stochastic trend and require differencing to eliminate non-stationarity—an attribute frequently noted in environmental time series data, as observed by Romero-Ávila (2008), who found persistent unit root behavior in emission indicators due to enduring technological and structural factors. Similarly, the green bonds variable is non-stationary at level (probability value 0.9905) but attains stationarity at the first difference (probability value 0.0127), indicating it is integrated of order one and does not revert to a long-term mean without transformation. A similar outcome is seen with environmental protection expenditures, further supporting the view that both financial and industrial environmental indicators evolve structurally over the long term rather than mean-reverting in the short term, in line with Perron (1989), who identified the susceptibility of such macroeconomic variables to structural breaks and external shocks.

Environmental patent data also exhibit unit root characteristics at the level, with a probability of 0.9388, achieving stationarity only after first differencing. This result implies that technological innovation variables require transformation to attain statistical stability, reflecting global competition, regulatory change, and technology diffusion as described by Zivot and Andrews (2002). Renewable energy consumption, too, is integrated of order one, with non-significance at the level and significance after first differencing. This persistence reflects long-term adoption trends shaped by strategic policy and infrastructure decisions, as documented by Narayan and Smyth (2008), who noted the slow evolution of energy time series due to sectoral inertia.

An exception is found in the environmental policy stringency index, which is stationary at the level with a probability value of 0.0847. This result explains the index oscillates around a stable mean, consistent with the institutional stability of environmental policy regimes in Finland and Sweden. Stern (2004) contended that such policy variables change discretely, not gradually, accounting for their statistical stationarity. The share of new electric vehicles, however, exhibits a more complex pattern: it remains non-stationary at both level and first difference, only reaching stationarity at the second difference. This strong persistence may be indicative of rapid technological adoption or nonlinear diffusion, reflecting S-shaped transitions in vehicle fleets as outlined by Dargay et al. (2007). Overall, these unit root test results validate the use of econometric techniques that accommodate variables with mixed integration orders, such as the autoregressive distributed lag model or the bounds testing approach. The predominance of first-order integration underscores the importance of differencing for avoiding spurious regression and ensuring robustness in the empirical modeling strategy (Pesaran et al., 2001).

TABLE 4: ADF UNIT ROOT TEST

Variables	I(0)	I(1)	I(2)	Decision
GHG	0.1012	0.0308	0.003	I(1)
BONDS	0.9905	0.0127	0	I(1)
ENV_EXP	0.9436	0.1747	0.0008	I(1)
PATENTS	0.9388	0.0002	0.0007	I(1)

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REN	0.3516	0.0068	0	I(1)
EPSI	0.0847	0	0	I(0)
EV	1	1	0.8793	I(1)

The regression results in Table 5 provide an in-depth view of how sustainability-oriented variables influence greenhouse gas emissions across the panel dataset. Among the predictors, the share of renewable energy in total final energy consumption emerges as the most statistically significant determinant, exhibiting a substantial negative coefficient and a probability value of 0.0000. This strong inverse association underscores that increasing renewable energy adoption is closely linked to marked reductions in greenhouse gas emissions, reinforcing the critical role of clean energy transitions in combating environmental degradation. This outcome is consistent with Omri and Nguyen (2014), who emphasized the efficacy of renewable energy in reducing carbon intensity across advanced economies. In contrast, the coefficient for industrial environmental protection expenditures, although negative, does not reach statistical significance (probability value of 0.1123), indicating that while increased industrial spending may contribute to emission reductions, the effect is not robust within the sample. This result may be due to inefficiencies, time lags, or the long-term nature of many environmental projects, as highlighted by Fredriksson et al. (2005), who noted that the effectiveness of environmental expenditures depends on institutional quality and regulatory enforcement.

The estimated coefficient for green bond issuance is also negative, explaining a potential association with reduced greenhouse gas emissions, yet it is statistically insignificant (probability value of 0.7519). This implies that while green finance instruments such as green bonds may signal environmental commitment, their immediate and direct impact on emissions is limited or conditional on project characteristics. Karpf and Mandel (2018) similarly found that inconsistencies and gaps in green bond allocation can diminish their measurable short-term environmental benefits. The environmental policy stringency index is likewise associated with a negative but statistically insignificant coefficient (probability value of 0.8204), reflecting limited immediate effects of policy rigor on emissions. This may be attributable to structural inertia, implementation delays, or compliance challenges, a phenomenon noted by Levinson (2009), who argued that environmental regulations often take time to manifest in tangible emission reductions due to economic and administrative constraints.

Unexpectedly, the share of electric vehicles is positively, but not significantly, associated with greenhouse gas emissions (probability value of 0.8347). This result may be a function of the early stage of the transport sector's transition, where the increase in electric vehicles has not yet reached a threshold sufficient to outweigh emissions from traditional vehicles. It may also point to rebound effects where higher electricity demand, especially from fossil fuel-dominated grids, mitigates potential environmental gains. Sorrell (2009) highlighted that the anticipated benefits of clean technology adoption can be diminished by behavioral and systemic adjustments. Similarly, environmental patent activity reveals a positive, statistically insignificant association with emissions (probability value of 0.8888), explaining that increased patenting in environmental technologies has not yet translated into immediate emission reductions. This is consistent with Jaffe and Trajtenberg (2002), who distinguished between the input of innovation (such as patent filings) and the output (realized, deployed technologies), particularly in the environmental sphere. The constant term in the regression is large and highly statistically significant, reflecting the persistent baseline level of greenhouse gas emissions independent of the included explanatory variables. This finding highlights the enduring influence of structural and historical factors, including industrial composition, energy mix, and established policy frameworks, in shaping emission trends—a phenomenon extensively discussed by Stern (2007) in the context of path dependence in national emission trajectories.

TABLE 5: PANEL LEAST SQUARES REGRESSION

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EV	31.63364	148.8304	0.212548	0.8347
EPSI	-1466.759	6338.949	-0.231388	0.8204
ENV_EXP	-0.084281	0.049744	-1.694272	0.1123
BONDS	-83.58172	259.1818	-0.322483	0.7519
PATENTS	59.84292	420.3165	0.142376	0.8888
REN	-997.3303	157.4426	-6.334565	0
C	107351.5	26265.33	4.087195	0.0011

The results presented in Table 6 reveal that lagged environmental policy stringency is positively and significantly associated with greenhouse gas emissions, with a probability value of 0.0368. Although this outcome may initially appear counterintuitive, as stricter environmental regulations are generally expected to lower emissions, it likely reflects transitional or rebound effects. When policy measures are newly introduced, emissions may remain elevated before the full impact of the regulation is realized, or policy tightening may occur in response to recent increases in emissions, indicating a possible reverse causality. This interpretation aligns with

Eskeland and Harrison (2003), who observed that policy adjustments in advanced industrial economies often follow episodes of environmental degradation rather than precede them.

Lagged renewable energy consumption exhibits a strong and statistically significant negative association with greenhouse gas emissions (probability value of 0.0012), reinforcing the conclusion that renewable energy deployment effectively reduces emissions over time. The use of lagged values in the analysis more accurately captures the time required for energy infrastructure investments and systemic transformations to influence aggregate emission levels. This finding is consistent with Apergis and Payne (2010), who reported that the environmental benefits of renewable energy become increasingly pronounced in dynamic modeling contexts. Policy implication: Scaling up renewable energy deployment should remain the top priority for immediate emission reductions in advanced economies. Similarly, the lagged share of electric vehicles is found to have a statistically significant and negative effect on greenhouse gas emissions (probability value of 0.0147), indicating that the environmental benefits of electric vehicle adoption accrue over time as fleets grow and charging infrastructure matures. This result validates the role of transportation electrification in long-term emission mitigation, as highlighted by Gnann et al. (2015), who documented that emission-reducing effects intensify with market penetration and infrastructure development.

Environmental protection expenditures, when lagged, also show a negative relationship with greenhouse gas emissions, although the effect is only marginally insignificant at the five percent level (probability value of 0.0782). This trend explains that investments in environmental programs and compliance measures require time to materialize as effective emission reductions, reflecting the delay inherent in project implementation and technological integration. Johnstone et al. (2010) similarly emphasized the importance of considering temporal lags when assessing the impact of capital-intensive environmental initiatives. This explains that expenditure effectiveness could be improved by targeting projects with measurable, near-term emission impacts.

In contrast, lagged green bond issuance is associated with a positive, but statistically insignificant, coefficient (probability value of 0.2132). This finding explains that green bonds may not yield immediate emission reductions, with their effectiveness likely dependent on the specific sectors targeted and the stringency of outcome measurement and regulatory oversight. This aligns with Maltais and Nykvist (2020), who found that the environmental returns of green bonds are variable without robust, standardized outcome frameworks. Future research should explore why green bonds are not yielding immediate emission reductions, potentially due to allocation delays or sector targeting

Lagged environmental patent activity is negatively associated with greenhouse gas emissions, but this relationship is statistically insignificant (probability value of 0.5325). This explains that, while innovation is generally directionally aligned with emission reduction, its benefits may not be immediately evident due to the gap between patent registration and the commercial adoption of new technologies. Popp et al. (2011) also noted that significant environmental benefits from innovation are realized only after new technologies achieve widespread diffusion. Finally, the constant term is positive and statistically insignificant, indicating that, in the absence of variation in the explanatory variables, baseline greenhouse gas emissions remain elevated. This persistence is indicative of the structural inertia present in national emission profiles, shaped by entrenched economic patterns, demographic trends, and energy dependencies, as documented by Burnett et al. (2013), who observed stable baseline emissions across high-income countries.

In summary, renewable energy has the most robust effect, while policy, finance, and innovation demonstrate lagged or conditional impacts. Policymakers should differentiate between interventions with immediate versus delayed returns when designing climate strategies

TABLE 6: GMM ANALYSIS

Variables	Coefficients	Std. Error	t-Statistic	Prob.
C	34863.54	22233.31	1.568077	0.1452
EPSI_L1	14414.33	6069.424	2.374909	0.0368
REN_L1	-565.7415	130.1503	-4.346833	0.0012
EV_L1	-1107.512	383.258	-2.889731	0.0147
PATENTS_L1	-300.3958	466.157	-0.644409	0.5325
BONDS_L1	454.8631	344.2451	1.321335	0.2132
ENV_EXP_L1	-0.091327	0.04704	-1.941462	0.0782

CONCLUSIONS

This study provides a rigorous assessment of the impact of sustainability initiatives on environmental outcomes in Sweden and Finland, yielding important insights into the interplay between policy measures, technological innovation, and ecological improvement. The analysis highlights the pivotal role of well-designed sustainability interventions in advancing climate action and reducing greenhouse gas emissions. Among the various strategies investigated, the adoption and integration of renewable energy sources stand out as the most consequential driver of environmental improvement. Empirical evidence demonstrates that renewable energy not only facilitates immediate reductions in emissions but also offers a model for effective climate action in developed economies. Furthermore, while investments in green technologies and the issuance of green bonds exhibit delayed effects, they are projected to deliver increasingly significant benefits over time, supporting the case for a long-term, innovation-focused approach to sustainability. A notable trend revealed in this study is the increasing engagement of industries in environmental stewardship, as evidenced by rising expenditures on sustainability-related initiatives. This development reflects a broader shift in the private sector toward recognizing environmental responsibility as a core element of corporate practice. However, the research also uncovers certain limitations in the current framework of sustainability efforts. Specifically, the Environmental Policy Stringency Index was not found to have a significant direct effect on greenhouse gas emissions, indicating a possible disconnect between policy adoption and effective enforcement. This raises concerns that the proliferation of sustainability reporting may, in some cases, be oriented more toward compliance than substantive environmental progress, underscoring the need for stronger accountability and implementation mechanisms.

Based on these findings, the study recommends a recalibration of policy priorities to ensure that enacted measures translate into tangible emission reductions. Policymakers should focus on developing and enforcing initiatives that are directly linked to measurable outcomes, moving beyond a reliance on procedural compliance and reporting obligations. Strengthening enforcement agencies' capacity, including their ability to rigorously monitor compliance and apply sanctions or incentives, is essential for bridging the gap between policy formulation and practical outcomes. The observed gradual but positive effects of green technology investments highlight the importance of strategically allocating both public and private resources and maintaining robust oversight to maximize environmental benefits.

Governments must prioritize the efficient deployment and transparent monitoring of funds designated for environmental innovation, ensuring that investments achieve their intended impacts. Accelerating the adoption and diffusion of advanced technologies should be emphasized to enhance both environmental and economic outcomes while minimizing the risk of further ecological harm. Additionally, the lag in observable benefits from increased industrial environmental spending suggests the need for a more proactive, preventative approach. Implementing independent audits and periodic policy evaluations can help guarantee that financial commitments target not just remediation but also the prevention of future environmental degradation. By shifting the focus from reactive to preventive strategies, such measures would foster more resilient, forward-looking approaches to sustainability. This study's findings, drawn from Sweden and Finland's experience, provide an empirical benchmark for other advanced economies. Future research should test the scalability of these insights across broader high-income settings and examine how institutional quality shapes the speed of impact from various sustainability initiatives.

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