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TOWARDS A CLEAN ECONOMY: THE ROLE OF ENVIRONMENTAL INNOVATION IN REDUCING EMISSIONS IN SWEDEN

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Abstract
The present study investigates the role of environmental innovation, represented by the number of environment-related patents, in mitigating greenhouse gas emissions in Sweden during the period from 1990 to 2020. The study emphasizes that accelerated economic growth and increased energy consumption have exacerbated environmental problems, such as the rise of greenhouse gas emissions. This underscores the importance of transitioning towards a clean economy through advancements in technology, especially in the field of environmental innovation. Sweden serves as a pioneering model in areas of technology and sustainability, focusing on policies and investments that support environmental innovation.
The study utilizes semi-annual data, conducting unit root tests to determine the degree of variable integration. The ARDL methodology is employed to verify the long-term relationship (co-integration) between greenhouse gas emissions and explanatory variables, including financial development, energy efficiency, GDP, and environmental innovation. The findings demonstrate that environmental innovation plays a positive role in reducing emissions in Sweden, with the potential for greater benefits in the long term if these technologies are adopted more widely.

Keywords: Industrial Acidification, Carbon Neutrality, Financial Development, Environmental Kuznets Curve, Efficiency Rebound.

Introduction

Over the past four decades, the global economy has experienced significant growth, accompanied by a substantial increase in energy consumption. Rapid economic growth and escalating energy consumption have had adverse effects on the environment. Achieving sustainable growth presents a formidable challenge if environmental issues, such as global warming and climate change, continue to intensify, posing a direct threat to environmental sustainability and humanity's present and future [1].

To ensure sustainable growth, it is imperative to enhance resource and energy efficiency and transition to an economy that relies less on their consumption. This can be achieved by decoupling the strong correlation between resource consumption and economic growth. Additionally, sustainable development, integrating environmental sustainability with economic prosperity, becomes a feasible goal [2]. Globalization, as a worldwide phenomenon, significantly influences the political, economic, and social dimensions of individuals' lives. It facilitates the exchange of modern technologies and enhances the flow of capital and investments, rendering globalization both economically beneficial yet environmentally detrimental [3]. Consequently, emerging economies have become preferred destinations for polluting companies from industrialized nations, seeking to avoid the high costs of adhering to stringent environmental regulations in their home countries. These companies relocate to nations with less stringent environmental systems to maintain their competitiveness [4].

The 21st Conference of the Parties (COP-21) in Paris highlighted the critical need for world leaders to commit to reducing global warming and working collaboratively to combat climate change and mitigate its impacts. This urgency was echoed in the United Nations' 2030 Sustainable Development Goals. Similarly, the Intergovernmental Panel on Climate Change (IPCC) reported in 2010 that global CO_2 emissions reached 49 gigatons, with sectors such as transportation contributing 14%, electricity 25%, forestry, agriculture, and land use 24%, industries 21%, other buildings 6.4%, and the energy sector 9.6% [5].

Environmental innovation is pivotal in improving energy efficiency and reducing CO_2 emissions. It promotes the effective use of both renewable and conventional energy sources, enhancing renewable energy capacity and supply to meet future demand [6]. While studies have affirmed the critical role of environmental innovation in mitigating CO_2 emissions, it remains an underexplored area [7].

Sweden, part of the Scandinavian region, boasts a robust economy marked by notable growth, with a GDP of $584.91 billion in 2023, projected to reach $760.93 billion by 2029. The country has emphasized the significance of technological innovation in achieving green growth. The oil crisis of the 1970s served as a key driver of innovation during that period. For environmental innovations, this was particularly important, as the crisis directed economic attention to alternative fuel and energy sources [8].

The Swedish government has undertaken ambitious measures to promote innovation policies in areas such as smart cities, sustainable development, housing, electric transportation, circular economy, energy efficiency, and sustainable consumption, thereby avoiding becoming an obstacle to global environmental transformation. In 2021, Sweden ranked second in the United Nations Sustainable Development Report and the Global Innovation Index. To achieve a sustainable future, Sweden outlined an ambitious plan to establish a fossil-free transportation sector and attain carbon neutrality by 2045. It has also heavily invested in approximately 3,500 clean technology startups, reinforcing its position as a global leader in environmental innovation. In 2022, Sweden ranked third globally in innovation among 132 countries, following Switzerland and the United States. Sweden has been a pioneer in environmental issues, establishing the first Environmental Protection Agency in 1965 [9], hosting the first UN conference on the human environment in 1972, introducing the first carbon tax in 1995, and becoming the first country to ratify and sign the Kyoto Protocol in 2002 [10].

Despite these achievements, Sweden faces significant environmental challenges, such as the timber industry’s impact on forests, threatening approximately 2,000 forest species. Additionally, pollution in the Baltic Sea from agricultural and industrial waste has caused severe environmental damage. In 2020, around 50% of adults in Sweden consumed Baltic Sea fish contaminated with dioxins and polychlorinated biphenyls (PCBs), despite these substances being banned since the 1980s [11].

Moreover, a study highlighted that ship gas scrubbers contributed to releasing hazardous pollutants into the Baltic Sea, leading to industrial acidification in Sweden's lakes and threatening biodiversity [12], [13]. The present study aims to enrich economic knowledge by examining the relationship between environmental innovation and greenhouse gas emissions in Sweden from 1990 to 2020. Given Sweden's commitment to reducing emissions by 59% by 2030 compared to 2005, the study poses the following question;

Does environmental innovation reduce emissions in Sweden as one of the leading decarbonization nations?

The present study seeks to bridge the knowledge gap on how environmental innovation can support the transition to a clean economy through an analytical econometric study emphasizing economic, environmental, and technological dimensions. The significance of the present study lies in elucidating Sweden's role in reducing emissions through environmental innovation, as it stands as a global environmental leader. Section 2 reviews the literature on related studies and their alignment with the findings of the present study. Section 3 describes the data and model development. Section 4 analyzes the econometric results. Section 5 provides the discussion and conclusions.

2. Literature Review

The body of literature addressing the relationship between environmental innovation and carbon dioxide emissions demonstrates a broad consensus, as evidenced by numerous studies on the subject. The effects of green energy on environmental performance were assessed in the economies of (G7). Study [14] revealed that green energy and energy prices contributed to a reduction in carbon dioxide emissions, whereas the adverse impact on emissions reduction was attributed to increased trade volumes. Study [15] aimed to investigate the role of green finance (GFIN) and green technologies in achieving carbon neutrality within the economies of (G10). Long- and short-term estimates confirmed that green finance and technologies reinforce carbon neutrality. Study [16], on the other hand, explored the relationship between renewable energy consumption, international trade, and environmental quality in the Nordic countries. The results indicated that renewable energy consumption positively influenced environmental quality. Hence, policies that support environmental innovation may facilitate economic growth and environmental sustainability, contributing to the achievement of Sustainable Development Goals.

Furthermore, study [17] examined the reciprocal relationship between technological innovation and carbon dioxide emissions across 62 countries during the period 2003–2018. Using panel data techniques, the findings unveiled a positive correlation between technological innovation and carbon dioxide emissions in the selected countries. Study [18] analyzed the interplay between technological innovation, carbon dioxide emissions, and economic growth from 1985 to 2019 in 35 countries participating in the Belt and Road Initiative. The findings indicated that investments in research and development significantly contribute to reducing carbon emissions

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and enhancing environmental quality. Additionally, the study provided key policy implications for the countries analyzed, particularly in developing policies related to economic growth, technological innovations, and environmental improvement.

However, the existing literature lacks a clear consensus on the capacity of environmental technology-related innovations to offer a reliable assessment of environmental degradation for the formulation of policy recommendations. Moreover, questions persist regarding the presence of other variables that may explain global environmental degradation.

3. Data Description and Model Construction

Amid the accelerating pace of environmental degradation and the rise in greenhouse gases in recent times, scientific studies continue to debate the extent to which environmental innovation mitigates emissions, which constitute a critical component of environmental degradation. In addition, questions arise regarding the potential relevance between other variables and emissions reduction. To address these queries, this study endeavors to analyze the influence of environmental innovation on emissions reduction in Sweden. The analysis employs semi-annual data spanning the period 1990–2020, as outlined in Table (1).

Table (1) Variables, Symbols, and Study Data

Source	Measurement Unit	Symbol	Variable
Eurostat	Ton per Individual	GHG	Global Warming Gas Emissions
World Bank	Credit Granted to Private Sector %GDP	FD	Financial Development
Eurostat	Million Tons Oil Equivalent	EE	Energy Efficiency
World Bank	USD for 2015	GDP	GDP per capita (a proxy for economic growth)
European patent office	Number of Patents in Environmental Technologies	EPI	Environmental Innovation

In the present study, greenhouse gas (GHG) emissions were utilized as the dependent variable, while the independent variables included environmental innovation and energy efficiency. Additionally, per capita GDP and financial development were employed as control variables in the model. The present study implemented two models, namely Model (1) and Model (2), for the variables under consideration:

$$GHG_t = f(FD_t, EE_t, GDP_t, EPI_t) \quad (1)$$

$$GHG_t = B_0 + B_1 FD_t + B_2 EE_t + B_3 GDP_t + B_4 EPI_t + \varepsilon_t \quad (2)$$

We subsequently reformulated Equation (2) in logarithmic form:

$$\text{Ln}\, GHG = B_0 + B_1 \ln FD_t + B_2 \ln EE_t + B_3 \ln GDP_t + B_4 \ln EPI_t + \varepsilon_t \quad (3)$$

The logarithmic transformation of Equation (3) was performed to interpret the parameters $(B_1, B_2, B_3, B4)$ as elasticities. This approach also mitigates multicollinearity issues, yielding more accurate results [19]. Moreover, the inclusion of the error term in the model accounts for external factors not addressed in the study, which contribute to the reduction of emissions.

4. Empirical Results and Analysis

4.1 Descriptive Statistics

The findings in Table (2) reveal a moderate-to-limited variation across most variables, particularly LnGHG and LnEE, whereas LnEPI and LnFD exhibit relatively greater variability. This highlight differing degrees of stability in the dataset.

Table (2): Descriptive Statistics

Variable	OBS	MEAN	STD. DEV.	MIN	MAX
LnGHG	62	1.958122	0.184641	1.504077	2.186051
LnFD	62	4.396359	0.528731	3.444256	4.928918
LnEE	62	3.501277	0.0446448	3.418054	3.583796
LnGDP	62	10.617306	0.294627	10.101934	11.016073
LnEPI	62	4.056073	0.793177	2.199444	5.116795

4.2 Unit Root Test

Table (3) presents the outcomes of the unit root tests, which assess the presence of stochastic stationarity in the data. According to these tests, with the exception of GHG and EE, the series were non-stationary at level (indicating the presence of unit roots) but became stationary at first difference. Consequently, most of the examined variables were stationary at first difference. The ARDL methodology permits variables to be integrated either at the same or mixed orders [19], making it suitable for modeling the dynamics of the GHG variable alongside EE, which exhibited stationarity at level. This validates the selection of the Autoregressive Distributed Lag (ARDL) model to investigate long-term relationships and the connections among variables.

Table (3): Unit Root Test Results

variable	Level	1^{st} difference
	ADF	ADF
LnGHG	-3.532706*	…..
LnFD	-0.743197	-4.087778*
LnEE	-3.384107**	……
LnGDP	-0.926630	-3.779394*
LnEPI	-2.207382	-5.806760*

*Indicates significant at 1% level. **Indicates significant at 5% level

4.3 Cointegration Test

To determine the existence of a long-term relationship (cointegration) among the variables, the Bounds Test was applied to evaluate the model (Equation (3)). As shown in Table (4), the Fstatistic (9.3199) for the estimated model surpasses the upper critical values at the significance level of (1%), leading to the rejection of the null hypothesis.

Table (4): Cointegration Test Results using Bounds Testing

F – Statistics	**Value**	**Significant**	**I (0)**	**I (1)**
	9.319996	10%	2.345	3.280
		5%	2.763	3.813
		1%	3.738	4.947

4.4 Long-Term Relationship Analysis

Numerous scholars have posited that financial development fosters investments in research and development or steers appropriate investments toward enhancing environmental quality. Others suggest that advanced financial sectors help reduce credit costs and bolster investments [20]. The results in Table (5) reveal a statistically significant positive relationship between financial development (FD) and GHG emissions. This implies that a 1% increase in FD corresponds to a 0.076% rise in GHG, indicating that financial development drives economic growth, which in turn amplifies energy demand, thereby escalating emissions [21]. Thus, financial development is expected to contribute to higher emissions over the long term.

Furthermore, the findings underscore a positive significant relationship between energy efficiency (EE) and increased emissions, reflecting the so-called "efficiency rebound effect." This phenomenon occurs when enhanced energy efficiency indirectly leads to higher energy consumption. Despite technological advancements reducing energy use per unit of production, lowered costs spur greater energy utilization, diminishing or negating the anticipated benefits of efficiency [22].

A significant inverse relationship was observed between GDP and emissions, which may be attributed to the presence of the "Environmental Kuznets Curve" (EKC) in certain GDP ranges, whereby increased output drives the adoption of cleaner technologies [23]. Meanwhile, the findings indicate a statistically significant relationship between environmental innovation, represented in the present study by the number of patents (EPI) related to clean energy technologies, and emissions. However, certain indicators suggest that environmental innovations struggle to achieve market success and widespread adoption among potential users compared to other types of innovations. These challenges may lead to product development failures or market entry delays [24].

Table (5): Long-Term Coefficient Estimates via ARDL Methodology

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnFD	0.076247	0.021005	3.629904	0.0007
LnEE	0.490984	0.142060	3.456154	0.0011
LnGDP	-0.240570	0.093307	2.578256	0.0131
LnEPI	-0.008888	0.009457	0.939825	0.0522
C	0.719760	0.952491	0.756560	0.0537

4.5. Short-Term Relationship Analysis

The results of Table (6) indicate a significant negative relationship in the short term between financial development, energy efficiency, environmental innovation, and emissions. Conversely, a significant positive relationship exists between GDP and emissions, which is attributed to the so-called "Scale Effect" that typically emerges in the short term before environmental factors and green policies intervene in the long term. The Error Correction Model (ECM) coefficient (-1) signals a speed of adjustment towards long-term equilibrium at approximately 9.7% per period.

Table (6) The Error Correction Mechanism Using the ARDL Approach

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LnFD	-0.038043	0.022090	-1.722169	0.0910
LnEE	-1.163624	0.140962	8.254839	0.0000
LnGDP	0.441756	0.135107	3.269651	0.0019
LnEPI	-0.030839	0.011538	2.672620	0.0100
ECM (-1)	-0.096849	0.012300	-7.873895	0.0000

4.6 Diagnostic Tests

Diagnostic tests are employed to assess the efficiency of the models and to ensure the validity of the fundamental statistical assumptions. These tests further ensure the precision and reliability of the obtained results for analysis. The following tests were conducted:

4.6.1 Heteroskedasticity Test (Breusch-Pagan-Godfrey)

The heteroskedasticity test is a statistical procedure utilized to verify the homoscedasticity assumption in errors. Homoscedasticity implies that the variance of errors remains constant across all levels of independent variables. If heteroskedasticity is present, the model suffers from variance inconsistency, which could negatively impact the validity of statistical conclusions.

Table (7) The Heteroskedasticity Test Results

test	Value	Prob.
F- statistics	0.034669	0.8529
Obs* R Squared	0.035864	0.849765

The results in Table (7) of the heteroskedasticity test suggest that all p-values exceed 5%, which means that the null hypothesis (indicating homoscedasticity in residuals) cannot be rejected. This outcome confirms that the variance in errors does not depend on independent variables or expected values but rather on external factors not included in the studied model.

4.6.2 Stability of the Estimated Model

Ensuring the stability of the estimated model and the absence of structural changes in the estimated data is critical to harmonizing short-term parameters with long-term ones. This

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stability is assessed using the CUSUM and CUSUM Square tests, as shown in Figures (1 and 2).

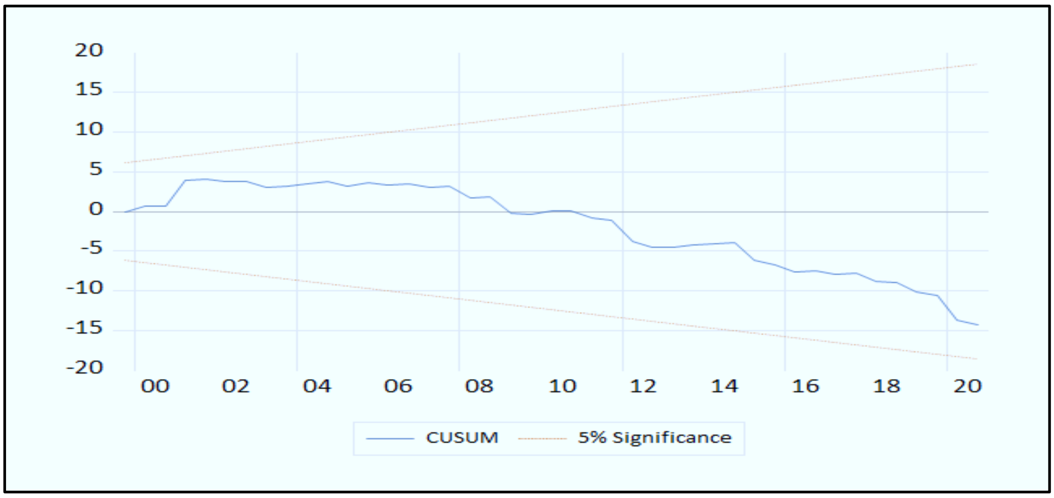

Fig. 1: Plot of CUSUM Test

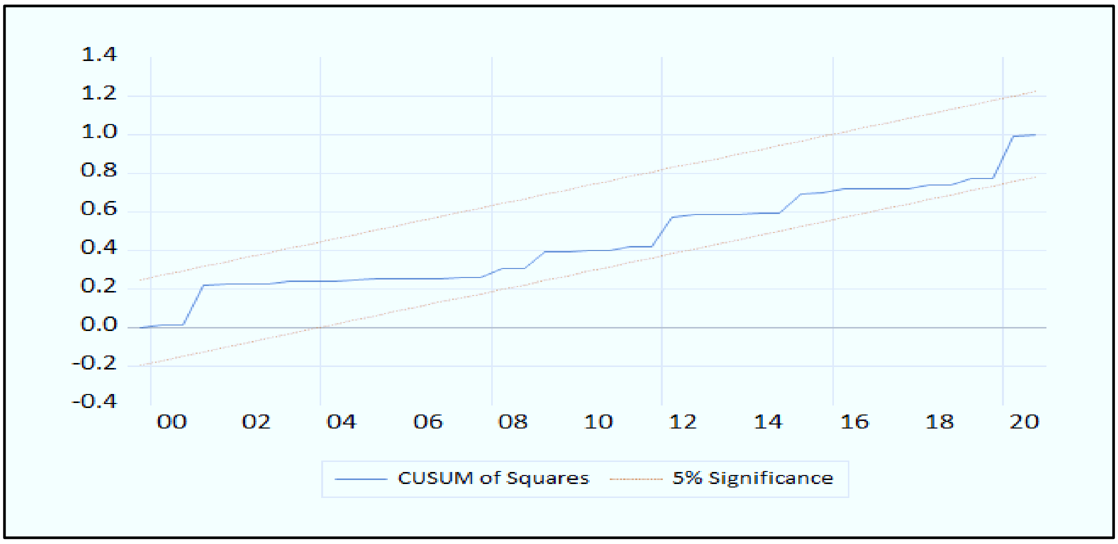

Fig. 2: The plot of CUSUM Squares Test

From Figures (1 and 2), it is evident that the cumulative sum of residuals and the cumulative sum of squared residuals lie within the critical bounds, indicating that both short-term and long-term parameters are stable and the values fall within the critical limits at a significance level of 5%).

5. Discussion

The study emphasizes the critical role of environmental innovation in reducing gas emissions in Sweden, considering other control factors like financial development and GDP. Through the analysis, a long-term relationship is identified between environmental innovation (represented by environmentally-related patents) and emissions, with the effect being more apparent in the short term. This highlights the need for governmental policies to support the transition of innovation from research and development phases to widespread practical application in the long term, ensuring a greater effect on reducing emissions.

The results also point to the "efficiency rebound" phenomenon, where technological improvements sometimes lead to increased energy consumption. On the other hand, a long-term rise in GDP could contribute to emission reduction, supporting the Environmental Kuznets Curve hypothesis.

Financial development, however, is linked to higher emissions in the long term. Schumpeter was among the first to recognize the contribution of financial development to economic output. With the advent of endogenous growth theory, economists affirmed that economic activity damages nature. This underscores the necessity of redirecting investments toward more sustainable projects.

Environmental innovation faces what is known as the double externality problem. General theory suggests that R&D investments are limited due to knowledge leakage. This challenge is even more pronounced in environmental innovations, where private returns on investments are lower than societal returns. Consequently, it becomes crucial to implement complementary governmental policies to enhance investment in clean technologies, mitigate efficiency rebound effects, and harmonize economic and environmental objectives through an integrated approach that fosters low-carbon innovation.

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