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GREEN GROWTH IN SCANDINAVIA: ASSESSING THE ROLE OF ENVIRONMENTAL TAXATION, GREEN INNOVATION, TRADE, AND URBANIZATION IN ADVANCING CLEAN ENERGY CONSUMPTION

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ABSTRACT

The research analyses the drivers of clean energy use (CEU) in Scandinavian countries by assessing the influence of environmental taxation (ETR), green innovation (GRI), trade openness (TRD), economic growth (ECG), and urbanization (URB). In exploring these relationships, the research is mainly theorized within the Energy Transition Theory and Environmental Kuznets Curve (EKC) hypothesis framework while employing panel data from 1990 to 2023 and advanced econometric tools. Results show that while GRI and ECG significantly contribute to adopting clean energies, the URB process enhances CEU through improved infrastructure and technology adoption. It reveals that environmental taxation has an adverse short-term impact by raising energy costs, while trade openness yields ambiguous results. The study confirms the theoretical frameworks and highlights the interplay among socio-technical and economic dimensions as critical enablers and barriers for energy transitions. Thus, environmental taxation should be complemented with subsidies, more significant investments in green innovation should be made, and economic growth should be used to ensure clean energy infrastructure and clean energy in urban planning. These findings provide actionable strategies to fast-track clean energy transitions in Scandinavia and beyond, thus ensuring economic growth and harmony with environmental sustainability.

Keywords: *Carbon taxes, Renewable transitions, Nordic Region, Urban Planning, Technology infrastructure*

1. INTRODUCTION

The quest for sustainable development has emerged as the most compelling international challenge amid growing environmental concerns, global warming, and natural resource degradation (Bekun et al., 2025; Haider et al., 2024; Moro et al., 2025). As nations across the globe contend with reconciling economic development with the preservation of the environment, the transition to clean energy systems has dominated sustainable development agendas (Fumey et al., 2024; Streimikiene, 2024a, Prasetyo & Kistanti, 2023). This paradigm shift is reflected in the 2015 Paris Agreement and the United Nations' Sustainable Development Goals, which demand urgent delinking of economic prosperity from carbon emissions (Sampene et al., 2024; Wiredu et al., 2025). The contribution of various policy instruments and socioeconomic drivers like environmental taxation (ETR), innovation potential, international trade flows, economic growth (ECG), and urbanization (URB) patterns as drivers of clean energy transition (CEU) has been argued (Mabrouki, 2019; Trimech, 2024; Wang et al., 2024). It is necessary to comprehend how these determinants interact and influence the energy transition to create effective policy frameworks that can accelerate the global transition towards sustainable energy systems without undermining economic competitiveness in an increasingly carbon-constrained world (Bashir et al., 2024; I. Khan et al., 2022).

In this global context, the Scandinavian nations Denmark, Finland, Sweden, and Norway are particularly compelling examples for analysis of clean energy transitions (Hassan et al., 2024; Sovacool, 2017; Sovacool et al., 2018). These nations are leaders in enacting environmental policies and penetration with clean energy, but also face niche challenges that render their paths to sustainable development uniquely complicated (Nketiah et al., 2024; Ramachandran et al., 2022; Sovacool et al., 2018). Despite their superior environmental control mechanisms and lofty climate targets, Scandinavian countries continue to experience varying degrees of fossil fuel reliance, Norway's petroleum sector creating a colossal paradox between domestic clean energy usage and carbon-sullied exports (Dai et al., 2024). Additionally, these nations must reconcile the pursuit of economic competitiveness with implementing stringent environmental controls and taxation (Bruce & Ellis, 2023; Cui, 2024; Zhu et al., 2023; Zaghdoud, 2025). The region's distinct characteristics of high social welfare, the ability for innovation, high trade exposure, and a highly concentrated urban population offer a singular laboratory to study the interaction between policy levers and socioeconomic drivers and how they cause clean energy transitions (Durán & Saqib, 2024; Lawal et al., 2020; Marra et al., 2024). However, limited comparative research thoroughly examines how environmental taxation (ETR), green innovation (GRI), openness to trade (TRD), economic growth (ECG), and urbanization (URB) all collectively impact clean energy adoption (CEU) in these Nordic economies. This is an essential gap in knowledge that this study aims to address.

Furthermore, ETRs are supposed to reduce carbon emissions and promote cleaner energy use. Environmental taxes have benefited clean energy usage by promoting declining carbon emissions and using renewable energy technology (Dobrovolska et al., 2024). In China, substantial environmental taxes have effectively persuaded businesses towards green productivity, such as using clean energy (Sun et al., 2023). However, the impact of ecological taxation varies from location to location and situation to situation, as some countries may experience a discouraging effect on decarbonization (Dobrovolska et al., 2024). Green innovation (GRI) is also essential in encouraging clean energy use by developing new technology that increases efficiency in energy use and reduces emissions (Masoud, 2024). Similarly, Green finance and ETR policies in China have significantly boosted green patent filings, an essential marker of innovation-linkage with clean energy (Masoud, 2024). Encouragement of GRI through monetary policies has been discovered to aid clean energy development, particularly in cities with localized innovation (Pantelaiou et al., 2020, Elhassan, 2025).

TRD can permit the exportation and importation of clean technologies and best practices, facilitating the potential greater use of clean energy (Aneja et al., 2024). It can also increase the use of more energy as GDP increases, effectively offsetting part of the benefits of CEU (Aneja et al., 2024; Barkat et al., 2024). The Environmental Kuznets Curve (EKC) hypothesis contends that EKC initially increases environmental degradation but that once a certain income level is reached, cleaner types of technology and energy are used, improving ecological quality (Aneja et al., 2024). Similarly, URB can drive clean energy utilization through the concentration of individuals and economic activity, thereby leading to practical usage and adoption of cleaner technology (Chen et al., 2023). However, it can also increase energy consumption and emissions unless handled using sustainable development and infrastructure (Aneja et al., 2024). Therefore, the current study investigates the role of ETR, URB, ECG, GRI, and TRD in shaping the Scandinavian nation's transition pathways to clean energy adoption.

This study aims first to analyse the relative contribution of ETR, GTI, TRD, ECG, and URB to the demand for CEU in Denmark, Finland, Sweden, and Norway. Second, describe the potential synergistic or antagonistic interactions among these determinants in driving clean energy transitions. Third, develop insight considering specific Scandinavian countries' unique institutional, economic, and historical contexts. Fourth, create policy guidelines that can optimize the effectiveness of various tools toward encouraging clean energy use while maintaining economic competitiveness. This research is necessary because it addresses the pressing need to understand how fiscal, technological, and socio-economic factors collectively influence clean energy transitions, particularly in the context of advanced economies that have already made significant progress in renewable energy adoption. The motivation for conducting this research stems from the lack of comprehensive empirical studies that assess the joint impact of environmental taxation, green innovation, trade openness, economic growth, and urbanization on clean energy use in the Scandinavian region. Accordingly, this study seeks to answer the following research question: What impact do environmental taxation, green innovation, trade openness, economic growth, and urbanization have on clean energy use in Scandinavian countries?

Aside from the introduction, the remainder of the work is systematized: Section two summarizes appropriate literary works on the research topic. Section three provides the theoretical underpinning, data, and assessment technique. Section four shows the empirical findings and discussion. The conclusion, implication, limitation, and future investigation of the study are given in part five.

2. LITERATURE REVIEW

The purpose of this literature review section is to provide a comprehensive analysis of the existing academic discourse concerning the relationship between clean energy use and its key determinants, namely environmental taxation (ETR), green innovation (GRI), trade openness (TRD), economic growth (ECG), and urbanization (URB). This section critically assesses previous empirical and theoretical studies on each determinant to establish our research model's foundations and clarify each variable's relevance to the Scandinavian context. Such an organized review is essential as it identifies existing knowledge gaps, helps position the current study within the broader literature, and justifies the selection of variables in the empirical analysis.

2. 1. ETR AND CEU LINKAGE

Environmental taxation (ETR) and clean energy use (CEU) are mutually supportive strategies to promote sustainable development and reduce environmental impact (Wu et al., 2024). ETR is a mechanism aimed at encouraging pollution reduction and the adoption of cleaner energy sources through an economic incentive (Sommer et al., 2022). At the same time, CEU promotes the shift from fossil fuel-based energy sources to renewable sources (Shen et al., 2021). Zolkover et al., (2024) argued that ETR stimulates advanced firms in developed regions like the EU, USA, and China to invest in CEU. Green taxation will discourage greenhouse gas emissions while encouraging sustainable development in these countries. It highlights modernizing the industrial sector and implementing carbon capture technologies as key strategies indirectly supported by legal regulations and governmental incentives, especially the European Union and the New Deal. The positive correlation between ETR and CEU in the fifteen European countries from 1994 to 2020 is discussed in this study of (Alper et al., 2024). Higher ETR leads to increased renewable energy consumption, and more such energy in total energy indicates that such taxes act as a stimulus to increased renewable consumption (Alper et al., 2024). These findings further suggest the viability of environmentally related tax policy designs for sustainable energy use and environmental protection, as they would provide sound guidance to policymakers seeking to redesign tax policies in support of clean energy initiatives.

However, ETR has quite a negligible impact on the new EU states (Fatur Šikić & Hodžić, 2023). To realize climate neutrality in 2050, these countries must implement stringent regulations and reforms to improve the share of clean energy sources in their energy mix and thus work with CEU against ETR (Fatur Šikić & Hodžić, 2023). Although environmental taxation is perhaps the most potent force driving clean energy use, its success can only be achieved through appropriate policy design and implementation. Considering that such taxes could prove regressive, especially during times of economic crisis, it becomes salient that progressive tax reforms consider social justice and equity.

2. 2. GRI AND CEU LINKAGE

Green innovations (GRI) have an intrinsic meaning of a voluntary commitment to companies developing green products and processes; as is typical, green innovations require a shift from one form of business model to another, with the latter balancing economic, social, and environmental oriented perspectives (Tolliver et al., 2021). GRI would increase uptake by the MENA region in renewable energy as they invest in GRI, adding value to its case for sustainable energy generation (Esmaeilpour Moghadam & Karami, 2024). Borgi et al., (2024) emphasize that ecological innovations and clean energy usage significantly reduce CO_2 emissions within the G-7 countries in isolation and governance variables. It finds that individualism and long-term orientation are Hofstede dimensions that positively moderate the relationship between eco-innovation.

GRI has been identified as a new paradigm that specifies the core model of opening strategic imperatives for sustainable growth in business as a strategic imperative (Zhang et al., 2024). Some GRI literature areas, like green product innovation and green absorptive capacity, are closely associated with clean energy initiatives (Zhang et al., 2024). The bibliometric study evidences upward growth in GRI-related publications while limiting research collaboration (Zhang et al., 2024). This shows the way forward for future research into GRI and its possible contribution to facilitating green practices, whether in terms of clean energy or not (Milutinović et al., 2024). GRI and CEU are primordial for sustainable development; however, challenges such as high initial costs, supply chain constraints, and regulatory barriers may inhibit their implementation. Overcoming these challenges requires an integrated policy approach and international cooperation to promote green growth and environmental sustainability (Moro et al., 2025). Furthermore, the role played by cultural and governance factors in moderating the impacts of green innovation and clean energy use adds to the complexity of the sustainable development challenge.

2. 3. TRD AND CEU LINKAGE

Siddique & Alvi, (2025) delve into the relationship between trade openness (TRD) and renewable energy (RNW) use within South Asia. The results demonstrated a strong and direct correlation between TO and GDP, positively influencing RNW. Nonetheless, both TO and GDP are long-term negative factors affecting environmental quality through increased CO_2 emissions (Siddique & Alvi, 2025). Conversely, while RNW tends to reduce CO_2 emissions, it does so to a limited degree compared to the impact posed by TO and GDP, which adds an extra dimension to the complex interrelationships among these variables. Furthermore, TRD enhances CO_2 emissions, albeit statistically regarded as insignificant (Obobisa, 2024). The report posits the necessity of promoting clean energy sources and eco-innovation to achieve carbon neutrality and sustainable development among OECD countries, reinforcing the call for the relevant policies to favor both (Obobisa, 2024).

Conversely, TRD has multifaceted implications for CEU, thus either positive or negative in the developing economies from the developed countries (Le, 2022). Energy intensity is expected to be lowered using energy-efficient technology (Le, 2022). Most importantly, increased trade implies increased energy consumption, with fossil fuels as the primary resource and corresponding pollution emissions (Iorember et al., 2019). Thus, the trade-induced advantages of accessing clean energy would still be mitigated by policies that would translate into more emissions and worse environmental quality (Aydin, 2023). While arrangements for TRD can work to drive ECG and facilitate CEU, this has also brought ecological degradation challenges. A careful balance between these ends can be brought about with effective policies that support clean energy use and those mitigating the adverse effects of increased trade activities.

2. 4. ECG AND CEU LINKAGE

Renewable energy sources are positively linked with economic growth (ECG), as indicated in recent studies within the European Union (Fajdetić & Festić, 2024). The uptake of renewable energy and higher energy efficiency is fundamental for achieving sustainable economic growth because of investment attraction and productivity enhancement (Yan et al., 2023). According to the spatial theory of clean growth, renewables will dominate the global power system and provide significant welfare gains by 2040 (Arkolakis & Walsh, 2023). Policy initiatives such as the US Inflation Reduction Act would speed up the pace of renewable uptake and thus realizable economic value.

Regarding challenges and complexities for economic progression in South Asian economies, studies have called for a shift from traditional renewable to more modern, non-renewable energy sources, mainly for industrial use (Khan et al., 2024). The challenge here is that several effects of prosperity might harm sustainable development unless provision is made for renewable energy. Indeed, much of the good that renewable energy does for economic growth may be offset by excessive reliance on fossils, which accounts for more CO_2 emissions in the EU, calling for measures to reconcile economic development with environmental sustainability through policy instruments (Madaleno & Nogueira, 2023).

Though the general perception has been that CEU stimulates ECG, the link is intricate and affected by regional conditions, the existing energy infrastructure, and pertinent policy frameworks (Shen et al., 2021). Fossil fuel dependency and the need for a hefty infrastructure setup also hinder some regions from transitioning to clean energy (Depren et al., 2022). Therefore, generating sustainable economic growth on clean energy will demand broad policy measures, investment in technology, and dedication towards environmental sustainability.

2. 5. URB AND CEU LINKAGE

Urbanization (URB) increases energy consumption, expanding infrastructure, transportation, and industrial development. A case in point is the South Asian Association for Regional Cooperation (SAARC) region, where urbanization has fully increased energy demand, mainly from non-renewable sources (Dev et al., 2024). According to the mixed impacts of urbanization on CO_2 emissions in the Middle East, such countries as Saudi Arabia and Jordan showed effectiveness due to their urban policies having a reduction; on the contrary, Egypt has not manifested much change (Aldegheishem, 2024). Research continuously argues that integrating renewable energy systems with the urban planning process would lead to greenhouse gas reductions and energy savings (Hussein & Basel, 2024). Such strategies, for example, would result in 1.2 million tons of CO_2 emission reductions annually, providing for 35% of the urban energy demand (Toni, 2025).

An example of such a novel urban energy system is the Urban Building Energy CPS framework, which combines best practices with digital technologies to minimize city energy consumption and optimize the use of renewables to enhance urban sustainability (Srinivasan et al., 2020). CEU calls for comprehensive urban planning and policy frameworks. Coordinated settlement development and spatial planning can enhance energy efficiency and improve socio-economic welfare (Khiali-Miab et al., 2024). Policymakers should channel investments into renewable energy sources, green technologies, and the education of populations on the environmental implications of energy use (Dev et al., 2024).

2. 6. KNOWLEDGE GAP AND RESEARCH CONTRIBUTIONS

Even though comprehensive treatments are available on sustainability development and energy transitions (Bashir et al., 2024; Caragliu & Graziano, 2022; Ghorbani et al., 2024; I. Khan et al., 2022; Dašić et al., 2024; Mastilo et al., 2025), much ground remains unexplored in understanding the thick nexus of factors responsible for clean energy adoption in Scandinavia. While previous investigations have studied specific determinants of ETR or innovation in isolation, very few have adopted a more integrated approach that would simultaneously assess the interaction between ecological taxation, green innovation, trade openness, economic growth, and urbanization on clean energy use.

This study contributes immensely to the body of literature and policy discourse. ***First,*** applying a comprehensive analytical framework evaluating multiple determinants of CEU yields a relatively more holistic understanding than any single-factor approach entails. ***Second,*** the novel evidence demonstrates the differential effects of environmental tax, innovation, trade, growth, and urbanization among Scandinavian countries concerning their synergies and divergences in the clean energy pathway. ***Thirdly,*** the current study offers actionable insights for optimizing the combination of fiscal, innovation, trade, and urban planning tools to accelerate the clean energy transition. ***Lastly***, as a comparative framework in its own right, this research has the potential to be translated into other geographic reference frames to examine CEU determinants, thus extending the relevance of this research beyond the Scandinavian region and into the more significant development discourse of sustainability.

3. MATERIALS AND METHODS

3. 1. THEORETICAL BACKGROUND- ENERGY TRANSITION THEORY

Energy transition theory, which views the change from fossil fuels to renewable energy as a complex socio-technical process rather than just technological substitution, serves as the grounding for this study (Andrews-Speed, 2016; Wiredu et al., 2023). The multi-level perspective of this theory discusses niche innovations (emerging clean technologies), socio-technical regimes (for established energy systems), and landscape developments (broader contextual forces) (Geels & Schot, 2007). The ETR serves as a landscape-level instrument, creating economic pressure for change, and green innovation (GRI) signifies niche-level activities developing alternative technologies (Nong et al., 2021; Wu et al., 2024; Zhu et al., 2023). Trade openness (TRD) favours technology diffusion across borders, economic growth (ECG) creates conditions that are either enabling or constraining, and urbanization (URB) patterns energy demand and infrastructure development (Aydin, 2023; D. Chen, 2022). Energy transition theory sees different pathways for countries with other contexts and institutional configurations, which makes it most apt for understanding the differences in clean energy adoption across Scandinavian countries that have the same level of development and near geographical distance (Caragliu & Graziano, 2022; Khan et al., 2022). The functional form of the model assessing the determinants of clean energy use (CEU) is specified as:

$$CEU_{it} = f(ETR_{it}, GRI_{it}, TRD_{it}, ECG_{it}, URB_{it}) \quad (1)$$

Based on this, the log-linear econometric specification of the model is expressed as:

$$lnCEU_{it} = \alpha_{it} + \beta_1 lnETR_{it} + \beta_2 lnGRI_{it} + \beta_3 lnTRD_{it} + \beta_4 lnECG_{it} + U\beta_5 lnRB_{it} + \varepsilon_{it}\ eqn \quad (2)$$

Where t is the period of time and i the country, α_i is country-specific effects, and ε_i is the error term. The variables were also transformed into natural logs to eliminate the non-normality issues identified in the descriptive statistics. The log transformation puts the variance on a constant condition, minimizes skewness, and puts the distribution of the variables on a generally distributed condition so that statistical inference is more accurate. Logs also facilitate the explanation of the estimated coefficients as elasticities, so the intuitive explanation of the relative change in the consumption of clean energy is given based on each explanatory variable.

3. 2. DESCRIPTION OF DATA

The study utilizes panel data covering Scandinavian countries from 1990 to 2023 to examine determinants of the use of clean energy (CEU). CEU is the dependent variable, denoting the energy ratio from low-carbon and renewable resources. Independent variables are Environmental Taxation (ETR), standing for policy intervention aimed at reducing environmental harm; Green Innovation (GRI), representing green technology advancement; Trade Openness (TRD), referring to the degree of economic exposure to the world market; Economic Growth (ECG); and Urbanization (URB), indicating the proportion of people living in cities. All variable data were drawn from the (WDI, 2024) and (OECD, 2024) databases to maintain country and time consistency and reliability. Table 1 describes the study variables.

Table 1. Description of variables

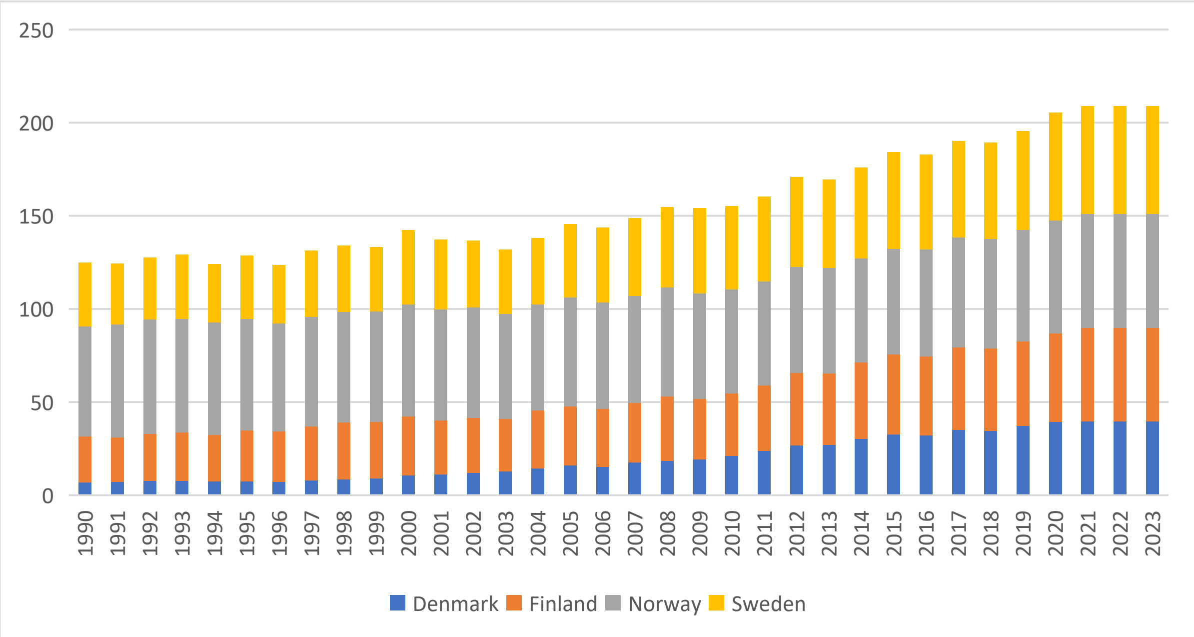
Indicators	Acronyms	Measurement	Source
Clean Energy Use	CEU	Renewable energy consumption (% of total final energy consumption)	(WDI, 2024)
Environmental Taxation	ETR	Environmentally related tax % of GDP	(OECD, 2024)
Green Innovation	GRI	Green Technologies (Patent on environmental technologies)	(OECD, 2024)
Trade Openness	TRD	Trade (% of GDP)	(WDI, 2024)
Economic Growth	ECG	GDP per capita (constant 2015 US$)	(WDI, 2024)
Urbanization	URB	Urban population (% of total population)	(WDI, 2024)

Source: Author's own construction

3. 3. TREND ANALYSIS OF VARIABLES

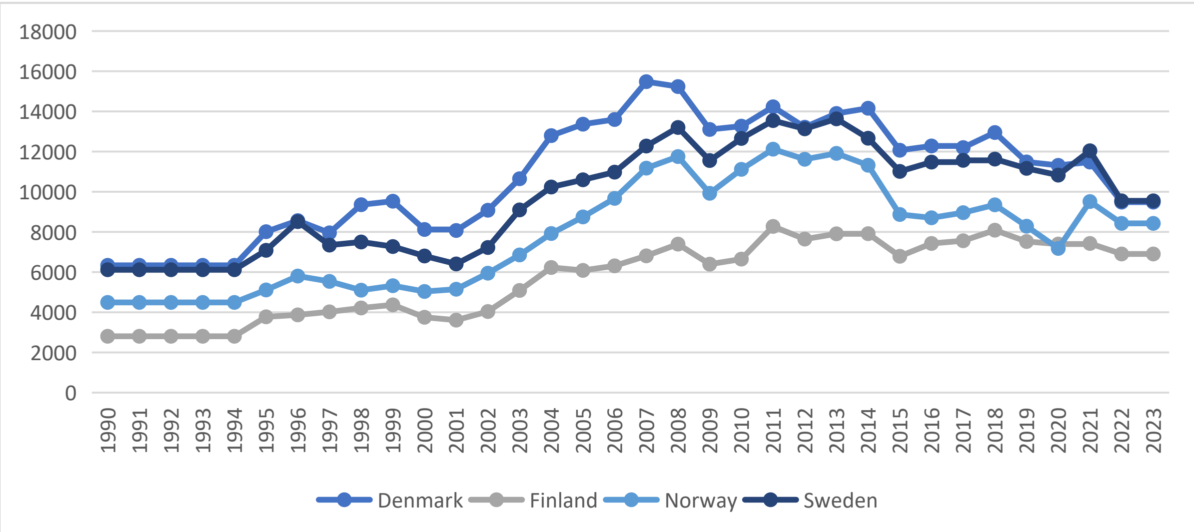
The trend line of clean energy use (Figure 1) in Scandinavian countries from 1990 to 2023 steadily increases, reflecting a strong commitment to sustainability and embracing renewable energy. Environmental tax (Figure 2) is gradually increasing, suggesting policy efforts to promote greener energy. Green innovation (Figure 3) has increased steadily, with a steeper increase in recent years, reflecting the region's investment in green technologies. Generally, these trends align with Scandinavia's pursuit of green growth and clean energy transition.

Figure 1. Trend Analysis of Clean Energy Use for Scandinavian Countries from 1990 to 2023



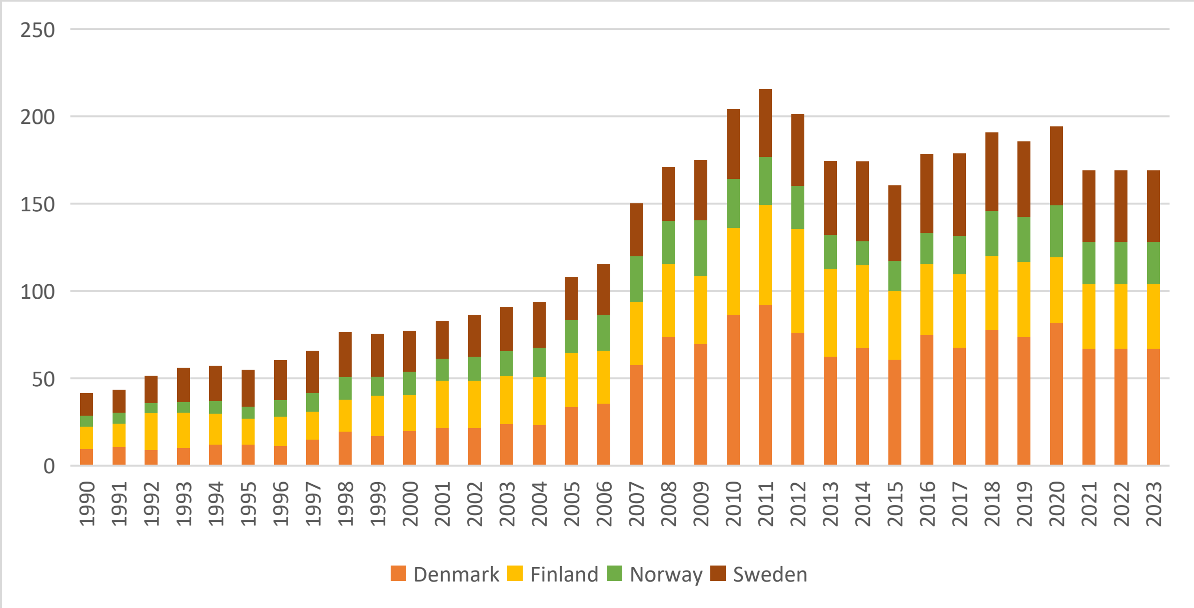
Source: WDI, 2024

Figure 2. Trend Analysis of Environmental Taxation for Scandinavian Countries from 1990 to 2023



Source: OECD, 2024

Figure 3. Trend Analysis of Green Innovation for Scandinavian Countries from 1990 to 2023



Source: OECD, 2024

3. 4. CROSS-SECTION DEPENDENCE (CSD) AND SLOPE HOMOGENEITY TEST (SHT)

To ensure panel estimations are valid, the research first tests for cross-sectional dependence among the variables through four standard tests: Breusch-Pagan LM test (Breusch & Pagan, 1980), Pesaran's scaled LM test (Pesaran et al., 2004), Bias-corrected scaled LM test (Baltagi et al., 2012), and Pesaran's CD test (Pesaran et al., 2004). These tests determine if residuals between cross-sectional units are interrelated, significant in panels with potential economic or spatial interdependencies, as is the case of the Scandinavian countries. The Breusch-Pagan LM statistic is given as:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{3}$$

where $\hat{\rho}_{ij}$ is the estimated pairwise correlation of residuals. Pesaran's scaled LM test modifies this for large panels:

$$LM_{scaled} = \frac{1}{N} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T}\, \hat{\rho}_{ij}^2 \tag{4}$$

and the Bias-corrected scaled LM accounts for finite sample bias. Pesaran's CD test is calculated as:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \tag{5}$$

Significant results indicate the presence of cross-sectional dependence, which necessitates second-generation panel methods.

Slope Homogeneity Assessment

Following the test for cross-sectional dependence, the study estimates slope homogeneity between panel units using Pesaran & Yamagata (2008) Delta tests to test the null hypothesis of homogeneity of slopes against the alternative of heterogeneity. Heterogeneous slopes in this instance would imply that clean energy consumption and determinants of clean energy consumption have varying relationships in various countries. Delta test statistics are represented as:

$$\Delta = \sqrt{N}\left(\frac{\hat{S}-k}{\sqrt{2k}}\right), \quad \Delta_{adj} = \sqrt{N}\left(\frac{\hat{S}-E(\hat{S})}{\sqrt{Var(\hat{S})}}\right) \tag{6}$$

where $\hat{S}$ is Swamy's test statistic, k is the number of regressors, and $E(\hat{S})$ and $Var(\hat{S})$ are the expected value and variance of $\hat{S}$, respectively. The null rejection would imply slope heterogeneity, so it is best to utilize heterogeneous panel estimation techniques for consistent inference.

3. 5. PANEL STATIONARITY TEST

To determine the time series properties of the variables and to eliminate spurious regression results, the study employs second-generation panel unit root tests, namely the Cross-sectionally Augmented Dickey-Fuller (CADF) and Cross-sectionally Augmented IPS (CIPS) tests developed by Pesaran et al. (2008). These are suitable for panels with cross-sectional dependence, as was confirmed in the initial analysis. The CADF test combines the standard ADF regression with cross-sectional averages of first differences and lagged levels to account for common factors between units, and is defined as:

$$\Delta_{yit} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \delta_t \Delta \bar{y}_t + \varepsilon_{it} \tag{7}$$

where denotes the cross-sectional average of $y_{i,t}$. The corresponding CIPS statistic is the cross-sectional average of individual CADF statistics, given by:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i^{CADF} \tag{8}$$

where t_i^{CADF} is the t-statistic of β_i in the CADF regression. These tests are more desirable because they are powerful under cross-sectional dependence, prevalent in regional panels such as Scandinavia, and offer more consistent stationarity outcomes than first-generation tests. CIPS and CADF null rejection implies stationarity of the variables.

3. 6. PANEL COINTEGRATION TEST

A cointegration between the determinants of clean energy consumption is explored to analyze the long-run relationship using the Kao (1999) residual-based cointegration test and the panel cointegration tests of Westerlund (2007). Kao (1999) assumes that the cointegrating vectors are homogeneous and are derived from the augmented Engle-Granger approach, with the test equation being:

$$\hat{e}_{it} = \rho\hat{e}_{i,t-1} + \sum_{j=1}^{p}\theta_j \Delta\hat{e}_{i,t-j} + v_{it} \tag{9}$$

where $\hat{e}_{it}$ are the panel regression residuals and the null hypothesis H_0: ρ = 1 represents no cointegration. To supplement this is the Westerlund test that is robust to cross-sectional dependence and heterogeneity and uses four statistics: two group-mean tests (*Ga and Gt*) and two-panel tests (*Pa and Pt*), from the error adjustment model:

$$\Delta y_{it} = \alpha_i + \delta_i t + \gamma_i\left(y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \sum_{j=1}^{p} \phi_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q} \theta_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (10)$$

where γ_i denotes the speed of adjustment. The null hypothesis $H_0 : \gamma_i = 0$ for all i means there is no cointegration. The Westerlund test is cross-sectionally robust and can deal with individual heterogeneity. Therefore, it is ideal for panel data for economically integrated heterogeneous economies like Scandinavia.

3. 7. LONG-TERM ESTIMATION

For the long-run relationship between clean energy use and its determinants to be estimated, the study utilizes the Driscoll-Kraay Standard Errors (DKSE) approach that allows for consistent inference against cross-sectional dependence, heteroskedasticity, as well as autocorrelation in panel data. It was suggested by Driscoll & Kraay (1998) as a technique to estimate standard errors via a nonparametric estimator of the covariance matrix that will be robust regardless of the nature of spatial and temporal dependence in the panel. The DKSE technique is most applicable in this research because cross-section dependence among the Scandinavian countries has been established in prior tests to be most likely due to the unification of economic and environmental policies. Furthermore, DKSE functions effectively in panels with relatively fewer cross-sectional units and a more extended time horizon, as is the current situation. As it accommodates common econometric issues such as heteroskedasticity and serial correlation, DKSE ensures that the long-run parameter estimates are efficient. At the same time, the statistical inferences remain robust, hence an adequate and plausible model to analyze clean energy dynamics within the area.

$$y_{it} = x_{it-1}\beta + z_{it}\gamma + \mu_{it} i = 1, \dots, N, t = 1 \dots T \quad (11)$$

where y_{it} displays the outcome variable (CEU); x_{it} shows the regressors (ETR, GRI, TRD, ECG, and URB), μ is the error term, i denotes the nations under study and t shows the time of the study.

3. 8. ROBUSTNESS CHECKS

To examine the consistency and robustness of the long-run estimates of the Driscoll-Kraay estimator, robustness tests with Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are employed. FMOLS eliminates serial correlation and endogeneity by modifying the OLS estimator with non-parametric corrections. Therefore, it is suitable for cointegrated panels with feedback effects. DOLS addresses the same issues by incorporating leads and lags of differenced regressors, thus eliminating serial correlation and endogeneity in parametric terms. Both methods are widely known to produce unbiased and efficient long-run estimates in cointegrated settings. Their employment in this study ensures that the results are robust to different estimation procedures, mainly where probable endogeneity and serial correlation are widespread in energy-economic data. This enhances the trust in the findings on the determinants of clean energy consumption in Scandinavian countries.

3. 9. CAUSALITY ASSESSMENT

To study the directional causality relationship between the consumption of clean energy and its determinants, the study employs Dumitrescu & Hurlin (2012), which is suited for the scenario of heterogeneous panel data. The test can allow for heterogeneity in the causality relationship across the cross-sectional units by providing for the potential cross-sectional dependence. The standard model employed to investigate causality from variable X to Y is specified as:

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{i,k} Y_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k} X_{i,t-k} + \varepsilon_{i,t} \tag{12}$$

where $i = 1, \ldots, N$ and $t = 1, \ldots, T$ with the null hypothesis $H_0 : \beta_{ik} = 0$ for all i and k, indicating no Granger causality. The test computes individual Wald statistics and averages them to get the panel statistic $\overline{W}$, which the Z-bar statistic is standardized to allow inferences to be made.

4. RESULTS AND DISCUSSION

4. 1. DESCRIPTIVE AND CORRELATION ASSESSMENT

The descriptive statistics reveal that clean energy consumption (CEU) in Scandinavian countries exhibits a moderate average with relatively low skewness, indicating reasonably evenly spread variations over time. Environmental taxation (ETR) and economic growth (ECG) have high means, indicating good budget policies and sustainable long-run economic growth. Green innovation (GRI) illustrates extensive variations, likely exhibiting divergence of policy applications, spending patterns, and technological changes around the region. Trade openness (TRD) and urbanization (URB) also have moderate dispersion, which denotes steady growth with variation. The skewness and kurtosis values show that most of the variables are not normally distributed, as evidenced by the Jarque-Bera test results that reveal potential non-normality in the data, hence the use of the log form of the data for subsequent analysis. The correlation matrix indicates positive associations between clean energy use and key indicators such as green innovation, trade openness, and economic growth, which can underpin the use of clean energy through technological advancement, increased market integration, and economic performance. Environmental taxation and urbanization have weaker correlations with clean energy use, and therefore, their impacts can be indirect or conditional on other moderating variables. These results provide fundamental knowledge of the dynamics that affect green growth in Scandinavian economies. Table 2 shows the results of the descriptive and correlation matrix.

Table 2. Descriptive and Correlation Matrix

Series	CEU	ETR	GRI	TRD	ECG	URB
Mean	39.1162	8521.3742	31.5953	78.2441	51108.5475	5220835.0956
Median	39.0000	8079.5518	25.5463	74.4809	49311.3391	4588124
Maximum	61.4000	15480.9942	91.8292	131.5432	79434.6256	9349997
Minimum	7.0000	2805.7612	5.7591	43.4814	27807.8615	3051994
Std. Dev.	16.3145	3141.3135	19.4437	14.9947	13200.2256	1696646.9512
Skewness	-0.3326	0.1561	1.0582	0.8623	0.5416	1.0238
Kurtosis	2.1166	2.1033	3.5075	4.2257	2.5141	2.7374
Jarque-Bera	6.9296	5.1090	26.8435	25.3675	7.9877	24.1514
Probability	0.0313	0.0777	0.0000	0.0000	0.0184	0.0000
Correlation Matrix						
	LNCEU	LNETR	LNGRI	LNTRD	LNECG	LNURB
LNCEU	1	0.0376	0.1024	0.0516	0.4659	0.0550
LNETR	0.0376	1	0.6276	0.6896	0.5095	0.4323
LNGRI	0.1024	0.6276	1	0.7206	0.0817	0.4270
LNTRD	0.0516	0.6896	0.7206	1	0.3290	0.3179
LNECG	0.4659	0.5095	0.0817	0.3290	1	-0.2572

LNURB3	0.0550	0.4323	0.4270	0.3179	-0.2572	1

Source: Author's own construction

4. 2. CROSS-SECTIONAL DEPENDENCE (CSD) AND SLOPE HOMOGENEITY TEST (SHT) ASSESSMENT

The evidence from tests for cross-sectional dependence (CSD) through the Breusch-Pagan LM, Pesaran scaled LM, bias-corrected scaled LM, and Pesaran CD in Table 3 indicates the presence of significant cross-sectional dependence for all the study variables. It suggests that economic and environmental drivers of clean energy consumption, ecological tax, green innovation, trade openness, economic growth, and urbanization are interconnected among Scandinavian countries. The reasons for such connections could be regional policies, financial ties, or common environmental goals. In addition, Slope Homogeneity Test results with highly significant Delta tilde and Adjusted Delta tilde statistics verify slope heterogeneity, which suggests discontinuities in the relationships between independent variables and clean energy consumption across countries, calling for the use of econometric methods allowing for cross-country heterogeneity. These findings warrant the application of robust estimation methods such as Driscoll-Kraay Standard Errors to control for cross-sectional dependence and heterogeneity in the study.

Table 3. Outcome of CSD and SHT

Series	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LNCEU	96.8177***	26.2168***	26.1562***	6.3432***
LNETR	183.2019***	51.1538***	51.0932***	13.5326***
LNGRI	164.8879***	45.8670***	45.8064***	12.8294***
LNTRD	102.1969***	27.7697***	27.7090***	9.6001***
LNECG	187.8651***	52.4999***	52.4393***	13.7055***
LNURB	196.5092***	54.9953***	54.9347***	14.0165***
SHT				
Delta tilde	15.738***			
Delta tilde Adjusted	17.661***			

Note: Significance levels: *** p<0.01

Source: Author's own construction

4. 3. STATIONARITY ASSESSMENT

Findings of the stationarity tests of the CIPS and CADF unit root tests indicate that the variables are non-stationary at their levels but stationary after first differencing at a 1% significance level. Specifically, variables like LNGRI and LNTRD are stationary at a level in the CIPS test but not in the CADF test, confirming some differences by methods. But because all the variables become stationarity in the first difference, the study recommends the presence of an I(1) process, which makes them eligible for long-run econometric modeling techniques such as Driscoll-Kraay Standard Errors (DKSE), Fully Modified OLS (FMOLS), and Dynamic OLS (DOLS). The results of the stationarity tests are shown in Table 4.

Table 4. Outcome of Stationarity Test

	CIPS		CADF	
Series	Level	First Difference	Level	First Difference
LNCEU	-0.924	-3.676***	-0.726	-3.229***
LNETR	-2.081	-5.905***	-1.359	-3.229***
LNGRI	-3.24***	-5.882***	-2.896***	-3.926***
LNTRD	-3.108***	-4.318***	-2.734***	-3.361***
LNECG	-2.051	-4.064***	-1.911	-2.852***
LNURB	-1.909	-3.262***	-1.909	-2.644***

Note: Significance levels: *** p<0.01

Source: Author's own construction

4. 4. COINTEGRATION ASSESSMENT

The Kao residual cointegration tests present substantial evidence of a cointegrating relationship between the variables as much as the ADF test statistic (3.3948) falls on the 1% level (p = 0.0003). Nonetheless, the results of Westerlund cointegration tests present mixed evidence. Even though the test statistics (*Gτ, Gα, Pτ, and Pα*) are significant at conventional levels, their respective p-values are all more than 0.01, thus implying no strong cointegration evidence. However, their respective robust P-values are all 0.0000, and the possibility of the variables being cointegrated at a higher probability level after correcting for cross-sectional dependence is inferred. In all, the evidence favors a relationship in the long run and, thus, the use of long-run estimation methods such as DKSE, FMOLS, and DOLS. The outcome of the cointegration test is shown in Table 5.

Table 5. Outcome of Cointegration Test

Kao Residual Cointegration Test			Westerlund			
	t-Statistic	Prob.		Test Statistics	P-value	Robust P-value
ADF	-3.3948***	0.0003		-1.3210***	0.9580	0.0000
Residual variance	0.0005			-1.0370***	0.9970	0.0000
HAC variance	0.0007			-1.3520***	0.9760	0.0000
				-0.9490***	0.9630	0.0000

Note: Significance levels: *** p<0.01

Source: Author's own construction

4. 5. DRISCOLL-KRAAY STANDARD ERRORS (DKSE)

The DKSE estimates in Table 6 yield the principal findings concerning the determinants of the utilization of clean energy in the Scandinavian countries. Different variables have an essential influence on finding the utilization level of clean energy, as represented in the estimates. The value of the environmental taxation coefficient is -1.4523, and statistical significance is at a 1% level. A negative sign suggests that an increase in ecological taxation reduces the use of clean energy. The findings, however, do not support the traditional assertion that ETR is a mechanism aimed at encouraging pollution reduction and the adoption of cleaner energy sources through an economic incentive (Sommer et al., 2022). This could be because environmental taxation focuses on discouraging the use of fossil fuel and promoting the use of cleaner alternatives to fuel; in the process, it also lifts the energy price in the short run, resulting in the use of clean energy being costly for firms and households (Su et al., 2023). Firms might also respond by curtailing energy use rather than adjusting precisely to cleaner fuel alternatives. The implication of the result suggests complementary policies such as subsidies on renewable energy and taxation credits on energy-efficient devices to reduce the adverse effect environmental taxation might have on using clean energy.

Green innovation significantly and positively contributes to using clean energy with a coefficient of 0.4856. This shows how green technology development, innovation, and environment-friendly innovations contribute considerably to increasing the use of clean energy resources (Saleem et al., 2022). Countries investing in technological innovations such as renewable energy storage plants, intelligent grid technology, and energy-efficient production technology consume more clean energy resources (Tan et al., 2021). This finding shows the need to continue investing in innovation and technology-based solutions to speed up the use of clean energy, as iterated in Esmaeilpour Moghadam & Karami (2024). Green patents supported by policy, investing in renewable energy start-ups, and industry-institution collaborative work could further improve this positive relationship (Senthil, 2022).

Trade openness carries a negative coefficient of -0.6726. The fact that the variable is negative suggests that increased transparency in trade might discourage clean energy consumption to some degree. This aligns with studies that showed fossil fuel consumption increases due to trade openness without the proper environmental protection policies (Iorember et al., 2019; Siddique & Alvi, 2025). One possible reason this result holds may lie in the fact that the process of trade itself can have both positive and negative effects on clean energy consumption. On the positive side, open trade enables importing cleaner production and technology methods (Li et al., 2021). On the negative side, however, it might lead to increased industrial production, energy use, and utilization of cheaper conventional energy sources (Han et al., 2022).

Economic growth significantly enhances the utilization of clean energy, as evidenced by its positive and statistically significant coefficient of 2.6703. This suggests that increased economic development leads to increased investments in clean energy sources, energy transition programs, and infrastructural development to support renewable energy investments, smart grid infrastructural development, and clean production technology (Yan et al., 2023). At a higher level of economic development, governments and private investors have the financial capacity to undertake renewable energy investments, infrastructural development for a smart grid, and investments in clean production technology. Wealthier economies also have better regulatory frameworks and green policies supporting clean energy use (Zhao et al., 2022). This agrees with the Environmental Kuznets Curve (EKC) theory, which states that economic development first leads to environmental degradation but ultimately to improved environmental quality as societies develop and increasingly prioritize sustainability (Ahmad et al., 2021).

Urbanization positively and significantly relates to clean energy consumption with a value of 1.2587. The finding confirms that clean energy consumption also grows as urbanization grows (Hussein & Basel, 2024). One possible reason could be that urban places typically have better infrastructures, higher technology adoption and awareness, and better environmental policies than rural places (Srinivasan et al., 2020). Urban areas have better chances of implementing strict emission standards and investing in renewable energy sources and energy-efficient building systems (Nematchoua et al., 2021). Furthermore, the urban agglomeration of people gives economies of scale, and thus, investing in clean energy becomes cheaper (Bai et al., 2024). This finding highlights the importance of urban planning policy towards clean energy consumption, for instance, implementing clean energy-based public transportation systems and energy-efficient building codes.

The model's explanatory power is relatively high, as evidenced by the R-squared value of 0.592, indicating that the independent variables explain around 59.2% of the variation in clean energy consumption. Adjusted R-squared (0.576) ensures the model fits well despite adjustment for the number of predictor variables. The f-statistic (15.8) and its p-value (0.000) imply that the model is statistically significant and indicates the joint effect of independent variables explaining a meaningful proportion of variance in clean energy consumption. Jarque-Bera test (7.478, p = 0.026) implies that the residuals are almost generally distributed with minor deviance from normality. Wald test (62.8181, p = 0.000) ensures joint significance of the explanatory variables, further supporting the model's reliability. Wooldridge test (8.458, p = 0.0621) bears no firm evidence of serial correlation and implies the model estimates as free from autocorrelation problems.

Table 6. Outcome of DKSE Model

Indicators	Coefficient	Drisc/Kraay Std Error	P-value
LNETR	-1.4523***	0.3021	0.0000
LNGRI	0.4856***	0.0901	0.0000
LNTRD	-0.6726*	0.3667	0.0760
LNECG	2.6703***	0.3829	0.0000
LNURB	1.2587***	0.2148	0.0000
Constant	-13.1897***	2.4438	0.0000
Diagnostic Test			
R-squared	0.5923	Jarque Bera test	7.478 (0.026)
Adjusted R-squared	0.5766	Wald test	62.8181 (0.000)
F-Statistics	15.8***	Wooldridge test	8.458 (0.0621)
Prob (F-Statistics)	0.0000		

Note: Significance levels: *** p<0.01, * p<0.1

Source: Author's own construction

4. 6. ROBUSTNESS CHECKS

The results of the robustness tests using FMOLS and DOLS provide additional evidence and, for the most part, support the main findings of the Driscoll-Kraay Standard Errors (DKSE) model, but with some variation in signs and sizes of coefficients. For FMOLS and DOLS, LNETR retains a statistically significant and negative effect on CEU, consistent with the DKSE result, though the effect size is smaller in FMOLS (-0.3597) and DOLS (-0.5534) compared to DKSE (-1.4523). LNGRI shows a positive and significant correlation with CEU in every model, affirming its crucial part in guaranteeing clean energy: FMOLS (0.5086), DOLS (1.0139), and DKSE (0.4856). Interestingly, LNTRD positively and significantly affects CEU in FMOLS (1.2815) and DOLS (1.0843), contrary to the negative impact in DKSE (-0.6726), implying that under cointegration-based approaches, trade could promote CEU, perhaps through the importation of green technologies. Also, LNECG negatively affects CEU in FMOLS (-0.4828) and DOLS (-1.0136), contrary to the positive relation in DKSE (2.6703). This discrepancy may be explained by how endogeneity and dynamics are handled in the models, implying a cautious interpretation of the contribution of economic growth. Lastly, LNURB is negative in FMOLS (-0.0136) but positive and significant in DOLS (0.7239), which is different from the positive DKSE result (1.2587). Overall, while Green Innovation and Environmental Taxation show strong effects throughout specifications, Trade Openness, Economic Growth, and Urbanization display model-dependent dynamics, which confirms the necessity of robustness tests for empirical studies. The outcome of the FMOLS and DOLS tests is shown in Table 7.

Table 7. Outcome of Robustness Checks

FMOLS				DOLS		
Variable	Coefficient	t-Statistic	Prob.	Coefficient	t-Statistic	Prob.
LNETR	-0.3597***	-7.1114	0.0000	-0.5534***	-3.5637	0.0007
LNGRI	0.5086***	8.7391	0.0000	1.0139***	11.1261	0.0000
LNTRD	1.2815***	22.6875	0.0000	1.0843***	3.8627	0.0003
LNECG	-0.4828***	-14.2791	0.0000	-1.0136***	-4.0712	0.0001
LNURB	-0.0136***	-3.5454	0.0006	0.7239***	5.7708	0.0000
R-squared	0.9166			R-squared	0.9708	
Adjusted R-squared	0.9112			Adjusted R-squared	0.9391	

Note: Significance levels: *** p<0.01

Source: Author's own construction

Our finding of an adverse short-term effect of environmental taxation on clean energy use aligns with Su et al. (2023), who argued that such taxes might initially increase energy costs, discouraging immediate adoption of clean energy. The positive role of green innovation in promoting clean energy use is consistent with Saleem et al. (2022) and Tan et al. (2021), who found that technological development enhances renewable energy uptake. Our result indicating the ambiguous influence of trade openness is comparable to Iorember et al. (2019) and Siddique & Alvi (2025), who reported mixed outcomes depending on the trade structure and environmental policies of the countries studied. The positive relationship between economic growth and clean energy use supports the Environmental Kuznets Curve hypothesis, as noted in Ahmad et al. (2021). Lastly, the positive impact of urbanization aligns with findings from Hussein & Basel (2024) and Srinivasan et al. (2020), who documented the enabling role of urban infrastructure in fostering clean energy transitions.

4. 7. CAUSALITY ASSESSMENT

The panel causality test results in Table 8 confirm strong causal connections between variables for the CEU of Scandinavian countries. The test shows unidirectional causality from LNETR to LNCEU, demonstrating that changes in environmental taxation measures significantly influence clean energy consumption but not vice versa. Similarly, LNGRI causes CEU, with the implication being that the advancement of green technology will spur the use of clean energy, yet CEU does not cause green innovation. Also, CEU causes LNURB, which implies that using more clean energy will result in cleaner cities. However, urbanization does not do much in terms of influencing clean energy in this instance. There is uni-causality between LNETR and LNGRI, implying that higher environmental taxes can stimulate green technology innovation. Interestingly, the test shows a bi-causal relationship between LNECG and LNTRD, implying a reinforcing relationship where economic growth and trade openness influence each other. Moreover, LNECG stimulates LNGRI, LNTRD, and LNURB, supporting its central role in driving technological progress and structural transformation in favour of clean energy. Lastly, LNURB stimulates LNTRD. Thus, urbanization can boost foreign trade activity. These causal relations point to the complex interrelation among fiscal, technological, economic, and urban drivers in developing the utilization of clean energy within Scandinavia, with Environmental Taxation and Economic Growth as key agents.

Table 8. D-H Panel Causality Tests

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.	
LNETR ≠> LNCEU	6.9110	4.0601	0.0000	Uni-directional
LNCEU ≠> LNETR	1.4628	-0.5958	0.5513	
LNGRI ≠> LNCEU	4.1567	1.7063	0.0879	Uni-directional
LNCEU ≠> LNGRI	0.8223	-1.1432	0.2529	
LNURB ≠> LNCEU	2.8138	0.5588	0.5763	
LNCEU ≠> LNURB	7.7305	4.7605	0.0000	Uni-directional
LNGRI ≠> LNETR	3.9465	1.5267	0.1268	
LNETR ≠> LNGRI	8.7964	5.6714	0.0000	Uni-directional
LNURB ≠> LNETR	1.0501	-0.9485	0.3429	
LNETR ≠> LNURB	5.7918	3.1037	0.0019	Uni-directional
LNECG ≠> LNGRI	8.4312	5.3593	0.0000	Uni-directional
LNGRI ≠> LNECG	2.2662	0.0907	0.9277	
LNECG ≠> LNTRD	7.0372	4.1680	0.0000	Bi-directional
LNTRD ≠> LNECG	5.6637	2.9942	0.0028	
LNURB ≠> LNTRD	4.9898	2.4183	0.0156	Uni-directional
LNTRD ≠> LNURB	3.0798	0.7860	0.4319	
LNURB ≠> LNECG	3.8176	1.4166	0.1566	
LNECG ≠> LNURB	6.0639	3.3362	0.0008	Uni-directional

Source: Author’s own construction

5. CONCLUSION AND POLICY RECOMMENDATIONS

5. 1. CONCLUSIONS

The research is rooted in the Energy Transition Theory that analyses the process of this shift as a very complex socio-technical process made up of niche innovations, socio-technical regimes, and broader landscape developments to present the view that this transition is from fossil fuels to new energies. The application of this theoretical framework will be developed for the clean energy transition in Scandinavian countries due to the specificities of their institutional, economic, and geographical contexts. The study will prove this theory regarding the particular conditions under which environmental taxation (ETR) and green innovation (GRI) act as landscape- and niche-level drivers, respectively, while trade openness (TRD), economic growth (ECG), and urbanization (URB) influence the socio-technical regimes. The results related to the hypothesis are that the theory indicates that green innovation and economic growth are positively related to clean energy use. At the same time, environmental taxation, although intended, has a short-term adverse effect by increasing energy costs. This proves the theory’s premise that energy transitions result from several factors working at different levels.

Empirical results from the study also substantiate the Environmental Kuznets Curve (EKC) hypothesis, which avers that economic development causes environmental degradation until societies mature enough to emphasize sustainability. The threshold for attaining a sustainable economy in Scandinavian countries is typically linked to higher income per capita, enabling significant investments in clean energy technologies and green innovations. This income level allows for the prioritization of environmental sustainability over industrialization-driven degradation. The proven relationship establishes a positive relationship between economic growth and clean energy in Scandinavia, further alluding to societies' ability to invest in renewable energy and green technologies as their income level progresses. Nonetheless, the mixed results concerning trade openness and urbanization hint that their effects may be context-dependent, thus underscoring the theory's assertion on energy transition pathways variability under different institutional and economic settings. In summary, this research validates theoretical frameworks. It provides a way to guide policymakers on optimizing the mixture of monetary, technological, and urban planning instruments for an incredible speed in the transition to cleaner energy.

5. 2. POLICY RECOMMENDATIONS

The empirical outcomes derived from the study furnish an unquestionable basis for formulating specific policy recommendations aimed at hastening the clean energy transition in Scandinavian countries. Whereas environmental taxation (ETR) is a much-popularized method of discouraging fossil fuel use, its unintended short-run adverse effects on encouraging the adoption of clean energy technologies warrant the urgent consideration of supplementary interventions. In addition to environmental taxation, the compensatory funding measures that need to be directed towards renewable energy projects and tax credits for energy-efficient technologies will certainly assist households and businesses in countering the rise in energy prices. This would ensure a relatively smoother transition towards cleaner energy sources and safeguards against losing economic competitiveness. Besides, the robust positive correlation between green innovation (GRI) and clean energy usage affirms that value must be profoundly attested to green technology R&D; accordingly, governments must expedite the funding of innovative renewable energy storage, smart grid solutions, and energy-efficient production processes, while fostering joint efforts between the industrial sector, academia, and policymakers to hasten the implementation of innovative clean energy solutions.

These two above-mentioned areas make up an opportunity for expedited clean adoption of energy: First, economic growth (ECG) and urbanization (URB) positively correlate with each other and with clean energy use. The same reasoning applies to facilitate clean energy use by economic growth. Since clean energy implementation thrives on infrastructure development and maintenance, part of the economic gains should go into constructing renewable energy infrastructure (solar and wind farms) and modernizing energy grids. Additional efforts can be derived from facilitating the private sector through investment incentives like green bonds and public-private partnerships. On the other hand, urbanization embodies concentrations in infrastructure and technology adoption, thus providing another avenue for promoting clean energy. Therefore, understanding clean energy within urban planning should involve energy-efficient building codes, clean energy-based public transportation systems, and smart city technologies to optimize energy use. Trade openness (TRD), being mildly ambiguous to the outcome, implies that trade and accompanying policies will determine how useful it will be in clean energy matters. Governments must encourage sustainable trade by rewarding the import and export of green technologies and renewable energy equipment so that trade can be an accelerator instead of an obstacle to the clean energy transition. The interlinkage between environmental taxation, green innovation, economic growth, and urban planning makes for a compact policy framework through which Scandinavian countries can accelerate their transition into clean energy and set an example for other regions in the sustainable development paradigm.

5. 3. LIMITATIONS AND FUTURE RESEARCH AGENDA

The study has several limitations, which bring forth opportunities for future work. First, it is directed at Scandinavian countries to limit generalizability toward others about economic, institutional, and geographical differences. Given the unique socio-economic, institutional, and geographical context of Scandinavian countries, the findings may not directly apply to regions with differing economic conditions, governance structures, or levels of renewable energy infrastructure. The distinct policy frameworks and societal values in Scandinavia, which prioritize environmental sustainability, could limit the generalizability of the results to countries where such factors are less pronounced. Future attempts could also include other developed and developing countries for a better view of differences in the way these features differ across contexts. Longitudinal studies could provide insights into the long-term effects of environmental taxation on increased clean energy adoption. Third, the research does not consider the cultural and governance factors that might significantly affect clean energy transitions. Incorporating such variables in future research could reveal a much more nuanced understanding of increased clean energy usage.

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