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RESEARCH ARTICLE

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Are green resource productivity and environmental technologies the face of environmental sustainability in the Nordic region?

Andrew Adewale Alola[1,2] | Tomiwa Sunday Adebayo[3]

[1]Department of Economics, School of Accounting and Finance, University of Vaasa, Vaasa, Finland

[2]Department of Economics and Finance, South Ural State University, Chelyabinsk, Russia

[3]Department of Economics, Faculty of Economic and Administrative Science, Cyprus International University, Mersin, Turkey

Correspondence
Andrew Adewale Alola, Department of Economics, School of Accounting and Finance, University of Vaasa, Finland.
Email: andrew.alola@uwasa.fi

Abstract

This study examines whether the raw material productivity, export intensification, and environmental-related technologies in the Nordic region (i.e., Denmark, Finland, Iceland, Norway, and Sweden) drives the region's carbon neutrality target. By adopting both symmetric and asymmetric empirical approaches over the period 1990–2019, the study found that positive and negative shifts in environmental-related technologies mitigates greenhouse gas (GHG) emissions in the region with the former causing a larger impact. Furthermore, the findings reveal that a positive shift in raw material productivity mitigates GHG emissions while a negative shift in raw material productivity causes a surge in GHG emissions especially in the long-run. Moreover, a positive (negative) shift in export intensity yields a decline (upsurge) in GHG emissions in the long-run. In the symmetric framework, in both long- and short-run, the result reveals that economic growth upsurges GHG emissions while raw material productivity for green growth and environmental-related technologies mitigates GHG emissions. This demonstrates the efficient raw material productivity profile of the Nordic countries. Alongside the Granger causality inference, the result further informs that energy intensity is crucial to curbing GHG emissions in the region. Thus, the result from the study offers relevant policy instructions.

KEYWORDS

environmental technologies, material and export intensity, Nordic region, resource productivity, sustainable development

1 | INTRODUCTION

Raw materials are essentially of high critical value across the globe and especially in the European region based on the economic importance and associated supply risk. Essentially, being the core base of industrial activities and the production of goods and services that are utilized in everyday life, raw materials are important linked with modern technology (such as in smartphone), industry (such as in non-energy materials), and the environment (in clean technologies) (European Commission, 2022). Thus, thriving for economy's green growth potential, otherwise reparametrized as the resource productivity, the output level relative to (raw) material utilization provides information about the seemingly complex pathway to green output. Moreover, the drive toward green growth is not without sustainable benefit to the environment. For instance, as illustrated in Figure 1, the pathway toward resource productivity in the European Union

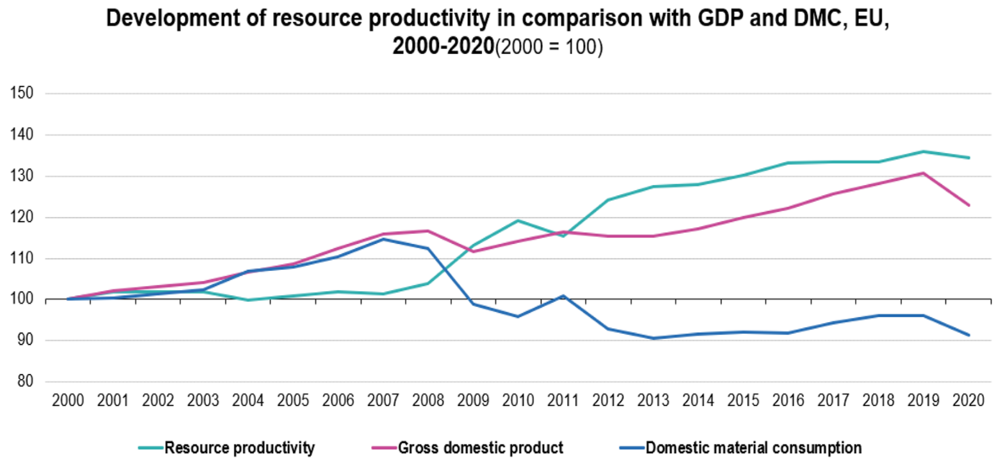

FIGURE 1 European Union's resource productivity, gross domestic product (GDP), and domestic material consumption. *Source*: European statistics [Colour figure can be viewed at wileyonlinelibrary.com]

reportedly followed distinct pre- and post-global financial crisis (2007–2008) scenarios. Considering the environmental and climate change challenges that arises from the greenhouse gas (GHG) emissions as largely associated with material resource utilization, efficient resource productivity and environmental sustainability goals remained paramount to several leading economies across the globe.

Interestingly, at the forefront of advancing green transition and sustainable economy are Denmark, Finland, Iceland, Norway, and Sweden (NordForsk, 2022). By forging toward becoming the world's most sustainable and integrated region by 2030, the region is leaning on its recently drafted "Action plan for Vision 2030" to implementation from 2021 to 2024 (Nordic Co-operation, 2022). Moreover, through the Nordic cooperation for sustainable development, the region is now well-positioned as a leading force in pursuing a sustainable environment and carbon neutrality. Notably, the Nordic's natural resources, such as the large forest resources for timber and other use, iron ore reserves from mineral resources (especially in Sweden), and fishery and energy sources (especially in Iceland and Norway), have remained important export products and development for decades. In general, the rich natural resources abundance of the Nordic countries has remained a significant part of the countries' material utilization for both domestic and export purposes. For instance, Denmark's arable land endowment has made agriculture part of the country's, thus making Denmark a net exporter of food industry products while some of the countries are known net exporters in telecommunications and clean energy technologies alongside other resource-intensive products (Nordics info, 2019).

Given the above highlight about the Nordic countries especially from the perspectives of material and export intensification profile, the current study further explores the region's ambitious goals toward decarbonization by 2050. As an objective, this study is designed to investigate the role of raw material productivity (RMP), export intensity (EI), and the advancement of environmental-related technologies (ERT) in the region's pursuit of environmental sustainability via a low GHG emission. Thus, the baseline questions of the study are: (i) whether each of aforementioned indicators exert a significant long-run influence on GHG emission in the region, and (ii) whether there is a quantifiable asymmetric impact of these indicators on GHG emission. So far, both panel and country-specific studies have been carried out on the trend of environmental sustainability in the Nordic region considering that there is limited information about the role of EI (measured as the amount of exports in kilogram per United States Dollars) on environmental sustainability. In addition to the study's novelty, the efficiency of the region's resource productivity and its success in ERT is brought to bear on the metric of environmental sustainability. Meanwhile, the aforementioned frameworks are performed under symmetric and asymmetric conditions. Furthermore, depending on the circumstances, not all policy instruments may have the ability to concurrently enrich policy strategy especially when lag effect is not accounted for in an investigation. These components must be taken into account when choosing the research approach. Therefore, the nonlinear panel autoregressive distributed lag (ARDL) that combines the approaches in the studies of Shin et al. (2014) and Pesaran et al. (2001). This econometric approach assists in evaluating the asymmetric interrelationship between GHG emissions and the regressor. By extending the literature on green economy in the Nordics (Khan et al., 2021), the results from this study are potential additions to strategic policy tools for decision-makers toward complimenting greening economy pursuit in the region.

The remainder of this article is organized as follows: The literature review is presented under the heading "review of related studies" while the "Data" heading is reserved for the description of the dataset. The methodology and results from the empirical examination come under the heading "methodology" and "findings and discussion." Finally, the summarized information about the study and the recommended policy relevance are presented under the section "conclusion and policy recommendation."

2 | REVIEW OF RELATED STUDIES

Earlier studies such as Holdren and Ehrlich (1974) offered useful information on the environmental effect of material utilization, population, and technology-related aspects. Following this early revelation, environmental dimensions of the specificity of resource use (such as energy and [non]metallic ores) and socioeconomic aspects (such as globalization, policy uncertainties, etc.) have continued to dominate the literature. More recently, especially as the world continues to intensify its campaign for carbon neutrality plan, the role of environmental-related and clean energy technologies in emissions mitigation are being extensively examined.

One significant indicator that have been widely examined as a contributor to environmental deterioration is income or affluence as measured by the gross domestic product (GDP). Even though quality of life is favorably correlated with per capita income, environmental drawback is often associated with per capita income due to the rise in the desire for goods which are produced from a significant amount of energy (Adebayo et al., 2022; Balsalobre-Lorente et al., 2018). In this section, three subsequent sub-sections are reserved to detailed other determinants of GHG emissions.

2.1 | Environment and ERT

Both advanced and emerging nations worldwide are looking for new solutions to curb ecological deterioration. One of the most well-known and effective methods for mitigating ecological damage is through environmental technologies. Eco-innovation assists countries in reorienting their industries toward green technologies like renewable sources of energy (Acheampong, Dzator, et al., 2022; Yu & Du, 2019). The literature that is currently available on eco-innovation has highlighted many ways that eco-innovation might enhance ecological integrity (Cetin et al., 2021). These developments improve the cutting-edge technical applications, which immediately lower energy use and improve energy efficiency. Eco-friendly technology also significantly aids in economic transformation and improvement. To lessen ecological deterioration, it is doing this by transforming conventional economic development, which depends on conventional production components, into an innovation-driven style (Gupta et al., 2022). Through their direct and indirect effects, eco-friendly technologies can contribute to reducing ecological damage. Ecofriendly technologies also indirectly influence other factors, including the development of renewable resources, energy efficiency, and the green and efficient use of traditional resources (Costantini et al., 2017). Most research in the earlier literature shows a bad correlation between innovation and ecological deterioration. Moreover, Ibrahim and Ajide (2021) have reinterpreted the role of green innovation in ecological sustainability. Their empirical findings demonstrate that, over the long run, green innovation assists the sample of highly fiscally decentralized nations to reduce ecological deterioration. Parallel to this, Ali et al. (2021) went into detail on innovation's beneficial effect in improving ecological integrity in the advanced states. The wavelet approach was employed by Adebayo and Kirikkaleli (2021) to investigate how technological advancements affect ecological sustainability. According to the report, technological advancement is a crucial cause of environmental destruction in Japan. Likewise, Obobisa et al. (2022) used data from 2000 to 2018 to evaluate the nexus between innovation and environmental deterioration in 25 African countries. The study results show that green innovation boosts ecological sustainability.

2.2 | Environment and energy intensity

Although there is sparse literature on the environmental effect of EI, the related aspects of export activities that affect environmental quality abound in the literature (Acheampong, Shahbaz, et al., 2022; Fareed et al., 2021; Zafar et al., 2022). Specifically, using the Fourier quantile causality, the empirical approach of Fareed et al. (2021) considered the case of Indonesia. It examined the impact of export diversification and non-conventional energy utilization on the load capacity factor over the quarterly period 1965Q1–2014Q4. The result of the investigation implies that nonconventional energy and diversification of export activities are significant causals of environmental quality, especially from the middle to higher quantiles. Moreover, in the study of Bas et al. (2021) for the case of Turkey over the period 1991–2019, econometric approaches were employed to examine the impact of value-added from agriculture, export, share, and merchandize goods, among other factors, on environmental quality. Importantly, the result revealed that value-added from export activities is significant enough to mitigate carbon emission in Turkey. Similarly, Shokoohi et al. (2022) study using the populous Middle East countries on the EI-environment nexus using data between 1971 and 2015 documented that EI triggers growth in ecological destruction. Moreover, Chen et al. (2019) evaluate the role of EI on the ecosystem in Chinese provinces. The study employed panel methods with 18 years of panel data. The result gathered disclosed that emissions intensification is caused by intense EI.

2.3 | Environment and RMP for green growth

The recent work of Adebayo et al. (2022) is a recent study that examined the impact of the interaction between natural resources and globalization on environmental quality of the newly industrialized countries. By employing empirical approaches via the fully-modified ordinary least squares and the Method of Moments Quantile Regression, the investigation establishes that globalization moderates natural resources to improve environmental quality in the examined countries. Meanwhile, without considering the moderating effect of globalization, the role of domestic material consumption in environmental quality has been established in the literature (Alola et al., 2021; Baniya & Aryal, 2022; Usman et al., 2022). By using different empirical approaches, both Alola et al. (2021) and Usman et al. (2022) established that domestic material consumption worsens environmental quality in the panel of 28 European Union member countries.

In spite of the above-illustrated literature, there is a glaring gap in the literature on the specificity of both export intensification and material productivity, especially for the Nordic countries. Thus, following the outlined approach, the result from the current study provides extensive information to the existing literature.

3 | DATA, THEORETICAL UNDERPINNING, AND METHODS

3.1 | Data

The study utilizes data on GHG, and EI obtained from the database of World Development Indicators (WDI). Moreover, ERT data is obtained from the database of OECD. In addition, RMP for green growth and economic growth (GDP) is obtained from Global Material Flows Database. Furthermore, GHG is measured in thousand tons, GDP is measured in constant 2015, EI is measured in kg/USD, RMP is measured in USD/KG and ERT is measured in % of all technologies. The timeframe of the data (1990–2019) is based on the unavailability of data beyond 2019. The study utilized the Nordic nations (Norway, Denmark, Finland, Iceland and Sweden) to assess GHG drivers. Despite the data limitations, it is crucial to emphasize that our sample includes all NORDIC countries. This gives us a broad picture of the relationship between ERT, GDP, EI and GHG. The parameters are expressed in their natural logarithm form to reduce skewness and ensure conformity to normal distribution. Table 1 shows the most common descriptive statistics for the variables under investigation. Figure 2a–d presents the connection between GHG and the regressors (ERT, GDP, RMP, and EI). The observations from Figure 1a–d provide insight into the nonlinearities in the interrelationship between GHG and ERT, GDP, RMP and EI. The outcomes of the Jarque–Bera strengthen this instinct. The flow of analysis is presented in Figure 3.

3.2 | Theoretical background

The current research has split the impacts of income, on environmental quality into scale, technique, and composition effects from a theoretical standpoint. Economic operations (such as assembling, waste management and manufacturing, among others) have the impact of scaling up levels of pollution in a proportionate way (Ahmad et al., 2020; Obobisa et al., 2022). The technique effects become apparent later when the economy is doing well and, through lowering ecological pollutants, contribute to more substantial technological advancements. The composition effects shows the economy's production composition, which has unclear consequences on the environment (Magazzino & Giolli, 2021). According to the comparative advantage, a nation with open commerce might, for example, have one of two effects on the concentration of pollutants (factor endowment and pollution policy). The factor endowment hypothesis argues that high-income countries with sufficient capital will have a comparative advantage to export polluting goods and services (Fareed et al., 2021; Zafar et al., 2022). This narrative is further consistent with the Heckscher–Ohlin theory, which illustrates that the country should design the manufacturing and export product basket as per its factor intensity of manufacturing (Ozturk & Acaravci, 2016; Ullah et al., 2020).

Patent serves as a measure of technological innovation since it documents firm's internal research and development (R&D) activities. Environmental technologies patent applications serve as a useful proxy for environmental breakthroughs. Though literature discusses the relationship between CO_2 and renewable energy and economic expansion, the lack of technological progress substantially impairs the validity of this research. Since technological progress is essential to maximizing the efficiency of current machinery in both unconventional and traditional energy generation and usage, it also assists in exploring new renewable energy technologies. For instance, the energy sector is being revolutionized by the increased efficiency of wind, biomass, solar, and hydro energy; LED lighting for industrial and domestic use; hybrid electric vehicles; Hyperloop for the transportation sector, smart irrigation systems for agriculture, which of course does have a direct impact on the ecosystem. Recent empirical research (such as Ahmad et al., 2020; Gupta et al., 2022; Lin & Ma, 2022; Yu & Du, 2019) examined how innovation affects ecological integrity. These studies generally agree that technological advancement and innovation have a beneficial effect on environmental quality, which is sometimes referred to as the technical effect.

RMP is regarded as a critical strategy for attaining poverty reduction and sustainable development. Furthermore, it is especially important for attaining sustainable development because it has the power to meet both environmental and economic sustainability. It is seen as both economically competent and crucial for the future of Nordic

TABLE 1 Descriptive statistics

	GHG	GDP	ERT	EI	RMP
Mean	39528.69	2.43E+11	10.25500	0.309635	1.441442
Median	35533.40	2.55E+11	8.245000	0.233050	1.600350
Maximum	95911.08	5.46E+11	33.33000	0.680600	2.262100
Minimum	12565.19	8.58E+09	1.860000	0.153300	0.443900
SD	21631.27	1.42E+11	5.530880	0.159165	0.503317
Skewness	0.599964	−0.243677	1.139132	1.093774	−0.381319
Kurtosis	2.488132	2.408456	4.145183	2.559119	1.865677
Jarque–Bera	10.63646	3.671492	40.63708	31.12341	11.67691
Probability	0.004901	0.159494	0.000000	0.000000	0.002913

Abbreviations: EI, export intensity; ERT, environmental-related technologies; GDP, gross domestic product; GHG, greenhouse gas; RMP, raw material productivity.

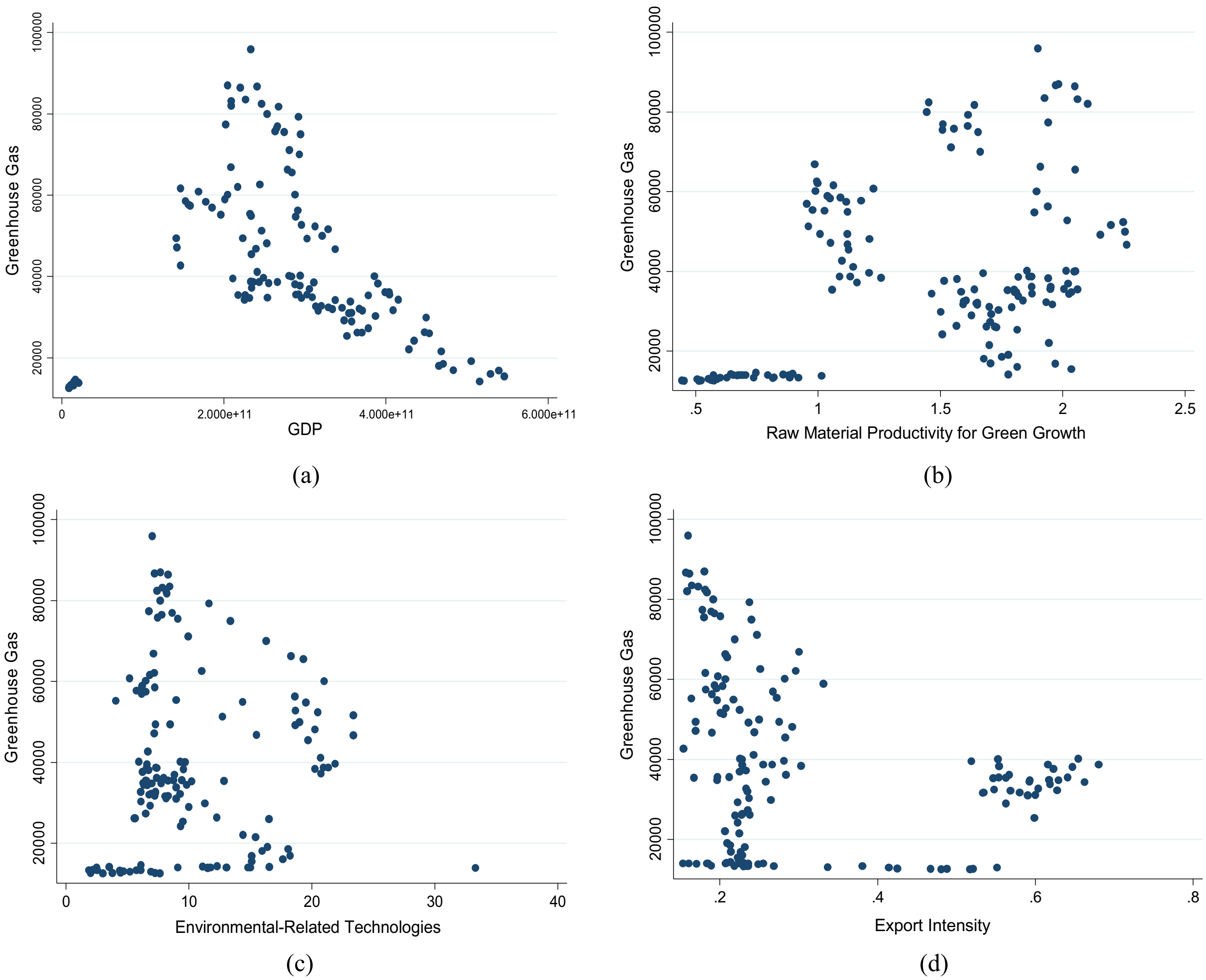

FIGURE 2 (a) Greenhouse gas–gross domestic product (GHG–GDP) nexus in Nordic nations. (b) GHG–raw material productivity (RMP) nexus in Nordic nations. (c) GHG–environmental-related technologies (ERT) nexus in Nordic nations. (d) GHG–export intensity (EI) nexus in Nordic nations [Colour figure can be viewed at wileyonlinelibrary.com]

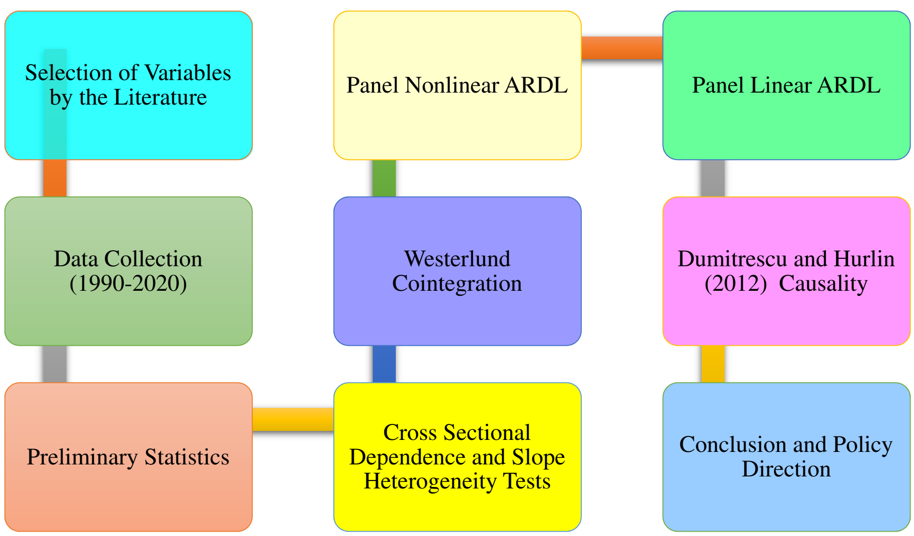

FIGURE 3 Flow of analysis [Colour figure can be viewed at wileyonlinelibrary.com]

nations as it can yield enormous economic and social benefits. Similar results are communicated by the study of Usman et al. (2022), which reported that green growth lessens emissions.

3.3 | Methodology

Following the highlighted theoretical framework from extant literature as indicated in the previous section, the following models are designed to evaluate the asymmetric effect of ERT, RMP, and EI on GHG.

$$\text{GHG}_{it} = f\left(\text{GDP}_{it}, \text{RMP}^{+}_{it}, \text{RMP}^{-}_{it},\right) \tag{1}$$

$$\text{GHG}_{it} = f\left(\text{GDP}_{it}, \text{ERT}^{+}_{it}, \text{ERT}^{-}_{it},\right) \tag{2}$$

$$\text{GHG}_{it} = f\left(\text{GDP}_{it}, \text{EI}^{+}_{it}, \text{EI}^{-}_{it},\right) \tag{3}$$

where; GHG, GDP, ERT, EI, and RMP depict greenhouse gas, economic growth, environmental-related technologies, energy intensity, and raw material productivity for green growth. The partial negative and positive decomposition are depicted by a superscript $-$ and $+$, respectively.

3.4 | Heterogeneity and unit root tests

Though the data description in the preceding section showed the heterogeneity of our data and the possibility of nonlinearities between GHG and the independent variables, it is critical to test this utilizing econometric instruments. The initial reaction will be to investigate the data's stochastic qualities using a unit root test. For large panel data, such as that presented in this research, the existence of a unit root must be investigated. We explore the studies on unit root testing to see which tests could be used to test for stationarity while also pointing to an indication of heterogeneity. One of the decent options seems to be CIPS initiated by Pesaran (2007). The null and alternative hypotheses are homogeneous non-stationarity and heterogeneous alternatives. In addition, the test works in the face of CD, which is a common problem in panel investigation. The Pesaran (2007) test is more effective than other prior tests (first generation tests) because of these characteristics. Equation (4) presents the CIPS as follows:

$$\text{CIPS}(N,T) = N^{-1}\sum_{i=1}^{N} t_i(N,T) \tag{4}$$

The Pesaran (2004) CD test, is utilized to identify the absence or presence of cross-sectional dependence. The test can be used in large panels and is ideal for dynamic panel designs. Equation (5) presents the CD test as follows:

$$\text{CD} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum\nolimits_{j=i+1}^{N}\widehat{p}_{ij}\right) \tag{5}$$

3.5 | Westerlund cointegration

When dealing with large panels of data, investigating cointegration is critical since it enables for the avoidance of misleading regression issues when the variables have unit roots. The study proceeds by testing for cointegration between the variables before they are decomposed into positive and negative parts. Cross-sectional dependence may be a concern when studying cointegration, much as it is with panel unit root tests. The panel cointegration test initiated by Westerlund (2007) is used to eliminate the likelihood of cross-sectional dependence. It computes robust *p* values based on bootstrap replications to account for CD in the data. Four test statistics are used to construct the test. The test uses an error correction model to determine whether or not there is cointegration in the whole panel or specific panels. The G_t and G_a test statistics, on the one hand, test the null hypothesis of "no cointegration" for at least one of the cross-sectional units. Individual weighted average method and individual t-statistic are used in these statistics. As a result, dismissing the G_t and G_a null hypothesis implies that at least one of the cross-sections is cointegrated. The P_t and P_a test statistics, on the flip side, test the null hypothesis of "no cointegration" for all panels. These statistics utilize a cross-section pooling procedure, and rejecting the null hypothesis indicates that the parameters in the panel as a whole are cointegrated. The general form of this test are as follows:

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \tag{6}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{T\acute{\alpha}_i}{\acute{\alpha}_i(1)} \tag{7}$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \tag{8}$$

$$P_\alpha = T\acute{\alpha} \tag{9}$$

where; the alternative and null hypotheses are "no cointegration" and "cointegration exists" respectively.

3.6 | Asymmetric panel ARDL

The panel ARDL model or pooled mean group (PMG) was developed by Pesaran and Shin (1995) and Pesaran et al. (1999) to estimate non-stationary dynamic panels. PMG is utilized to evaluate the long- and short-run relationships between variables, as well as to look into heterogeneous dynamic issues across nations. The basic form of an ARDL panel or PMG model is as follows:

$$Y_{it} = \sum_{j=1}^{p}\lambda_{ij}Y_{i,}t-j + \sum_{j=0}^{q}\delta^{\prime}_{ij}X_{i,} + \mu_i + \varepsilon_{it} \tag{10}$$

where the dependent variable is depicted by Y_{it}, the vector of the independent variables is depicted by X_{it} is ($k \times 1$), the fixed effect is illustrated by μ_i, lagged dependent variable coefficient is denoted by λ_{ij}, the coefficient vector of the regressor is depicted by δ_{ij} is $(k \times 1)$, the number of cross-section is illustrated by i (1, 2, …, N), time is depicted by t (1, 2, … T) and error term is shown by $\varepsilon_{it.}$

Equation (10) can be re-structured as a vector error correction model as follows:

$$\Delta Y_{it} = \theta_i ECT_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,}t - j + \sum_{j=0}^{q-1} \delta_{ij}^{*\prime} \Delta X_{i,}t - j + \mu_i + \varepsilon_{it} \tag{11}$$

where: $ECT_{it} = \emptyset_i Y_{i,t-1} - \beta_i^{\prime} X_{i,t.}$

The ECT parameter θ_i gives the adjustment speed. Moreover, the rate of adjustment of a parameter toward a long-run balance is depicted by ECT, whereas the short-run convergence is depicted by the negative sign. Nevertheless, the study objective is to evaluate the asymmetric effect of ERT, RMP, and EI on GHG in panel form. Shin et al. (2014) offered the outline for nonlinear ARDL (NARDL) founded on Pesaran et al. (2001) and Pesaran et al. (1999) linear ARDL model. In order to decompose a stationary variable into negative and positive shifts, Shin et al. (2014) followed the methodology of Granger and Yoon (2002). Therefore, the two portions of the partial sum for a variable X are:

$$X^{+} = \sum_{j=1}^{t} \Delta X_j^{+} = \sum_{j=1}^{t} \max\left(\Delta X_{j,} 0\right) \tag{12}$$

$$X^{-} = \sum_{j=1}^{t} \Delta X_j^{-} = \sum_{j=1}^{t} \min\left(\Delta X_{j,} 0\right) \tag{13}$$

In a nonlinear structure, the long-run relationship between Y and X is expressed as:

$$Y_t = \beta^{+} X_t^{+} + \beta^{-} X_t^{-} + \mu_t \tag{14}$$

$$X_t = X_0 + X_t^{+} + X_t^{-} \tag{15}$$

where, the long-run parameters are depicted by β^{+} and β^{-} and the scalar for decomposed partial sum are illustrated by X^{+} and X^{-}.

This research merged Shin et al. (2014) NARDL methodology and Pesaran et al. (1999) panel ARDL methodology to estimate the panel nonlinear ARDL (PNARDL) to accomplish the study objectives. As a result, this panel nonlinear ARDL approach has three advantages over NARDL and panel ARDL. First, it determines the asymmetries in the data. Second, it calculates the data's heterogeneity effect. Finally, it is more suited when variables are stationary at mixed order. Hence the PNARDL is specified as follows:

$$\Delta Y_{it} = \theta_i ECT_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta Y_{i,}t - j + \sum_{j=0}^{q-1} \left(\delta_{ij}^{*\prime +} \Delta X_{i,}^{+} t - j + \delta_{ij}^{*\prime -} \Delta X_{i,}^{-}\right) + \mu_i + \varepsilon_{it} \tag{16}$$

where: $ECT_{it} = \emptyset_i Y_{i,t-1} - \left(\beta_i^{\prime} X_{i,t}^{+} + \beta_i^{\prime -} X_{i,t}^{-}\right)$

4 | FINDINGS AND DISCUSSION

The research's empirical findings are presented in this section. The preliminary analysis' findings are presented in the first subsection. The results of the cointegration test are shown in the second subsection. The findings of the symmetric and asymmetric panel ARDL model are presented in the third subsection, while outcomes of the causality test are presented in the fourth subsection.

4.1 | Preliminary analysis

We check the slope heterogeneity in the three models (see Table 2) by utilizing Pesaran and Yamagata (2008) test. The Slope heterogeneity outcomes dismissed the null hypothesis of "slope homogenous" which indicates that all models have an issue with heterogeneity, implying that traditional cointegration and unit root tests will produce partial results. For all models, the test statistics are significant at a 1% level of significance. The CD test outcome is depicted in Table 3 and the outcomes show dismissal of the null hypothesis of "no CD" which implies the presence of CD in the panel data.

As a result of these findings, we execute CIPS unit root test. As previously stated, this test will offer us hints regarding the possible heterogeneous nature of the series in addition to testing for the existence of unit root under the assumption of CD. The results are reported in Table 3. Irrespective of the model specification or specified lag, all parameters are heterogeneous stationary of order one. First, this shows that the nations are heterogeneous and that we can use the Westerlund (2007) approach to investigate cointegration. Second, this demonstrates that the primary criteria for assessing the NPARDL have been met. Certainly, while utilizing MG or PMG to estimate our models, we must make sure that none of the indicators are I(2), the predictor variables are I(1) and not I(2) and the dependent variable must be I(1).

4.2 | Cointegration analysis outcomes

In each of the three models, we check whether GHG and the predictor variables are cointegrated. The Westerlund (2007) cointegration test is appropriate for the series that showcase CD. We adjust for CD when executing this test by obtaining resilient critical values based on

TABLE 2 Slope heterogeneity test outcomes

Model 1		Model 2		Model 3	
$\widehat{\Delta}$	$\widehat{\widehat{\Delta}}_{adjusted}$	$\widehat{\Delta}$	$\widehat{\widehat{\Delta}}_{adjusted}$	$\widehat{\Delta}$	$\widehat{\widehat{\Delta}}_{adjusted}$
13.726*	15.036*	6.869*	7.429*	5.320*	6.637*

*p < 1%.

TABLE 3 CD and CIPS and CADF test outcomes

Variables	CD outcomes: Breusch–Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD	CIPS outcomes: I(0)	I(I)	CADF outcomes: I(0)	I(I)
GHG	105.39*	21.330*	21.243*	0.9463	−2.186	−5.623*	−2.587	−3.859*
GDP	285.69*	61.648*	61.562*	16.901*	−2.119	−5.082*	−2.572	−3.479*
ERT	204.59*	43.512*	43.426*	14.191*	−2.403***	−5.547*	−2.541***	−3.842*
RMP	62.737*	11.792*	11.706*	5.0558*	−0.585	−4.337*	−2.697	−3.761*
EI	47.479*	8.3805*	8.2943*	−0.8036	−2.010	−5.026*	−2.083	−4.231*

Abbreviations: EI, export intensity; ERT, environmental-related technologies; GDP, gross domestic product; GHG, greenhouse gas; RMP, raw material productivity.
p* < 1%; * *p* < 10%.

TABLE 4 Westerlund cointegration outcomes

	Model-1		Model-2		Model-3	
	Value	*p* Value	Value	*p* Value	Value	*p* Value
G_t	−3.516	.019**	−3.372	.043**	−3.669	.007*
G_a	−8.18	.980	−7.745	.985	−9.657	.949
P_t	−8.632	.001*	−8.922	.000*	−8.234	.002*
P_a	−9.967	.741	−9.063	.819	−10.786	.657

***p* < 5%. **p* < 1%.

100 bootstrap simulations. Table 4 shows that in the Nordic nations, there is cointegration between GHG emissions and the predictor variables. Furthermore, the robust *p* values are all less than the significance levels (0.10, 0.05, and 0.01), implying that the null hypothesis is rejected.

4.3 | Asymmetric panel ARDL model outcomes

All of the equations are first estimated using the PMG and MG estimators, and afterward, the findings are subjected to the Hausman test. The PMG estimator is used when the null hypothesis is not rejected, but the MG estimator is used when the null hypothesis is rejected. To put it another way, the PMG estimator is the most effective when the null hypothesis is not dismissed, but the MG estimator is the most effective when the alternative hypothesis is not refuted. The PMG estimator is the most efficient estimator for modeling the nonlinear association between GHG emissions and the regressors (ERT, GDP, RMP, and EI) in the Nordic nations. Table 5 reveals that utilizing PMG as an effective estimator underneath the null hypothesis. For that purpose, only the recommended estimator's results were conveyed and discussed in this empirical analysis.

In the three models, the effect of GDP on GHG emissions is positive suggesting that economic expansion contributes to the rising emissions levels in the Nordic countries. Thus, $0.164\% \sim \text{Model}-1$, $0.167\% \sim \text{Model}-2$, and $0.145\% \sim \text{Model}-3$ increase in GHG emissions in Nordic nations is caused by a 1% upsurge in GDP keeping other indicators constant. This further reinforces that the growth trajectory of the Nordic nations is not sustainable without implementation of more stringent environmental and climate change polices. Furthermore, the Nordic nations GHG emissions per capita is higher than the top-emitting countries such as China, United States, and India despite possessing a relatively decarbonized electricity supply. This is partly attributable to the abundance of energy-intensive industries and cold environments. Although the government of these countries is committed to attaining carbon neutrality by 2050, more needs to be done in order for the countries to meet their SDGs target. A similar result is documented by the study of Kirikkaleli and Adebayo (2021) on the interrelationship between CO_2 emissions and real GDP using the global economy. Similarly, the studies of Ojekemi et al. (2022) nations, Magazzino and Giolli (2021) and Magazzino et al. (2022) documented similar results.

Moreover, in the long-term, positive (negative) shifts in RMP decrease (increase) GHG emissions in the Nordic nations. This implies that a 1% positive shift in RMP contributes to a 0.0892% decrease in GHG emissions while 1% negative shift in RMP contributes to a 0.1258% upsurge in GHG emissions in the Nordic nation. Furthermore, only the positive shift in RMP decrease GHG emissions in the short-run. These results have significant implications for policymakers in the Nordic nation. Since positive shock in RMP helps in curbing GHG emissions, measures should be taken to encourage it. These results are as expected given the fact that RMP is regarded as a critical strategy for attaining poverty reduction and sustainable development. Furthermore, it is especially important for attaining sustainable development because it has the power to meet both environmental and economic sustainability. It is seen as both economically

TABLE 5 Results of the panel asymmetric ARDL

	Model-1			Model-2			Model-3		
	Coefficient	*t* Statistics	*p* Value	Coefficient	*t* Statistics	*p* Value	Coefficient	*t* Statistics	*p* Value
GDP	0.1640**	2.51	.012	0.1678***	1.71	.088	0.1451*	4.13	.000
ΔGDP	1.7488*	2.25	.002	1.5030**	2.43	.015	1.7172**	2.03	.042
RMP^+	−0.0892*	−4.70	.000						
RMP^-	0.1258*	2.80	.008						
ΔRMP^+	−0.1115***	−1.66	.097						
ΔRMP^-	0.0318	0.33	.738						
ERT^+				−0.8567*	−5.94	.000			
ERT^-				−0.2634*	−3.96	.000			
ΔERT^+				−0.1041	1.51	.130			
ΔERT^-				0.1106**	2.55	.011			
EI^+							−0.4174***	−1.95	.051
EI^-							0.3666***	1.88	.060
ΔEI^+							0.2424	1.45	.147
ΔEI^-							0.2380***	1.72	.082
ECT (−1)	−0.2455**	−4.06	0.000	−0.3588*	−5.79	.000	−0.6210*	−3.63	.0002
Log likelihood	206.6964			214.4248			210.681		
Observation	145			145			145		
Hausman test	3.84 (0.2787)			1.97 (0.5782)			0.368 (0.839)		
Wooldridge test for autocorrelation	1.162 (0.3192)			0.345 (0.6011)			0.495 (0.6649)		

Note: Δ denote short-run estimates.
Abbreviations: EI, export intensity; ERT, environmental-related technologies; GDP, gross domestic product; GHG, greenhouse gas; RMP, raw material productivity.
***Depicts 10% level of significance.
**Depicts 5% level of significance.
*Depicts 1% level of significance.

competent and crucial for the future of Nordic nations as it can yield enormous economic and social benefits. Similar results are communicated by the study of Hao et al. (2021) which reported that green growth lessens the emissions level in the G7 nations.

In Model 2, positive and negative shifts in ERT decrease GHG emissions in the Nordic nations. Though the magnitude of the positive shift is more than the negative shift. Holding other factors contestant, a 1% positive shift and a negative shift in ERT lessens GHG emissions by 0.85% and 0.263% respectively. The ERT coefficient is inversely proportional to GHG emissions and thus has a positive impact on the quality of the environment. This implies that shifts in ERT in the Nordic nations play a critical role in enhancing ecological integrity. This suggests that ERT has a positive influence on the quality of the environment by reducing GHG emissions in Nordic countries. According to research, all initiatives associated with controlling emissions (deterrence of unsafe substance release), waste disposal (treatment, waste elimination, and handling), clean-up technology (cleanup technology) and green technology (progress in manufacturing technologies) have an advantageous influence on the quality of the environment (Chen & Lee, 2020; Chunling et al., 2021). Moreover, the industries and states are putting increased emphasis on R&D aimed at generating environmentally friendly capital goods and boosting the efficacy of industrial technology that uses less energy (Ibrahim & Ajide, 2021; Kumar & Managi, 2009). The outcomes of the current research comply with the past studies. For example, the research of Lin and Ma (2022) reported that innovation curbs the degradation of the environment while similar findings were also documented by Ahmed et al. (2021).

On the nonlinearity of the long-run relationship between EI and GHG emissions, we discovered intriguing findings. We found that positive (negative) changes in EI decrease (increase) GHG emissions in the Nordic nations. This demonstrates that a 1% positive shift in EI contributes to a 0.4174% decrease in GHG emissions while a 1% negative shift in EI contributes to a 0.3666% upsurge in GHG emissions in the Nordic nation. In the short-term, a negative shift in EI damage the quality of the environment. As a result, increasing EI by prioritizing greener, more efficient, and ecologically friendly production process has the potential to reduce GHG emissions. In this respect, thorough and broad-based policy initiatives to improve EI will be extremely helpful in enhancing quality of the environment in the Nordic nations without compromising intended economic expansion. The studies of

Khan et al. (2020) for oil-exporting nations and Rahman and Velayutham (2020) documented similar results.

The error-correction term (ECT) coefficient is negative and significant at 1% level of significance in the three models. These values indicate that the adjustment speed toward the long-run balance is ~24% (Model-1), 35% (Model-2), and 62% (Model-3) per year. The ECT's significance and negative signs indicate that the variables would be adjusted toward long-run dynamics. Last, we evaluate the serial correlation in each model. Table 5 presents the serial correlation outcomes with resulting suggestion no serial correlation in each model. All the results are statistically significant and follow normality assumption with no problem of autocorrelation.

4.4 | Symmetric panel ARDL outcomes

As a robust check to the asymmetric panel ARDL, we used the symmetric panel ARDL. We used the PMG estimator since the null hypothesis is dismissed. Therefore, the PMG estimator is the most efficient estimator for modeling the linear association between GHG emissions and the regressors (ERT, GDP, RMP, and EI) in the Nordic nations (see Table 6). In the long and short-run, we find that upsurge in GHG emissions is caused by an upsurge in GDP in the Nordic nations which implies that GDP contributes to damage to the environment. Moreover, RMP curbs GHG emissions in both long and short-term. This demonstrates that RMP boosts the quality of the environment. Moreover, in the long-term, ERT lessen GHG emissions in the Nordic nation. However, in the short-term, ERT contributes to the deterioration of the environment. Last, EI plays a crucial role in curbing GHG emissions in the Nordic nations. The ECT coefficient is negative and significant at a 1% level of significance in the three models. These values indicate that the adjustment speed toward the long-run balance is ~38% (Model-1), 55% (Model-2), and 43% (Model-3) per year. The ECT's significance and negative signs indicate that the variables would be adjusted toward long-run dynamics.

TABLE 7 Asymmetric panel causality outcomes

Null hypothesis	W-stat	Zbar-stat	Prob	Conclusion
$RMP^- \neq GHG$	4.9403	3.2874	.0010	$RMP^- \rightarrow GHG$
$GHG \neq RMP^-$	1.1105	−0.9945	.3163	
$RMP^+ \neq GHG$	3.8752	2.0966	.0360	$RMP^+ \rightarrow GHG$
$GHG \neq RMP^+$	0.9171	−1.2108	.2260	
$ERT^- \neq GHG$	1.4898	−0.5704	.5684	$ERT^- \neq GHG$
$GHG \neq ERT^-$	2.6642	0.742	.4578	
$ERT^+ \neq GHG$	3.9930	2.2282	.0259	$ERT^+ \rightarrow GHG$
$GHG \neq ERT^+$	1.7259	−0.3065	.7592	
$EI^- \neq GHG$	3.98300	1.66312	.0963	$EI^- \rightarrow GHG$
$GHG \neq EI^-$	1.2176	0.3440	.7308	
$EI^+ \neq GHG$	5.27339	2.86036	.0042	$EI^+ \rightarrow GHG$
$GHG \neq EI^+$	2.82772	0.59125	.5544	
$GDP \neq GHG$	4.41229	2.06143	.0393	$GDP \rightarrow GHG$
$GHG \neq GDP$	2.26089	0.06533	.9479	

Abbreviations: EI, export intensity; ERT, environmental-related technologies; GDP, gross domestic product; GHG, greenhouse gas; RMP, raw material productivity.

TABLE 6 Results of the panel symmetric ARDL (robustness check)

	Model-1			Model-2			Model-3		
	Coefficient	*t* Statistics	*p* Value	Coefficient	*t* Statistics	*p* Value	Coefficient	*t* Statistics	*p* Value
GDP	0.1664*	2.85	.004	0.1703***	1.70	.089	1.0101*	4.43	.000
ΔGDP	1.6499**	2.10	.036	1.5436**	2.50	.012	1.7707**	2.14	.033
RMP	−0.0913*	−3.83	.001						
ΔRMP	−0.0320*	−2.94	.002						
ERT				−0.2606*	−6.02	.000			
ΔERT				0.1173	1.60	.110			
EI							−0.0149***	1.69	.091
ΔEI							−0.7278	−0.17	.863
ECT (−1)	−0.3895**	−3.17	.000	−0.5582*	−4.77	.000	−0.4319*	−3.93	.000
Log likelihood	204.7837			212.8055			209.5771		
Nos of obs	145			145			145		
Hausman test	2.08 (0.3543)			4.06 (0.1314)			0.420 (0.781)		

Note: Δ denote short-run estimates.
Abbreviations: EI, export intensity; ERT, environmental-related technologies; GDP, gross domestic product; GHG, greenhouse gas; RMP, raw material productivity.
***Depicts 10% level of significance.
**Depicts 5% level of significance.
*Depicts 1% level of significance.

4.5 | Asymmetric panel causality outcomes

Last, we assess the causal association between the variables of the study utilizing DH causality initiated by Dumitrescu and Hurlin (2012). We found unidirectional causality from a negative and positive shift in RMP to GHG emissions (see Table 7). This implies that negative and positive alterations in RMP can forecast GHG emissions. Moreover, no causality exists between negative alterations in ERT and GHG emissions while a positive shift in ERT can predict GHG emissions. Besides, we found unidirectional causality from a negative and positive shift in EI to GHG emissions. This implies that negative and positive alterations in EI can forecast GHG emissions. Last, GDP can predict GHG emissions. These outcomes are vital for policymakers in the Nordic nations. As shifts in the variables of investigation have a different effect on GHG emissions in the Nordic nations.

5 | CONCLUSION AND POLICY RECOMMENDATION

The attempt made in this study followed the direction of extending the literature on environmental sustainability and carbon neutrality goal of the Nordic economies, that is, Denmark, Finland, Iceland, Norway, and Sweden. In achieving this aim, the role of export intensification (measured as the amount of exports in Kilogram per United States Dollars), RMP, ERT, and economic performance vis-à-vis GDP on the GHG emission profile of the Nordic region is examined under both symmetric and asymmetric framework for the period 1990–2019. By using a combination of econometric approaches, the results obtained offers interesting and relevant information along the dimension of the study objective.

From the asymmetric investigation, positive shift in RMP decrease GHG emissions in the Nordic nations while the negative shift causes an increase in GHG emissions both in the long-term. In the short-run, only the positive shift in RMP mitigates GHG emissions. Furthermore, both positive and negative shifts in ERT decrease GHG emissions in the Nordic nations but the magnitude of the positive shift is more than the negative shift. Moreover, the result posits that positive (negative) changes in exports intensity decrease (increase) GHG emissions in the Nordic nations but a negative shift in EI worsens the quality of the environment.

The PMG estimator provides the most efficient estimator under the symmetric framework. In both long- and short-run, the result revealed that GDP still upsurges GHG emissions while RMP curbs GHG emissions. This demonstrates that raw material is efficiently utilized in the Nordic region, thus boosting a sustainable environment. Similar to the effect of RMP, ERT mitigate GHG emissions in the Nordic nation but only in the long-run. At the same time, EI also plays a crucial role in curbing GHG emissions in the region. Moreover, there is a statistically significant causality from positive and negative shock in RMP and EI to GHG emission, while only a positive shock in ERT Granger causes GHG emission.

5.1 | Policy recommendation

Although this study is limited in that it does not provide country-specific information about how the dimension of EI, RMP, and ERT affect the countries' nationally determined goals, there are policy relevance associated with the result of the investigation. The fact that a positive shift in both RMP and EI promotes environmental quality shows that the countries have significantly shifted toward the use of environmentally sustainable and/or renewable material for circular economy. This paper also makes the case that the Nordic governments' environmental-related regulatory agencies should be more critical on the sustainable development strategies especially on issues relating to exports, industrial and manufacturing activities. To address the negative externalities of climate change, EI strategies, trade relations, and the promotion of new goods should all be part of environmental and sustainable development policies. Institutions in charge of enforcing regulations and formulating policies must be free from political sway and interference from corporate entities. Additionally, with the current reality from the fallout of dependency on Russian energy, the Nordics energy transition policy should be approached with more urgent strategies toward increasing the percentage of renewables/alternative energy in the overall energy mix. At the same time, circular economy policy should be further encouraged alongside the use of ERT and more policy dimensions that promote the green components of the economy, especially the non-energy sector.

5.2 | Limitation of study and future direction

It is anticipated that some of the study's shortcomings will provide opportunities for future research. Specifically, although the paper utilized RMP for green growth for the regional case, future studies are invigorated to explore green growth by utilizing income nation-levels and country-specific investigation. Additionally, future research may compare results using alternative, dependent variables, such as load capacity factor or ecological footprint, in place of GHG emission. Moreover, future studies can examine the EKC hypothesis' applicability to EI. By using this strategy, it may be possible to determine if EI has an environmental threshold and the study could be replicated by considering several panel data sets, including MINT, BRICS, ASEAN, OECD, and EU nations, among others.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Andrew Adewale Alola https://orcid.org/0000-0001-5355-3707

Tomiwa Sunday Adebayo https://orcid.org/0000-0003-0094-1778

REFERENCES

Acheampong, A. O., Dzator, J., Dzator, M., & Salim, R. (2022). Unveiling the effect of transport infrastructure and technological innovation on economic growth, energy consumption and CO2 emissions.

Technological Forecasting and Social Change, *182*, 121843. https://doi.org/10.1016/j.techfore.2022.121843

Acheampong, A. O., Shahbaz, M., Dzator, J., & Jiao, Z. (2022). Effects of income inequality and governance on energy poverty alleviation: Implications for sustainable development policy. *Utilities Policy*, *78*, 101403. https://doi.org/10.1016/j.jup.2022.101403

Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: Application of wavelet tools. *Environment, Development and Sustainability*, *23*(11), 16057–16082. https://doi.org/10.1007/s10668-021-01322-2

Adebayo, T. S., Onifade, S. T., Alola, A. A., & Muoneke, O. B. (2022). Does it take international integration of natural resources to ascend the ladder of environmental quality in the newly industrialized countries? *Resources Policy*, *76*, 102616. https://doi.org/10.1016/j.resourpol.2022.102616

Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., & Muhammad, S. (2020). The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. *Resources Policy*, *69*, 101817. https://doi.org/10.1016/j.resourpol.2020.101817

Ahmed, Z., Nathaniel, S. P., & Shahbaz, M. (2021). The criticality of information and communication technology and human capital in environmental sustainability: Evidence from Latin American and Caribbean countries. *Journal of Cleaner Production*, *286*, 125529. https://doi.org/10.1016/j.jclepro.2020.125529

Ali, S. A., Alharthi, M., Hussain, H. I., Rasul, F., Hanif, I. Haider, J., Ullah, S., Rahman, S. U., & Abbas, Q. (2021). A clean technological innovation and eco-efficiency enhancement: A multi-index assessment of sustainable economic and environmental management. *Technological Forecasting and Social Change*, *166*, 120573.

Alola, A. A., Akadiri, S. S., & Usman, O. (2021). Domestic material consumption and greenhouse gas emissions in the EU-28 countries: Implications for environmental sustainability targets. *Sustainable Development*, *29*(2), 388–397. https://doi.org/10.1002/sd.2154

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO2 emissions? *Energy Policy*, *113*, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Baniya, B., & Aryal, P. P. (2022). Nepal's domestic material consumption—Projection and causal impact of external financial inflows, services value-added, population, and economic growth. *Environmental Science and Pollution Research*, *29*(22), 33674–33697. https://doi.org/10.1007/s11356-021-18050-9

Bas, T., Kara, F., & Alola, A. A. (2021). The environmental aspects of agriculture, merchandize, share, and export value-added calibrations in Turkey. *Environmental Science and Pollution Research*, *28*(44), 62677–62689. https://doi.org/10.1007/s11356-021-15171-z

Cetin, M., Demir, H., & Saygin, S. (2021). Financial development, technological innovation and income inequality: Time series evidence from Turkey. *Social Indicators Research*, *156*(1), 47–69. https://doi.org/10.1007/s11205-021-02641-7

Chen, Y., & Lee, C.-C. (2020). Does technological innovation reduce CO2 emissions? Cross-country evidence. *Journal of Cleaner Production*, *263*, 121550. https://doi.org/10.1016/j.jclepro.2020.121550

Chen, Y., Wang, Z., & Zhong, Z. (2019). CO2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. *Renewable Energy*, *131*, 208–216. https://doi.org/10.1016/j.renene.2018.07.047

Chunling, L., Memon, J. A., Thanh, T. L., Ali, M., & Kirikkaleli, D. (2021). The impact of public-private partnership investment in energy and technological innovation on ecological footprint: The case of Pakistan. *Sustainability*, *13*(18), 10085. https://doi.org/10.3390/su131810085

Costantini, V., Crespi, F., Marin, G., & Paglialunga, E. (2017). Eco-innovation, sustainable supply chains and environmental performance in European industries11We gratefully acknowledge the support by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 649186—ISIGrowth. The comments and suggestions by three anonymous referees are also acknowledged. The usual disclaimers apply. *Journal of Cleaner Production*, *155*, 141–154. https://doi.org/10.1016/j.jclepro.2016.09.038

Dumitrescu, E.-I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

European Commission. (2022). Critical raw materials. Retrieved August 25, 2022, from https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en.

Fareed, Z., Salem, S., Adebayo, T. S., Pata, U. K., & Shahzad, F. (2021). Role of export diversification and renewable energy on the load capacity factor in Indonesia: A Fourier quantile causality approach. *Frontiers in Environmental Science*, 434. https://doi.org/10.3389/fenvs.2021.770152

Granger, C. W. J., & Yoon, G. (2002). *Hidden Cointegration* [SSRN Scholarly Paper]. https://doi.org/10.2139/ssrn.313831

Gupta, M., Saini, S., & Sahoo, M. (2022). Determinants of ecological footprint and PM2.5: Role of urbanization, natural resources and technological innovation. *Environmental Challenges*, *7*, 100467. https://doi.org/10.1016/j.envc.2022.100467

Hao, L.-N., Umar, M., Khan, Z., & Ali, W. (2021). Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *Science of the Total Environment*, *752*, 141853. https://doi.org/10.1016/j.scitotenv.2020.141853

Holdren, J. P., & Ehrlich, P. R. (1974). Human Population and the Global Environment: Population growth, rising per capita material consumption, and disruptive technologies have made civilization a global ecological force. *American scientist*, *62*(3), 282–292.

Ibrahim, R. L., & Ajide, K. B. (2021). Nonrenewable and renewable energy consumption, trade openness, and environmental quality in G-7 countries: The conditional role of technological progress. *Environmental Science and Pollution Research*, *28*(33), 45212–45229. https://doi.org/10.1007/s11356-021-13926-2

Khan, Z., Ali, M., Jinyu, L., Shahbaz, M., & Siqun, Y. (2020). Consumption-based carbon emissions and trade nexus: Evidence from nine oil exporting countries. *Energy Economics*, *89*, 104806. https://doi.org/10.1016/j.eneco.2020.104806

Khan, J., Johansson, B., & Hildingsson, R. (2021). Strategies for greening the economy in three Nordic countries. *Environmental Policy and Governance*, *31*(6), 592–604.

Kirikkaleli, D., & Adebayo, T. S. (2021). Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. *Sustainable Development*, *29*(4), 583–594. https://doi.org/10.1002/sd.2159

Kumar, S., & Managi, S. (2009). Energy price-induced and exogenous technological change: Assessing the economic and environmental outcomes. *Resource and Energy Economics*, *31*(4), 334–353. https://doi.org/10.1016/j.reseneeco.2009.05.001

Lin, B., & Ma, R. (2022). Green technology innovations, urban innovation environment and CO2 emission reduction in China: Fresh evidence from a partially linear functional-coefficient panel model. *Technological Forecasting and Social Change*, *176*, 121434. https://doi.org/10.1016/j.techfore.2021.121434

Magazzino, C., Forte, F., & Giolli, L. (2022). On the Italian public accounts' sustainability: A wavelet approach. *International Journal of Finance & Economics*, *27*(1), 943–952. https://doi.org/10.1002/ijfe.2184

Magazzino, C., & Giolli, L. (2021). The relationship among railway networks, energy consumption, and real added value in Italy. Evidence form ARDL and wavelet analysis. *Research in Transportation Economics*, *90*, 101126. https://doi.org/10.1016/j.retrec.2021.101126

Nordic Co-operation. (2022). Action plan for vision 2030. Retrieved August 25, 2022, from https://www.norden.org/en/information/action-plan-vision-2030.

Nordics info. (2019). Economic development in the Nordic countries. Retrieved August 25, 2022, from https://nordics.info/show/artikel/economic-development-in-the-nordic-countries.

NordForsk. (2022). The green economy grows in the Nordic region. Retrieved August 25, 2022, from https://www.nordforsk.org/news/green-economy-grows-nordic-region.

Obobisa, E. S., Chen, H., & Mensah, I. A. (2022). The impact of green technological innovation and institutional quality on CO2 emissions in African countries. *Technological Forecasting and Social Change*, *180*, 121670. https://doi.org/10.1016/j.techfore.2022.121670

Ojekemi, O. S., Rjoub, H., Awosusi, A. A., & Agyekum, E. B. (2022). Toward a sustainable environment and economic growth in BRICS economies: Do innovation and globalization matter? *Environmental Science and Pollution Research.*, *29*, 57740–57757. https://doi.org/10.1007/s11356-022-19742-6

Ozturk, I., & Acaravci, A. (2016). Energy consumption, CO2 emissions, economic growth, and foreign trade relationship in Cyprus and Malta. *Energy Sources, Part B: Economics, Planning, and Policy*, *11*(4), 321–327. https://doi.org/10.1080/15567249.2011.617353

Pesaran. (2004). *General diagnostic tests for cross section dependence in panels* [Working Papers in Economics No. 0435]. University of Cambridge, Faculty of Economics.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H., & Shin, Y. (1995). *An autoregressive distributed lag modelling approach to cointegration analysis* [Cambridge Working Papers in Economics No. 9514]. Faculty of Economics, University of Cambridge. https://ideas.repec.org/p/cam/camdae/9514.html

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/jae.616

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, *94*(446), 621–634. https://doi.org/10.1080/01621459.1999.10474156

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of econometrics*, *142*(1), 50–93.

Rahman, M. M., & Velayutham, E. (2020). Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. *Renewable Energy*, *147*, 399–408. https://doi.org/10.1016/j.renene.2019.09.007

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In R. C. Sickles & W. C. Horrace (Eds.), *Festschrift in honor of Peter Schmidt: Econometric methods and applications* (pp. 281–314). Springer. https://doi.org/10.1007/978-1-4899-8008-3_9

Shokoohi, Z., Dehbidi, N. K., & Tarazkar, M. H. (2022). Energy intensity, economic growth and environmental quality in populous Middle East countries. *Energy*, *239*, 122164. https://doi.org/10.1016/j.energy.2021.122164

Ullah, S., Ozturk, I., Usman, A., Majeed, M. T., & Akhtar, P. (2020). On the asymmetric effects of premature deindustrialization on CO2 emissions: Evidence from Pakistan. *Environmental Science and Pollution Research*, *27*(12), 13692–13702. https://doi.org/10.1007/s11356-020-07931-0

Usman, O., Alola, A. A., & Akadiri, S. S. (2022). Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: Evidence from a GMM panel-VAR. *Renewable Energy*, *184*, 239–251. https://doi.org/10.1016/j.renene.2021.11.086

Westerlund, J. (2007). Testing for error correction in panel data*. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Yu, Y., & Du, Y. (2019). Impact of technological innovation on CO2 emissions and emissions trend prediction on 'New Normal' economy in China. *Atmospheric Pollution Research*, *10*(1), 152–161. https://doi.org/10.1016/j.apr.2018.07.005

Zafar, M. W., Saleem, M. M., Destek, M. A., & Caglar, A. E. (2022). The dynamic linkage between remittances, export diversification, education, renewable energy consumption, economic growth, and CO2 emissions in top remittance-receiving countries. *Sustainable Development*, *30*(1), 165–175. https://doi.org/10.1002/sd.2236

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