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RESEARCH ARTICLE

Environmental innovation and environmental sustainability in a Nordic country: evidence from nonlinear approaches

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Abstract
Environmental sustainability has been a priority of energy study experts, yet, until recently, the approaches largely ignored innovation issues. This paper investigates the relationship between environmental innovation and environmental sustainability in a Nordic country, Norway, from 1990:Q1 to 2019:Q4. In Norway, climate change, protection of the ozone layer, biodiversity, urbanization, acidification, eutrophication, persistently high toxic waste, and increased fragility have injected volatility and uncertainty into the Norwegians—a reality that may continue for a while. This study is unique in that it uses the nonlinear ARDL approach to analyze in depth how environmental innovation affects environmental sustainability in Norway while controlling for economic growth, renewable energy, and financial development. In particular, the findings reveal that (i) environmental innovation improves the environment in Norway over long-term horizons; (ii) strengthening patents on environmental innovations can foster clean living, green growth, and zero CO_2 emissions; (iii) investing in renewable energy sources benefits the Norwegian environment by reducing carbon emission growth; and (iv) economic growth and financial development promote CO_2 emission growth. The policy consequence is that Norway's policymakers should continue to invest in cleaner technologies and encourage environmental education and training of employees, suppliers, and consumers.

Keywords Environmental sustainability · Asymmetric modeling · Environmental innovation · Patents on environmental technologies · Norway

Introduction

The world has enjoyed unparalleled economic progress, but it has been accompanied by a considerable increase in pollution emissions. As a result, the globe faces difficult environmental concerns that endanger human survival, such as pollution and climate change caused by fast population expansion, industrialization and urbanization, and rising energy demand. These environmental difficulties and risks constitute a direct threat to environmental sustainability, and they also affect our present and future. As a result, in order for humanity to continue to grow in a sustainable manner, it is vital to increase resource and energy efficiency and transition to a sustainable economy that consumes less resources and energy. The strong linkages between resource consumption and economic growth can be severed if we do so. Furthermore, sustainable development that ensures both environmental sustainability and economic prosperity is possible.

Environmental sustainability is critical to long-term growth. Given the growing importance of environmental sustainability, environmental technology innovation (also known as environmental innovation) is the most viable option for achieving environmental sustainability. Environmental innovation has emerged as the most powerful means of overcoming environmental difficulties and risks in recent years. Environmental innovation is critical because it has the potential to turn the "trade-off relations" between economic growth and environmental betterment into mutually beneficial "win–win" relationships, so contributing to the achievement of more sustainable development (Sowah and

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Kirikkaleli 2022). In this regard, environmental innovation is increasingly being stressed not just in tackling current environmental challenges but also in ensuring future generations' environmental sustainability. Environmental innovation, in general, refers to environmentally oriented innovation that aims to reduce negative environmental externalities. Environmental innovation includes advances in products, processes, and management that are less detrimental to the environment than relevant alternatives.

Historically, firms have exploited technology as an engine of progress since at least the Industrial Revolution, which provided extraordinary ways to marshal the physical environment for human benefit. Innovation, which we define as the successful implementation of new breakthroughs and ideas, is dependent on much more than technological advancement, yet technology has continuously created chances to make and sell better goods and services in a cleaner and safer manner. Many of today's social and economic advancements are the consequence of technological breakthroughs in areas such as communications, information processing, health sciences, and energy supply. These promise better, more personalized solutions to the jobs we want to complete. Rather than being a one-size-fits-all strategy, the technologies are employed by dynamic and responsive networks of small and large public and commercial entities, cooperating, and competing in ways never before possible. The changes are enormous, and the prospects are vast, but it is obvious that technology can only play a limited role in achieving more sustainable development, and its contribution is not always as beneficial as we would like. Furthermore, other elements that can drive and support advancement are changing and must be comprehended.

Recent COP-21 in Paris enlightened world leaders to limit global warming and bilaterally combat or mitigate climate change and its impacts; this issue also has been emphasized in the UN's 2030 Sustainable Development Goals (SDGs). Similarly, the International Panel on Climate Change (IPCC) in 2010 (Usman and Radulescu 2022) reported that carbon dioxide emissions had reached 49Gt, transportation (14%), electricity contributed 25%, forestry, agricultural and land use showed 24%, while industrializations showed 21%, other buildings (6.4%) and energy (9.6%). Thus, energy sector dynamics remain the major contributor to anthropogenic carbon dioxide emissions. To halt the current extreme trajectory of the global average temperature to the acceptable 1.5 degrees Celsius compared to pre-industrial levels (Kirikkaleli and Sowah 2021), adopting mitigating policy option is required by individual nations. A robust policy perspective that could deliver accessibility of information, availability, and technological advancement is necessary. The study suggests that economists, World Bank, and other multilateral development banks have all committed themselves to COP-21 goals (Bazbauers 2022). The concept of green growth, the standard growth theory of comparative advantage (Bazbauers 2022), and other core concepts of sustainable development have all emerged in international policy discourse in recent years. For instance, the Global Green Growth Institute (GGGI), a new international body supported by a number of governments, is to advise countries on the implementation of sustainable development concepts (Hwang et al. 2017). Although numerous empirical literature has emerged on the nexus between economic growth, financial development, and energy consumption, the literature on the long-run effect of environmental innovation (i.e., patents on environmental innovation) and environmental sustainability remains severally unexplored. Hence, this paper examines the asymmetric and long-run effects of environmental innovation on environmental sustainability in Norway.

Norway is one of the Nordic countries, occupying a vital geographical location for oil production and commonly shares borders in the east and north-eastern part with three countries (Sweden, Finland, and Russia) and to the western part with the Norwegian Sea. The country has invested heavily in technological development and innovation to support its green transition. Moreover, Norway as the country is committed to reducing climate vulnerabilities; it has adopted some of the most ambitious mitigation targets among the Nordic and OECD countries. However, other issues, such as climate change, bring new challenges, e.g., increased precipitation, floods, and rising sea levels. 2020 data on CO_2 emissions show 49.3Mt, ranked 10th globally. In 2018, renewable energy consumption as a share of total energy was 60.8% while fossil fuels accounted for 55% of Norway's energy production. The level of pollution per IQAir in 2020 in Norway shows an average value of 5.7ug/m^2, ranking 34th out of 106 countries. Financial development is strong, unemployment is low, business is increasing labor shortages, patents on environmental innovation are demanding, and wage and price inflation are picking up energy prices. GDP is forecast to grow by 3.6% in 2022 and 2.3% in 2023. Cross-cutting initiatives involving policymaking are reflected in the final phase of recovery in the wake of the COVID-19 pandemic.

This paper contributes to economics knowledge by providing an empirical basis for the aforementioned postulations by taking innovation into account to investigate environmental innovation and environmental sustainability in f Norway from 1990Q1 to 2019Q4. This study is, therefore, among the few in mainstream journals to devote nonlinear ARDL and Markov Switching regression. The use of the nonlinear ARDL (NARDL) technique allows the modeling of both short-run and long-run estimates and the detection of associated asymmetric effects (Shin et al. 2014; Liu et al. 2023) and also discovering hidden cointegration (Kirikkaleli and Sowah 2023). The uniqueness of Lee and Strazicich 2013 unit-root test regression model is in being able to typify different structures in a time series into different regimes in order to capture the dynamic patterns that exist within the series (Kirikkaleli and Sowah 2021). For the cointegration test, the Gregory-Hansen test for Cointegration of Regime Shifts approach is employed, given its ability to capture nonlinearity without losing degrees of freedom when the model contains many dummy variables (Sowah et al. 2023). These attributes make it a suitable choice for the analysis in view. Furthermore, the use of DOLS, FMOLS, and CCR models was employed as robustness checks (Kirikkaleli and Sowah 2020; Wang et al. 2020). Employing these varied advanced estimation techniques push the boundary of existing literature in this subject area.

The next section, which is the "Literature review" section, presents the literature review and a research gap and the "Study methodology" section presents the detailed methods of analysis. In the "Empirical finding and discussion" section, the results of the empirical study are presented and discussed and conclusions and policy implications are given in the "Conclusion and policy implication" section.

Literature review

There appears to be a consensus in the literature examining the link between environmental innovation and CO_2 emissions as various studies such as Sharif et al. (2020) and Khan et al. (2019) have alluded to the decremental impact of environmental innovation on CO_2 emission. Climate change remains one of the greatest threats of the twenty-first century; and mitigating its effects requires innovative policy actions. This study is aimed at examining environmental innovation on environmental sustainability in Norway. The theoretical concepts of comparative advantage, green growth, and other core concepts of sustainable development have emerged in international policy discourse in recent years. In particular, Smulders et al. (2014), Jian and Afshan (2022), Alvarez-Herranz et al. (2017), Ike et al. (2020), Sun et al. (2022), Omri and Belaïd (2021), Chen et al. (2019), Sun et al. (2022), Saint Akadiri et al. (2020), Umar et al. (2020), Solarin et al. (2017), and Oyebanji et al. (2022) are among the recent studies that have investigated the relationship between our selected variables.

Smulders et al. (2014), Jian and Afshan (2022), and Alvarez-Herranz et al. (2017) are studies that have applied theoretical concepts of green growth, comparative advantage, and ecological innovation, respectively. Smulders et al.'s (2014) study highlighted the significance of technological innovation in generating growth, correcting of market failures, and investing in natural capital could help to mitigate CO_2 emissions. Worldwide varieties of technologies have been created by individuals, businesses, and industries since the 1990s (Smulders et al. 2014). In order to sustain technological innovation, Jian and Afshan (2022) suggest patents on technology innovation. Nevertheless, Alvarez-Herranz et al.'s (2017) study criticized the emergence of greener environment concepts for not consciously tackling climate change.

The argument on green energy, renewable energy, and clean energy technologies were critically studied by Ike et al. (2020), Sun et al. (2022), and Omri and Belaïd (2021), respectively. They found that renewable energy sources have the potential to significantly improve environmental quality. In their applications, they generally break down renewable energy sources into two categories: "on-grid" and "off-grid." Consciously, both on-grid and off-grid describe the processes through which electricity's distributed. Their results show that renewable energy sources negatively impact CO_2 emissions. They further suggested that promoting clean energy technologies and renewable energy resources are noticeable mechanisms for breaking the long-standing debates among economists. Similarly, Chen et al. (2019), Sun et al. (2022), and Saint Akadiri et al. (2020) are among the recent studies that examined the interlinkages between economic growth, nonrenewable energy consumption, and renewable energy and CO_2 emissions, respectively. They reported that, in particular, economic growth is crucial for an economy's prosperity, nonrenewable energy resources, and increased CO_2 emissions. They also found that renewable energy resources negatively and significantly affect CO_2 emissions from the data covered.

Furthermore, a country's prosperity depends on financial sector stability and financial development, symbolized by an increased in the monetization of the economy and financial innovations. Umar et al. (2020) and Solarin et al. (2017) studies investigated the relationship between financial developments, energy consumption, and CO_2 emissions using time series data, respectively. The outcomes for these studies have mixed results (Usman and Balsalobre-Lorente 2022). The overall results show that financial sector development increased stimulated FDI inflow, thereby influencing the increase in CO_2 emissions. Promoting environmentally friendly innovations such as patents/intellectual properties (IP), research and development in recent years have become a fundamental priority for developed nations. Since the creation of its first mechanism to protect inventions in the fifteenth century, the patent system has evolved to promote innovation and encourage economic development and, recently, climate-smart technology (i.e., identifies all the innovations with the capacity to reduce GHG emissions). Moreover, offering exclusive patents/intellectual property (IP) rights for a limited period provides the strong economic incentive for innovators, inventor, increases investment resilience, or decreases the vulnerability of people. The UK, Australia, Japan, USA, and Australia in May 2009 were among the first countries that launched green patent applications. Canada, Brazil, and China launched similar programs in 2012. A recent study by Oyebanji et al. (2022) on Spain covering the time series data of 1990:Q1–2018:Q4 shows that patents on environmental technologies positively and significantly reduced CO_2 emissions.

Based on the theoretical and empirical arguments in the above literature, studies on environmental innovation and environmental sustainability in Norway remain substantially limited. Unfortunately, most studies are concerned with the imposition of a linear long-run relationship which may not be appropriate, in fact, when the cointegration relationship is nonlinear. Up-to-data, a limited number of studies have employed a nonlinear model. Hence, we examine the asymmetric and long-run effect of environmental innovation on environmental sustainability in Norway using the Nonlinear-ARDL bound test of cointegration developed by Shin et al. (2014). Other econometric techniques to deepen our findings included Lee and Strazicich's (2013) unit-root test, Broock et al. (1996) test, and Gregory-Hansen's (1996) test for cointegration with regime shifts and followed the time series robustness checks of DOLS, FMOLS, and CCR econometric method; they are detailed in the "Study methodology" section.

Study methodology

The present study is aimed at exploring the asymmetric and long-run effect of environmental innovation on environmental sustainability in Norway, covering the period 1990Q1–2019Q4. Considering the availability/limitation of data and sample size, the data spans show about two decades. We transformed the annual time series data to quarterly observations utilizing Eviews (Lucini et al. 2020). Data on Economic Growth (GDP), Financial Development (FD), Renewable Energy (RE), environmental innovation (measured by Patents on Environmental Technology (PATENTS)), and environmental sustainability (measured by CO_2 emissions) are time series variables under squinting and were obtained from World Bank, World Development Indicators, and OECD 2021 database, respectively. In order to avoid data inconsistency, the variable selection was based on theories and empirical insights (Kirikkaleli and Sowah 2021; Wang et al. 2020. All variables were seasonally adjusted and logged. Table 1 demonstrates the basic future of our time series variables, while Fig. 1 presents an exciting analytical flowchart for the present paper.

The theoretical underpinning for this study is given by seminal literature based on Schumpeter's (1992) hypothesis. This hypothesis expressed that the smooth

Table 1 Descriptive statistics

	LCO_2	LFD	LGDP	LRE	LPATENTS
Mean	1.639571	−0.196687	11.52861	1.823798	1.010692
Median	1.644849	−0.186962	11.54582	1.825861	1.008723
Maximum	1.661848	−0.114071	11.60989	1.861317	1.187832
Minimum	1.566293	−0.384369	11.39621	1.789666	0.739686
Std. Dev	0.016813	0.055709	0.056913	0.014033	0.110944
Skewness	−1.533885	−1.031202	−0.506929	−0.188092	−0.102673
Kurtosis	6.688577	4.306384	2.315771	3.169775	1.984966
Jarque–Bera	95.90339	24.83395	6.233655	0.709744	4.468587
Probability	0.000000	0.000004	0.044297	0.701263	0.107068

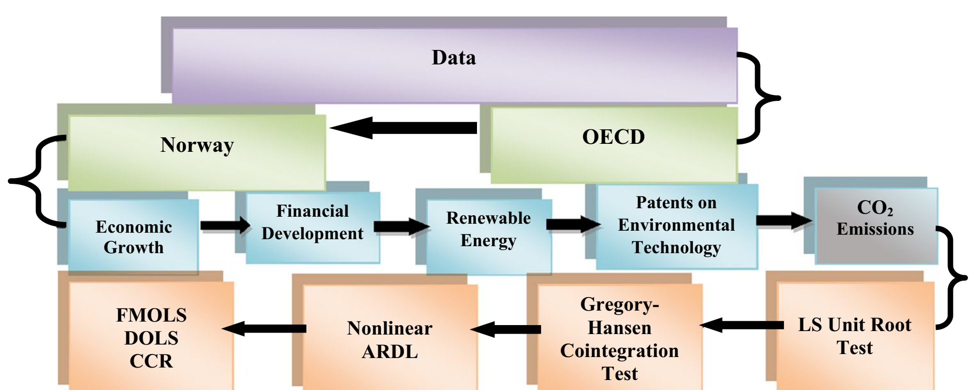

Fig. 1 Analysis flowchart

implementation of this green growth theory and environmental innovations are based on two milestones to environmental. Many forms of environmental sustainability hypotheses are clusters based on three effects. Recent literature by Oyebanji et al. (2022) shows that GDP growth was found as the principal driver of pollution and causing environmental degradation in Spain. A similar study by Riti and Shu (2016) expressed those technical effects such as eco-friendly innovative growth policies which can facilitate better environments. The scientific augment is to weigh the pros and cons of the growth of the model, one most important components that make the research interesting.

Further, the use of patents on environmental technology is still unexplored in the economics literature (Perruchas et al. 2020), but a debate on patents appears to be widespread in recent times. From the International Economics perspective, most often, investors seek patent rights in countries where they expect to invest, export, or otherwise market their products. Also, granting intellectual property to local businesses helps them take advantage of existing technologies and importantly make new solutions to climatic issues. This paper included patents on environmental technology as a proxy variable for environmental innovation because patent data present a number of attractive properties compared to other alternatives (Baumann et al. 2021). Also, research and development in high-tech seem as a hub for controlling environmental contamination. In addition, renewable energy supplies are other phenomena considered to have reduced demand for fossil fuels (Baumann et al. 2021).

Renewable energy is included in this study because there are variations among renewable energy resources, which can be divided into numerous categories depending on the country's political goals or objectives under consideration. Some renewable energy has immediate development potential as well as cost-effectiveness for on-grid applications, while others are for off-grid applications. From a policy strategist's perspective, it is important to determine whether and to what extent energy plans, laws, and regulations may be developed. Further, financial development implies the increased scale of financial institutions, financial innovation, and capital growth. The financial development variable was included in this study because literature has shown that a nation's economic growth and prosperity are dependent on financial stability and development (Umar et al. 2020) and Solarin et al. (2017). In Norway, the financial deregulation policy brought rapid credit expansion in the 1980s and improved the oil exporter sector. Norway as a country has enjoyed substantial financial buffers. However, financial development has come under criticism for having led to increased greenhouse gas emissions (Umar et al. 2020).

In sum, every country wants to increase economic growth, regulate renewable energy, develop the financial sector, and encourage patents on environmental technologies, but how these variables will affect the level of CO_2 emissions at the country level remains severally unknown. This present study on Norway provides some answers by performing robust econometrics applications. The linear mathematical specification function for our selected variables under investigation is presented in Eqs. (1) and (2).

$$\mathrm{LCO_2} = f(\mathrm{LFD, LGDP, LRE, LPATENTS}) \quad (1)$$

$$LCO_{2it} = \vartheta_0 + \vartheta_1 LFD_{it} + \vartheta_2 LGDP_{it} + \vartheta_3 LRE_{it} + \vartheta_4 LPATENTS_{it} + \varepsilon_{it} \quad (2)$$

where LCO_2 denotes the log value of CO_2 emissions, LFD presents the log value of financial development, and LGDP stands for the ′log value of economic growth, while LER denotes the log value of renewable energy and LPATENTS presents the log value of patents on environmental technologies. Based on the above linear function, the present study formulates four basis empirical hypotheses:

Hypothesis 1 (H_{o1}): financial development increases CO_2 emissions.

In Hypothesis 1, we hypothesized that financial development has significantly increased CO_2 emissions in Norway in that the country's prosperity depends on financial sector stability. Financial development is symbolized by the monetization of the economy and an increase in toxic release emissions (Umar et al. 2020). Norway as a major oil exporter in the last few decades which has stimulated money-related development by boosting oil premiums; this study assumed that a steady increase in financial development has significantly increased CO_2 emissions in Norway; i.e., $\vartheta 1 = \frac{\vartheta \mathrm{LCO_2}E}{\vartheta \mathrm{LFD_{it}}} > 0$; this hypothesis supports a study by Umar et al. (2020).

Hypothesis 2 (H_{o2}): economic growth is associated with a steady increase in CO_2 emissions.

Economic growth is crucial for a country's economy's prosperity; however, the pathway to reducing carbon dioxide emissions remains as a country's policy matter. Norway, as the country, has accumulated one of the world's largest sovereign wealth funds, with approximately US$1 trillion in assets, and has shown predominance and continuous economic growth of about 260 percent of the world's GDP (Niles and Moore 2021). Norway has been more successful than many counties, and its GDP per capita remains among the highest in the OECD countries. The study has argued continuous economic growth is associated with a steady increase in pollution (Sun et al. 2022). Thus, this paper hypothesizes that economic growth has steadily increased CO_2 emissions in Norway, i.e., $\vartheta 2 = \frac{\vartheta LCO_2E}{\partial LGDP} > 0$; this hypothesis supports Sun et al.'s (2022) empirical study.

Hypothesis 3 (H_{o3}): renewable energy negatively affects CO_2 emissions.

Renewable energy might replace nonrenewable energy; the use of renewable energy sources shows potential alternative measures contributing to improving environmental quality. Its applications are generally broken down into two categories: larger megawatt installations tend to be on-grid, while off-grid applications are most generally used in remote or rural settings. This present study has hypothesized that applications of renewable energy negatively affect CO_2 emissions in Norway, i.e., $\vartheta 3 = \frac{\vartheta LCO_2E}{\partial LRE} < 0$; this hypothesis corroborates with the recent study by Sun et al. (2022).

Hypothesis 4 (H_{o4}): patents on environmental technologies reduce CO_2 emissions.

Promoting and prioritizing environmentally friendly innovation in recent years has become one of the fundamentals and open debates among economists and government policymakers. The UK, Australia, Japan, the USA, and Australia were among the first countries to launch green patent applications in 2009. Patents/intellectual properties (IP) provide strong economic incentives for innovators, increase resilience, or decrease the vulnerability of people (Oyebanji et al. 2022). Hence, this study hypothesizes that patents on environmental technologies negatively affect CO_2 emissions in Norway, i.e., $\vartheta 3 = \frac{\vartheta LCO_2E}{\partial LPATENTS} < 0$; this assumption supports a study by Oyebanji et al. (2022). The empirical applications of these hypotheses are presented in the "Empirical finding and discussion" section.

Empirical finding and discussion

This section of the paper presents the outcomes of the methodologies applied. As a matter of sequencing, we first use descriptive statistics to describe the future of our datasets and observe the level outliers within the variables. The analysis critically checked the levels of Kurtosis, skewness, Jarque–Bera statistics, etc. (Sowah and Kirikkaleli 2022). The outcomes of the descriptive statistics indicated no outlier in the datasets (Table 1). The study proceeds by assessing the stationarity features of the series of investigations. In doing so, we applied Lee and Strazicich (2013) unit root test. The outcomes of the Lee and Strazicich (2013) test are presented in Table 2. The outcomes unveiled that at level, CO_2, FD, GDP, RE, and PATENTS are stationary; however, at first difference, all the series are stationary. Furthermore, we applied the Lee and Strazicich (2013) unit-root test, which is an advancement over the conventional ADF test. The advantage of the Lee and Strazicich (2013) unit-root test over Phillips and Perron (1988) unit-root test, Zivot and Andrews (2002), and the conventional Lee and Strazicich (2013) unit root tests (Glynn et al. 2007); it can identify series stationarity characteristics if the series are nonlinear. The outcomes of the Lee and Strazicich (2013) are disclosed in Table 2, and the outcomes unveiled that at level, economic growth, financial development, renewable energy, and the patents

Table 2 Unit root tests

		LCO_2	LFD	LGDP	LRE	LPATENTS
At level						
LS	*t*-statistic (tau)	−4.130420	−4.698428	−4.071412	−4.801505	−4.722398
	Break points	2000Q4–2008Q4	2000Q4–2007Q3	2004Q1–2009Q3	1999Q3–2004Q3	2012Q1–2017Q1
Test critical values	1% level	−6.932000	−6.932000	−6.821000	−6.750000	−7.196000
	5% level	−6.175000	−6.175000	−6.166000	−6.108000	−6.312000
	10% level	−5.825000	−5.825000	−5.832000	−5.779000	−5.893000
At first difference						
LS	*t*-statistic (tau)	−6.771744**	−6.613313**	−6.512959**	−6.299573**	−6.958713**
	Break points	1997Q3–2016Q3	2002Q3–2012Q3	2003Q3–2011Q1	1999Q3–2003Q3	1998Q4–2013Q3
	1% level	−6.821000	−6.691000	−6.978000	−6.750000	−6.691000
	5% level	−5.917000	−6.152000	−6.288000	−6.108000	−6.152000
	10% level	−5.541000	−5.798000	−5.998000	−5.779000	−5.798000

***, **, and * present 1%, 5%, and 10% levels of significance, respectively on environmental technologies and CO_2 are stationary; nonetheless, at first difference, all the variables of the study are stationary with various breakpoints.

As part of the initial assessment, we proceeded with the Brock et al. (1987) test to detect the hidden nonlinear patterns in the stochastic time series of our datasets. The Broock-Dechert-Schinkman (BDS) test has the advantage of guiding the model against misspecification and judgmental error. Table 3 presents the outcomes of the BDS inputs. The result shows that all variables' values are far bigger than BDS "critical values in dimensions"; thus, we reject the null hypothesis at 1% significant levels that variables are linearly dependent. This implies that our estimated variables used in this analysis are non-linearly dependent, as indicated in Table 3.

Table 3 BDS test

Dimension	BDS statistic	Std. error	*z*-statistic	Prob
LCO_2				
2	0.168316***	0.007737	21.75403	0.0000
3	0.283795***	0.012368	22.94651	0.0000
4	0.359338***	0.014812	24.26011	0.0000
5	0.406884***	0.015526	26.20583	0.0000
6	0.438087***	0.015059	29.09110	0.0000
LFD				
2	0.196533***	0.008143	24.13404	0.0000
3	0.333124***	0.013000	25.62441	0.0000
4	0.425515***	0.015551	27.36304	0.0000
5	0.486251***	0.016282	29.86472	0.0000
6	0.524011***	0.015774	33.22095	0.0000
LGDP				
2	0.206274***	0.005371	38.40511	0.0000
3	0.350489***	0.008575	40.87364	0.0000
4	0.451995***	0.010253	44.08257	0.0000
5	0.524054***	0.010729	48.84303	0.0000
6	0.575553***	0.010387	55.40981	0.0000
LPATENTS				
2	0.175717***	0.004739	37.07760	0.0000
3	0.289681***	0.007566	38.28881	0.0000
4	0.360892***	0.009045	39.89899	0.0000
5	0.403054***	0.009463	42.59198	0.0000
6	0.429104***	0.009159	46.84884	0.0000
LRE				
2	0.143721***	0.007774	18.48745	0.0000
3	0.226231***	0.012448	18.17460	0.0000
4	0.269320***	0.014933	18.03506	0.0000
5	0.285611***	0.015680	18.21456	0.0000
6	0.285535***	0.015234	18.74269	0.0000

***, **, and * present 1%, 5%, and 10% levels of significance, respectively

Subsequently, the authors proceed to assess the long-run connection between CO_2 and FD, GDP, RE, and PATENTS. Unlike prior studies, we applied the NARDL cointegration test to identify the long-run connection between CO2 and FD, GDP, RE, and PATENTS. The benefit of the NARDL cointegration test is that it can capture long-run association between series; the series is nonlinear and also taken into account. The analysis provides both positive (POS) and negative (NEG) changes in the series. The outcome of the NARDL cointegration is presented in Table 3. The test statistic outcome is 5.103375 which is greater than the critical value at the significance level of 1%, 5% and 10%, respectively. Since the *t*-statistics is greater than 1%, 5%, and 10%; the null hypothesis "No Cointegration" is rejected at all the significance levels. Further, the ECM of − 0.220499 demonstrates that CO_2 and FD, GDP, RE, and PATENTS move together in the long run. Furthermore, the Gregory-Hansen residual-based cointegration test's outcomes are presented in Table 4, confirming the long-run cointegration relationship between CO_2 and FD, GDP, RE, and PATENTS in Norway.

After the pre-estimations, data checks and the long-run association between CO_2 and the regressors were established; the authors applied a nonlinear ARDL estimator to capture the influence of FD, GDP, RE, and PATENTS on CO_2 emissions. The analysis provides both positive (POS) and negative (NEG) changes of FD, GDP, RE, and PATENTS on CO_2 emissions. That is using ceteris paribus or all other things being equal scenario. The outcomes of the NARDL's long-run form of bounds test are unveiled in Table 5. According to our empirical analysis, with regard to financial development (FD), both POS and NEG shock unveil positive shift in FD increased CO_2 emissions in Norway. That is, a 1% unit increase in financial development will cause carbon emissions to increase by 16.56%, and it is statistically insignificant. In other words, positive shock in financial development is insignificant to the Norwegian economy.

On the other hand, a negative shock in financial development will increase carbon emissions in Norway by 43.39%, and it is statistically significant. In other words, financial sector development affects highly polluting industries such as chemicals, tobacco processing, metal products, and petroleum products in Norway; the Norwegians' environmental quality will deteriorate by 43.39%. The study has confirmed that Financial development is symbolized monetization of the economy and an increase in toxic release emissions (Wang et al. 2023; Umar et al. 2020; Ahmed et al. 2022) and has negatively impacted the environmental quality; also supports the Hypothesis 1(H_{o1}) of this current study. Norwegian greenhouse gas emissions rose by around 5% from 1997Q3 to 2013Q4 (Table 2), a long-term trend of a rise in total emissions. Particularly, mercury is a highly toxic and dangerous

Table 4 Gregory-Hansen test for cointegration with regime shifts

Intercept and regime shifts	Test statistic	Breakpoint	Asymptotic critical values		
			1%	5%	10%
ADF	− 7.25***	2010Q1	− 6.89	− 6.32	− 6.16
Zt	− 6.92***	2019Q3	− 6.89	− 6.32	− 6.16
Za	− 44.35	2019Q3	− 90.84	− 78.87	− 72.75

*, **, and *** represent 10%, 5%, and 1% significance levels

pollutant and currently represents a threat to the environment and human health both in Norway and globally. Also, the effect of expanding monetization in the country has always contributed to cheap credit, higher sovereign debt and budget deficit, and public sector growth. Certainly, these processes will always release carbon-related emissions into the atmosphere, thus negatively reducing the quality of the environment. Contrarily, our study contradicts the research of (Kirikkaleli and Sowah 2022), who established a negative interrelation between financial development utilization and CO_2 emission.

The pathway to economic growth has come at the expense of the environment. Norway, as the country, has accumulated one of the world's largest sovereigns totaling approximately US$1 trillion in assets. Contrary to financial development results, our analysis with respect to economic growth, both POS and NEG shock GDP growth has both POS and NEG effect on carbon emissions and both changes are statistically insignificant. If economic growth increases by 1% unit, carbon emissions will increase by 61.12% per unit, and if economic growth decreases by 1% per unit, carbon emissions will decrease by 207.23% per unit. The result supports Hypothesis 2(H_{o2}) and is confirmed by the recent study of Sun et al. (2022). Sun et al. (2022) paper expressed that fossil fuels, huge export of petroleum products, and textile-related activities are intertwined with GDP growth, causing a rise in carbon emissions and thereby harming environmental quality. Norway as the country has shown continuous predominance GDP growth of 260%, the highest than countries in the OECD (Niles and Moore 2021). Although in recent times, growth rates have been fluctuating due to the impact of the spread of COVID-19 in Norway.

Further, the long-term causal effect of renewable energy shows that both POS and NEG shocks in renewable energy have a negative causal effect on carbon emissions in Norway due to the data covered, and the reductions are statistically significant at both 5% and 1% levels. Table 4 shows that 1% rise in renewable energy resources will reduce carbon emissions by 51.86% in Norway, while 1% negative shock in renewable energy resources will cause carbon emissions to decrease in carbon emissions by 48.64%. These results support Hypothesis 3(H_{o3}) of this present paper and in with a recent study by Sun et al. (2022). Jåstad et al.

Table 5 Nonlinear-ARDL long run form and bounds test

Nonlinear-ARDL long run form				
Variable	Coefficient	Std. error	*t*-statistic	Prob
LFD_POS	0.165602	0.229898	0.720327	0.4738
LFD_NEG	0.433954***	0.161945	2.679640	0.0093
LGDP_POS	0.611208	0.628375	0.972682	0.3342
LGDP_NEG	− 2.072347	2.030373	− 1.020673	0.3111
LRE_POS	− 0.518620**	0.226052	− 2.294247	0.0249
LRE_NEG	− 0.486479***	0.170025	− 2.861226	0.0056
LPATENTS_POS	− 0.115753**	0.046373	− 2.496153	0.0150
LPATENTS_NEG	− 0.044605	0.050680	− 0.880120	0.3819
C	1.547366***	0.017233	89.78885	0.0000
CointEq(-1)*	− 0.220499***	0.028981	− 7.608484	0.0000
Bounds test				
F-bounds test		Null hypothesis: no level relationship		
Test statistic	Value	Signif	I(0)	I(1)
			Asymptotic: $n = 1000$	
F-statistic	5.103375***	10%	1.85	2.85
k	8	5%	2.11	3.15
		2.5%	2.33	3.42
		1%	2.62	3.77

*, **, and *** represent 10%, 5%, and 1% significance levels

(2022) study noted that most of Norway's carbon emission reduction would be achieved within consumption because the country is close to 100% renewable energy production onshore, thereby enhancing environmental quality. One of the novelties of this paper lies in the thorough examination of how patents on environmental technology affect carbon emissions using the NARDL approach.

Similar to the findings from renewable energy data, positive and negative shocks in environmental technology patents have a negative causal influence on carbon emissions. According to a recent study by Oyebanji et al. (2022), environmental innovation patents contain substantial economic incentives for innovators and the potential to lessen people's susceptibility, as demonstrated in this study. The findings show that a 1% increase in environmental technology patents reduces carbon emissions by 11.575% and is statistically significant at the 5% level, whereas a negative shock to environmental technology patents reduces carbon emissions by 4.460% and is statistically insignificant. The results support Hypothesis 4 of this study. The United States, Australia, the United Kingdom, Australia, and Japan were among the first countries to file for green patents or intellectual property applications in 2009. Environmental technology patents will help to address a long-standing radical challenge of industrial transformation that can contribute to the Nordic countries' green path. Furthermore, patents on innovation include the ideal ingredient for combating CO_2 emissions and thereby reaching the UN's 2030 Sustainable Development Goals. (SDGs). In conclusion, our findings support the conclusions of Sowah and Kirikkaleli (2022) and Shin et al. (2014).

The stability of the estimated model is necessary for any econometric analysis is important. The results of the heteroscedasticity of Harvey Test and Breusch-Godfrey Serial Correlation LM Test of *Q*-statistics are illustrated in Table 6. The outcome of the models indicates no series correlation, and the model coefficients are stable at 5% significant level, respectively.

Table 6 Summary of heteroscedasticity of Harvey Test and Breusch-Godfrey Serial Correlation LM Test of *Q*-statistics

Heteroscedasticity test: Harvey			
Null hypothesis: homoscedasticity			
F-statistic	1.230263	Prob. *F*(27,67)	0.2438
Obs**R*-squared	31.48788	Prob. chi-square (27)	0.2516
Scaled explained SS	38.67883	Prob. chi-square (27)	0.0677
Breusch-Godfrey Serial Correlation LM Test:			
Null hypothesis: no serial correlation at up to 2 lags			
F-statistic	0.073312	Prob. *F*(2,65)	0.9294
Obs**R*-squared	0.213814	Prob. chi-square (2)	0.8986

As a robustness check, Table 7 presents the results of the DOLS, FMOLS, and CCR models used as a baseline for robustness checks (Kirikkaleli and Sowah 2021). These models have advantages in addressing serial correlation, endogeneity issues, and second-order bias. The results show that all estimated models have the correct expected signs and they are statistically significant, as highlighted earlier by the NARDL results. In other words, the effect of financial development on CO_2 emissions in Norway is positive and significant, i.e., 1% increase in financial development causes CO_2 emissions to rise to 0.193% (DOLS), 0.217% (CCR), and 0.213% (FMOLS). These outcomes support H_{o1} of this present study and in line with the study by Umar et al. (2020). In our second H_{o2}, we assumed that economic growth has a steady increase in CO_2 emissions in Norway, i.e., every 1% increase in economic growth causes CO_2 emissions to rise to 0.137% (DOLS), 0.132% (CCR), and 0.133% (FMOLS). This finding support study by Sun et al. (2022). Further, in our third H_{o3}, we assumed that renewable energy has negatively and significantly affected CO_2 emissions in Norway.

Furthermore, the robustness checks show that 1% changes in renewable energy will lead to a decline in CO_2 emissions by 0.310% (DOLS), 0.306% (CCR), and 0.298% (FMOLS). The outcome supports the outcomes of Oyebanji et al. (2022) which expressed that renewable energy resources have a beneficial influence on CO_2 emissions. Finally, our fourth H_{o4} presented that patents on environmental technologies offer a critical solution for reducing CO_2 emissions; in other words, 1% achievement of patents on environmental technologies decreases CO_2 emissions to 0.044% (DOLS), 0.053% (CCR), and 0.052% (FMOLS).

Conclusion and policy implication

With the significant progress made in the adoption of renewable energy in Norway and a considerable decline in CO_2 emissions experienced in 2020, which was largely plagued by ravaging innovation, it became pertinent to examine the effect of renewable energy on CO_2 emissions in Norway while accounting for environmental innovation. The empirical evidence based on the subject is relatively technical, lacks transparency, and is inconclusive. This paper examines the effect of environmental innovation on environmental sustainability in Norway from 1990 Q1 to 2019 Q4 while controlling renewable energy, economic growth, and financial development. To capture the magnitude (asymmetry) in the estimated variables, this study employed nonlinear ARDL techniques, the Gregory-Hansen Test of regime shifts, followed by the DOLS, FMOLS, and CCR econometric models, which are advanced econometric analysis, in the empirical investigation to achieve this objective. The findings of the nonlinear ARDL model suggested asymmetric

Table 7 Robustness checks

DOLS				
Variable	Coefficient	Std. error	*t*-statistic	Prob
LFD	0.193233***	0.042067	4.593445	0.0000
LGDP	0.137577***	0.032883	4.183835	0.0001
LRE	−0.310678***	0.099857	−3.111214	0.0025
LPATENTS	−0.044831**	0.019238	−2.330334	0.0220
C	0.703062*	0.394715	1.781188	0.0783
R-squared	0.810598	Mean dependent var		1.640311
Adjusted *R*-squared	0.793762	SD dependent var		0.015173
SE of regression	0.006890	Sum squared resid		0.004273
Long-run variance	0.000127			
CCR				
Variable	Coefficient	Std. error	*t*-statistic	Prob
LFD	0.217154***	0.037030	5.864307	0.0000
LGDP	0.132024***	0.031749	4.158325	0.0001
LRE	−0.306581***	0.079893	−3.837380	0.0002
LPATENTS	−0.053038***	0.017178	−3.087547	0.0027
C	0.772345**	0.362257	2.132034	0.0356
R-squared	0.786061	Mean dependent var		1.640311
Adjusted *R*-squared	0.776957	SD dependent var		0.015173
SE of regression	0.007166	Sum squared resid		0.004827
Long-run variance	0.000125			
FMOLS				
Variable	Coefficient	Std. error	*t*-statistic	Prob
LFD	0.213427***	0.038328	5.568445	0.0000
LGDP	0.133371***	0.031440	4.242076	0.0001
LRE	−0.298846***	0.088438	−3.379144	0.0011
LPATENTS	−0.052447***	0.017602	−2.979663	0.0037
C	0.741465**	0.357478	2.074156	0.0408
R-squared	0.787381	Mean dependent var		1.640311
Adjusted *R*-squared	0.778333	SD dependent var		0.015173
SE of regression	0.007144	Sum squared resid		0.004797
Long-run variance	0.000125			

***, **, and * present 1%, 5%, and 10% levels of significance, respectively

long-run relationships among economic growth, financial development, renewable energy, patents on environmental technology, and environmental sustainability in Norway. In addition, the relevant insights of the nonlinear ARDL long-run form were captured: (a) for renewable energy, the positive and negative shocks have a negative causal effect on carbon emissions in Norway; (b) similarly, both positive and negative shocks in patents on environmental technology have a negative causal effect on carbon emissions. These results show that renewable energy and patents on environmental technology are the two major drivers for enhancing the quality of the environment in Norway, while financial development and economic growth remain major challenges for Norway's government, according to the time series data covered. Hence, this present paper presents the following recommendation:

1. A long-run effect of financial development and economic growth causing carbon emissions to rise in Norway is grave. The Norwegian government should ensure that green growth and clean energy sources drive the economic growth process in Norway because economic growth, as reported by this study, adversely affects environmental quality. Norway could suffer from environmental degradation if the excessive growth trend is not eco-friendly regulated. For Norway to achieve it commitment to reducing its greenhouse gas emission to about 90% and all new cars sold by 2025 to be zero-emission vehicles, government authorities much be willing to address the following challenges: (a) economic rationale of exempting some emitters from paying the full rate of the CO_2 emissions tax, considering environmental implications much be reformed; (b) continue

to extend the use of economic, environmental friendly instruments such as eco-friendly policy and legislation, with relevant supervision of enforcement for both pollution abatement; (c) review cheap credit, budget deficit and adjust sectorial subsidies with negative environmental implications, in order to achieve environmental efficiency; (d) one concrete change could be consumers pay fewer taxes for cleaner fuels versus fossil-based fuels; and (e) prepare and sustain national sustainable development strategy to achieve environmental quality.

2. The Norway authorities should encourage robust environment policies that drive renewable energy, energy productivity, and patents on environmental technologies. Control pollution, decarbonize transport, and encourage innovations for electric vehicles, and other general renewable energy technology policies that have strong environmental benefits should be adopted. Intensify efforts to decouple waste generation from economic growth. Reduce discharges of oil from offshore oil and gas operations. In order to reduce nonrenewable energy consumption, open communication such as newspapers, forum discussions on energy conservation, green initiatives, clean energy, circular economy, green energy, the environmental benefit of a patent on technologies, and the importance of green growth, among others, should be highlighted and encouraged by policymakers.
3. Evidence of nonlinear long-run asymmetry relationship demonstrates major importance for more efficient policymaking and forecasting of Norwegian's environmental sector. Policymakers can use this finding to prioritize policies that promote research and development, patents on innovation, clean technologies, and renewable energy sources to combat CO_2 emissions/ GHG emissions, thus achieving UN 2030s Sustainable Development Goals (SDGs).

This study employed aggregated environmental innovation and CO_2 data to achieve the stated objective of investigating the effect of renewable energy on CO_2 emissions in Norway while accounting for environmental innovation. Future studies can focus on utilizing disaggregated data from Norway to analyze the environmental innovation-CO_2 nexus in other countries such as Wales, Scotland, England, and Northern Ireland. More so, given that this study focuses on Norway only, future research can extend the scope of this research to cover other countries and regions and conduct a comparative analysis between and among countries.

Author contribution Kwaku Addai designed the experiment and collected the dataset. The introduction and literature review sections are written by James Karmoh Sowah Jr. and Kwaku Addai. Dervis Kirikkaleli constructed the methodology section and empirical outcomes in the study. James Karmoh Sowah Jr. contributed to the interpretation of the outcomes. All the authors read and approved the final manuscript.

Data availability The data that support the findings of this study are available from the World Bank and OECD.

Code availability Not applicable.

Declarations

Ethics approval We confirmed that this manuscript has not been published elsewhere and is not under consideration by another journal. Ethical approval and informed consent are not applicable for this study.

Consent to participate Not applicable.

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Competing interests The authors declare no competing interests.

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