Journal of Technology Innovations and Energy
https://doi.org/10.56556/jtie.v2i1.421
ISSN: 2957-8809

RESEARCH ARTICLE

The role of renewable energy and technological innovations toward achieving Iceland's goal of carbon neutrality by 2040

Asif Raihan[1*], Almagul Tuspekova[2]

[1]Institute of Climate Change, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia.
Email: asifraihan666@gmail.com
[2] Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia
Email: tuspekova.almagul@gmail.com

*Corresponding author:Asif Raihan: asifraihan666@gmail.com, ORCID ID: 0000-0001-9757-9730
Received: 22 December, 2022, Accepted: 05 March, 2023, Published: 09 March, 2023

Abstract

Iceland has set a target of becoming carbon neutral by the year 2040, and this study looks into the role that economic growth, renewable energy use, and technological innovation could play in getting them there. The Dynamic Ordinary Least Squares (DOLS) technique was used to analyze time series data from 1990 to 2021. According to the results of the DOLS estimation, a one-percentage-point increase in economic growth is associated with a 0.39% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related to a reduction in CO_2 emissions of 1.46 percent over the long run, as indicated by the coefficient of renewable energy use being negative and statistically significant. The calculated long-run coefficient of technical innovation is negative and statistically significant, suggesting that a 1% increase in technological innovation results in a 0.02% reduction in CO_2 emissions. The empirical results show that as Iceland's economy grows, so do its CO_2 emissions, but that the country may get closer to its objective of carbon neutrality through the growing use of renewable energy and technological innovation. Alternative estimators, such as fully modified least squares (FMOLS) and canonical cointegrating regression, do not significantly affect the estimated results (CCR). Furthermore, the pairwise Granger causality test is employed to capture the causal relationship between the variables. In order for Iceland to reach its objective of carbon neutrality by 2040, this article offers policy ideas centered on a low-carbon economy, the promotion of the use of renewable energy sources, and the financing of technical progress.

Keywords: CO_2 emissions; Renewable energy; Technological innovation; Climate change; Sustainability; Carbon neutrality

Introduction

Human activities like burning fossil fuels and clearing forests contribute significantly to increasing atmospheric concentrations of GHGs, making climate change a pressing issue in the 21st century (Raihan et al., 2018; Jaafar et al., 2020; Raihan et al., 2021a; Isfat & Raihan, 2022). Consistently rising CO_2 emissions are predicted to have far-reaching implications for the global climate system, with disastrous effects for every sector of society (Raihan et al., 2019; Raihan et al., 2021b; Ali et al., 2022; Islam et al., 2022). In order to build a sustainable, progressive, and successful society in which no one is left behind, the world must work toward the goal of a climate-neutral future (Raihan et al., 2022a; Raihan & Said, 2022). Therefore, current academics have made it a priority to find ways to reduce CO_2 emissions as part of creating a green and sustainable future by considering a wide range of enabling factors, including renewable energy, technological innovation, and economic development (Raihan et al., 2022b). The United Nations has proposed Sustainable Development Goals (SDGs) for 2030 that highlight the importance of affordable and clean energy, comprehensive and sustainable economic growth, and technical innovation in the fight against climate change (SDGs 7, 8, 9, and 13).

The United Nations Framework Convention on Climate Change (UNFCCC) negotiated the Paris Pact, a multilateral environmental agreement, to enhance the global response to the risks posed by climate change within the context of sustainable development. After signing the Paris Agreement in 2016, Iceland became part of a global effort to keep global warming far below 2 degrees Celsius, with the ultimate goal of keeping it to 1.5 degrees Celsius. As part of the Paris Agreement, Iceland has committed to reducing greenhouse gas emissions by 40 percent from 1990 levels by 2030 and to achieving carbon neutrality by 2040. However, industrial activities, especially the creation of aluminum and ferrosilicon, account for the vast majority of Iceland's emissions. There are a number of other industries that contribute significantly to global warming, but transportation on the road, farming, fishing, and garbage collection all rank high. Rapid emission reduction is essential to reach climate neutrality. By taking steps to mitigate climate change, Iceland hopes to achieve multiple environmental goals at once, including better air quality, a circular economy, and biodiversity protection, as well as ensure sustainable growth and a just transition. Iceland's authorities need a better understanding of the country's net-zero emission potential if they are to strike a compromise between climate change mitigation and sustainable growth.

The question of whether or not the benefits of economic growth outweigh the costs of environmental damage informs decisions about how best to promote environmental sustainability and development (Raihan & Tuspekova, 2022a). Increases in economic growth allow for the replacement of older, more polluting technologies with newer, more environmentally friendly ones, thereby improving environmental quality (Raihan & Tuspekova, 2022b). There are a number of factors that can help decouple economic growth from environmental degradation, including shifts in output composition, the adoption of cleaner manufacturing technology, stricter environmental regulation, and a heightened public awareness of environmental issues (Raihan & Tuspekova, 2022c). As of 2022, however, Iceland's GDP per capita of USD 73,981 placed it eighth globally. At 5.8 percent, 19.7 percent, and 74.6 percent, respectively, agriculture, industry, and services all play important roles in the country's gross domestic product. Alcoa's smelter in Iceland is one of the country's main economic drivers, alongside fishing and tourism. As a result, a major issue is whether or not Iceland's growing economy is consistent with its ambition to become carbon neutral.

The importance of renewable energy has been underscored by the growing concern about global climate change and environmental sustainability (Raihan et al., 2022c; Voumik et al., 2022a). International economies are shifting toward more sustainable renewable energy sources as a result of the rapid depletion of fossil fuels and the severe environmental impacts of doing so (Raihan et al., 2022d). Renewable energy's benefits include cutting down on the use of traditional energy sources while protecting the world's economy for the long haul (Raihan et al., 2022e). Solar, water (hydropower), wind, geothermal, and biomass are the five primary sources of renewable energy (Raihan et al., 2022f). Wind, sun, and other renewable sources of energy are plentiful, clean, and safe alternatives to traditional power sources. Many people believe that renewable energy can solve the problems of energy security and pollution (Raihan et al., 2022g). The objective of reducing global emissions by half by 2050 (Raihan et al., 2022h) and of becoming carbon neutral in Iceland by 2040 both rely heavily on the use of renewable energy sources. Despite being geographically and climatically isolated, as well as having been hit hard by the 2008 financial crisis, Iceland has effectively transitioned away from fossil fuels and toward renewable sources of energy. Nearly all of Iceland's energy needs are met by hydrothermal-, geothermal-, and wind power, and the proportion of domestic renewable energy to the entire energy budget is approximately 85%, which is a far larger share than in most other countries. When compared to the usage of fossil fuels, the metal sector in Iceland is able to reduce its CO_2 emissions per ton of metal produced because of the abundance of renewable energy sources such as hydropower. The vision for sustainable energy forms the basis for Iceland's Energy Policy for 2050, which seeks to eliminate the use of fossil fuels and replace it with energy generated only from renewable sources by the year 2050. To get to carbon neutrality, Iceland needs to maximize its usage of renewable energy, hence this is an important topic for study.

At this time, technological development is the single most important factor in reducing global climate change (Raihan et al., 2022i). The consistent growth of direct environmental technology with the aim of reducing CO_2 emissions has been facilitated by the advancement of environmental legislation. The process of economic reorganization and optimization relies heavily on technological innovation (Raihan & Voumik, 2022a). To lessen the carbon dioxide (CO_2) emissions caused by industrialization, conventional economic development is shifting its focus from production to innovation. In addition, technical advancement is viewed as crucial to enhancing a nation's energy efficiency (Raihan & Voumik, 2022b). When applied to the economy, modern technologies allow for a certain level of production to be attained while requiring less energy overall. Furthermore, technological development permits the economy to shift from using nonrenewable energy sources to meeting energy needs with renewable energy sources (Raihan & Tuspekova, 2023). Technological advancements have reduced the need for fossil fuels and the resulting emissions of carbon dioxide. Almost all of Iceland's energy needs, including power and heating, are now met by renewable sources, and the country is in a prime position to take advantage of emerging technologies that will allow for the widespread electrification of transportation. Iceland's industrial structure may be modernized with the help of technological advancements, and this would be an excellent catalyst for the country's economic progress. To boost economic growth and reach carbon neutrality, studying the impact of technological innovation on environmental sustainability is essential from a theoretical and practical standpoint.

Getting to a climate-neutral society will need the concerted efforts of numerous groups working in tandem. This intricacy presents a problem for the government, which must begin with defining who is responsible for what and how at the federal, state, and municipal levels, as well as among commercial and public actors and individual individuals. Finding innovative ways to collaborate between different tiers of government and the Government and civil society actors will also be a component of this. Considering that Iceland wants to be carbon neutral by 2040, it is crucial to analyze how policy, instruments, and measures promote a low-emission pathway up to 2050. A clear explanation of the most important parameters is necessary before a target of climate neutrality can be set. For practically any country, planning the strategy to achieve the goal of net zero emissions within a few decades is an enormous task that will call for bold and effective steps. There must be openness and clarity about the goal's associated parameters. Even while studies into the possibility of emission reduction factors using econometric methodologies has become a hot topic in recent years, there has been surprisingly little investigation of this question in Iceland. This study tries to fill this knowledge vacuum by using the dynamic ordinary least squares (OLS) method to examine how GDP growth, renewable energy consumption, and technological innovation affect CO_2 emissions in Iceland.

This research is important because it provides insights that may be used in a variety of ways to both existing literature and ongoing policy debates in Iceland. To begin with, the novel findings from the in-depth econometric analysis of the relationship between CO_2 emissions and emission reduction factors in the context of Iceland fill a void in the prior academic literature. New to this study is an analysis of how the adoption of renewable energy sources and technology advancements can affect Iceland's carbon footprint. Second, our study sheds light on the often-overlooked but crucial function of patent applications in emission reduction. And third, the study included the most recent and comprehensive data available over a 32-year time frame (1990–2021). To ensure the reliability of the findings, multiple diagnostic tests and cointegration models (including the ADF, DF-GLS, and P-P tests) were used. Fifth, the Granger causality test was used to determine the direction of the relationship between the variables. For Iceland to reach its objective of carbon neutrality by 2040, the findings of this study will give policymakers more complete and relevant information for formulating successful policies in the areas of a low-carbon economy, boosting renewable energy consumption, and supporting technological innovation. Furthermore, the results of this study can be applied to the review and development of environmental policies to help get Iceland ready for a 1.5°C world by bolstering policy and action plan to lessen the effects of climate change and ensure sustainable development. The findings from this study may also be useful for other developing nations as they seek to fortify their own climate change mitigation and adaptation plans.

The rest of the article is structured as follows. The Introduction is followed by the section Literature Review, where relevant research studies have been discussed. The third section is the Methodology section, followed by the Results and Discussion section. Subsequently, the last section presents the Conclusion, policy recommendations, limitations of the study, and future research directions.

Literature Review

Numerous studies have been performed over the past several years to determine how and to what degree renewable energy can cut down on carbon dioxide emissions. A number of economic analyses have concluded that expanding the usage of renewable energy sources would lead to lower levels of carbon dioxide emissions. Moreover, several empirical studies have demonstrated the link between expanding economies and rising CO_2 emissions. Multiple studies were taken into account, from a number of different nations, considering a number of different aspects and using a number of different approaches. Chen et al. (2019) looked at China's CO_2 emissions, economic growth, and use of renewable energy sources between 1980 and 2014 and found that the latter two were inversely associated with the former. Using a sophisticated panel quantile regression model, Azam et al. (2022) found a positive correlation between GDP growth and CO_2 emissions in the top five emitter countries for the years 1995–2017, and a negative correlation between renewable energy and CO_2 emissions in these same countries. Using data from 1990 to 2018, Raihan and Tuspekova (2022a) found that economic growth was positively related to CO_2 emissions, whereas the use of renewable energy was negatively related to emissions. Using data from 1990 to 2019, Raihan and Tuspekova (2022c) discovered that the usage of renewable energy was inversely related to CO_2 emissions in Nepal, while the use of fossil fuels was positively related to emissions.

Furthermore, Liu et al. (2017) used time data from 1970-2013 to find a negative correlation between CO_2 emissions and the utilization of renewable energy sources in Indonesia, Malaysia, the Philippines, and Thailand. Using data from 1990 to 2019, Raihan and Tuspekova (2022d) discovered that economic expansion positively affected CO_2 emissions in Brazil, whereas the use of renewable energy negatively affected CO_2 emissions. With data from 1990 to 2020, Raihan and Tuspekova (2022e) found that economic expansion positively affected CO_2 emissions in Turkey, while renewable energy negatively affected CO_2 emissions. Data from 1990-2019 was also used by Raihan and Tuspekova (2022f) to show that economic expansion positively affected CO_2 emissions in Mexico, whereas the use of renewable energy negatively affected CO_2 emissions in the country. Using data from 1970 to 2013, Raihan et al. (2022h) found that in Argentina, increasing economic activity was associated with higher CO_2 emissions, whereas increasing reliance on renewable energy sources was associated with lower emissions.

In addition, increasing R&D spending can improve economic production efficiency and resource consumption efficiency, hence the connection between technical innovation and CO_2 emissions has been studied extensively in recent years. We anticipate that technological progress will have a significant impact on cleaning up the environment. Many countries have successfully decreased their CO_2 emissions and enhanced their environmental performance thanks to new technologies and environmental protection measures. The favorable impact that technology advancements might have on carbon dioxide emissions has been the subject of a lot of prior research. Because patents safeguard business interests and intellectual property, they are favored by most academics as a proxy for technological innovation in the service of solving environmental issues. Green technology innovation is widely regarded as having positive effects on the environment, and Chen and Lee (2020) argue that this is especially true of technological advancements in high-income countries, where they can be reduced effectively. There are several empirical studies demonstrating that technical progress helps lower carbon dioxide emissions. Increasing the efficiency of technological innovation in China has a profoundly beneficial effect on environmental performance, claim Shahbaz et al. (2020). According to Rahman et al. (2019), if foreign companies use clean technology, it could improve environmental quality in Pakistan by reducing carbon emissions. To better the environment, technological advancements have been shown to decrease CO_2 emissions in 24 European countries (Ahmed et al., 2016).

In addition, using data from 1990 to 2019, Raihan et al. (2022b) found that in Malaysia, increasing economic activity was positively correlated with CO_2 emissions, whereas increasing usage of renewable energy sources and technological advancement was negatively correlated with CO_2 production. With data from 1996-2018, Raihan and Tuspekova (2022b) found that economic expansion positively affected CO_2 emissions in Kazakhstan, but the usage of renewable energy and technical innovation negatively affected CO_2 emissions. Using data from 1990 to 2020, Raihan and Voumik (2022a) found that economic expansion positively affected CO_2 emissions in India, while the usage of renewable energy and technical innovation negatively affected CO_2 emissions in India. Using data from 1990 to 2020, Raihan and Voumik (2022b) found that economic expansion positively affected CO_2 emissions in China, while the usage of renewable energy and technical innovation negatively affected CO_2 emissions in China. Using data from 1990-2019, Raihan et al. (2022f) found that economic expansion increased CO_2 emissions in Bangladesh, whereas the usage of renewable energy and technological advancement decreased them. Using data from 1990 to 2020, Raihan et al. (2022g) also demonstrated the beneficial benefits of economic growth on CO_2 emissions, as well as the detrimental consequences of renewable energy consumption and technical advancement. As it is already generally understood that technological innovations play a substantial role in reducing emissions while sustaining economic growth, any greater understanding of the process of technological innovation is likely to increase our knowledge of mitigation possibilities.

Despite this encouraging trend, the entire potential of renewable energy use and technical innovation is yet unclear, as are the methods of knowledge acquisition. Therefore, the current study aims to address the vacuum in the literature by combining multiple econometric methodologies to investigate the potential of economic growth, renewable energy use, and technical breakthroughs to help Iceland reach its objective of carbon neutrality.

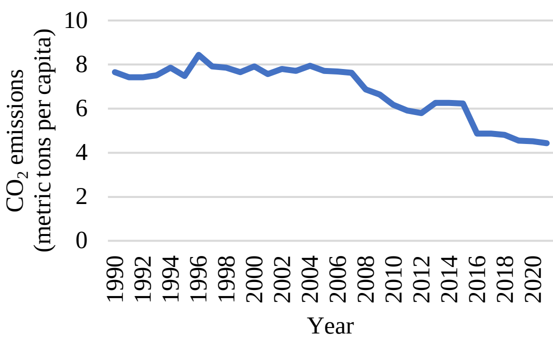
Methodology

Data

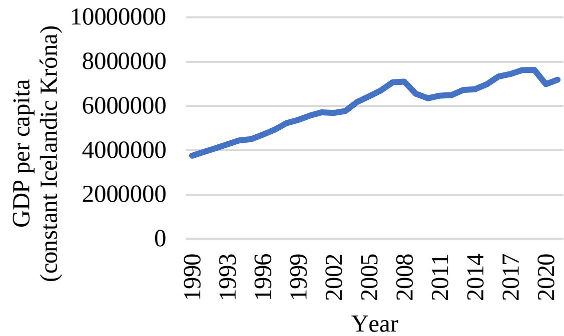
By applying the DOLS method of cointegration developed by Stock and Watson (1993), this study offers an empirical examination of the dynamic effects of economic development, renewable energy utilization, and technical advancement on CO_2 emissions in Iceland. This study's econometric analysis made use of the most up-to-date Icelandic time series data, which stretched from 1990 to 2021. The numbers were taken from the World Development Indicator (WDI) database (World Bank, 2022). In this study, carbon dioxide emissions served as the dependent variable, while economic expansion, renewable energy use, and technological progress served as the explanatory variables. Furthermore, it should be mentioned that technical innovation refers to the interest in finding new technology shown by a country's industrial and commercial entities, which may be quantified using a metric like the number of patents. Since patents are the formalized form of technology, patenting activities can stand in for innovation in that field. An increase in patent applications is a sign that businesses and individuals want to adopt cutting-edge innovations. As a result, the total number of patent applications has been used as a stand-in for technological progress (both domestic and foreign). In addition, a logarithmic transformation is applied to the variables to guarantee a normal distribution. Table 1 displays the variables, their logarithmic representations, the units of measurement, and the researchers that collected the data. Moreover, Figure 1 displays the annual trends of the research variable.

Table 1. Data sources, units of measure, and logarithms of the variables

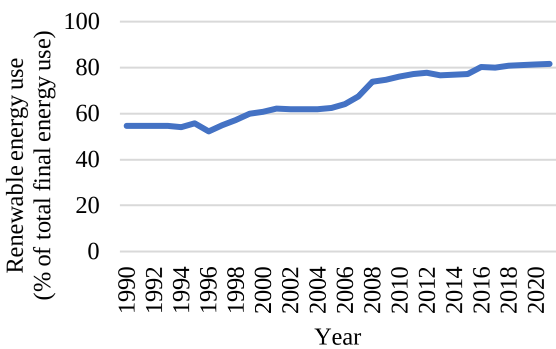
Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Metric tons per capita	WDI
GDP	Economic growth	LGDP	GDP per capita (constant Icelandic Króna)	WDI
RNE	Renewable energy use	LRNE	% of total final energy use	WDI
TI	Technological innovation	LTI	Number of patent applications	WDI



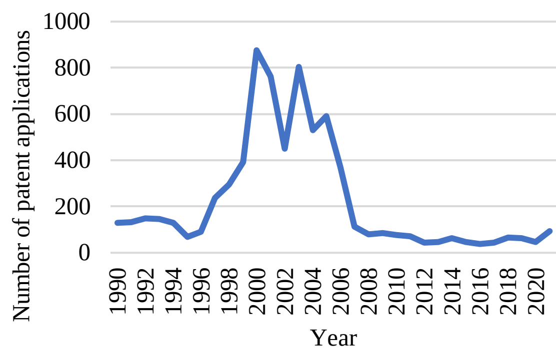
(a) CO_2 emissions



(b) Economic growth



(c) Renewable energy



(d) Technological innovation

Figure 1. Annual trends of the study variables

Theoretical framework

In this research, we use the framework of a Cobb-Douglas production function to analyze the hypothesis (Cobb & Douglas, 1928). This research topic uses standard production economics to assess how GDP growth, renewable energy adoption, and technical progress have affected CO_2 emissions in Iceland. If we assume a constant rate of return and use a typical Cobb-Douglas production function, we can derive the aggregate output function as follows:

$$Y_t = f\,(K_t, L_t) \tag{1}$$

where Y_t is the GDP at time t, K_t is capital at time t, and L_t is effective labor at time t

There is a theoretical link between CO_2 emissions and financial success. Given the widespread belief that emissions of carbon dioxide (CO_2) are caused by human economic activity, we can express the CO_2 emission function as:

$$CO_{2t} = f\,(GDP_t) \tag{2}$$

where CO_{2t} is the CO_2 emissions at time t

Moreover, rapid economic expansion is associated with increased energy consumption in the manufacturing process (Raihan, 2023a), while increasing the amount of renewable energy in the overall final energy use helps to achieve environmental sustainability by lowering carbon emissions from fossil fuel energy sources (Raihan, 2023b). Therefore, the goal of this research is to provide an estimate of how much renewable energy utilization affects carbon dioxide emissions. As a result, Eq. (2) may be rewritten as:

$$CO_{2t} = f\ (GDP_t;\ RNE_t) \tag{3}$$

where RNE_t is the renewable energy use at time t

This study takes into account technological innovation in the model as a result of the discussion in the introduction and literature review sections, which show that technological innovation can have multiple effects on CO_2 emissions. Technological advancement is also important since it increases factor productivity and guarantees energy efficiency, both of which contribute to economic growth. In order to understand the relationship between CO_2 emissions, economic growth, renewable energy consumption, and technological innovation, the current study employed the following economic functions:

$$CO_{2t} = f\ (GDP_t;\ RNE_t;\ TI_t) \tag{4}$$

where TI_t is the number of patent applications at time t

Econometric model

Equation (5) depicts the empirical model:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t \tag{5}$$

Equation (5) is further expanded as the econometric model in the following form:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t + \varepsilon_t \tag{6}$$

where τ_0 and ε_t stand for intercept and error term, respectively. In addition, τ_1, τ_2, and τ_3 denote the coefficients.

Moreover, Equation (7) shows the logarithmic arrangement of Equation (6):

$$LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LRNE_t + \tau_3 LTI_t + \varepsilon_t \tag{7}$$

Figure 2 is a flowchart of the analytic methods used to investigate the impact of Iceland's expanding economy, increasing reliance on renewable energy, and rapid technological advancement on the country's carbon footprint.

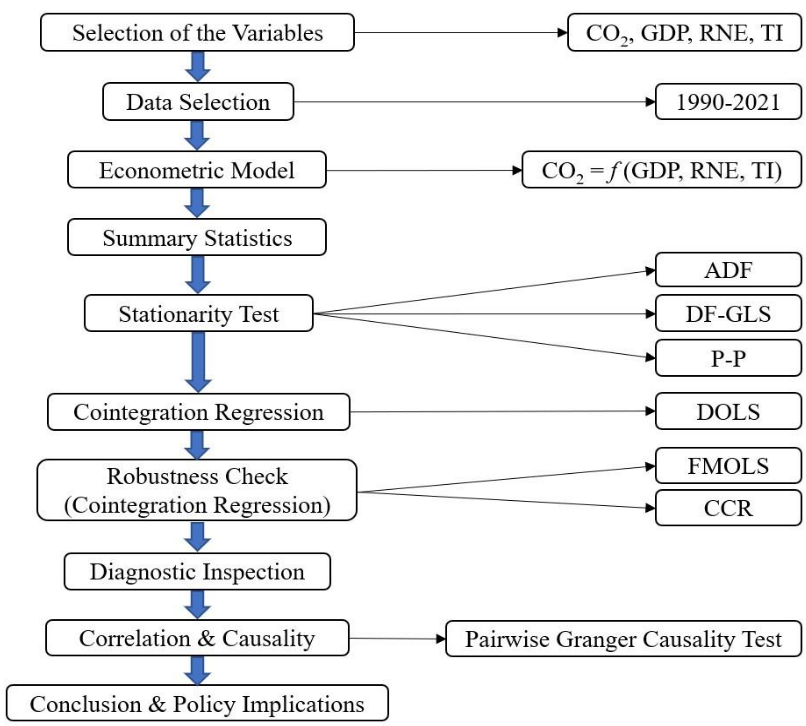


Figure 2. Flow chart of the analytical techniques employed in the study

Stationarity techniques for data

Using a unit root test is essential for preventing erroneous regression. By differentiating the variables in the regression and using stationary processes to estimate the equation of interest, this method ensures that the variables are, in fact, stationary (Raihan & Tuspekova, 2022g). Before investigating cointegration between variables, the empirical literature recognizes the requirement to define the sequence of integration. Since the power of unit root testing varies with sample size, several studies recommend using multiple tests to determine the best sequence for series integration (Raihan & Tuspekova, 2022h; Raihan, 2023c). We employed the Augmented Dickey-Fuller (ADF) test proposed by Dickey and Fuller (1979), the Dickey-Fuller generalized least squares (DF-GLS) test proposed by Elliott et al. (1992), and the Phillips-Perron (P-P) test proposed by Phillips and Perron (1996) to identify the autoregressive unit root (1988). To guarantee that no variables in this study surpassed the order of integration and to provide more evidence for the superiority of the DOLS technique over conventional cointegration methods, the unit root test was employed.

DOLS cointegration regression

The time series data in this research was analyzed using DOLS, an extended equation of ordinary least squares estimation. The DOLS cointegration test uses explanatory factors together with leads and lags of their initial difference terms to regulate endogeneity and calculate standard deviations using a covariance matrix of errors that is resistant to serial correlation (Raihan & Tuspekova, 2022i). The orthogonalization of the error term is shown by the inclusion of the leading and trailing terms of the individual ones. Using the DOLS estimator's standard deviations as a test for statistical significance is a safe bet because they follow a normal asymptotic distribution. The DOLS method is useful for integrating cointegrated outlines with factors that integrate in a different order, as it estimates the dependent variable based on the explanatory variables in levels, leads, and lags (Raihan & Tuspekova, 2022j). The mixed-order integration of individual variables in the cointegrated outline is the primary benefit of the DOLS estimation. Some of the other variables in the regression were also I(1) variables with leads (p) and lags (-p) of the initial difference, while others were I(0) variables with a constant term, as in DOLS estimation (Begum et al., 2020). This estimate eliminates problems with small sample bias, endogeneity, and autocorrelation by summing the leads and lags among explanatory factors (Raihan et al., 2023a). It is only after establishing that the variables are cointegrated that the study moves on to estimating the long-run coefficient with DOLS (using Equation 8).

$$\Delta LCO2_t = \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LRNE_{t-1} + \tau_4 LTI_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LRNE_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LTI_{t-i} + \varepsilon_t \quad (8)$$

where Δ is the first difference operator and q is the optimum lag length in Equation (8).

Robustness check

In order to ensure the validity of the DOLS results, we used the fully modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR). Hansen and Phillips (1990) created the FMOLS regression to integrate the most accurate estimates of cointegration. The FMOLS method is a modification of least squares that allows for endogeneity in the independent variables and serial correlation effects due to cointegration. The FMOLS method aids with spurious regressions by employing conventional regression techniques (OLS) for nonstationary (unit root) data. The CCR method, which involves transforming data with only the stationary component of a cointegrating model, was also pioneered by Park (1992). A cointegrating link from the cointegrating model will remain unchanged after such data processing. The CCR transformation eliminates the zero-frequency dependence of the error term on the regressors in a cointegrating model. The CCR method yields asymptotically efficient estimators and asymptotic chi-square tests that are devoid of nuisance parameters. Asymptotic coherence can be established with the help of FMOLS and CCR techniques by examining the impact of serial correlation (Raihan & Tuspekova, 2022k). Consequently, the FMOLS and CCR estimators are utilized to determine the long-term elasticity, as demonstrated by Equation (8).

Pairwise Granger causality

The goal of this study is to identify the relationships between the variables that lead to the observed effects. Therefore, in order to determine whether or not there is a causative relationship between the variables, the paired linear Granger-causality test introduced by Granger (1969) was implemented in this study. The present study adopts the "statistical notion of causation based on prediction" of Granger causality because of its many benefits over alternative time-series evaluation methods. To say that one time series Y "Granger-causes" another is to say that it aids in the forecasting of another time series X. The time series for these two variables has a length of T, where X_t and Y_t (t=1,2,...,T) are the values for X and Y at time t. Following are some equations for applying a bivariate autoregressive model to the Xt and Yt models:

$$X_t = \beta_1 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=1}^{n} \mu_i X_{t-1} + e_t \quad (9)$$

$$Y_t = \beta_2 + \sum_{i=1}^{n} \Omega_i Y_{t-1} + \sum_{i=1}^{n} \infty_i X_{t-i} + u_t \quad (10)$$

where n signifies the number of lags, as stipulated by the data measures β_1, β_2, α_i, Ω_i, μ_i, and ∞_i as factors for assessment; and e_t and u_t are residual terms.

Estimation of the coefficients can be done using the ordinary least squares method, and Granger causality between X and Y can be determined using F tests.

Results and Discussion

Summary statistics

Table 2 displays the statistical values of many normality tests (skewness, probability, kurtosis, and Jarque-Bera) applied to the outcomes of the summary measures between variables. Icelandic time series data for each variable spans the years 1990 through 2021 and features 32 observations. Negative skewness values indicate that all of the variables are normally distributed. Researchers also used kurtosis to determine whether or not the series they were studying deviated significantly from a normal distribution. All empirical series are shown to be platykurtic, with values below 3. All the parameters are normal, as shown by the tiny values of the Jarque-Bera probability.

Table 2. Summary statistics of the variables

Variables	LCO2	LGDP	LRNE	LTI
Mean	1.897761	15.58626	4.195806	4.911573
Median	2.008804	15.67194	4.146941	4.641562
Maximum	2.133136	15.84703	4.401940	6.775366
Minimum	1.488630	15.13740	3.956101	3.637586
Std. Dev.	0.199138	0.210312	0.157950	0.975610
Skewness	-0.917764	-0.687887	-0.021779	0.578600
Kurtosis	2.432830	2.253088	1.396069	2.035290
Jarque-Bera	2.921124	2.267509	2.432657	2.026372
Probability	0.185387	0.195195	0.179725	0.220207
Observations	32	32	32	32

Results of unit root tests

To ensure that no variables had an order of integration I higher than the others, we used the unit root test to support the use of the DOLS estimator rather than cointegration (1). We employed trend-and-constants-based ADF and DF-GLS and P-P methods to isolate the autoregressive unit root. The outcomes of the ADF, DF-GLS and P-P tests for locating the unit root are shown in Table 3. All three unit root tests show that the variables were not level-stationary, but did become stationary once the first difference was taken. Therefore, the unit root results suggest that the variables share a first-difference order of integration. This means that there is no possibility of a deceptive regression analysis because all of the variables included in the empirical investigations tend toward their true values.

Table 3. The results of unit root tests

Logarithmic form of the variables		LCO2	LGDP	LRNE	LTI
ADF	Log levels	0.315282	-2.198261	-0.351326	-1.224113
	Log first difference	-6.210401***	-3.725762***	-4.767828***	-4.443520***
DF-GLS	Log levels	0.322991	-0.394066	-0.043295	-1.250108
	Log first difference	-6.266548***	-3.628563***	-4.738730***	-4.465485***
P-P	Log levels	0.989018	-2.604318	-0.351326	-1.402678
	Log first difference	-6.184393***	-3.725762***	-4.792888***	-4.390266***

*** denotes significance at the 1% level

DOLS outcomes

The DOLS estimation results are shown in Table 4. The estimated long-run coefficient of LGDP is positive and statistically significant at the 5% level, indicating that a 1% increase in economic growth would result in a 0.39% increase in CO_2 emissions when all other variables are held constant. This research shows that economic expansion causes environmental deterioration over time. The positive correlation between GDP and CO_2 emissions is substantiated by previous studies (Chen et al., 2019; Raihan et al., 2022h; Azam et al., 2022; Raihan and Tuspekova, 2022a; Liu et al., 2017; Raihan and Voumik, 2022a; Raihan et al., 2022b; Raihan and Tuspekova, 2022e; Raihan, 2023d). Emissions have increased as industrialization has led to more energy use, infrastructural development, and economic capitalization, all of which have had a positive effect on investments and business output. When the economy expands, pollution levels tend to rise alongside it. It causes greater pollution, waste, and environmental deterioration as more societal demands are met through consumption and development activities (Voumik et al., 2022b). As a result, economic activities appear to be appropriate for environmental protection and development, rather than posing a threat to long-term environmental quality. As a result, the ability to attain carbon neutrality may be at risk unless the economy makes a massive transition to using low-carbon technology for manufacturing products and services. Consequently, in order to achieve carbon neutrality in Iceland, effective policies and ways to reduce dependency on fossil fuel supply, energy intensity, and CO_2 emissions are required.

Table 4. The outcomes of DOLS: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.388981**	0.162696	2.390848	0.0238
LRNE	-1.458025***	0.274945	-5.302967	0.0000
LTI	-0.025821**	0.015863	-1.627737	0.0148
C	1.825774	1.451903	1.257504	0.2190
R^2	0.914452			
Adjusted R^2	0.907823			

*** and ** signify significance at the 1% and 5% levels, respectively

When looking at long-term effects, however, the estimated coefficient of renewable energy use is negative and statistically significant at the 1% level, suggesting that increasing the use of renewable energy by 1% is linked to a reduction in CO_2 emissions of 1.46 percent. This demonstrates the possibility of reducing emissions by increasing the usage of renewable energy sources in Iceland. Our data suggest that the use of renewable energy sources is crucial for Iceland to reach carbon neutrality. The results of this study are in line with those of numerous other studies, including those by Chen et al. (2019), Raihan et al. (2022h), Azam et al. (2022), Raihan and Tuspekova (2022a), Liu et al. (2017), Raihan and Voumik (2022a), Raihan et al. (2022b), Raihan and Tuspekova (2022b), and Raihan et al. (2023b) Using renewable sources for energy generation is crucial to both sustainable development and climate change mitigation in the face of the looming threat of climate change. Renewable energy provides substantial economic benefits, such as greater energy availability, improved energy security, and the use of local renewable resources, in addition to reducing carbon emissions.

We also investigate how technological progress can help Iceland reach carbon neutrality. At the 5% significance level, the predicted long-run coefficient of technological innovation is negative, meaning that for every 1% increase in technical innovation, CO_2 emissions decrease by 0.02%. The empirical result suggests that a rise in patent applications may result in lower levels of carbon dioxide emissions. This suggests that the adoption of green technologies in Iceland's industrial sector may contribute to the country's efforts to improve environmental quality by achieving its target of zero emissions. Our findings are consistent with those of other researchers who have found that technological advancements aid in environmental sustainability, including Chen and Lee (2020), Shahbaz et al. (2020), Ahmed et al., (2016), Raihan and Voumik (2022a), Raihan et al. (2022b), Raihan and Tuspekova (2022b), and Raihan et al. (2023c). With the help of a green economy and green technologies, Iceland can reach its goal of becoming a carbon-neutral country by 2040. The debate over the part that patent applications should play in reducing climate change is heating up as we enter an era in which there is a greater awareness of the need for environmental sustainability. Green technology patents guarantee that the environment will always be preserved for future generations even as they are used to advance the field.

It is also worth noting that the theoretical and practical indications of the estimated coefficients are consistent. It appears that the computed regression model fits the data pretty well, with R^2 and modified R^2 values of 0.9144 and 0.9078, respectively. This suggests that the changes in the independent variables may explain 90% of the variation in the dependent variable.

Robustness check

To ensure that DOLS estimation was consistent, we used the FMOLS and CCR estimators. Tables 5 and 6 display the model's estimated FMOLS and CCR values, respectively. The results of the FMOLS and CCR estimations show how reliable the DOLS estimation is. The positive coefficient of economic growth was validated at a 5% level of significance by both the FMOLS and CCR estimation results. Moreover, the negative coefficient of renewable energy use was confirmed at the 1% level of significance in both FMOLS and CCR estimate results. In addition, FMOLS and CCR estimation results corroborate the negative relationship between technological progress and carbon dioxide emissions at the 5% significant level. Additionally, the goodness of fit is reflected in the estimated R2 and modified R2 values from FMOLS and CCR estimates. Thus, it can be concluded that CO_2 emissions rise as the Icelandic economy expands, while progress in renewable energy and technology allows the country to become carbon neutral.

Table 5. The results of FMOLS: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.378047**	0.289937	1.303895	0.0233
LRNE	-1.517329***	0.468830	-3.236418	0.0003
LTI	-0.027211**	0.034247	-0.794547	0.0348
C	2.228276	2.714170	0.820979	0.1488
R^2	0.919242			
Adjusted R^2	0.906533			

*** and ** signify significance at the 1% and 5% levels, respectively

Table 6. The results of CCR: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.371311**	0.322907	1.149902	0.0263
LRNE	-1.499439***	0.478408	-3.134225	0.0001
LTI	-0.028437**	0.034894	-0.814965	0.0422
C	2.253500	3.187279	0.707029	0.1856
R^2	0.912023			
Adjusted R^2	0.900785			

*** and ** signify significance at the 1% and 5% levels, respectively

Diagnostic inspection

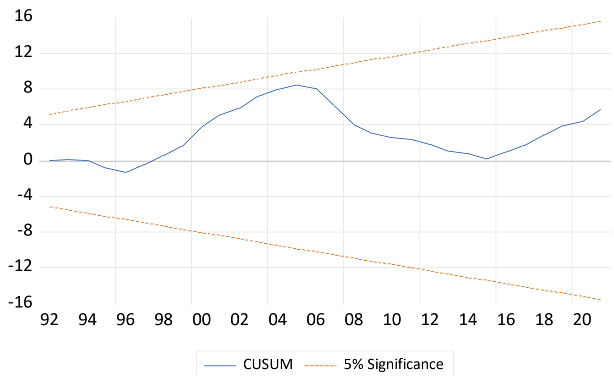
We ran tests for normality, heteroscedasticity, and serial correlation to make sure the cointegration assessment was accurate. The outcomes of the diagnostic procedures are summarized in Table 7. There is no autocorrelation or heteroscedasticity in the model, and the data are normally distributed. Moreover, we used the CUSUM and CUSUMQ tests to examine the model's robustness to recursive changes. In Figure 3, we see the CUSUM and CUSUMQ plots at the 5% level of significance. The blue lines show the residual values, while the red lines show the confidence intervals. The estimated values of the examined residuals are consistent with the confidence intervals, indicating that the model is stable at the 5% level of significance.

Table 7. The results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	2.022942	0.3637	Residuals are normally distributed
Breusch-Godfrey LM test	1.864723	0.3214	No serial correlation exits
Breusch-Pagan-Godfrey test	1.534236	0.1897	No heteroscedasticity exists

Results of the pairwise Granger causality

The existence of Granger causality is established using the F-statistic, which measures the strength of the correlation between the variables. Table 8 displays an overview of the pairwise Granger causality. The statistical significance of the findings of the pairwise Granger causality tests leads to the rejection of the null hypothesis, indicating that there is unidirectional causality from LGDP to LCO2, LCO2 to LRNE, LGDP to LRNE, LGDP to TI, and LTI to LRNE. This means that in Iceland, economic growth leads to increased CO_2 emissions, which in turn leads to increased use of renewable energy sources, which in turn leads to increased economic growth, which in turn leads to increased use of renewable energy sources, etc. The results show that the usage of renewable energy sources becomes more crucial when CO_2 emissions rise in tandem with economic development. More evidence is that a thriving economy may spur the development of cutting-edge renewable energy sources. As a result of the resources made available by a flourishing economy, research into and development of renewable energy technology and infrastructure can expand. To meet growing energy needs and improve efficiency, technological advancements are aiding the shift away from fossil fuels and toward renewable energy. In contrast, the results of a pairwise Granger causality test show that advancements in technology are not a direct result of increases in carbon dioxide emissions. In Figure 4, we see the relationships between the studied factors.



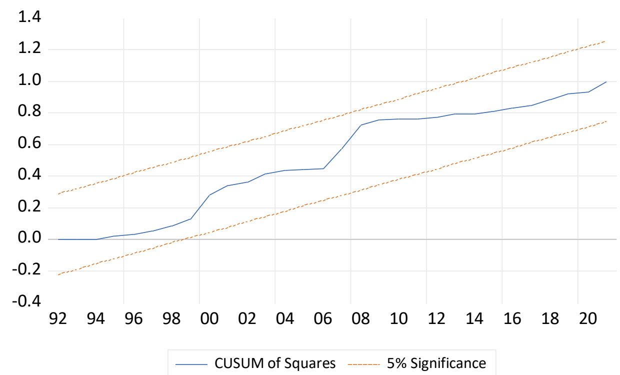


Figure 3. The plots of CUSUM and CUSUMQ tests

Table 8. The results of the pairwise Granger causality test

Causality direction	F-statistic	Decision
LGDP → LCO2	3.72452**	√
LCO2 → LGDP	1.72349	×
LRNE → LCO2	2.18945	×
LCO2 → LRNE	3.82529*	√
LTI → LCO2	1.82365	×
LCO2 → LTI	2.41381	×
LRNE → LGDP	0.87423	×
LGDP → LRNE	7.80137***	√
LTI → LGDP	0.20184	×
LGDP → LTI	3.19236**	√
LTI → LRNE	3.98125**	√
LRNE → LTI	0.49813	×

***, **, and * denote significance at the 1%, 5%, and 10% levels

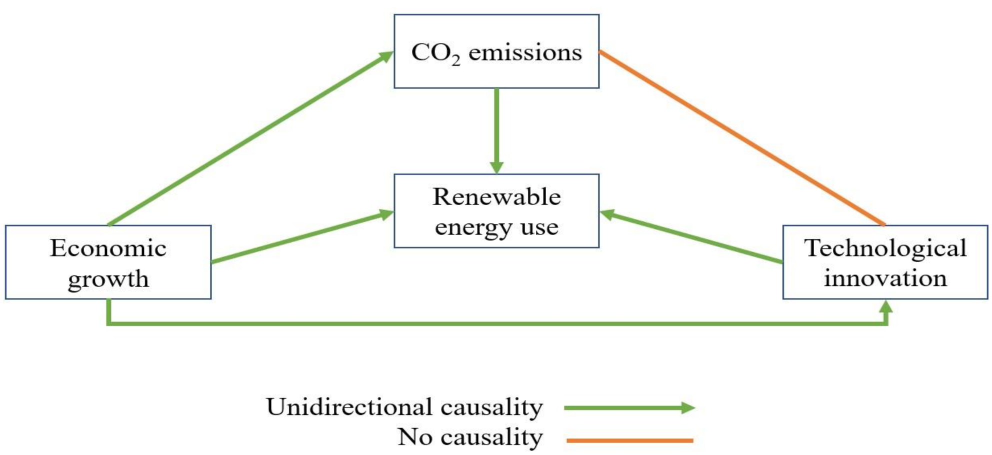


Figure 4. Granger causality between the examined variables

Our research also shows that there is a one-way causality between economic growth and technical innovation, with the former serving to spur the latter. When a nation's GDP grows, it has more disposable income to put toward R&D and the introduction of cutting-edge technologies. Increases in technological efficacy lead to less waste and pollution as a result of reduced resource use and product by-products. The environmental quality is predicted to increase, for instance, if more money is invested in research and development. Our research also shows that the adoption of renewable energy is a direct result of economic development and technological progress. As the economy expands, new technologies will enable the widespread adoption of renewable energy. Instead, thanks to the government's extensive renewable energy promotion strategy, the renewable energy industry is now an important economic sector that greatly contributes to the country's socioeconomic and long-term progress. Jobs, lower prices, and a less polluted environment are just a few of the ways in which the expansion of renewable energy has improved people's quality of life and helped to improve the world overall. In order for Iceland to become carbon neutral, the economy must continue to grow, as this will provide the funds necessary to investigate and develop renewable energy technologies and infrastructure.

The growth of environmentally friendly industries and the electrification of transportation are both bolstered by the responsible use of renewable energy sources. Low-carbon businesses like data centers and high-tech horticulture are vital to Iceland's economy, which once relied on aluminum smelters. Iceland's economy still relies heavily on the fishing and tourist industries. Using technological solutions, Iceland has achieved a carbon footprint of zero. In this energy infrastructure, renewable resources are used extensively. Electricity, hydrogen, and synfuels power land transportation, while the aviation and maritime industries have only partially adopted low-carbon alternatives. However, hydrogen and synfuels have replaced fossil fuels in Iceland's fishing sector. Capturing emissions from energy-intensive sectors and either mineralizing them or using them to create synfuels. The number of farm animals has decreased, and manure management has improved. In order to become carbon neutral by 2040, all of Iceland's organic waste is composted and/or gasified.

Conclusion and Policy Implications

This research looks into how carbon neutrality in Iceland can be accomplished by factors like economic development, renewable energy adoption, and technical advancement. The DOLS technique was used on time series data that extended from 1990 to 2021. In this research, we used the ADF, DF-GLS, and P-P unit root tests to determine the order of integration of the series. According to the results of the DOLS estimation, a one-percentage-point increase in economic growth is associated with a 0.39% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related to a reduction in CO_2 emissions of 1.46 percent over the long run, as indicated by the coefficient of renewable energy use being negative and statistically significant. The calculated long-run coefficient of technical innovation is negative and statistically significant, suggesting that a 1% increase in technological innovation results in a 0.02% reduction in CO_2 emissions. Estimates hold up well when compared with both the FMOLS and CCR methods. The paired Granger causality test was also used to capture the causal relationship between the variables. Our research provides fresh insight into how the adoption of renewable energy sources and cutting-edge technological advancements in Iceland has contributed to the country's progress toward carbon neutrality. Recommendations for policy were made in this article to promote sustainable development through the introduction of robust regulatory policy tools targeted at achieving carbon neutrality.

It will take new methods and procedures to get to net zero emissions, which is not an easy aim to achieve. An all-out effort, substantial investment, and careful planning are needed to make the leap to a climate-neutral civilization. In order to keep the political debate on the future's direction going strong, it is crucial to keep gathering facts and best practices. To reach carbon neutrality, all emissions must be reduced, and the many causes and potential remedies must be taken into account. For this reason, it's possible that a variety of sector-specific policies and initiatives will need to be implemented simultaneously in order to move forward. To reach carbon neutrality, the strategy must be adaptable and leave room for novel, creative ideas. Government actors, industrial partners, non-governmental organizations, and local municipalities must all work together and actively participate in the development and systematic reevaluation of a viable strategy for a climate-neutral Iceland by no later than 2040. To achieve a fair transition to a circular, competitive, climate-neutral future, the public must be involved in its development. Many local governments, businesses, and non-profits, as well as national organizations, have taken action to address climate change. Iceland's greenhouse gas emissions are predicted to decrease as a result of these measures. Since government effort alone won't be enough to combat climate change, it's crucial to back such projects.

Our study suggests that the Icelandic government aid markets by constructing a strong legislative framework that creates lasting value for carbon neutrality and consistently encourages innovative technologies that result in a less carbon-intensive economy. Iceland's government is considering expanding its use of carbon capture and storage systems with the goal of becoming carbon neutral. Policymakers should also support and promote renewable energy businesses and innovations. These steps will aid the transition to a low-carbon economy by replacing more traditional energy sources that produce a lot of carbon dioxide. The need to diversify the economy was made clear by the decline in international tourism and travel caused by the pandemic. If emission reductions are to be a priority, Iceland will need to strengthen its ability to withstand shocks and find alternative ways to boost productivity and employment. More entrepreneurial vigor would be helpful in diversifying the economy and starting along the low-carbon route. The economic recovery and productivity growth in the medium term may be slowed by Iceland's high barriers to entry in goods and service markets, which are among the highest in the OECD. Weakening competitiveness and slowing productivity are excessive occupational licensing in the building industry and heavy administrative costs in the tourism industry. It would be easier for the government to reallocate funds if regulations were simplified across the board to lower barriers to both domestic and international competition.

In order to achieve the goals of a future without fossil fuels, in which all energy production comes from the renewable origin by 2050, the government could create and implement effective policies to support investment in new renewable energy technology. As a corollary, new technologies will need to be created through research and patent applications in order to reach the carbon neutrality goal. The creation of energy-saving technology is a part of this effort and will likely play a major role in any future stability policy. Hybrid vehicles are one example of how modern technology can reduce energy use without compromising performance. The government may raise funding for enterprises conducting technological innovation research on energy conservation and emission reduction in order to foster the development of low-carbon technology. The Icelandic government is considering increasing its cooperation with academic institutions in an effort to promote technical innovation, especially in the field of green technology. Green technology, such as renewable energy sources, energy storage, management, recycling and waste technologies, and GHG disposal, can all contribute to a more sustainable way of life. Innovative green technology utilization in the industry may have positive effects on all three of these fronts. In addition, the government should encourage the commercialization of patents and the development of novel energy sources and environmental protection measures.

Although our approach has significant weaknesses, which may be addressed in future studies, our current study did produce substantial empirical findings in the case of Iceland. The inaccessibility of data beyond the study period severely restricts the usefulness of the econometric methods we employed. This research, however, looks at the interplay between Iceland's expanding economy, renewable energy sources, technological progress, and carbon dioxide emissions. Increasing forest cover, recycling items, decreasing water and electricity consumption, switching to organic food, etc. are all potential factors in lowering emissions that could be investigated in future research. Degradation of the environment due to GHG emissions were also measured using CO_2 in this study. Consumption-based carbon emissions, along with other emission indicators such as nitrous oxide, sulfur dioxide, methane, and other transient climate pressures, could be used as proxies for environmental deterioration in more studies. CO_2 emissions are not the main contributor to environmental degradation, but they are used as a proxy for pollution in this study. Water and soil contamination are two forms of environmental pollution that could be studied in greater depth in future studies of Iceland.

Funding: Not applicable

Acknowledgments: Not applicable

Conflict of interest: The authors declare no conflict of interest.

References

Ahmed, A., Uddin, G. S., & Sohag, K. (2016). Biomass energy, technological progress and the environmental Kuznets curve: Evidence from selected European countries. Biomass and Bioenergy, 90, 202-208. https://doi.org/10.1016/j.biombioe.2016.04.004

Ali, A. Z., Rahman, M. S., Raihan, A. (2022). Soil Carbon Sequestration in Agroforestry Systems as a Mitigation Strategy of Climate Change: A Case Study from Dinajpur, Bangladesh. Advances in Environmental and Engineering Research, 3(4), 1-15. http://dx.doi.org/10.21926/aeer.2204056

Azam, A., Rafiq, M., Shafique, M., & Yuan, J. (2022). Towards Achieving Environmental Sustainability: The Role of Nuclear Energy, Renewable Energy, and ICT in the Top-Five Carbon Emitting Countries. Frontiers in Energy Research, 9, 804706. https://doi.org/10.3389/fenrg.2021.804706

Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability, 12(22), 9375. https://doi.org/10.3390/su12229375

Chen, Y., & Lee, C. C. (2020). Does technological innovation reduce CO_2 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). CO_2 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

Cobb, C. W., & Douglas, P. H. (1928). A theory of production'. American Economic Review, 18, 139-165.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American statistical association, 74, 427-431. https://doi.org/10.1080/01621459.1979.10482531

Elliott, G., Rothenberg, T. J., & Stock, J. H. (1992). Efficient tests for an autoregressive unit root. National Bureau of Economic Research.

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. Econometrica: journal of the Econometric Society, 37, 424-438. https://doi.org/10.2307/1912791

Hansen, B. E., & Phillips, P. C. (1990). Estimation and inference in models of cointegration: A simulation study. Advances in econometrics, 8, 225-248.

Isfat, M., & Raihan, A. (2022). Current Practices, Challenges, and Future Directions of Climate Change Adaptation in Bangladesh. International Journal of Research Publication and Reviews, 3(5), 3429-3437.

Islam, M. M., Chowdhury, M. A. M., Begum, R. A., & Amir, A. A. (2022). A bibliometric analysis on the research trends of climate change effects on economic vulnerability. Environmental Science and Pollution Research, 29, 59300–59315. https://doi.org/10.1007/s11356-022-20028-0

Jaafar, W. S. W. M., Maulud, K. N. A., Kamarulzaman, A. M. M., Raihan, A., Sah, S. M., Ahmad, A., Saad, S. N. M., Azmi, A. T. M., Syukri, N. K. A. J., & Khan, W. R. (2020). The influence of forest degradation on land surface temperature–a case study of Perak and Kedah, Malaysia. Forests, 11(6), 670. https://doi.org/10.3390/f11060670

Liu, X., Zhang, S., & Bae, J. (2017). The impact of renewable energy and agriculture on carbon dioxide emissions: investigating the environmental Kuznets curve in four selected ASEAN countries. Journal of cleaner production, 164, 1239-1247. https://doi.org/10.1016/j.jclepro.2017.07.086

Park, J. Y. (1992). Canonical cointegrating regressions. Econometrica: Journal of the Econometric Society, 60, 119-143. https://doi.org/10.2307/2951679

Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.

Rahman, Z., Chongbo, W., & Ahmad, M. (2019). An (a) symmetric analysis of the pollution haven hypothesis in the context of Pakistan: a non-linear approach. Carbon Management, 10(3), 227-239. https://doi.org/10.1080/17583004.2019.1577179

Raihan A (2023a) An econometric evaluation of the effects of economic growth, energy use, and agricultural value added on carbon dioxide emissions in Vietnam. Asia-Pacific Journal of Regional Science 7(1). https://doi.org/10.1007/s41685-023-00278-7

Raihan A (2023b) The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. Energy Nexus 9:100180. https://doi.org/10.1016/j.nexus.2023.100180

Raihan A (2023c) Toward sustainable and green development in Chile: dynamic influences of carbon emission reduction variables. Innovation and Green Development 2:100038. https://doi.org/10.1016/j.igd.2023.100038

Raihan A (2023d) Nexus between economic growth, natural resources rents, trade globalization, financial development, and carbon emissions toward environmental sustainability in Uruguay. Electronic Journal of Education, Social Economics and Technology 4(2):55-65. https://doi.org/10.33122/ejeset.v4i2.102

Raihan, A., Begum, R. A., Said, M. N. M., & Abdullah, S. M. S. (2018). Climate change mitigation options in the forestry sector of Malaysia. J. Kejuruter, 1, 89-98. http://dx.doi.org/10.17576/jkukm-2018-si1(6)-11

Raihan, A., Begum, R. A., Mohd Said, M. N., & Abdullah, S. M. S. (2019). A review of emission reduction potential and cost savings through forest carbon sequestration. Asian Journal of Water, Environment and Pollution, 16(3), 1-7. https://doi.org/10.3233/AJW190027

Raihan, A., Begum, R. A., & Said, M. N. M. (2021a). A meta-analysis of the economic value of forest carbon stock. Geografia–Malaysian Journal of Society and Space, 17(4), 321-338. https://doi.org/10.17576/geo-2021-1704-22

Raihan, A., Begum, R. A., Mohd Said, M. N., & Pereira, J. J. (2021b). Assessment of carbon stock in forest biomass and emission reduction potential in Malaysia. Forests, 12(10), 1294. https://doi.org/10.3390/f12101294

Raihan, A., Begum, R. A., Nizam, M., Said, M., & Pereira, J. J. (2022a). Dynamic impacts of energy use, agricultural land expansion, and deforestation on CO_2 emissions in Malaysia. Environmental and Ecological Statistics, 29, 477-507. https://doi.org/10.1007/s10651-022-00532-9

Raihan, A., Begum, R. A., Said, M. N. M., & Pereira, J. J. (2022b). Relationship between economic growth, renewable energy use, technological innovation, and carbon emission toward achieving Malaysia's Paris agreement. Environment Systems and Decisions, 42, 586-607. https://doi.org/10.1007/s10669-022-09848-0

Raihan, A., Farhana, S., Muhtasim, D. A., Hasan, M. A. U., Paul, A., & Faruk, O. (2022c). The nexus between carbon emission, energy use, and health expenditure: empirical evidence from Bangladesh. Carbon Research, 1(1), 30. https://doi.org/10.1007/s44246-022-00030-4

Raihan, A., Muhtasim, D. A., Farhana, S., Hasan, M. A. U., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022d). Nexus between economic growth, energy use, urbanization, agricultural productivity, and carbon dioxide emissions: New insights from Bangladesh. Energy Nexus, 8, 100144. https://doi.org/10.1016/j.nexus.2022.100144

Raihan A, Muhtasim DA, Farhana S, Hasan MAU, Pavel MI, Faruk O, Rahman M, Mahmood A (2023a) An econometric analysis of Greenhouse gas emissions from different agricultural factors in Bangladesh. Energy Nexus 9:100179. https://doi.org/10.1016/j.nexus.2023.100179

Raihan A, Muhtasim DA, Farhana S, Hasan MAU, Paul A, Faruk O (2022e) Toward environmental sustainability: Nexus between tourism, economic growth, energy use and carbon emissions in Singapore. Global Sustainability Research 1(2):53–65. https://doi.org/10.56556/gssr.v1i2.408

Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., & Mahmood, A. (2022f). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080. https://doi.org/10.1016/j.egycc.2022.100080

Raihan A, Muhtasim DA, Farhana S, Rahman M, Hasan MAU, Paul A, Faruk O (2023b) Dynamic Linkages Between Environmental Factors and Carbon Emissions in Thailand. Environmental Processes 10(1):5. https://doi.org/10.1007/s40710-023-00618-x

Raihan, A., Muhtasim, D. A., Pavel, M. I., Faruk, O., & Rahman, M. (2022g). An econometric analysis of the potential emission reduction components in Indonesia. Cleaner Production Letters, 3, 100008. https://doi.org/10.1016/j.clpl.2022.100008

Raihan, A., Muhtasim, D. A., Pavel, M. I., Faruk, O., & Rahman, M. (2022h). Dynamic impacts of economic growth, renewable energy use, urbanization, and tourism on carbon dioxide emissions in Argentina. Environmental Processes, 9, 38. https://doi.org/10.1007/s40710-022-00590-y

Raihan, A., Muhtasim, D. A., Khan, M. N. A., Pavel, M. I., & Faruk, O. (2022i). Nexus between carbon emissions, economic growth, renewable energy use, and technological innovation towards achieving environmental sustainability in Bangladesh. Cleaner Energy Systems, 3, 100032. https://doi.org/10.1016/j.cles.2022.100032

Raihan A, Pavel MI, Muhtasim DA, Farhana S, Faruk O, Paul A (2023c) The role of renewable energy use, technological innovation, and forest cover toward green development: evidence from Indonesia. Innovation and Green Development 2:100035. https://doi.org/10.1016/j.igd.2023.100035

Raihan, A., & Said, M. N. M. (2022). Cost–benefit analysis of climate change mitigation measures in the forestry sector of Peninsular Malaysia. Earth Systems and Environment, 6(2), 405-419. https://doi.org/10.1007/s41748-021-00241-6

Raihan, A., & Tuspekova, A. (2022a). The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: New insights from Peru. Energy Nexus, 6, 100067. https://doi.org/10.1016/j.nexus.2022.100067

Raihan, A., & Tuspekova, A. (2022b). Role of economic growth, renewable energy, and technological innovation to achieve environmental sustainability in Kazakhstan. Current Research in Environmental Sustainability, 4, 100165. https://doi.org/10.1016/j.crsust.2022.100165

Raihan, A., & Tuspekova, A. (2022c). Nexus between economic growth, energy use, agricultural productivity, and carbon dioxide emissions: new evidence from Nepal. Energy Nexus, 7, 100113. https://doi.org/10.1016/j.nexus.2022.100113

Raihan, A., & Tuspekova, A. (2022d). Dynamic impacts of economic growth, energy use, urbanization, tourism, agricultural value-added, and forested area on carbon dioxide emissions in Brazil. Journal of Environmental Studies and Sciences, 12(4), 794-814. https://doi.org/10.1007/s13412-022-00782-w

Raihan, A., & Tuspekova, A. (2022e). Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, tourism, agriculture, and forests on carbon emissions in Turkey. Carbon Research, 1(1), 20. https://doi.org/10.1007/s44246-022-00019-z

Raihan, A., & Tuspekova, A. (2022f). Towards sustainability: Dynamic nexus between carbon emission and its determining factors in Mexico. Energy Nexus, 8, 100148. https://doi.org/10.1016/j.nexus.2022.100148

Raihan, A., & Tuspekova, A. (2022g). Nexus between emission reduction factors and anthropogenic carbon emissions in India. Anthropocene Science, 1(2), 295-310. https://doi.org/10.1007/s44177-022-00028-y

Raihan, A., & Tuspekova, A. (2022h). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096. https://doi.org/10.1016/j.rcradv.2022.200096

Raihan, A., & Tuspekova, A. (2022i). Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions:

New insights from Kazakhstan. World Development Sustainability, 1, 100019. https://doi.org/10.1016/j.wds.2022.100019

Raihan, A., & Tuspekova, A. (2022j). Nexus between energy use, industrialization, forest area, and carbon dioxide emissions: New insights from Russia. Journal of Environmental Science and Economics, 1(4), 1-11. https://doi.org/10.56556/jescae.v1i4.269

Raihan, A., & Tuspekova, A. (2022k). The nexus between economic growth, energy use, urbanization, tourism, and carbon dioxide emissions: New insights from Singapore. Sustainability Analytics and Modeling, 2, 100009. https://doi.org/10.1016/j.samod.2022.100009

Raihan, A., & Tuspekova, A. (2023). Towards net zero emissions by 2050: the role of renewable energy, technological innovations, and forests in New Zealand. Journal of Environmental Science and Economics, 2(1), 1–16. https://doi.org/10.56556/jescae.v2i1.422

Raihan, A., & Voumik, L. C. (2022a). Carbon emission dynamics in India due to financial development, renewable energy utilization, technological innovation, economic growth, and urbanization. Journal of Environmental Science and Economics, 1(4), 36-50. https://doi.org/10.56556/jescae.v1i4.412

Raihan, A., & Voumik, L. C. (2022b). Carbon emission reduction potential of renewable energy, remittance, and technological innovation: empirical evidence from China. Journal of Technology Innovations and Energy, 1(4), 25-36. https://doi.org/10.56556/jtie.v1i4.398

Shahbaz. M., Raghutla, C., Song, M., Zameer, H., & Jiao, Z. (2020). Public-private partnerships investment in energy as new determinant of CO_2 emissions: the role of technological innovations in China. Energy Economics, 86, 104664. https://doi.org/10.1016/j.eneco.2020.104664

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica: journal of the Econometric Society, 61(4), 783-820.

Voumik, L. C., Islam, M. J., & Raihan, A. (2022a). Electricity production sources and CO_2 emission in OECD countries: static and dynamic panel analysis. Global Sustainability Research, 1(2), 12-21. https://doi.org/10.56556/gssr.v1i2.327

Voumik, L. C., Nafi, S. M., Kuri, B. C., Raihan, A. (2022b). How tourism affects women's employment in Asian countries: an application of Generalized Method of Moments and Quantile Regression. Journal of Social Sciences and Management Studies, 1(4), 57-72. https://doi.org/10.56556/jssms.v1i4.335

World Bank. (2022). World Development Indicators (WDI), Data series by The World Bank Group, The World Bank: Washington, DC, USA. Retrieved from https://databank.worldbank.org/source/world-development-indicators