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RESEARCH ARTICLE

Towards net zero emissions by 2050: the role of renewable energy, technological innovations, and forests in New Zealand

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Abstract

New Zealand has set a target of net zero emissions by 2050, and this study looks into the role that economic growth, renewable energy use, technological innovation, and forests 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 0.24% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related with a reduction in CO_2 emissions of 0.81 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 long-run coefficient of forest area is notably negative and significant, which means that increasing forest area by 1% reduces CO_2 emissions by 4.78%. The empirical results show that as New Zealand's economy grows, so do its CO_2 emissions, but that the country may get closer to its goal of carbon neutrality through the growing use of renewable energy, technological innovation, and sustainable forest management. Alternative estimators, such as fully modified least squares (FMOLS) and canonical cointegrating regression (CCR), do not significantly affect the estimated results. In order for New Zealand to reach its goal of net zero emissions by 2050, this article offers policy ideas centered on a low-carbon economy, the promotion of the use of renewable energy sources, the financing of technical progress, and sustainable forest management.

Keywords: CO_2 emissions; Renewable energy; Technological innovation; Forests; Net zero emissions; Sustainability

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., 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 (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). 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, enhancing forest area, 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, technical innovation, and sustainable forest management in the fight against climate change (SDGs 7, 8, 9, 13, and 15).

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, New Zealand 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, New Zealand has pledged to cut net emissions in half from a baseline of 2005 gross emissions by 2030 and reach net zero emissions by 2050. Rapid emission reduction is essential to reach climate neutrality. By taking steps to mitigate climate change, New Zealand 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. The authorities in New Zealand 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). Although emissions in New Zealand continue to rise as a result of rapid population and economic expansion, the country is working to decouple emissions from economic growth.

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. Solar, water (hydropower), wind, geothermal, and biomass are the five primary sources of renewable energy (Raihan et al., 2022e). 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., 2022f). The objective of reducing global emissions by half by 2050 (Raihan et al., 2022g) and of becoming net zero emissions in New Zealand by 2050 both rely heavily on the use of renewable energy sources. New Zealand uses a lot of renewable energy and has a long history of developing renewable energy. In New Zealand, the percentage of primary energy (heat and power) derived from renewable sources is about 40%. About 80% of the country's electricity is produced by renewable sources, mostly geothermal and hydroelectricity. Since the beginning of the previous two decades, the amount of electricity produced by geothermal and wind energy has more than tripled. There is less scope for the energy sector to reduce gross emissions than in many other jurisdictions due to the high levels of renewable electricity generation already in use. This makes abatement strategies difficult. Despite this, New Zealand is aiming to advance further in this field. By 2035, the government hopes to produce all of its electricity from renewable sources, with five-yearly reviews to make sure that supply security and price remain stable. To get to net zero emissions, New Zealand 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., 2022h). 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 to renewable energy sources (Raihan, & Tuspekova, 2022b). Technological advancements have reduced the need for fossil fuels and the resulting reduced emissions of carbon dioxide. New Zealand'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 net zero emissions, studying the impact of technological innovation on environmental sustainability is essential from a theoretical and practical standpoint.

Forest regions are also under strain from the growing demands for food, shelter, agriculture, public transportation, and other infrastructures. Urbanization, industrialization, settlements, mining, and agriculture have all caused a loss of forest cover (Jaafar et al., 2020). Forest loss and other land use changes can significantly increase CO_2 emissions and contribute to climate change. Conversely, forests act as both carbon sources and sinks, significantly influencing the structure of the global climate (Raihan et al., 2021b). When trees capture CO_2 from the atmosphere and store it in their biomass, carbon sequestration takes place. This aids in reducing the speed of climate change. Around 300 billion tons of CO_2 are captured annually by forests; however, deforestation and forest degradation are expected to cause an additional three billion tons of CO_2 to escape into the atmosphere (Raihan et al., 2022a). Since temperatures are anticipated to increase by 1.5 degrees Celsius over pre-industrial levels between 2030 and 2052 under projected global warming and climate change scenarios, the role of forest regions in collecting atmospheric carbon has become increasingly important. Nearly 38% of New Zealand's land area is covered by forests (World Bank, 2022), which are crucial to the nation's carbon balance. In order to achieve net zero emissions in New Zealand, it is crucial to consider the forest's potential.

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 New Zealand wants to achieve net zero emissions by 2050, 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 study 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 New Zealand. This study tries to fill this knowledge vacuum by using the dynamic ordinary least squares (DOLS) method to examine how GDP growth, renewable energy consumption, technological innovation, and forest areas affect CO_2 emissions in New Zealand.

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 New Zealand. 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 New Zealand fill a void in the prior academic literature. New to this study is an analysis of how the adoption of renewable energy sources, technology advancements, and sustainable forest management can affect New Zealand'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 DOLS, FMOLS, and CCR tests) were used. For New Zealand to reach its objective of net zero emissions by 2050, the findings of this study will give policymakers with more complete and relevant information for formulating successful policies in the areas of low-carbon economy, boosting renewable energy consumption, supporting technical innovation, and sustainable management of the forests. Furthermore, the results of this study can be applied to the review and development of environmental policies to help get New Zealand ready for a 1.5°C world by bolstering policy and action plans 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.

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 to 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. 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 1970 to 2013, Raihan et al. (2022g) 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. 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.

Furthermore, the connection between forests and CO_2 emissions has recently been thoroughly studied. Waheed et al. (2018) reported the negative impacts of renewable energy use and forested area on CO_2 emissions using time series data for Pakistan spanning the years 1990-2014. By using time series data from 1990 to 2016, Begum et al. (2020) revealed a positive association between economic growth and CO_2 emissions while a negative relationship between forest area and CO_2 emissions in Malaysia. Parajuli et al. (2019) found a negative connection between wooded areas and CO2 emissions using country-specific panel data from 1990 to 2014 for 86 distinct nations. By using data from 1990-2019, Raihan et al. (2022e) 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. (2022f) 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. By 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 and forest area negatively affected CO_2 emissions.

Moreover, by using data from 1990 to 2020, Raihan and Tuspekova (2022e) found that economic expansion increases CO_2 emissions in Turkey, while renewable energy and forest area reduce 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 and forest area negatively affected CO_2 emissions in the country. Raihan and Tuspekova (2022g) discovered that economic expansion positively affected CO_2 emissions in India, whereas the use of renewable energy and forest area negatively affected CO_2 emissions by utilizing data from 1990 to 2020. With data from 1990 to 2019, Raihan and Tuspekova (2022h) found that economic expansion positively influences CO_2 emissions in Malaysia, while renewable energy and forest area negatively help to cut CO_2 emissions. Data from 1996-2020 was also used by Raihan and Tuspekova (2022i) to show that economic expansion positively affected CO_2 emissions in Kazakhstan, whereas the use of renewable energy utilization and enhancing forest area cut CO_2 emissions in the country. By using time series data from 1990 to 2020, Raihan and Tuspekova (2022j) revealed a positive association between economic growth and CO_2 emissions while a negative relationship between forest area and CO_2 emissions in Russia.

Despite this encouraging trend, the entire potential of renewable energy use, technical innovation, and forests are yet unclear, as are the methods of knowledge acquisition. The majority of environmental studies have concentrated on the relationship between CO2 emissions and its drivers, leaving out the research on the relationship between emission reduction mechanisms and CO2 emissions, particularly in New Zealand. 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, technical breakthroughs, and forest area to help New Zealand reach its goal of net zero emissions by 2050.

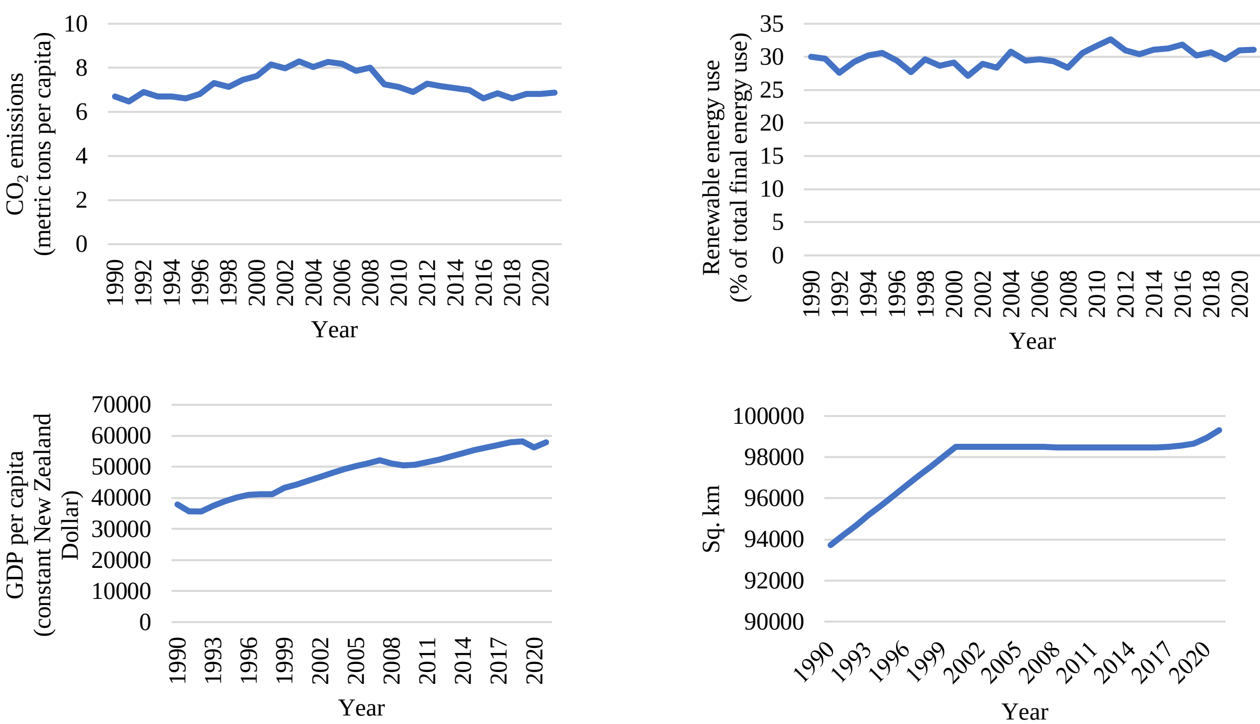
Methodology

Data

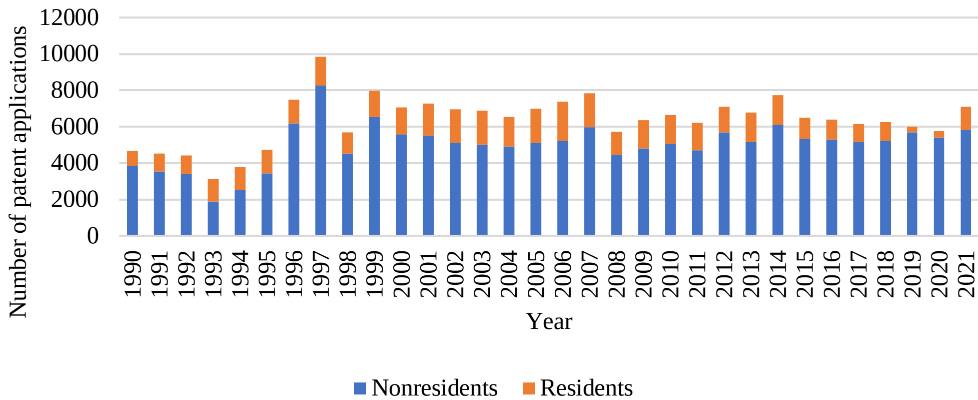
By applying the DOLS method of cointegration developed by Stock and Watson (1993), this study offers an empirical examination of the dynamic effects of economic development, renewable energy utilization, technical advancement, and forest area on CO_2 emissions in New Zealand. This study's econometric analysis made use of the most up-to-date time series data for New Zealand, which stretched from 1990 to 2021. The data 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, technological progress, and forest area 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 New Zealand Dollar)	WDI
RNE	Renewable energy use	LRNE	% of total final energy use	WDI
TI	Technological innovation	LTI	Number of patent applications	WDI
FA	Forest area	LFA	Square kilometers (sq. km)	WDI



(a) CO_2 emission (b) Economic growth (c) Renewable energy (d) Forest area



(e) 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, technical progress, and forest area have affected CO_2 emissions in New Zealand. 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, 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. 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. Furthermore, forests help to mitigate climate change by absorbing atmospheric CO_2. Hence, to understand the relationship between CO_2 emissions, economic growth, renewable energy consumption, technological innovation, and forest area, the current study employed the following economic functions:

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

where TI_t is the number of patent applications at time t and FA_t is the forest area at time t

Econometric model

The Equation (5) depicts the empirical model:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t + \tau_4 FA_t \tag{5}$$

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

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 TI_t + \tau_4 FA_t + \varepsilon_t \quad (6)$$

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):

$$LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LRNE_t + \tau_3 LTI_t + \tau_4 LFA_t + \varepsilon_t \quad (7)$$

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

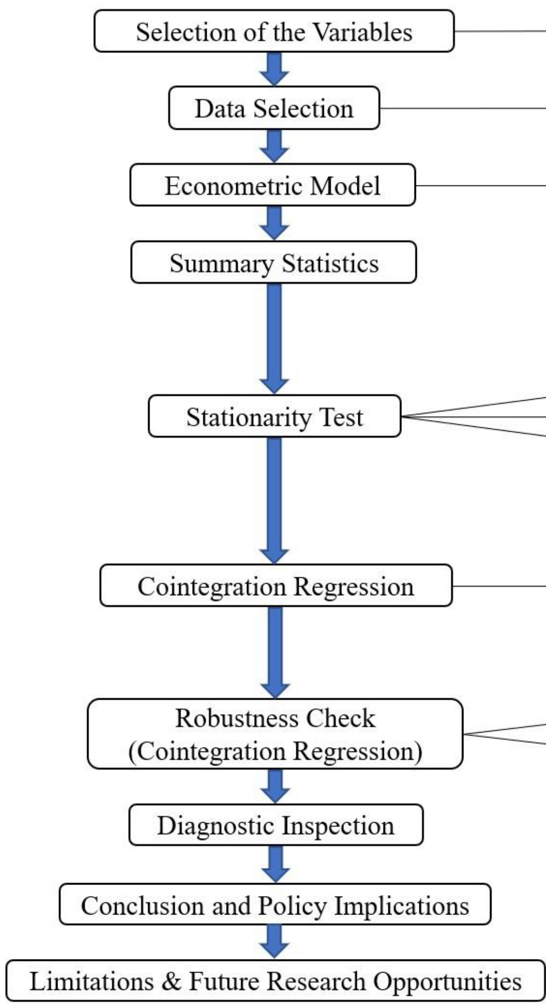


Figure 2. Flow chart of the analysis

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 research recommended using multiple tests to determine the best sequence for series integration (Raihan, & Tuspekova, 2022h). 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. 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).

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LRNE_{t-1} \\ & + \tau_4 LTI_{t-1} + \tau_5 LFA_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1 \, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \, \Delta LGDP_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3 \, \Delta LRNE_{t-i} + \sum_{i=1}^{q} \gamma_4 \, \Delta LTI_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5 \, \Delta LFA_{t-i} + \varepsilon_t \end{aligned} \tag{8}$$

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).

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. New Zealand's time series data for each variable spans the years 1990 through 2021 and feature 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	LFA
Mean	1.976764	10.77241	3.397096	8.734455	11.48972
Median	1.960301	10.82788	3.396327	8.782013	11.49761
Maximum	2.115485	10.97195	3.485845	9.193296	11.50602
Minimum	1.867914	10.48212	3.300640	8.039802	11.44810
Std. Dev.	0.077397	0.153388	0.043285	0.233645	0.105405
Skewness	0.546618	-0.467127	-0.293262	-0.164570	-0.150752
Kurtosis	1.933424	1.956100	2.703981	2.337041	1.935457
Jarque-Bera	2.110334	2.616744	0.575516	2.427888	1.328701
Probability	0.211154	0.270260	0.749943	0.180478	0.132674
Observations	32	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	LFA
ADF	Log levels	1.5230	-0.8241	-1.4237	-2.6480	-1.6297
	Log first difference	-2.8676**	-5.4515***	-6.0754***	-6.5964***	-3.0741**
DF-GLS	Log levels	-1.4062	-0.7032	-1.1669	-2.0392	-0.1194
	Log first difference	-2.6756**	-3.8051***	-5.7514***	-6.7168***	-3.1179**
P-P	Log levels	-1.5086	-0.8257	-2.0679	-2.4660	-1.4755
	Log first difference	6.9544***	-5.4175***	-6.963***	-7.9857***	-4.4819***

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

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 0.24% 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., 2022g; Azam et al., 2022; Raihan & Tuspekova, 2022a; Liu et al., 2017; Raihan & Voumik, 2022a; Raihan et al., 2022b; Raihan & Tuspekova, 2022e).
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 net zero emissions in New Zealand, effective policies and ways to reduce dependency on fossil fuel supply, energy intensity, and CO_2 emissions are required.

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 0.81 percent. This demonstrates the possibility of reducing emissions by increasing the usage of renewable energy sources in New Zealand. Our result suggests that the use of renewable energy sources is crucial for New Zealand to reach the net zero emissions goal. The results of this study are in line with those of numerous other studies, including those by Chen et al. (2019), Raihan et al. (2022g), 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. (2022e). 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 New Zealand 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 New Zealand's industrial sector may contribute to the country's efforts to improve environmental quality by achieving its target of net 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. (2022e). With the help of a green economy and green technologies, New Zealand can reach its goal of becoming a net zero-emissions country by 2050. 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.

Table 4. The outcomes of DOLS: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic	P-value
LGDP	0.244484**	0.142422	1.716618	0.0175
LRNE	-0.811868***	0.207749	-3.907930	0.0006
LTI	-0.022055**	0.052056	-0.423679	0.0275
LFA	-4.781928***	1.637232	-2.920739	0.0070
C	47.76719	17.52766	2.725247	0.1911
R^2	0.917681			
Adjusted R^2	0.903489			

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

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. 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, cheers 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 New Zealand to become an emission-free country, the economy must continue to grow, as this will provide the funds necessary to investigate and develop renewable energy technologies and infrastructure.

The long-run coefficient of forest area is notably negative at a 1% level, which means that increasing forest area by 1% reduces CO_2 emissions by 4.78%. According to this study, forest ecosystems improve New Zealand's ecology because they catch CO_2 from the atmosphere and store it in the soil and vegetation of the woods. According to the empirical results, increasing forest carbon sinks via increasing forest reserves slows down environmental deterioration over time. The findings of the current study, which show a negative correlation between forest area and CO_2 emissions, are also supported by Waheed et al. (2018), Raihan and Tuspekova (2022d), Raihan and Tuspekova (2022e), Raihan et al. (2022e), Parajuli et al. (2019), Raihan et al. (2022a), Raihan and Tuspekova (2022f), Raihan et al. (2022f), Raihan and Tuspekova (2022g), Raihan and Tuspekova (2022h), Raihan and Tuspekova (2022i), and Begum et al. (2020).

Since forests are the second-largest source of CO2 emissions in the world, forest degradation has been seen as a contributing factor to environmental destruction (Raihan et al., 2018). Therefore, minimizing deforestation may be the simplest method for reducing CO2 emissions. Undoubtedly, the most cost-effective strategy for halting environmental deterioration and reducing climate change is to increase forest carbon sequestration (Raihan et al., 2019). A major issue in the current climate research community is the importance of restoring, preserving, and conserving forests as a means of reducing climate change. Additionally, forestry-based mitigation strategies (forest protection, afforestation, and natural regeneration) may serve a number of purposes, including carbon sequestration, biodiversity preservation, ecosystem regrowth, and the production of goods and services for society (Raihan & Said, 2022). By reducing CO2 emissions and increasing forest biomass, which in turn increases the country's carbon sink, New Zealand's forestry sector has a major power to mitigate forestry-based global climate change. To put it briefly, improving forest areas would be an effective approach to reducing carbon emissions and support New Zealand's effort to reach net zero emissions by 2050.

It is also worth mentioning 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 0.9176 and 0.9034, 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 coefficients of renewable energy use and forest area were 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 R^2 and modified R^2 values from FMOLS and CCR estimates. Thus, it can be concluded that CO_2 emissions rise as New Zealand’s 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	0.295552**	0.198395	1.489714	0.0148
LRNE	-0.938338***	0.344416	-2.724428	0.0014
LTI	-0.021761**	0.075756	-0.287245	0.0267
LFA	-4.502139***	2.321290	-1.939499	0.0064
C	43.56625	24.76614	1.759105	0.1903
R^2	0.913436			
Adjusted R^2	0.903888			

*** 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	0.328070**	0.229916	1.426915	0.0165
LRNE	-0.973327***	0.444771	-2.188376	0.0078
LTI	-0.007238**	0.091665	-0.078963	0.0377
LFA	-5.173000***	2.357410	-2.194357	0.0073
C	50.67951	25.12318	2.017241	0.1541
R^2	0.913436			
Adjusted R^2	0.901838			

*** 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	2.655548	0.2651	Residuals are normally distributed
Breusch-Godfrey LM test	1.672349	0.2399	No serial correlation exits
Breusch-Pagan-Godfrey test	0.729577	0.5796	No heteroscedasticity exists

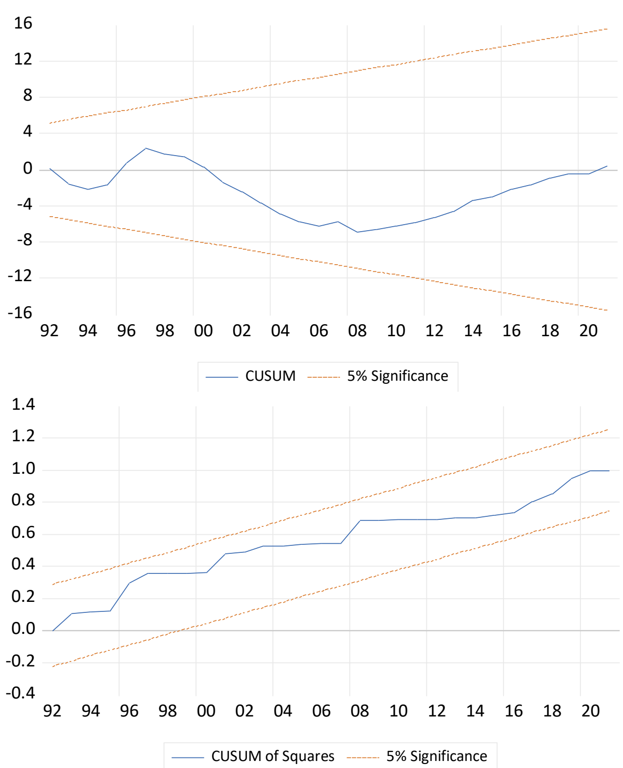


Figure 3. The plots of CUSUM and CUSUMQ tests

Conclusion and Policy Implications

This research looks into how net zero emissions in New Zealand can be accomplished by factors like economic development, renewable energy adoption, technical advancement, and forest area. 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 0.24% increase in CO_2 emissions. Furthermore, increasing the use of renewable energy by 1% is related with a reduction in CO_2 emissions of 0.81 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 long-run coefficient of forest area is notably negative and significant, which means that increasing forest area by 1% reduces CO_2 emissions by 4.78%. Estimates hold up well when compared with both the FMOLS and CCR methods. Our research provides fresh insight into how the adoption of renewable energy sources, cutting-edge technical advancements, and sustainable forest management in New Zealand have contributed to the country's progress toward net zero emissions. Recommendations for policy were made in this article to promote sustainable development through the introduction of robust regulatory policy tools targeted at achieving net zero emissions by 2050.

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 New Zealand by 2050. 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. New Zealand'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 New Zealand 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. New Zealand'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. In order to achieve the goals of a future without fossil fuels, in which all energy production comes from 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. 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. New Zealand's 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 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.

Additionally, this study's findings advised New Zealand's politicians to design appropriate environmental and climate-resilient plans, with a focus on reducing CO2 emissions through forest development. New Zealand's forest policy may include the goal of attaining sustainable development, with sustainable forest management in particular aiding in preserving the quality of the environment and the socioeconomic benefits from forests. As a result, a sound forest management strategy and effective policy implementation may be taken into account. The government of New Zealand may raise investments while enacting rigorous forest regulations with the goal of lowering CO2 emissions by increasing forest biomass through the preservation and protection of forests. The authority may also create commercial forest plantation portions to attract involvement from the business sector in sustainable forest management. By implementing a variety of forestry-based mitigation strategies, New Zealand may be better able to combat climate change and meet its goal of net zero emissions. Because of better and more economical methods of managing forests, such as afforestation, reforestation, forest conservation, agroforestry, greater natural regeneration, and urban forestry, forests will continue to serve as carbon sinks. Last but not least, effective forest policy development might aid New Zealand in increasing its national carbon sink, assuring national green growth, and sustainable forest management, which would result in net zero emissions by 2050.

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 New Zealand. 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 New Zealand's expanding economy, renewable energy sources, technological progress, forest area, and carbon dioxide emissions. However, 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 was 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 New Zealand.

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