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Article

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The Causal Relationship between Public Investment in Renewable Energy and Climate Change Performance Index

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ABSTRACT

Addressing the current environmental challenges requires optimizing climate actions and understanding the complex relationships among them. This paper aims to provide insights into how public investment in renewable energy influences various dimensions of climate change, including emissions, efficiency, renewable energy deployment, and policy effectiveness. This study seeks to explore the causal connection between public investment in renewable energy and the Climate Change Performance Indicator (CPI) from 2007 to 2017, utilizing data provided by German Watch. The method used is Dumitrescu and Hurlin's (2012) Granger Causality. The study unveils a unidirectional causality from Renewable Energy Investment (REI) to climate change performance. Additionally, it emphasizes the critical role of energy efficiency in attracting investments in renewable energy. Surprisingly, the study finds that REI influences the quality of climate policy. Furthermore, the study identifies a bi-directional causality between a renewable energy share and REI. The contribution of the paper lies in its analysis of public investment in renewable energy, covering areas beyond just public finance for R&D in renewable energy, as also exploring the causal link between this investment and CPI. It offers policymakers insights on how financial governmental interventions can effectively drive climate action.

Keywords: Renewable Energy, Public Investment in Renewable Energy, Energy Efficiency, Climate Policy
JEL Classifications: Q280, Q540, Q580.

1. INTRODUCTION

Our planet faces serious environmental challenges due to fossil fuel burning and unsustainable practices, significantly contributing to global warming. The IPCC's first assessment report in 1992 indicated a high likelihood that doubling CO_2 concentration would increase global mean surface temperature by 1.5°C-4.5°C. Despite early warnings, the IPCC's Sixth Assessment Report in 2023 confirmed human activity has undoubtedly caused global warming. Unsustainable energy use, land-use practices, and consumption patterns remain critical contributors. International agreements like the UNFCCC in 1992, Kyoto Protocol in 1997, and Paris Agreement in 2015 have afforded progress (Schipper, 2006; Kuyper et al., 2018; Dimitrov, 2016), but current efforts are insufficient to meet critical climate targets (Matthews and Wynes, 2022). More decisive action and investigation into the effectiveness of these actions are needed.

Promoting energy efficiency, renewable energy, and energy policies are crucial for mitigating climate change. Their significance is underscored by initiatives such as the Climate Performance Indicator developed by the German Watch in 2007.[1] This indicator serves as an annual comprehensive tool for assessing countries' performance in addressing climate change, considering variables such as GHG emissions, renewable energy deployment, energy efficiency measures, and governmental climate policies. By incorporating these factors, the Climate Performance Indicator offers insights into the level of climate efforts undertaken by

1 German Watch is an independent development, environmental, and human rights organisation that advocates for sustainable global development.

each country, facilitating comparisons and highlighting areas for improvement (Burck et al., 2017).

Expanding upon this discussion, it is evident that addressing climate change necessitates a multi-faceted approach. Within this context, in this paper, public investment in renewable energy takes center stage for the analysis. By directing attention toward public investment in renewable energy, we aim to delve deeper into the causal link between this investment and the Climate Performance Indicator and its sub-indicators.

Public investment is a pivotal in driving renewable energy deployment and innovation (OECD, 2017). The well-below-2°C goal of the Paris Agreement involves a 29% increase in renewable energy investments in the next 15 years compared to how things are currently (OECD, 2017). Insufficient finance is the primary obstacle to the green transformation of the world's energy systems (Abolhosseini and Heshmati, 2014). Even though financing is crucial for renewable energy because it is necessary to mobilize finance for investment and innovation in low-carbon energy to mitigate climate change, fossil fuel investments continue to dominate over investments in renewable energy, which poses a significant challenge for climate change mitigation (United Nations Environment Programme, 2015). A recent study by Tabash et al. (2023) found evidence that combining public and private financing is helpful. Their research suggests that when public and private sectors join forces to invest in energy, it leads to a decrease in CO_2 emissions. However, these two sectors approach renewable energy differently, as Mazzucato and Semieniuk (2018) pointed out. Public investors often choose riskier technologies in renewable energy, like concentrated solar power or advanced biofuels, which can help drive innovation in specific areas. This difference in approach between public and private funding highlights the value of understanding each type of investment.

There is a wealth of academic research exploring private investment in renewable energy across various domains (Aguilar and Cai, 2010; Aslani, 2014; Fadly, 2019; Liu and Chu, 2019; Cárdenas Rodriguez et al., 2015; Azhgaliyeva et al., 2022). While these studies offer valuable perspectives on private capital's role in renewables, a similar depth of research is crucial to understanding the impact of public investment in this sector.

According to a study conducted by Hailemariam et al., (2022), investment in renewable energy has shown positive impacts on greenhouse gas emissions reduction. Conversely, Yang et al. (2022) suggest that renewable energy investment (REI) can initially drive economic expansion, leading to increased energy usage and CO_2 emissions. Conversely, Zhang et al. (2021) highlight the influence of renewable energy sector types on the REI-CO_2 emissions relationship. Higher investment in wind energy correlates with reduced emissions, while increased proportions of solar and bioenergy investments may elevate emissions. These findings underscore the complexity of the relationship between REI and emissions, emphasizing the need for further research. A more in-depth review of the literature will be covered in a dedicated section.

The study mainly seeks to investigate the causal relationship between investments in renewable energy (REI) and the Climate Change Performance Indicator (CPI). It utilizes a dataset spanning from 2007 to 2017. The data is sourced from GermanWatch. The study employs the Climate Change Performance Indicator, which encompasses various critical components related to climate change, including emissions, efficiency, climate policy, and renewable energy. Using this indicator the study can capture a holistic view of climate change performance, offering nuanced insights into how renewable energy investments affect diverse dimensions of climate action.

The studies in the literature that covered public investment in renewable energy, like those by Shinwari et al. (2022) and Chen et al. (2022), have only explored funding for public investment in renewable energy research and development. However, a broader approach is necessary. Public investment must encompass not just R&D, but also crucial aspects like technology demonstration, manufacturing, deployment, energy efficiency, and large-scale electricity infrastructure development. Therefore, total public investment in renewable energy is used in our study. The role of public investments in renewable energy in shaping climate change performance is a subject of burgeoning interest and research.

The article's structure is as follows: In the upcoming section, a brief narrative from historical literature is presented to illustrate the gaps that this study aims to address. Section 3 includes data details and model specifications. Empirical findings and concise discussions are covered in Section 4. Section 5 proposes practical policies derived from concluding remarks and offers insights for future research.

2. LITERATURE REVIEW

In this section, we aim to compile literature about public investments in renewable energy, exploring its connections and causalities with greenhouse gas (GHG) emissions, energy efficiency, renewable energy adoption, and climate policy. Subsequently, a brief overview of the Climate Policy Index (CPI) is provided despite limited comprehensive studies directly addressing CPI.

Through this examination of existing literature, we aim to pinpoint gaps in research, which our study addresses.

2.1. GHG Emissions and Public Investments in Renewable Energy

This section examines existing literature regarding the correlation between REI and GHG emissions. The primary focus is on studies employing causality analysis to discern the directional influence between these variables. However, there is a notable gap in the literature concerning comprehensive causality analysis regarding investment in renewable energy and its effect on emissions. Therefore, a thorough review of available literature is provided, which has emphasizied the impacts of investment in renewable energy on emissions. This review is categorized into two main groups: papers acknowledging the beneficial aspects of REI and those highlighting its adverse effects.

REI is crucial in the global fight against climate change by mitigating GHG emissions. Studies have shown the effectiveness of REI in reducing emissions, with hydropower, wind, and solar emerging as critical sources. A survey by Mahesh and Jasmin (2013) compared the level of investments in renewable energy and the potential mitigation of emissions. Their results showed that investment boosted the grid-connected renewable power generating system's potential to mitigate CO_2 in India. The increase in the investment was due to advantageous legislative frameworks, investment prospects, and opportunities accessible for these technologies by the private sector. With anticipated investments in the renewable energy industry, the system's present mitigation capacity of 203.48 million tonnes of CO_2 wasforecasted to increase to 452.61 million tonnes of CO_2 in 2017 (Mahesh and Jasmin, 2013). Furthermore, analyzing countries leading in REI, He et al. (2023) showed that investing in renewable energy helps reduce CO_2 emissions, which is crucial for fighting climate change. They looked at how public spending on research and development (R&D) affects a climate change index in these countries, though they did not specify the time frame. The findings broadly confirmed that public R&D-related investment can help mitigate climate change.

While public investment in renewable energy is generally seen as a vital tool for reducing greenhouse gas emissions, several studies suggest potential drawbacks. Xu et al. (2023), analyzing E-7 countries (emerging economies), found that green investments, while found to have a positive impact in long-term emissions reduction, might also cause a temporary increase in the short term. Hailemariam et al. (2022) highlight the positive relationship of research and development investments in renewables on emissions reduction.

Further research papers stated their conclusions based on the investment stage. Zhang et al. (2021), analyzing China's data, found a slight reduction in emissions with renewable energy investment, but with variations depending on the investment stage. The studies by Yang et al. (2022) and Appiah-Otoo et al. (2023) delve deeper into these mechanisms. They suggest that the scale and type of renewable energy investment play a crucial role. Yang et al. (2022) propose that while the "technique effect" of renewables can indirectly reduce emissions, the "multiplier effect" might lead to a temporary increase. Appiah-Otoo et al. (2023) explore the varying relationships between different renewable energy sources and CO_2 emissions. Their findings suggest an inverted U-shaped relationship for solar and wind and a U-shaped relationship for hydropower and biofuels, highlighting the need for a targeted investment approach.

It is essential to pinpoint again that none of the reviewed papers directly addressed causality, highlighting a gap in the literature.

2.2. Energy Efficiency and Public Investments in Renewable Energy

This section delves into the intricate relationship between investment in renewable energy and energy efficiency, with a particular focusings on the causal link between the two.

Energy efficiency is a critical aspect of achieving sustainable development and reducing the environmental impact of energy consumption (Zhang et al., 2021; Dhakouani et al., 2019; Cucchiella et al., 2018; Chen et al., 2022). It is usually measured as GDP per unit of energy used to check the amount of energy per production (Chen et al., 2022; Shinwari et al., 2022). Several studies have explored the economic factors influencing energy efficiency. Chen et al. (2022) examined its determinants in the US economy, considering factors like investment in renewable energy R&D, financial inclusion, industrial production, and trade openness. Their findings confirmed the importance of these factors for improving energy efficiency (Chen et al., 2022). The study also identified causal relationships, highlighting the interconnectedness of energy efficiency with economic, financial, and trade aspects. Notably, they found evidence of causality flowing from energy efficiency to financial inclusion, industrial production, renewable energy R&D budgets, and trade openness. Furthermore, research by Shinwari et al. (2022) suggests that energy efficiency can positively impact investment in renewable energy sources (R&D) beyond just economic performance and technological innovation (based on their study of China). Their findings point towards a one-way causal relationship where GDP, natural resource rents, innovation, and energy efficiency all influence investment in renewable energy resources.

In contrast, Czakó (2012) studied Hungary's energy efficiency programs for buildings and offered recommendations for improvement, suggesting an indirect link between investment and efficiency through program design (Czakó, 2012). These studies emphasize that investment in clean energy and well-designed programs can be effective strategies to improve energy efficiency.

While existing research explores the causal link between energy efficiency and investment in renewable energy R&D, there is a gap regarding the broader impact of public investment in renewable energy (beyond R&D) on efficiency, highlighting the need for further studies in this area.

2.3. Renewable Energy and Public Investments in Renewable Energy

Transitioning to renewable energy sources is widely seen as the most promising solution, requiring substantial financial investment. This section explores the relationship between investment and renewable energy development, focusing on risks associated with renewable energy projects.

Abba et al. (2022) highlight various risks in renewable energy projects, including technical, economic, social, and political, and propose a holistic risk management framework for Sub-Saharan Africa. Mazzucato and Semieniuk G. (2018) analyze the risk preferences of financial actors in renewable energy innovation, finding that public and private financiers have distinct risk appetites, with public actors investing in higher-risk technologies, potentially driving innovation.

Studies also explore the role of innovation in attracting investment in renewable energy. Appiah-Otoo et al. (2021) found bi-directional causality between crowdfunding investment and renewable energy sources like solar and wind, indicating that innovative financing mechanisms are crucial for mobilizing capital. Prokopenko et al. (2021) examined how the COVID-19 pandemic could reorient investment flows toward renewable energy innovation, acting as a catalyst for clean energy solutions.

These studies highlight the relationship between renewable energy and investment, emphasizing the need to mitigate risks to attract investment. However, most studies focus on correlations rather than causality. Only Appiah-Otoo et al. (2021) explored causality using crowdfunding investment. Further research is needed to determine whether increased investment drives renewable energy deployment or if technological advancements attract greater investment.

2.4. Climate Policy and Public Investments in Renewable Energy

This review focuses on the interaction between these two investments in renewable energy and renewable energy policies, exploring how public policies influence investment decisions and how investment patterns can, in turn, shape policy development.

Several studies highlight the effectiveness of well-designed public policies in stimulating renewable energy investment (Reuter et al., 2012; Marques and Fuinhas, 2012; Polzin et al., 2015; Ali et al., 2022). Feed-in tariffs (FITs), which guarantee a fixed price for renewable energy production, are identified as a successful policy tool in Germany (Reuter et al., 2012) and Pakistan (Ali et al., 2022). Other policy instruments include tax incentives, subsidies, portfolio requirements, and certificate systems (Reuter et al., 2012; Waikar, 2010). Studies on Iran (Tabatabaei et al., 2017) and China (Yang et al., 2019) also emphasize the role of subsidies in promoting investment. However, the effectiveness of policy instruments is influenced by their design and implementation. Polzin et al. (2015) recommend technology-specific policies, with FITs being suitable for less mature technologies, while market-based instruments like emission trading systems can be effective for established ones. Several studies (Waikar, 2010; Polzin et al., 2015; Ali et al., 2022) stress the importance of long-term policy commitment and transparent regulatory frameworks to create a stable investment environment. Reuter et al. (2012) and Ma et al. (2021) highlight the need for balancing policy design to achieve cost-effectiveness and minimize burdens on consumers.

On the other hand, there is a suggestion of a two-way relationship where increased investment can also influence policy development (Ali et al., 2022). As the renewable energy sector grows, it may gain political clout and influence policy decisions. This is particularly evident in the study by Ali et al. (2022), which examines the case of Pakistan.

The reviewed studies highlight the link between renewable energy investment and public policy. Well-designed policies can boost investment, but a clear cause-and-effect understanding remains largely unexamined. This research on the causality of REI and climate policy has the potential to fill this gap and inform policy for a renewable energy future.

3. METHODOLOGY

3.1. Model Specification

To examine the causal relationship between Public Investment in Renewable Energy and Climate Performance Index and its sub-indicators, we employ the Dumitrescu and Hurlin (2012) panel Granger non-causality method. This approach is selected due to its capability to manage cross-sectional dependence and heterogeneity. The model is specified as follows:

$$CPI_{i,t} = \alpha + \sum_{k=1}^{K} \gamma_{i,k} CPI_{i,t-k} + \sum_{k=1}^{K} \beta_{i,k} REI_{i,t-k} + \varepsilon_{i,t} \qquad (1)$$

We searched for two-way causality between the variables. In the first test, we have REI on the right-hand side and CPI, EM, RE, EE, CL, RS, and RR on the left-hand side to see the causality from REI towards these variables. Then, in the second test, the roles are reversed to see the causality from CPI, EM, RE, EE, CL, RS, and RR towards REI in each causality test.

The countries under study are Algeria, Austria, Argentina, Belarus, Brazil, China, Croatia, Egypt, Finland, India, Indonesia, Kazakhstan, Malaysia, Mexico, Morocco, South Africa, Spain, Thailand, Türkiye, and Ukrania. The research employs a dataset covering the period from 2007 to 2017. The following section provides detailed explanations of the six main variables under investigation, besides two variables that are sub-indicators along with a description of the original sources of each variable:

3.1.1. The public investment in renewable energy (REI)

The dataset of public investment in renewable energy is collected from the International Renewable Energy Agency[2]. It consists of the total funds invested in the renewable energy sector each year. The natural logarithm is calculated to reduce the skewness of a measurement variable.

3.1.2. The climate change performance index (CPI)

We use the index developed by Germanwatch to evaluate the climate change performance of 58 countries responsible for over 90% of global carbon dioxide emissions. The index compares and ranks these countries based on uniform criteria, encompassing emissions, efficiency, renewable energies, and climate policy. In this study, only 20 countries were selected, as stated above, due to the availability of the public investment data of those countries.

The Index was launched in 2007 and is published annually. Before 2017, its calculation methodology followed a specific approach. However, a methodological shift was implemented in 2017, altering how the index has been calculated since then. Therefore, the period of the study that is chosen is 2007 to 2017.

The index allocates countries within the range of [0, 100], with higher values signifying more environmentally conscious

2 International Renewable Energy Agency (IRENA) https://www.irena.org/.

behavior. The Climate Performance ranking is derived from the weighted average of scores attained in individual indicators, as calculated by the following formula in Equation (2).

$$CPI = \sum_{i=1}^{n} W_i * X_i \quad (2)$$

where X_i represents a normalized indicator, and W_j denotes the corresponding weighting assigned to X_i. The allocation of the weighting system is based on the importance of each factor and its contribution to the performance of the climate. The index has the following components: emissions, energy efficiency, renewable energy, and climate policy (Appendix A).

These main components are explained in detail below:

3.1.3. GHG emissions (EM)

It is 60% of the overall score. It is given a higher weighting compared to other components due to the consensus among experts, who emphasize its paramount role in contributing significantly to global warming. The CPI uses a database from the PRIMAP[3] to examine all GHG emissions.

3.1.4. Renewable energy (RE)

It is 10% of the overall score. It measures the capacity of REs in each of the countries under study. The CPI uses statistical data from the International Energy Agency[4]. The share of renewable energy in total primary energy supply and development of energy supply from renewable energy sources is used to measure renewable energy.

The amount and recent advancement of renewable energy sources account for 10% of a nation's overall score. The percentage of which energy supply from renewable sources has been developed recently accounts for 80% of this indicator's score. The remaining 20% is assigned based on the proportion of renewable energies in the overall primary energy supply.

This calculation strategy ensures equitable recognition for countries such as Norway and Iceland, which have already achieved a substantial portion of their total energy supply from renewable sources. Consequently, these nations have limited potential to significantly increase their share of renewable energies further. However, none of these countries that recently developed renewable energy sources are included in this study. Therefore, both the Share of Renewable Energy in Total Primary Energy Supply and Development of Energy Supply, which are sub-indicators of the renewable energy indicator, will be part of the investigation individually. Also, because the common variable used to measure renewable energy, in the literature, is the share of renewable energy among the energy supplies available (Moutinho and Robaina, 2016; Saygin et al., 2015) Therefore, an individual causality test with each sub-indicator will be conducted and discussed in the section 4.

3 PRIMAP database is a comprehensive greenhouse gas emissions dataset for every country https://primap.org/

4 International Energy Agency provides data on the global energy sector. https://www.iea.org/

3.1.5. Energy efficiency (EE)

It is 10% of the overall score. It focuses on energy efficiency. The CPI uses data from the International Energy Agency. The efficiency level (5%) and efficiency trend (5%) are used to measure efficiency.

3.1.6. Climate policy (CL)

It is 20% of the overall score. It quantifies the efficacy of climate policies implemented across diverse nations. Evaluations of a country's performance in climate policy stem from an annually updated survey conducted with input from national climate and energy experts within civil society.

3.2. Testing the Hypothesis

Here, we discuss the anticipated causal relationships that REI is expected to have with the other variables, based on insights from existing literature and hypotheses are as follows:

Hypothesis 1: Public investment in renewable energy is expected to demonstrate Granger causality with climate change performance. The hypothesis posits that investment in renewable energy will influence critical aspects of climate performance.

Hypothesis 2: Public investment in renewable energy is anticipated to exhibit Granger causality with emissions. It is expected that renewable energy investment will impact the emission levels.

Hypothesis 3: Public investment in renewable energy, including RR and RS, is hypothesized to cause changes in Renewable Energy. The expectation is that renewable energy investment will influence greenhouse gas emissions. This interconnection implies that shifts and trends in renewable energy investment are expected to predict corresponding changes in these key factors.

Hypothesis 4: It is hypothesized that energy efficiency initiatives lead to subsequent changes in renewable energy investment levels, as suggested by existing research.

Hypothesis 5: The formulation of climate policies is anticipated to precede and impact subsequent variations in renewable energy investment levels, based on insights from the literature review.

This proposed framework for causality forms the basis for the subsequent empirical analysis, aiming to unravel and substantiate these anticipated relationships in the context of the study's objectives.

3.3. Econometrics Methodology

Our methodology unfolded in a structured sequence. We began with a descriptive analysis, followed by a stationary test to assess data stability. Next, we examined cross-sectional dependency in the panel data to scrutinize relationships between variables across different sections. Finally, we conducted a causality analysis to explore causal links within our dataset.

3.3.1. Descriptive statistics of variables

Here, we provide descriptive statistics to understand the characteristics and variability of the dataset before conducting further analysis. In this study, we summarize descriptive statistics of REI, CPI, EM, RE, EE, CL, RS, and RR for the period 2007-2017 in Table 1 below. The total number of observations per each variable employed in this study is 220 (Table 1).

The countries are categorized according to the World Bank's income classifications in 2017. Specifically, Austria, Croatia, Finland, and Spain are classified as "high-income" countries. The "upper-middle-income" category includes Algeria, Argentina, Belarus, Brazil, China, Kazakhstan, Malaysia, Mexico, South Africa, Thailand, and Turkey. "lower-middle-income" countries encompass Egypt, India, Indonesia, Morocco, and Ukraine.

These comparisons below highlight the interplay between income levels and climate-related variables. The mean values of various variables across different income categories reveal notable differences in climate-related indicators.

High-income countries exhibit a lower mean Climate Performance Indicator of 52.19 compared to upper middle-income countries (51.36), while lower-middle-income countries show a higher mean CPI of 57.21. This suggests that lower-middle-income countries may have better climate performance on average. The countries with the lowest emissions get the most points in this category. Lower-middle-income countries have higher mean total emissions compared to high-income and upper-middle-income countries, indicating potentially lower levels of pollution. Regarding renewable energy and energy efficiency, high-income countries lead with higher mean values, indicating greater adoption of renewable energy sources and more efficient energy use. Interestingly, despite lower mean values of renewable energy share in total primary energy supply and development of energy supply from renewable energy sources in lower-middle-income countries than in high-income countries, their mean public investment in renewable energy is slightly higher than that of upper-middle-income countries. This suggests a notable focus on renewable energy investment in lower-middle-income countries despite lower current adoption rates.

3.3.2. Preliminary examinations

For the stationarity of the variables, the Levin–Lin–Chu (LLC) test from first-generation stationary tests is used. Choosing Levin–Lin–Chu (LLC) unit-root test is due to the lack of cross-sectional dependency, which will be explained below. Another reason is because of the consistency, such that even if the data-generating process has heterogeneous autoregressive parameters, where convergence rates differ across units, the LLC test can still be consistent in identifying the stationary series and rejecting a unit root. This is because it uses a pooled estimator (single estimate for all units), which can be valid for testing the null hypothesis (Hurlin and Mignon, 2007).

Regarding the cross-sectional dependency, data for this study is not cross-sectionally dependent. It has been collected from multiple countries and selected based on data availability, covering a broad spectrum of income levels and geographical regions.

3.3.3. Granger causality

This section explains why Dumitrescu and Hurlin (2012) have been chosen and how Granger causality was used. The Dumitrescu and Hurlin Granger causality test addresses heterogeneity in panel datasets but assumes no cross-sectional dependency, making it ideal for our analysis. It determines the direction of causation between variables, allowing for one-way, two-way, or no causation. This test considers the heterogeneity of the regression model and causal relationship, proving more effective than the traditional Granger (1969) test. Unlike Kónya (2006) it does not require bootstrap critical values.

The model used in this study is the Panel Granger causality test with the following specification in Equation (3).

$$y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_{ik} y_{i,t-k} + \sum_{k=1}^{K} \beta_{ik} x_{i,t-k} + \varepsilon_{i,t} \tag{3}$$

If previous values of $x_{i,t}$ remain influential predictors of the present value of $y_{i,t}$, even when accounting for past values of $y_{i,t}$ within the model, it indicates that $x_{i,t}$ exerts a causal influence on $y_{i,t}$ In the given context, where $x_{i,t}$ and, $y_{i,t}$ represent the observations of two stationary variables for individual *i* in period *t*, coefficients are permitted to vary among individuals (as denoted by the *i* subscripts attached to coefficients) but are presumed to remain constant over time. The H-D methodology assumes that the lag order K is to be consistent across all individuals, and the panel must be balanced. The examination of the null hypothesis (H_0) is based on the lack of Granger causality among all non-homogeneous variables, whereas the assessment of the alternative hypothesis (H1) is based on the presence of Granger causality in the panel outcomes.

The null hypothesis is defined as:

Ho: $\beta_{i1} = \cdots = \beta_{iK} = 0$

This signifies the lack of causality across all individuals within the panel. The DH test operates on the assumption that causality may

Table 1: Descriptive statistics based on the world bank's income classifications

Income levels	High income		Upper middle income		Lower middle income	
Variables	**Mean**	**Std.err.**	**Mean**	**Std. err.**	**Mean**	**Std. err.**
CPI	52.18661	0.615287	51.36477	0.617167	57.21372	0.5085988
EM	36.15077	0.5415946	34.67977	0.4943589	39.74878	0.3775751
RE	2.476139	0.1964985	1.76073	0.112196	2.132833	0.1702075
EE	5.879531	0.1688691	4.418362	0.1575217	4.825093	0.1622491
CL	7.680176	0.4903088	10.50591	0.3462643	10.50702	0.533429
RS	0.3896127	0.0228687	0.2085092	0.0198509	0.3018217	0.0358084
RR	0.2121142	0.0243415	0.167964	0.0124888	0.1911487	0.0209143
REI	22.16698	0.2290501	22.43604	0.2075572	23.98483	0.1077739

exist for some individuals but not necessarily for all. Therefore, the alternative hypothesis is as follows:

H_1: $\beta_{i1} \neq 0$ or $\cdots$ or $\beta_{iK} \neq 0$

4. EMPIRICAL RESULTS

This section begins by presenting the results of the unit root test. Subsequently, the Granger causality results are presented.

4.1. Unit Root Results

As we discussed earlier, we used Levin–Lin–Chu test in examining the stationarity of the panel data. Our analysis yielded a P = 0.00 (Appendix-B), strongly rejecting the null hypothesis of a unit root in the panel data. This suggests that the data is stationary, which is preferable for Granger causality testing as it leads to more reliable results regarding causal relationships.

4.2. Granger Causality Results

In the following table, the results of the Granger causality test are presented. Then, these results are explained and discussed.

In this section, the results of the causality of REI with each variable are explained. In Table 2, the results show that REI is significantly granger causes the Climate Change Performance Indicator based on the P = 0.056. In simpler terms, changes in public investment in renewable energy seem to cause changes in climate change performance. However, the CPI does not significantly Granger cause REI based on the P = 0.435. Therefore, based on these results, we can conclude that there is unidirectional causality from REI to CPI.

Regarding the causality with emissions, the results show REI granger causes EM with a P = 0.00. This suggests that changes in renewable energy investment tend to lead to changes in overall emissions. Conversely, alterations in EM do not significantly Granger cause REI, as evidenced by a P = 0.524. Therefore, we observe a unidirectional causality from REI to EM, indicating that changes in public investment in renewable energy may influence overall emissions, but the reverse may not significantly be true, as it is not observed.

The observed unidirectional causality from REI to both CPI and EM suggests a potential role for public investment in renewable energy in mitigating climate change and reducing emissions. In the literature, it implies the influence of investment over emissions (Mahesh and Jasmin, 2013; He et al., 2023; Hailemariam et al., 2022; Yang et al., 2022; Zhang et al., 2021; Appiah-Otoo et al., 2023). The results above are consistent with the literature, where the influence of the investment is dominant on emissions, which makes it an effective tool for climate management.

In terms of energy efficiency, the amount of REI does not significantly influence EE based on the P = 0.2676. On the other hand, EE significantly granger causes the REI, where the results show a very low P = 0.001. The H_0 is rejected indicating a unidirectional causality from EE to REI.

This aligns with some reviewed studies by Chen et al. (2022) and Shinwari et al. (2022), who found causality running from efficiency to investment in renewable energy R&D (beyond just economic factors). This suggests regions with demonstrably high energy efficiency might be attracting more public investment in broader renewable energy projects.

For climate policy, public investment in renewable energy seems to directly cause changes in climate policy performance. It significantly influences CL based on the P = 0.000. However, The CL does not Granger-cause the REI since the P = 0.4112, indicating a unidirectional causality from the REI to the CL.

It was expected that the climate policy would cause the REI. But, here, it is observed that the REI is an impacting factor on the quality of climate policy. The past values of the REI can predict the future performance of climate policy. The observation that REI impacts the quality of climate policy implies that the level and nature of investments in renewable energy can shape the design, implementation, and effectiveness of climate policies.

This aligns with the reviewed literature that highlights the potential two-way relationship between investment and policy (Ali et al., 2022). Studies suggest that well-designed policies can stimulate investment, but our research suggests an additional dynamic. Public investment in renewables might lead to more robust climate policies. Increased investment in renewables and the resulting positive environmental impact could prompt policymakers to strengthen climate policies, in order to further accelerate progress.

Table 2: The results of Granger causality test on public investment in renewable energy with the main components of the climate change performance index

Time series pair	Direction of causality	P-value (Z-bar)	Conclusion
REI → CPI	REI Granger-causes CPI	0.056*	Unidirectional causality from REI to CPI
CPI → REI	CPI does not Granger-cause REI	0.435	
REI → EM	REI Granger-causes EM	0.000***	Unidirectional causality from REI to EM
EM → REI	EM does not Granger-cause REI	0.524	
REI → EE	REI does not Granger-cause EE	0.268	Unidirectional causality from EE to REI
EE → REI	EE Granger-causes REI	0.001***	
REI → CL	REI Granger-causes CL	0.000***	Unidirectional causality from REI to CL
CL → REI	CL does not Granger-causes REI	0.411	
REI → RE	REI does not Granger-causes RE	0.365	No Causality relationship
RE → REI	RE does not Granger-cause REI	0.966	

***, **and*represent significant levels at 1%, 5%, and 10% respectively

Table 3: The results of Granger causality of the public investment in renewable energy with the recent development of renewable energy and the share of energy from renewable resources

Time series pair	Direction of causality	P-value (Z-bar)	Conclusion
REI → RS	REI does Granger-cause RS	0.000***	Bi-directional causality
RS → REI	RS does Granger-cause REI	0.0043**	
RE → RR	REI does not Granger-cause RR	0.4513	No causality relationship
RR → REI	RR does not Granger-cause REI	0.4072	

***, **and *represent the significant level at 1%, 5%, and 10% respectively

Lastly, investing in REI does not appear to directly influence the overall RE. The Granger causality test suggests there is no significant causality in this direction. The opposite causality also suggests the level of RE does not directly affect the amount of REI. However, since the weight of RE indicator consists of a share of renewable energy (RS) that was given 20 percent weight of the RE indicator, and 80% of it is based on the recent development of energy supply from renewable sources (RR), more weight was given to the recent development to raise the ranking for the countries under this category. The majority of the countries under the study are not recent renewable energy developers, which can skew the results in a certain direction.

For the purpose of studying the relationship between the REI and RE and to have an understanding of the dynamic of their relationship, we needed to break down the underlying indicators and run the tests against them individually. Table 3, Below, shows the results of the Granger's test results for RR and RS.

The results in Table 3 show that the RS Granger-causes the REI, and vice versa. This indicates bi-directional causality, where both influence each other's future values. The two-way causality suggests a policy feedback loop where changes in public investment influence changes in renewable energy sources, which in turn stimulate further changes in public investment.

This is similar to the previous study by Appiah-Otoo et al. (2021), where they tested the causality between crowdfunding and renewable energy. Their results showed bi-directional causality between crowdfunding and renewable energy generation. This feedback loop may result from successful public investments that boost renewable energy adoption. As the share of energy from renewable sources increases, policymakers may respond by allocating more public funds to support and incentivize further growth in renewable energy. This response could be driven by environmental goals, energy security concerns, or economic opportunities associated with renewable energy.

On the other hand, RR does not seem to have any causal link with REI. It is possible that private investments have played a more significant role in recent renewable energy developments, with public investment playing a supplementary or supporting role. Another potential explanation for these results is that the countries under study are not recent developers of renewable energy.

5. CONCLUSIONS

We have investigated the causal relationship between public investment in renewable energy and the Climate Change Performance Indicator. The aim is to provide a more nuanced understanding of how public renewable energy investment impacts various aspects of climate action. Our study contributes to the literature by investigating, for the 1st time, the causal relationship between total public investment in renewable energy and the CPI, that encompasses emissions, efficiency, climate policy, and renewable energy itself.

In the literature, it has been reported that investment has a dominant influence on emissions. Additionally, energy efficiency is found to granger cause investment in renewable energy. For renewable energy, it has been shown a bidirectional causality with the investment in renewable energy. Moreover, climate policy plays a role in stimulating investment in renewable energy.

In summary, most of the findings revealed similar results to the literature, where a unidirectional causality from renewable energy investment to climate change performance index, which consists of 60 percent emissions, was found. Additionally, unidirectional causality was noted from public investment in renewable energy to overall emissions while a unidirectional causality was observed from energy efficiency to REI. Furthermore, bidirectional causality is found with a renewable energy share.

These results underscore the significance of REI as a pivotal tool for mitigating greenhouse gas emissions, given their substantial contribution to climate performance. However, the ability to foster investments in renewable energy hinges on enhancing energy efficiency. Regarding climate policy, contrary to expectations and contrary to the literature, our findings indicate that REI influences the quality of climate policy, rather than the reverse. The past values of REI can predict future performance in climate policy, suggesting that investments in renewable energy can shape the design, implementation, and effectiveness of climate policies. Recognizing the influence of REI on climate policy underscores the importance of incentivizing and supporting investments in renewable energy to drive broader climate action and achieve ecolologically-driven goals.

Furthermore, the results demonstrate a bi-directional causality between renewable energy share and REI, suggesting a policy feedback loop. This loop entails increased public investment stimulating the growth of renewable energy sources, which in turn incentivizes further investment. We could assume that as the share of energy from renewable sources rises, policymakers may respond by allocating more funds to support further growth in renewable energy, driven by environmental, energy security, or economic considerations.

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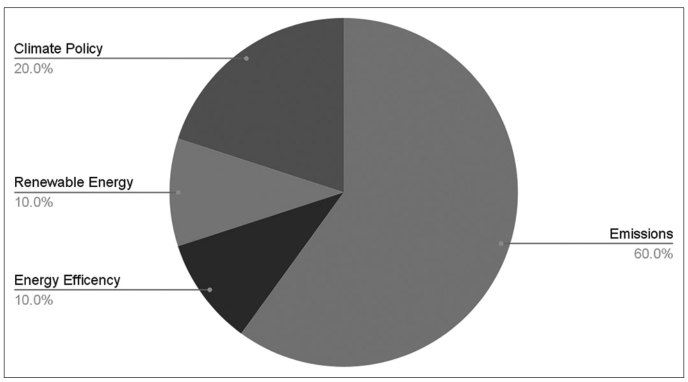
APPENDICES

Appendix A: Climate change performance index



Source: The climate performance index methodology report (2017)

Appendix B: Levin–Lin–Chu unit root test results

Variable	Adjusted t-value	P-value
CPI	−7.2374	0.0000***
EM	−6.4319	0.0000***
RE	−5.0544	0.0000***
EE	−2.9816	0.0014***
CL	−14.0761	0.0000***
RS	−3.1828	0.0000***
RR	−5.2612	0.0000***
REI	−21.3420	0.0000***

***represents significant level at 1%