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Can Renewable Energy, Carbon Taxes, and Economic Growth Mitigate Countries' Carbon Emissions?

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ABSTRACT

The objective of this study is to provide empirical evidence on the effect of different types of renewable energy use (wind, solar, and hydro), the existence of carbon taxes, and economic growth conditions on carbon emissions of countries. The sample of this research is countries in the world in the 11-year observation period from 2010 to 2020 for 47 countries. The analysis method uses the panel data method stage. The results show that renewable energy, especially wind and solar, significantly affects a country's carbon emissions in terms of electricity generation and installed capacity. While the installed capacity of hydropower affects emissions, its generation does not. The presence of a carbon tax and a country's GDP have no effect on the level of carbon emissions. These findings emphasize the paramount importance of renewable energy in mitigating carbon emissions.

Keywords: Renewable Energy, Carbon Tax, Economic Growth, Carbon Emissions
JEL Classifications: M41, M48, Q42, Q56

1. INTRODUCTION

Carbon emissions are influenced by a complex interplay of energy use and natural resources (Li et al., 2021; Cheng et al., 2019; Danish et al., 2019), technology and innovation (Ganda, 2019; Shuai et al., 2017), economic growth and structure (Anser et al., 2021; Li et al., 2021), country risks and policy (Zhang and Chiu, 2020; Anser et al., 2021). Understanding these factors is crucial for developing effective strategies to mitigate climate change. Even different types of renewable energy have different impacts on a country's carbon emissions. Wind resources can provide an important alternative to conventional electricity generation mainly based on fossil fuels, reducing CO_2 emissions (Pérez-Navarro et al., 2010). Aligns with Li et al. (2020)'s finding that findings that wind power projects have huge potential for emission reductions compared to general coal-fired stations. An additional Megawatt hour (MWh) of wind generation corresponds to a reduction in CO_2 emissions of 0.401 tons in Ireland and 0.459 tons when accounting for emissions offset in Great Britain (Oliveira et al., 2019). The annual displacement emission factor by wind energy may vary but still reducing total CO_2 abatement (Hernández et al., 2019).

Renewable technologies like solar and wind provide a better energetic return on energy invested than carbon capture and storage, even when combined with energy storage (Sgouridis et al., 2019). Using electricity from clean energy sources and improving efficiency in electricity generation, transmission, distribution, and utilization can lead to less carbon emission growth (Lin and Li, 2020). More use of electricity, especially from clean energy sources, significantly reduces carbon emission growth, while population, economic growth, urbanization, and industrialization have positive impacts. Meanwhile, natural water resources and geographical advantages greatly affect hydropower efficiency, which can bring carbon emission reduction efficiency (Liang et al., 2020).

Adopting carbon taxes in European countries has a positive and significant impact on stimulating the reduction of CO_2 emissions (Ghazouani et al., 2020). Similarly, carbon taxes significantly reduce CO_2 emissions from transport, with the largest share due to the carbon tax alone, and their true effect may be underestimated when using price elasticities for emission reductions (Andersson, 2019). When carbon tax implementation is differentiated into a fixed carbon tax and an increased block carbon tax, both have the same controlling influence on carbon emissions that limit total carbon emissions within the desired range (Zhou et al., 2019). A carbon tax significantly reduces energy consumption, carbon emissions, and pollutant emissions in China, outperforming resource taxes in these areas (Hu et al., 2021). A global carbon tax based on both CO_2 and non-CO_2 emissions has a more accurate impact on developing countries than a tax based only on CO_2 emissions, with higher GDP reductions in developing countries (Nong et al., 2021). Other studies have found that GDP and energy consumption increase emissions, promoting sustainable environmental goals (Sheraz et al., 2021).

Carbon taxes are considered a policy instrument to meet emission reduction targets under the Paris Climate Agreement (Timilsina, 2022). Economists and international organizations strongly advocate for carbon taxes as the most effective market-based mitigation tool (Lin and Li, 2011); interesting policy option for reducing emissions (Baranzini et al., 2000) and significantly improve environmental quality (Tu et al., 2022), but its contribution to carbon emissions varies considerably across countries carbon emission taxes. Carbon tax in Finland significantly reduces per capita CO_2 emissions, while Denmark, Sweden, and Netherlands have negative but not significant effects, and Norway has not realized its mitigation effects due to rapid growth in energy products (Lin and Li, 2011). Environmental taxes and Research and Development (R and D) significantly reduce carbon emissions in G7 countries, while GDP and imports increase them, suggesting policymakers should focus on these measures to achieve carbon neutrality (Safi et al., 2021). Similarly, carbon tax increases in China lead to increased carbon emission reduction, higher inflation rates, and negative effects on GDP and employment, but can also reduce carbon emissions (Zhao et al., 2023). A carbon tax in China is more regressive in rural areas than urban areas, highlighting the need for policy measures to alleviate income gaps among income groups and between urban and rural areas (Guo et al., 2022). This is why it is important to consider a carbon tax policy and the economic growth of a country's GDP.

The Natural-Resource-Based View (NRBV) paradigm, which emphasizes that businesses can gain a competitive edge by increasing the ability to manage environmental concerns and sustainably exploit natural resources (Hart and Dowell, 2011), provides the basis for this research. This theoretical perspective is significant to the efforts made by nations to reduce their carbon emissions using renewable energy sources and the implementation of carbon tax laws, considering those nations' economic growth conditions. To maintain its existence in the future, the state, acting as a representative of an entity, looks to acquire a competitive edge by focusing on environmental sustainability and natural resource management. In the context of carbon emission mitigation, this theory can be used to explain how natural resources, particularly renewable energy, carbon taxes, and economic growth are interrelated and influence emission reduction efforts.

It is interesting to investigate further the determinants of carbon emission levels in different countries. Therefore, the aim of the study is to provide empirical evidence on the effect of various types of renewable energy use (wind, solar and hydro), carbon tax, economic growth on a country's carbon emissions. The contribution of the findings of this study is useful for scientific development and the field of sustainability accounting research, especially the contribution of accountants to the aspects of assessment, measurement and disclosure of environmental and social information in financial reporting. Practically, the findings of this study are useful for industry and regulatory actors to evaluate the impact of the shifting initiation efforts they have taken for sustainability purposes.

The hypothesis is organized as follows:

H1: Wind Electricity Generation (GWh) influences carbon emissions

H2: Wind Electricity Installed Capacity (MW) influences carbon emissions

H3: Solar Electricity Generation (GWh) influences carbon emissions

H4: Solar Electricity Installed Capacity (MW) has an influence on carbon emissions

H5: Hydro Electricity Generation (GWh) influences on carbon emissions

H6: Hydro Electricity Installed Capacity (MW) influences carbon emissions

H7: Carbon Tax influences carbon emissions

H8: GDP has an influence on carbon emissions

2. METHODS

2.1. Sample, Variables and Measurements

The sample of this research is countries in the world in the 11-year observation range from 2010 to 2020. The number of countries used as samples is 47 countries, so the total observation data is 517 data. The data sources used to measure the renewable energy variables were obtained from the International Renewable Energy Agency (IRENA) statistical data publications. Meanwhile, data on carbon emissions and GDP were obtained from the World Bank database publication.

The dependent variable is Carbon Emissions which shows the level of carbon emissions of a country. Meanwhile, there are 8 independents variables in this study, i.e. Wind Electricity Generation, Wind Electricity Installed Capacity, Solar Electricity Generation, Solar Electricity Installed Capacity, Hydro Electricity Generation, Hydro Electricity Installed Capacity, Carbon Tax and GDP. The following is IRENA's operational definition of measurement electricity generation and electricity installed capacity (IRENA, 2024). Electricity generation is the total amount of electricity produced by power plants; it is measured in gigawatt hours (GWh). Electricity Installed Capacity is the maximum power a plant can produce continuously, it is measured in megawatts (MW). Electricity generation and Electricity Installed Capacity are applied to wind, solar and hydro renewable energy. Carbon Tax shows the countries in the world that have implemented carbon tax regulation policies and those that have not, giving the number 1 if they have and 0 if they have not. Meanwhile, GDP is the total value of final goods and services produced in a country in any period and is a representation of countries' economic growth.

2.2. Data Analysis Method

The data analysis method uses the panel data method which is carried out through the following stages: Determining the estimation model (whether common effect, fixed effect, or random effect), then determining the estimation method (Chow test, lagrange multiplier, Hausman test), then testing assumptions and model suitability. Finally, the results are interpreted by considering the F test value, R-squared, and t test value.

3. RESULTS AND DISCUSION

3.1. Descriptive Statistic

Table 1 presents the descriptive statistics of 517 observational data from 44 countries over an 11-year period. All variables in this study have a standard deviation value that is greater than the mean value, indicating that there is wide variation. Furthermore, only the GDP variable has a between variance value smaller than the within variance value, meaning that the variability between variables is smaller than the variability within the variable, or in other words, the variation between countries is smaller than the variation in changes in a country's GDP over time. Meanwhile, for other variables, the characteristics are the opposite. The achievement of a country's GDP involves a combination of interrelated global, regional, and internal factors. The variation in GDP changes within a country over the 11-year observation period is quite large. Looking at this period, there were several global events that contributed to these changes, such as pandemics and geopolitical events. These circumstances are indicated to be the cause of the variability of GDP changes over time, which can reduce or cause economic inequality, but can also grow slowly towards economic recovery and stability if the country manages to carry out good governance in practice.

3.2. Research Model Testing

In the analysis procedure, the Chow Test results show significant with below 0.05, so the best choice is fixed effect. Furthermore, to choose better fixed effect (FE) or random effect (RE) then enter the Hausman Test, where the results show significant so that the best model is FE. At the next stage, there is a multicollinearity problem but even so it will not affect the data results. There is also a problem of heteroskedasticity and autocorrelation so that the cluster standard error is carried out so that it can be justified. The results are presented in Table 2.

3.3. Hypothesis Testing

The hypothesis testing results show that Wind Electricity Generation has a negative effect on a country's carbon emissions, meaning that its increase will decrease carbon emissions, so Hypothesis 1 is accepted. Meanwhile, Wind Electricity Installed Capacity has a positive effect on carbon emissions, which means that it will increase carbon emissions, so hypothesis 2 is also accepted. Furthermore, Solar Electricity Generation has a negative effect, meaning that its increase will decrease carbon emissions, so hypothesis 3 is accepted. Meanwhile, Solar Electricity Installed Capacity has a positive effect, meaning that its increase will also increase carbon emissions in these countries, so hypothesis 4 is accepted. Hydro Electricity Generation has no effect on a country's

Table 1: Descriptive statistics results

Variable		Mean	SD	Min.	Max.	Obsv
Carbon emissions	Overall	552351.4	1588957	5835.6	1.09e+07	N=517
	Between		1600538	7385.809−916582.7	9943857	N=47
	Within		112731.3		1553180	T=11
Wind electricity generation (GWh)	Overall	6286.491	18607.69	0.662	192991.8	
	Between		13729.04	0.9455455−75890.49	82279.65	
	Within		12704.82		116998.7	
Wind electricity installed capacity (MW)	Overall	2831.282	7789.475	0.63	72767.22	
	Between		6122.72	0.7	31103.64	
	Within		4890.268	028243.06	44494.86	
Solar electricity generation (GWh)	Overall	3937.244	12007.98	0.5	72767.22	
	Between		9371.648	1.656091−37791.7	31103.64	
	Within		7163.933		44494.86	
Solar electricity installed capacity (MW)	Overall	3571.463	10045.33	0.507	74693.2	
	Between		8600.143	1.202−26357.26	38411.45	
	Within		5327.257		48488.24	
Hydro electricity Generation (GWh)	Overall	52650.16	164571.1	1.025	1322000	
	Between		163240.1	1.749091−300893.3	1041693	
	Within		30866.31		332956.7	
Hydro Electricity Installed Capacity (MW)	Overall	13804.71	42997.85	2.992	338670	
	Between		42868.8	2.992−67929.65	280861.5	
	Within		6833.462		71613.16	
Carbon Tax	Overall	0.205029	0.4041138	0	1	
	Between		0.3538546	0−0.7040619	1	
	Within		0.2012995		1.023211	
GDP	Overall	1.39e+12	3.12e+12	7.19e+09	2.15e+13	
	Between		3.11e+12	1.18e+10−3.40e+12	1.83e+13	
	Within		5.17e+11		5.20e+12	

SD: Standard deviation

carbon emissions, so hypothesis 5 is rejected. However, Hydro Electricity Installed Capacity has a positive effect on carbon emissions, meaning that increasing it will also increase carbon emissions, so Hypothesis 6 is accepted. The last two hypotheses, hypotheses 7 and 8, are rejected because the existence of a carbon tax policy and the condition of a country's GDP have no effect on the country's carbon emission level. The R-squared results of this research model show high results of 94.65%, which means that the existence of independent variables in this study can explain the state of the dependent variable. The carbon emission level of a country is largely dependent on the efforts made to utilize different types of renewable energy in the country. The results are summarized in Table 3.

3.4. Discussion

Wind electricity generation helps reduce carbon emissions because it doesn't involve burning fossil fuels like coal or natural gas during operation (Local Government Association, 2024). These traditional methods release significant amounts of carbon dioxide (CO_2) into the atmosphere, a major contributor to global warming. Wind turbines generate electricity by utilizing the kinetic energy of the wind, so they have a low carbon footprint (National Grid, 2024). The more wind energy that enters the power grid, the less electricity needs to be produced from burning fossil fuels, leading to a significant reduction in overall carbon emissions (EIA, 2022).

The finding that increased wind power capacity leads to higher carbon emissions warrants further investigation. These findings aligned with Kealy (2019) stated that there is no consistent correlation between the increase in wind turbine capacity and a reduction in CO_2 emissions. Generally, research on this topic relies on displacement estimation methods, which assume current power grid operations. However, these methods use a fixed displacement factor, as wind power is primarily seen as a replacement for high-carbon power plants. This approach may not hold true in the long term, as the global energy mix transitions towards lower-carbon sources. Hernández et al. (2019) proposes utilizing two dynamic displacement factors that adapt to the evolving energy mix, providing a more accurate range of avoided CO2 emissions. These factors represent the upper and lower limits of avoided CO_2 emissions. Thus, countries should carefully evaluate what methods are appropriate for their unique environmental situation to optimize, rather than increase, the contribution of wind electricity installed capacity to carbon emissions. Natural variability due to internal climate modes dominates over global-warming-induced non-stationarity over most areas with large wind energy installations or potential (Pryor et al., 2020). Higher-rated wind turbines have greater embodied carbon emissions, but their greater electricity output offsets these emissions more quickly, leading to greater environmental benefits (Smoucha and Fitzpatrick, 2016). This is why there seems to be conflicting consequences between wind electricity generation and wind electricity installed capacity.

Table 2: Model testing results

Test	Results
Chow test (Prob>F)	0.0000
Hausman test	0.0000
Model best Fit	**FE**
VIF	40.95
Modified Wald test (Heteroskedasticity test)	0.0000
Wooldridge test (Autocorrelation test)	0.0000

Table 3: Hypothesis testing results

Variable	Coef.	T	P > |t|
Wind Electricity Generation (GWh)	−10.84528	−2.36	0.023
Wind electricity Installed Capacity (MW)	29.97006	2.19	0.033
Solar Electricity Generation (GWh)	−20.84795	−2.73	0.009
Solar electricity installed capacity (MW)	19.70448	2.21	0.032
Hydro electricity generation (GWh)	−0.5293714	−0.85	0.399
Hydro electricity installed capacity (MW)	9.893523	6.51	0.000
Carbon Tax	6789.904	0.32	0.752
GDP	8.97e−08	1.73	0.091
Prob>F		0.0000	
R-squared		0.9465	

Solar electricity generation helps reduce carbon emissions in two keyways: Clean energy production and reduced reliance on fossil fuels. Unlike traditional power plants that burn fossil fuels like coal or natural gas, solar panels convert sunlight directly into electricity (Shahsavari and Akbari, 2018). This process emits minimal to no greenhouse gases, making it a clean and sustainable energy source. Solar could help reduce the atmospheric carbon burden (Keith et al., 2017). By generating clean electricity, solar power helps displace the need for electricity generated from burning fossil fuels electricity. It reduced demand for fossil fuel (Shahsavari and Akbari, 2018) and reduce fuel consumption (Son et al., 2019). As more solar energy enters the power grid, the demand for fossil fuel power plants decreases. This significantly reduces overall carbon emissions from the electricity sector (Schiermeier et al., 2008).

Miller et al. (2019) study using a modeling tool, found that the reversible temperature effect on the module increases the carbon intensity of silicon photovoltaic power if the device installation is in a warm area, in addition, solar tracking can increase the emission intensity depending on the installation location and module type. Tracking can increase emission intensity, this is due to the interaction between tracking energy gain, tracking production emissions, and module production emissions. Theoretically, switching from thermal to renewable electricity is the most efficient approach to lower carbon emissions. International experience, however, demonstrates that the limitations imposed by natural variables still provide challenges when trying to increase installed capacity of renewable energy (O'Shaughnessy et al., 2020). It is obviously irrelevant because the issue is not about whether there is installed capacity, as the availability of solar and wind energy may be limited in some areas while being extended in others. Installations with intermittent power supply are hence unable to reduce carbon emissions.

Hydro electricity generation does not contribute to carbon emissions could be due to hydropower having a higher carbon footprint than previously assumed but its contribution to climate change mitigation is still below fossil energy sources without carbon capture and sequestration technologies (Scherer and Pfister, 2016). Hydropower generally has a lower carbon footprint compared to fossil fuel-based power generation. This is an interesting finding to explore further. Hydropower plants do not directly burn fossil fuels, so they do not produce exhaust emissions, which could be why the effect seems to be non-existent. The interaction between the hydrological or water system and the climate (weather) system in a region or area is called hydroclimatic. These hydroclimate changes pose a challenge to the EU's decarbonization strategy, which leads to increased fossil fuel use and load shedding, thus jeopardizing emissions reduction targets (Carlino et al., 2021).

Meanwhile, the finding that hydroelectricity installed capacity affects a carbon emission is consistent with Ma et al. (2022), research conducted in China, where the share of hydroelectricity installed capacity is significant, thus driving the change in China's aggregate carbon intensity from 2015 to 2019. Hydro energy consumption can intensify CO_2 emissions in short runs and diminish CO_2 emissions in longer runs, depending on energy generation from hydro plants (Bilgili et al., 2021). Study Chu et al. (2022) which aimed to provide a system accounting framework for evaluating direct and indirect carbon emissions from hydropower plants, found that the life cycle of a hydropower plant includes both direct and indirect carbon emissions, with the largest emissions occurring in the end-use stage (38.4%) and construction stage (34.5%). Climate change affects hydropower by altering hydrologic regimes and increasing electricity demand, leading to a gap between supply and demand, which can contribute to additional greenhouse gas emissions (Qin et al., 2020). These arguments explain why increasing hydroelectricity installed capacity has the effect of increasing carbon emissions.

The carbon tax had no effect on the country's carbon emissions. Carbon taxes also have no effect on greenhouse gas emissions in 36 OECD countries from 1990 to 2018 (Nar, 2021). Similarly, Tu et al. (2022) found that while the shock of the carbon emission tax has an immediate impact on most economic indicators, the environmental quality is not immediately impacted. The possibility that carbon taxes will help solve the climate change issue is extremely remote (Nadel, 2016). Their tentative conclusion is that while carbon taxes can be a useful tool, they are unlikely to be the only solution to the climate change issue at the tax levels that have proven politically possible thus far. Greenhouse gas emissions have not yet decreased to the targeted levels, even in nations where taxes are levied at rates of approximately 40% and higher (Bruvoll and Larsen, 2004). Therefore, the tax ratio is something that needs to be carefully regulated, it should not be too low to allow carbon leakage or too high to inhibit CO_2 emissions.

The efficacy of carbon taxes in reducing carbon emissions is contingent upon various factors such as revenue utilization, sector taxation, and design concerns (Sumner et al., 2009). Other than that, when implementing a carbon tax policy, consideration should be given to the tax rate ratio and several implementation strategies, including whether the tax rate is flat, increased block carbon tax or stepped carbon tax (Hu et al., 2021; Zhou et al., 2019). Every country must consider the aforementioned factors for the establishment of a carbon tax to effectively contribute to the mitigation of carbon emissions. Descriptive statistics' findings also show that, in the study year, there are still not many countries implementing this policy. This makes sense as the introduction and incentives of the carbon tax policy have only recently drawn attention from around the globe. As a result, governments still need to go through a process to design the appropriate mechanisms and regulations in line with the goals they hope to accomplish. Because developed and developing countries have different focuses, especially the characteristics of the industry and the impact of its emissions. For example, carbon taxes tend to be regressive in developed economies, impacting lower income households, and trade-offs between efficiency and equity exist when designing carbon tax mechanisms (Wang et al., 2016).

The gross domestic product had no effect on the country's carbon emissions. The relationship between GDP and carbon emissions is a complex and multifaceted issue. Various studies have explored how economic growth impacts environmental sustainability, particularly focusing on CO_2 emissions. Despite the intuitive expectation that higher GDP would lead to increased carbon emissions due to higher industrial activity and energy consumption, some research suggests that GDP may not have a significant effect (or not strong enough to be considered significant) on a country's carbon emissions (Bieth, 2021; Galvan et al., 2022). Empirical studies on the relationship between GDPs per capita and CO_2 emissions at the country level tend to focus on the direct impact of GDP per capita growth, whereas there could be explanatory effects from moderators between the connection of the two variables, such as the presence of political institutions (Lægreid and Povitkina, 2018). GDP per capita CO_2 elasticity becomes non-monotonic and diminishing in countries with democratic, non-corrupt governments and high civil society participation, but the impact is small. The effect of the existence of this moderator explanatory may also occur in this study so it is interesting to explore further in the future. From other studies, higher-income countries' foreign direct investment, GDP, and trade have a stronger positive impact on CO_2 emissions than middle-income countries, and its impact of GDP on CO_2 emissions vary by sector (Galvan et al., 2022). In middle-income countries, the positive impact of GDP on emissions is weaker than in high-income countries. This suggests that economic structure, which is the level of income in each country and dominant sectors play an important role in determining the overall impact of GDP on emissions. There is a need for sustainable and pro-growth policies for middle-income countries. The long-term impact of GDP on carbon emissions is generally more pronounced than the short-term impact (Khan et al., 2020; Rehman et al., 2019), which is why in this finding the result has no effect. This indicates that economic policies and activities take time to realize their impact on emissions.

Natural Resources Based Theory provides a useful framework for understanding how natural resources, particularly renewable energy, can be key in mitigating carbon emissions. This is confirmed by research findings showing that different types of renewable energy contribute to countries' carbon emissions performance, thus these findings justify the theory's argument. Although the presence of carbon tax and economic growth in this empirical context has not shown significant results, the findings are valuable and invite further research opportunities. Normatively, by combining effective carbon tax policies and promoting sustainable economic growth, countries can achieve their emission reduction targets while safeguarding people's welfare.

4. CONCLUSION

The study reveals that renewable energy, particularly wind and solar, significantly influences a nation's carbon emissions in terms of electricity generation and installed capacity. While hydropower's installed capacity impacts emissions, its generation does not. Surprisingly, the presence of a carbon tax and a country's GDP has no effect on emissions levels. Perhaps because there are still so few countries in the world that have implemented this carbon tax policy, some countries are still in transition. These findings emphasize the paramount importance of renewable energy in mitigating carbon emissions. Therefore, every country should prioritize renewable energy adoption as a strategic imperative. The positive and negative implications of these results can guide energy industries and governments in establishing optimal renewable energy limits to ensure their contribution to sustainability. Effective policy measures and international cooperation are needed for mitigating carbon emissions and addressing global warming.

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