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# RÜZGAR ENERJİSİNİN KARBON EMİSYONLARINA ETKİSİ[1][2]

# THE EFFECT OF WIND ENERGY ON CARBON EMISSIONS

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## Öz

Ekonomilerdeki gelişmeler, daha fazla enerji tüketim ihtiyacı doğurmaktadır. Yenilenebilir olmayan enerji kaynakları yüksek miktarda karbon emisyonları üretmektedir. Küresel ısınma kaygıları ile birlikte, sera gazı emisyonlarının azaltılması bir önceliktir. Araştırma sorusu karbon emisyonlarının azaltılmasında rüzgar enerjisinin ne kadar etkin olduğudur. Bu makalede kullanılan değişkenler rüzgar enerjisi üretim kapasitesi, rüzgar enerjisi tüketiminin birincil enerji tüketimine oranı, rüzgar enerjisi üretiminin toplam enerji tüketimine oranı, reel gayri safi milli hasıla ve toplam nüfustur. Sonuçlara göre; rüzgar enerjisi tüketiminin birincil enerji tüketimine oranı karbon emisyonlarını azaltmaktadır. Araştırmadaki 33 ülke karbon emisyonları ortalamanın üzerinde olanlar ve karbon emisyonları ortalamanın altında olanlar olarak ikiye bölünmüştür. Bu etki karbon emisyonları ortalamanın üzerinde olan ülkeler için daha belirgindir. Gayri safi milli hasıla karbon emisyonlarında anlamlı, nüfus ise anlamsızdır. Kısa dönemli sonuçlara göre; rüzgar enerjisi üretim kapasitesi istatistiksel olarak anlamlı değildir. Rüzgar enerjisi üretiminin toplam enerji tüketimine oranı için katsayı tahmini tüm ülkeler için negatiftir ve istatistiksel olarak anlamlıdır. Rüzgar enerjisi tüketiminin birincil enerji tüketimine oranı karbon emisyonlarını azaltmaktadır. Sonuçlar literatürle tutarlıdır. Yenilenebilir enerji üzerine, özellikle rüzgar enerjisi ile ilgili teşviklerin artırılması, çevreye duyarlı ve verimli yatırımlar için faydalı olacaktır.

**Anahtar Kelimeler:** Enerji Politikası, Panel Veri, Karbon Emisyonları

**JEL Kodları:** C33, O13, Q42

## Abstract

The advances in economies require the need to consume more energy. Non-renewable energy resources produce high amount of carbon emissions. With global warning concerns, reducing greenhouse gas emissions is priority. The research question is how effective wind energy is for reducing carbon emissions. This study includes a panel data analysis to test the effect of wind energy on carbon emissions. The variables used in this article are installed capacity of wind energy production, the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption, real GDP and total population. According to the results, the increase in the ratio of wind energy consumption to primary energy consumption reduces carbon emissions. There are 33 countries available in this research which are divided into two categories; countries with higher than average and countries with lower than average. The effect is more significant for countries with higher than average carbon emissions. GDP is significant for carbon emissions, but population is not significant according to the results. According to short run results, installed capacity of wind energy production is not statistically significant. Coefficient estimation for the ratio of wind energy production to total electricity consumption is negative and statistically significant for all countries. The ratio of wind energy consumption to primary energy consumption reduces carbon emissions. The results are consistent with the literature. More incentives for renewable energy and wind energy in particular, would be beneficial for environmentally and economically sound investments.

**Keywords:** Energy Policy, Panel Data, Carbon Emissions.

**JEL Classification:** C33, O13, Q42.

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# 1. Introduction

As countries develop economically and population increase, more energy should be provided. In liberal economies, this requires an investment by private industry most of the time accompanied by some form of government support. The investments in energy industry and advances in economy often lead to increase in emissions.

Renewable energy is used to deal with this problem. According to Panwar et al. (2011) renewable energy is considered a clean alternative way to produce energy that generates minimum number of wastes. Most used types are solar, wind, geothermal, hydropower, wave and biomass. Renewable energy is considered sustainable economically and socially.

Solar energy is the root of all the energies. As Guney (2021) points out, it is a free source of energy which is technically enough to meet all the energy needs of the world on its own. With the advancement of technology, the investments are expected to increase which is crucial to sustainable development.

Wind energy is a major renewable energy source when there are efficient fields. An important point discussed by Saidur et al. (2011) is that it requires less financial investment compared to other types of renewable energy. With the use of wind energy, investment required for energy industry is provided where the emissions can be reduced. It has minimum environmental damage, contamination, and water consumption. The side effects such as birds and noise can be controlled with efficient design of the turbines.

There is still room for improvement to reduce carbon emissions in wind energy. As Mello et al. (2020) point out, obtaining raw materials, manufacturing and logistics are some points to consider. The design of turbines, building techniques and materials can be improved for a more environmentally friendly electricity production. Decommissioning, and recycling of materials are also phases that can be enhanced for better efficiency.

Increase in the concerns of global warming and population require the need to use alternative energy sources. As explaimed by Guney and Ustundag(2021) globalization and rapid development increase carbon emissions. Wind energy is one of the most efficient renewable energy source for the environment and the economy. It reduces pollution and emissions. The demand for wind energy is expected to increase in the future. Governments and policymakers should enforce policies that promote the use of wind energy. Effort in the research and application of wind energy in a greater scale by promoting strategic industries would lead to more efficient use of wind energy.

Due to global warming, there are increasing number of incentives on renewable energy sources. These include global solutions as well as incentives introduced by countries. Developing countries and countries with higher emissions are more inclined to increase renewable energy investments. Kaplan Donmez (2023) shows that interventions to Turkish renewable energy market are capital subsidies, public investments, favorable loans, purchase guarantees, tax incentives in investment and operations, and emission reduction-based incentives.

Panel data analysis with countries with higher carbon emissions than world average and countries with lower carbon emissions than world average are given in this research. The data include wind energy, emissions, GDP and population.

The remainder of this study is organized as follows. Section 2 is a review of the works in the field of emissions and wind energy. Introduction of the data and research methodology is given in Section 3. Section 4 includes research findings and a discussion on the results. Final remarks and policy suggestions are available in Section 5.

# 2. Literature Review

There are many empirical studies on carbon emissions and wind energy. To reduce negative effects of carbon dioxide ($CO_2$) emissions, energy may be obtained with renewable energy. Zoundi (2017) suggests the use of renewable energy as a way of reducing the negative effects on nature. Zoundi found negative relationship between increase in renewable energy production and carbon dioxide emissions.

There are some similar studies in the same region as Turkey where the research of this study is made. Al-Mamory (2017) made a feasibility study for wind energy plant with 75 mwh capacity in Iraq. According to the results there is negative correlation between electricity production from wind energy and amount of harmful gas.

Akpan& Akpan (2012) explain that greenhouse gases released by economic activities trap the solar energy which warms the atmosphere. Fossil fuels are responsible for 80% of climate change. Most of the fossil fuel consumption is due to the use of coal by large economies. There are also studies made in Turkey. Karatas (2020) worked with several scenarios in Eskisehir, Turkey. In a scenario with 40 mwh wind energy site, 37.192 tons of greenhouse gas emission reduction is obtained.

The study by Anser et al. (2019) shows that fossil fuels and industrial growth lead to carbon emissions in Latin America. Moreover, advanced technology based industrial products create less carbon emissions. Therefore, sustainable economic development in the region can be achieved by renewable energy and advanced technologies.

For energy industry, clean technologies include renewable energy supply and energy efficiency as stated by Abolhosseini et al. (2014). The transformation to modern technologies requires technological change and investment. Lower cost of fossil fuel based investments hinder the development of the renewable energy.

Several factors such as population, technology and globalization lead to a rise in energy demand as explained by Dllanchlev(2023). Developing economies need to consider switching to renewable energy due to life quality and environmental concerns. The findings show that renewable production is linked to urbanization, greenhouse emissions and economic growth in the long run.

The benefits of renewable energy are quantified in many studies. Mathew (2006) compares renewable energy with coal. Accordingly, 1 mwh of energy provides 2.1 kg nitrogen and 0.6 kg sodium reduction. Hamamcıoğlu (2010) studies wind power plant in Denmark with 600 kwh installed capacity. Accordingly, 0.03592 SO2, 0.04760 NOx and 13.22731 $CO_2$ reductions are obtained.

There are some studies which emphasize environmental aspects of renewable energy. Ates (2007) points out that each 1 kW energy production by fossil sources creates 0,7 kg of carbon dioxide emissions. A coal power plant of 600 kW capacity creates 1.200 tons of $CO_2$ annually. This kind of greenhouse gas emissions which pollute atmosphere and increase the temperature don't occur in wind energy power plants.

It is possible to consume all of the energy from renewable sources in some regions. Kursun et al. (2019) made a study in Kesan district of Edirne, Turkey. Accordingly, a wind power plant with 19 mwh capacity is sufficient for the district by 2018. According to the projections, 165 mwh capacity will be needed by 2050. This transformation would reduce $CO_2$ emissions by 97.96%.

There are additional benefits of wind energy investments. Parlak (2012) made a feasibility study for renewable energy. Accordingly, each wind energy power plant of 1 mwh capacity, avoids 1.415 tons of CO2 emissions annually and reduces 3.291 tons of oil equivalent.

There are some studies that link economic growth with carbon emissions. A study made in Azeerbaijan by Mukhtarov (2023) indicates that 1% change in GDP increases carbon emissions by 0,46%. On the other hand,1% increase in renewable energy decreases $CO_2$ emissions by 0,26%.

## 3. Data and Methodology

This article includes an empirical study to test the relationship between wind energy and carbon emissions. The variables used in this article are installed capacity of wind energy production, the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption. Real GDP and total population are control variables used in the study. The goal of the research is to investigate whether wind energy contributes to carbon emission reduction. The research period of the research is 2000-2021. Eviews 12 and Stata 16 softwares are used in the research. Information on the data used in the study is given in Table 1.

**Table 1.** Variables

| Abbreviation | Description | Sources |
|---|---|---|
| $NCO_2$ | Natural Logarithm of Carbon Emissions | BP Stats |
| NWC | Natural Logarithm of Wind Capacity | BP Stats |
| WC/PEC | Wind Consumption/Primary Energy Consumption | BP Stats |
| WP/TEC | Wind Production/Total Electricity Consumption | BP Stats |
| LGDP | Natural Logarithm of Real GDP | World Bank |
| LP | Natural Logarithm of Population | World Bank |

As carbon emissions are considered globally, the countries with above mentioned variables are selected for the research. 33 countries with available data are determined and listed in Table 2. These countries are analyzed in two different groups. These groups are countries above and below world average of carbon emissions. Because the tendency of the countries to invest in wind energy may differ based on current carbon emissions. Countries with high carbon emissions also need high renewable energy investment.

**Table 2:** List of Countries included in the research

| Countries with higher carbon emissions than world average | Countries with lower carbon emissions than world average |
|---|---|
| Canada | Portugal |
| Mexica | Spain |
| USA | Sweden |
| Argentine | Turkey |
| Brazil | Ukraine |
| Austria | UK |
| Belgium | Russia |
| Denmark | Iran |
| Finland | Egypt |
| France | Morocco |
| Germany | Australia |
| Greece | China |
| Ireland | India |
| Italy | Japan |
| Netherlands | New Zealand |
| Norway | North Korea |
| Poland | |

**Source:** BP Statistical Review of World Energy July 2021

The variables were first checked for cross sectional dependence. The results are given in Table 3. Accordingly, cross sectional dependence is detected for all of the variables.

**Table 3:** Tests for Cross Sectional Dependence

| Variable | | Test | | | |
|---|---|---|---|---|---|
| | | Breusch-Pagan LM | Pesaran Scaled LM | Bias-Corrected Scaled LM | Pesaran CD |
| NCO2 | Stat | 5858.827 | 158.162 | 157.352 | 16.510 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |
| NWC | Stat | 10598.210 | 299.652 | 298.842 | 102.442 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |
| WC/PEC | Stat | 9900.365 | 278.818 | 278.009 | 98.830 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |
| WP/TEC | Stat | 9872.139 | 277.975 | 277.166 | 98.666 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |
| LGDP | Stat | 8445.760 | 243.652 | 242.867 | 80.943 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |
| LP | Stat | 8468.180 | 244.342 | 243.556 | 46.131 |
| | Prob | 0.000 | 0.000 | 0.000 | 0.000 |

Since the variables have cross sectional dependence, second generation unit root tests should be used. The unit root test suggested by Pesaran (2007) is applied. The level of stationarity of variables under cross sectional dependence is determined with this test. The results are given in Table 4. Like Augmented Dickey Fuller, critical values are variable for models with constant, constant and trend and without constant and trend. Based on graphical analysis, models with constant and constant and trend are considered. The results reveal that all the variables are stationary at first difference.

**Table 4**: Tests for Stationarity of Variables

| Variable | Test Stat | 5% Critical Value |
|---|---|---|
| $NCO_2$ | -1.325 | -2.110 |
| Δ $NCO_2$ | -4.771 | -2.110 |
| NWC | -2.595 | -2.610 |
| Δ NWC | -4.073 | -2.110 |
| WC/PEC | -1.578 | -2.610 |
| Δ WC/PEC | -3.395 | -2.110 |
| WP/TEC | -2.057 | -2.610 |
| Δ WP/TEC | -3.268 | -2.110 |
| LGDP | -1.905 | -2.610 |
| Δ LGDP | -3.090 | -2.110 |
| LP | -1.748 | -2.610 |
| Δ LP | -2.340 | -2.110 |

3 main variables and 2 control variables are selected as determinants of carbon emissions. The correlation matrix of these variables is given in Table 5. The correlations between carbon emissions and main variables are low. However, there are high correlations between carbon emissions and control variables. Another high correlation to be noted is between the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption. If these variables are used in the same model, coefficients with high standard errors could be obtained. This would decrease the power of variables. (Gujarati and Porter, 2009: 323) In this study, two separate models are used to avoid multicollinearity problem.

**Table 5**: Correlation Matrix for Variables

| | NCO2 | NWC | WC/PEC | WP/TEC | LGDP | LP |
|---|---|---|---|---|---|---|
| $NCO_2$ | 1.0000 | | | | | |
| NWC | -0.2611 | 1.0000 | | | | |
| WC/PEC | -0.3402 | 0.4605 | 1.0000 | | | |
| WP/TEC | -0.3215 | 0.4523 | 0.9884 | 1.0000 | | |
| LGDP | 0.8348 | 0.5095 | -0.1043 | -0.0997 | 1.0000 | |
| LP | 0.8938 | 0.2176 | -0.3104 | -0.2985 | 0.6783 | 1.0000 |

## 4. Results and Discussion

The theoretical models to test the research problem is given below. The difference between Equation 1 and Equation 2 is that the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption are available in different models. The other variables are the same for both models. The coefficients for the variables installed capacity of wind energy production, the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption are expected to be negative. Whereas the coefficients for the variables real GDP and total population are expected to be positive. As installed capacity of wind energy production, the ratio of wind energy consumption to primary energy consumption, and the ratio of wind energy production to total electricity consumption increase, carbon emissions are expected to decline. But increase in the real GDP and total population are expected to lead to an increase in carbon emissions. The correlation results given in Table 5 also support this hypothesis.

Models:

$\mathrm{NCO2}_{it} = \alpha_i + \beta_1 NWC_{it} + \beta_2 \mathrm{WC/PEC}_{it} + \mathrm{LGD}P_{it} + LP_{it} + \varepsilon_{it}$ Equation (1)

$\mathrm{NCO2}_{it} = \alpha_i + \beta_1 NWC_{it} + \beta_2 \mathrm{WP/TEC}_{it} + \mathrm{LGD}P_{it} + LP_{it} + \varepsilon_{it}$ Equation (2)

Pesaran and Yamagata (2008) test is used to determine whether the slope parameters of Equation 1 and 2 are homogenous. As indicated in Table 6, both Δ and $\tilde{\Delta}_{\hat{a}dj}$ test stats show that slope parameters for Equation 1 and 2 are not homogenous.

**Table 6**: Slope Parameters Homogeneity Test Results

| Test Stat | Equation 1 | Equation 2 |
|---|---|---|
| Δ | 24.475 (0.000)* | 24.623 (0.000) |
| $\tilde{\Delta}_{\hat{a}dj}$ | 28.700 (0.000) | 28.873 (0.000) |

*Prob results are given in parenthesis.

According to Table 4, the variables are stationary at first difference. Therefore, they are first order integrated. The variables are tested to see if they are cointegrated. In panel cointegration analysis, cross sectional dependence and homogeneity of slope parameters are considered. Westerlund (2007) is applied which assumes cross sectional dependence and heterogeneity of slope parameters. The results are given in Table 7. Accordingly, the null hypothesis of no cointegration between variables is rejected at 0.01 significance. In other words, variables are cointegrated in long run.

**Table 7**: Cointegration Test Results

| Model | Test Stat | Prob. |
|---|---|---|
| Equation 1 | -3.611 | 0.000 |
| Equation 2 | -3.568 | 0.000 |

The long term coefficients for Equation 1 and 2 were estimated by adjusted mean group estimator developed by Eberhardt and Teal (2010), Bond and Eberhardt (2013). Three different models are developed for countries with all countries, countries with higher than average carbon emissions, and countries with lower than average carbon emissions for long run estimations. Because countries with lower than average carbon emissions may not invest as much as countries with higher than average carbon emissions due to high cost and lower need.

According to results given in Table 8, only the ratio of wind energy consumption to primary energy consumption, and real GDP are statistically significant in Equation 1 estimations for all countries, countries with higher than average carbon emissions, and countries with lower than average carbon emissions. Installed capacity of wind energy production is not statistically significant in carbon emissions. The ratio of wind energy consumption to primary energy consumption coefficient estimate is 1.835 for all countries, 1.259 for countries with lower than average carbon emissions, and -3.168 for countries with higher than average carbon emissions. This result shows that increase in the ratio of wind energy consumption to primary energy consumption reduces carbon emissions. Interestingly, carbon emissions reduce more for countries with higher than average carbon emissions compared to other models. This shows the importance of carbon emissions and wind energy which is one of the renewable energy sources for these countries. Coefficient estimation for population is statistically insignificant whereas other control variable GDP is statistically significant for all models. Increase in GDP causes more increase in carbon emissions for countries with higher than average carbon emissions.

The other results in Table 8 are the estimation results for Equation 2. Accordingly, the ratio of wind energy production to total electricity consumption is significant for all countries but insignificant for countries with higher than average carbon emissions, and countries with lower than average carbon emissions. The ratio of wind energy production to total electricity consumption reduces carbon emissions for all countries but it is insignificant for countries with higher than average carbon emissions, and countries with lower than average carbon emissions. Similar to Equation 1, coefficient estimation for population is statistically insignificant whereas other control variable GDP is statistically significant for all models. Installed capacity of wind energy production is not statistically significant in carbon emissions.

**Table 8:** Long Run Coefficient Estimations

| Variables | Model 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Full sample | | | Lower than average | | | More than average | | |
| | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob |
| $NCO_2 = f$(NWC, WC/PEC, LGDP, LP) | | | | | | | | | |
| NWC | 0.007 | 0.82 | 0.412 | 0.005 | 0.43 | 0.668 | 0.011 | 0.93 | 0.354 |
| WC/PEC | **-1.835** | -3.32 | 0.001 | **-1.259** | -2.04 | 0.041 | **-3.168** | -2.26 | 0.024 |
| LGDP | **0.651** | 8.66 | 0.000 | **0.498** | 4.75 | 0.000 | **0.876** | 7.69 | 0.000 |
| LP | 0.285 | 0.45 | 0.656 | 0.258 | 0.35 | 0.729 | 1.010 | 0.99 | 0.322 |
| C | -21.032 | -2.09 | 0.036 | -19.140 | -2.15 | 0.032 | -39.815 | -2.17 | 0.030 |
| | Model 2 | | | | | | | | |
| | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob |
| $NCO_2 = f$(NWC, WP/TEC, LGDP, LP) | | | | | | | | | |
| NWC | 0.009 | 1.03 | 0.302 | 0.008 | 0.62 | 0.537 | 0.011 | 1.10 | 0.272 |
| WP/TEC | **-0.406** | -1.69 | 0.092 | -0.219 | -0.91 | 0.365 | -1.016 | -1.32 | 0.186 |
| LGDP | **0.672** | 8.22 | 0.000 | **0.515** | 4.18 | 0.000 | **0.896** | 8.20 | 0.000 |
| LP | 0.352 | 0.53 | 0.595 | 0.489 | 0.64 | 0.522 | 0.925 | 0.88 | 0.377 |
| C | **-23.415** | -2.23 | 0.026 | **-20.700** | -2.09 | 0.037 | **-38.793** | -2.07 | 0.039 |

The short run coefficient estimations are given in Table 9. Short run estimations are estimated with first differences where the variables are stationary.  Hausmann test reveals that random effect model is suitable for all of the models. Considering violation of assumptions, coefficients are estimated with Driscoll-Kraay robust estimator.

According to short run results for Equation 1, installed capacity of wind energy production is not statistically significant in carbon emissions for all models. Coefficient estimation for the ratio of wind energy production to total electricity consumption is negative and statistically significant for all countries. This result shows that increase in the ratio of wind energy production to total electricity consumption reduces carbon emission in the short run. This is the most influential factor among the variables according to results. Real GDP is significant for all models. Real GDP causes more carbon emissions for countries with higher than average carbon emissions. Population is insignificant for carbon emissions for countries with higher than average carbon emissions but significant for all countries and countries with lower than average carbon emissions. Population is the most important factor for countries with lower than average carbon emissions.

The short run results for Equation 2 is similar to Equation 1 estimations. Installed capacity of wind energy production is not statistically significant in carbon emissions for all models as in Equation 1. The ratio of wind energy production to total electricity consumption is negative and statistically significant. The effect is most influential for countries with higher than average carbon emissions. Population is more influential than real GDP in carbon emissions. It is only insignificant for countries with higher than average carbon emissions. Real GDP increases carbon emission for all models. It is more influential for countries with higher than average carbon emissions.

**Table 9:** Short Run Coefficient Estimations

| Variables | Model 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Full Sample | | | Lower than average | | | More than average | | |
| | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob |
| $NCO_2 = f$(NWC, WC/PEC, LGDP, LP) | | | | | | | | | |
| NWC | 0.0012 | 0.23 | 0.821 | 0.0003 | 0.05 | 0.964 | 0.0014 | 0.26 | 0.796 |
| WC/PEC | **-3.3564** | -9.63 | 0.000 | **-3.3163** | -10.57 | 0.000 | **-3.3036** | -4.14 | 0.001 |
| LGDP | **0.8067** | 8.26 | 0.000 | **0.7100** | 8.12 | 0.000 | **0.9702** | 6.81 | 0.000 |
| LP | **0.8557** | 2.77 | 0.012 | **1.0204** | 3.38 | 0.003 | 0.6403 | 1.35 | 0.193 |
| C | **-0.0166** | -3.13 | 0.005 | **-0.0168** | -2.86 | 0.010 | **-0.0179** | -3.20 | 0.004 |
| | Model 2 | | | | | | | | |
| | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob | Coefficient | t-Stat | Prob |
| $NCO_2 = f$(NWC, WP/TEC, LGDP, LP) | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NWC | 0.0016 | 0.30 | 0.764 | 0.0005 | 0.07 | 0.946 | 0.0017 | 0.30 | 0.766 |
| WP/TEC | **-1.1635** | -6.79 | 0.000 | **-1.1055** | -6.71 | 0.000 | **-1.3485** | -4.28 | 0.000 |
| LGDP | **0.8495** | 7.18 | 0.000 | **0.7592** | 6.99 | 0.000 | **0.9961** | 6.61 | 0.000 |
| LP | **0.8619** | 2.88 | 0.009 | **1.0013** | 3.32 | 0.003 | 0.6755 | 1.42 | 0.171 |
| C | **-0.0200** | -3.22 | 0.004 | **-0.0211** | -2.95 | 0.008 | **-0.0193** | -3.39 | 0.003 |

The ratio of wind energy consumption to primary energy consumption reduces carbon emissions both in short run and long run. The ratio of wind energy production to total electricity consumption reduces carbon emissions in long run and is significant only for countries with higher than average carbon emissions and countries with lower than average carbon emissions. Population affects carbon emissions in short run only. Real GDP affects carbon emissions mostly in long run.

## 5. Conclusion

Due to global warming and environmental concerns countries and firms work on reducing greenhouse gas emissions. Renewable energy production is a major improvement in achieving this goal. The study includes a panel data analysis to test the effectiveness of renewable energy – wind energy in particular to reduce carbon emissions.

3 main and 2 control variables are selected for econometric analysis. Correlation matrix for the variables (Table 5) show weak correlation between the main variables and strong correlation for control variables.

Long term coefficient results (Table 8) indicate that full sample, above and below average countries, only the ratio of wind energy consumption to primary energy consumption, and real GDP is statistically significant. Installed wind energy capacity is not statistically significant.

Short term coefficient results are given in Table 9. Accordingly, wind energy production is not significant but the ratio of wind energy production to total electricity consumption is significant. The coefficients are negative. So, the ratio of wind energy production to total electricity consumption contribute to carbon emission reduction according to the results.

Control variable GDP is statistically significant for all cases and leads to higher carbon emissions. Population is not significant for above average countries and significant for other cases. There are other works in the literature that link GDP with emissions. Economic growth often comes with its side effects. Even renewable energy creates some emissions within its cycle. However fossil fuels do much greater damage. Therefore, promotion of renewable energy is critical.

Renewable energy also helps to achieve security of energy supply. If an economy relies on import fuels for development, it is open to energy crisis or economic problems. Renewable energy requires minimum energy input and is therefore a strategic investment.

The research results show that the ratio of wind energy consumption to primary energy consumption reduces carbon emissions. The result is consistent with the literature. The result is especially critical for developing economies. Renewable energy investments often require higher investments. In developing countries, it is not easy to access the funds required for these investments. Wind energy due to its wide application, comparatively less costly. Therefore it is more likely to be applied by emerging economies.

Renewable energy consists of investments such as solar, wind, hydropower, and biomass. According to the findings, more incentives for renewable energy and wind energy in particular, would be beneficial for environmentally and economically sound investments. Possible ways to promote renewable energy are government grants, capital subsidies, public private partnerships, favorable loans, purchase agreements, and tax incentives.

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