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Content

Analysis of the relationship between selected renewable energy and non-renewable resources

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Abstract

The aim of this paper is to determine the dependence between the installed capacity of wind power plants and annual CO2 production, as well as between coal energy use and CO2 production. Pearson and Spearman correlation methods are used for the analysis based on the normality of data, which was tested using the Shapiro-Wilk test of normality. The results show a negative correlation between the capacity of wind power plants and CO2 production in Belarus, Russia, and Norway, while in Spain and Germany, the correlation is positive. Furthermore, a positive correlation between coal energy use and CO2 production is found in the Czech Republic, Poland, Austria, Portugal, Italy, Greece, and Denmark, which aligns with expectations. Conversely, a negative correlation is found in Ireland and Lithuania, which may indicate more efficient energy use. Limitations are identified in the form of different correlation tests, which may partially distort the results. This work contributes to research in the field of energy and can be useful for the development of political and energy plans.

Keywords: Wind energy, angular energy, renewable energy, non-renewable energy, CO2

Introduction

Coal-fired power plants emit hazardous substances and heavy metals into the air. For example, in Chinese coal-fired power plants, values of heavy metals such as arsenic, copper, lead, zinc and others have been measured, where the soil around the power plants is moderately to heavily polluted with heavy metals (Hu et al, 2021), which have a very negative impact on the environment, especially if water supplies are contaminated with heavy metals. At that point, the water becomes undrinkable for humans and its long-term consumption has many negative side effects. Such as liver failure, kidney damage, stomach and skin cancer, mental problems and negative effects on the reproductive system. As for the impact on the environment, here we can talk about changes in geological and geochemical processes and the hydrological properties of streams will also change. Heavy metals can be extracted from water streams in several ways, but these processes tend to be expensive and cause secondary pollution (Zhang et al., 2023). Of course, soil and water pollution are not the only problems related to coal-fired power plants, another one is air pollution, which according to research (Zhang et al., 2022) has an impact on neurobehavioral disorders in children living in places where the air is polluted by coal-fired power plants. The overall issue of coal-fired power plants, as a representative of a non-renewable energy source, is complex, as as such they emit many harmful substances into the environment, which negatively affect both residents in the vicinity of the power plants, and nature and the environment itself.

The need to address this issue becomes more urgent after discovering that only 13.9% of energy comes from renewable sources and the very basis of the global energy system currently consists of 81% coming from power plants that use solid fuels as fuel, which, as already mentioned, have a very negative impact on both residents in the vicinity of the power plant and the environment itself. Of this 81%, 31.5% are oil-fired power plants, 22.8% are natural gas-fired power plants and 26.8% are the aforementioned coal-fired power plants. The remaining 4.9% of energy comes from nuclear power plants.

Otherwise, there are representatives of renewable energy sources, such as wind, photovoltaic, hydro, biogas power plants, where their integration into various sectors such as agriculture would enable their sustainable energy operation and at the same time reduce energy costs for farmers (Majeed et al., 2023). In relation to the economic indicator of unemployment, the transition to so-called green energy would have a small positive impact (Swain et al, 2022). Of course, renewable sources also have a certain negative impact on the environment. In the case of wind and photovoltaic power plants, there is a problem of their spatial requirements. This problem is partially solved by placing wind power plants on the water surface, and photovoltaic power plants often use the multifunctionality of the land, so the land can serve as a source of electricity or as pasture for livestock. These and similar ideas may reduce the issue of spatial requirements in the future, but this leads me to the topic of other ecological phenomena caused by renewable energy sources. For example, according to a study (Maclaurin et al. 2022), hundreds of thousands of bats die annually in North America due to the operation of wind farms. Despite all the above facts, it should be noted that renewable energy sources will eventually run out, i.e. they will run out. And this leads us to the conclusion that it is necessary to develop the use of renewable energy sources, which is also increasingly important for securing the energy future.

The aim of the work is to determine the dependence between the level of carbon dioxide emissions and the capacity of installed wind energy. As a selected type of renewable energy in the countries of the European Union for the period 2010-2022 and to determine the dependence between the use of coal energy and the level of CO_2 for the period 2008-2022. To meet the set goal, two research questions were set:

VO1: Is there a relationship between CO2 levels and wind energy use in the EU between 2010 and 2022?

VO2: Is there a relationship between CO2 levels and energy use from wind energy in the EU between 2008 and 2022?

Methods and Data

Data

The investigation of the first research question (RO1) will be based on data obtained from the global Our database World in Data. Specifically, data on the installed capacity of wind farms will be drawn from (Installed wind energy capacity) and annual CO2 emissions (Annual CO2 emissions) from the Our database World in Data. The countries selected for the analysis include Germany, Spain, Russia, Belarus and Norway. These countries were chosen due to their different locations, renewable energy positions and economic sizes. The analysis will be conducted over the period 2010 to 2022.

For the second research question (VO2), data from the global Our database will also be used. World in Data. From articles on the Energy Mix, from which coal consumption data will be obtained. We will extract annual CO2 emissions data from (Annual CO2 emissions) for countries such as Poland, Austria, Czech Republic, Denmark, Greece, Italy, Lithuania, Portugal and Ireland. Coal energy consumption data will be converted into percentage equivalents within the total coal consumption in Europe, while data on tonnes of CO2 emissions will be converted into percentage equivalents within the total CO2 emissions production in Europe. Such an approach will allow comparing the contribution of individual countries to total coal consumption and CO2 emissions in Europe.

Methods

For the first research question, content analysis will be used. Next, correlation analysis will be used, where we first convert the data obtained from ta Mw into their percentage equivalents from installed wind energy sources and total global CO2 production. Subsequently, we transfer these data to the analytical program RStudio, where, through the packages, ggplot2, tidyr and dplyr Hmisc and corrplot will create visualizations of correlation coefficients between the mentioned data.

First, you will need to import the extracted data from the Our database. Wordl in Data and convert it to data frame.

Figure 1: How to transfer data to RStudio

```
Mydata2 <- data.frame(
  Belarus_CO2 = c(0.00188, 0.00179, 0.0018, 0.00183, 0.0018, 0.00166, 0.00165, 0.00167, 0.0017, 0.00168, 0.00171, 0.00166, 0.00159),
  Belarus_wind = c(0, 0, 0, 0, 0, 0, 0.0001, 0.0002, 0.0002, 0.0002, 0.0002, 0.0001, 0.0001),
  Russia_CO2 = c(0.05, 0.0489, 0.0491, 0.0467, 0.0463, 0.0465, 0.0459, 0.0461, 0.0464, 0.0463, 0.047, 0.0469, 0.0447),
  Russia_wind = c(0, 0, 0, 0, 0, 0, 0, 0, 0.0001, 0.0002, 0.0013, 0.0024, 0.0025),
  Norway_CO2 = c(0.00146, 0.00128, 0.00126, 0.00127, 0.00127, 0.00128, 0.00126, 0.00124, 0.00123, 0.00116, 0.00111, 0.0011, 0.0011),
  Norway_wind = c(0, 0, 0, 0, 0, 0, 0, 0.0002, 0.0003, 0.0005, 0.0055, 0.0061, 0.0057),
  Spain_CO2 = c(0.00081, 0.00081, 0.00079, 0.00071, 0.00072, 0.00076, 0.00074, 0.00076, 0.00073, 0.00068, 0.00061, 0.00063, 0.00065),
  Spain_wind = c(0.1142, 0.0978, 0.1067, 0.0765, 0.0655, 0.0551, 0.0489, 0.0449, 0.0415, 0.0412, 0.0367, 0.0338, 0.0326),
  Germany_CO2 = c(0.02246, 0.0218, 0.02206, 0.02238, 0.0224, 0.0225, 0.02264, 0.02165, 0.01995, 0.01913, 0.01746, 0.01832, 0.01794),
  Germany_wind = c(0.1485, 0.1303, 0.1154, 0.1115, 0.1106, 0.107, 0.1059, 0.1082, 0.1039, 0.0979, 0.085, 0.0774, 0.0738)
```

Source: Developed by the author in RStudio.

In the second step, a test of data normality will be performed using the Shapiro normality test and we will specify the correlation methods for normality and non-normality, where for normality we will use Spearman correlation analysis and for non-normality we will use Pearson

Figure 2: Shapiro's normality test

```
check_normality <- function(co2_data, wind_data, country) {
  co2_test <- shapiro.test(co2_data)
  wind_test <- shapiro.test(wind_data)
  cat("Country:", country, "\n")
  cat("Shapiro-Wilk Test for CO2: W =", co2_test$statistic, "p-value =", co2_test$p.value, "\n")
  cat("Shapiro-Wilk Test for Wind: W =", wind_test$statistic, "p-value =", wind_test$p.value, "\n\n")

  use_spearman <- (co2_test$p.value < 0.05 | wind_test$p.value < 0.05)
  correlation_method <- if (use_spearman) "spearman" else "pearson"

  return(correlation_method)
```

Source: Developed by the author in RStudio.

We then define the names of the countries under study.

Figure 3: Definition of the name of the monitored countries

```
countries <- c("Belarus", "Russia", "Norway", "Spain", "Germany")
```

Source: Developed by the author in RStudio.

In the penultimate step, we define the items for the correlation and run it using the cor command. We then use the print command to generate the correlation coefficients and the methods that were used.

Figure 4: Method of performing correlation analysis

```
for (country in countries) {
  co2_data <- Mydata2[[paste0(country, "_CO2")]]
  wind_data <- Mydata2[[paste0(country, "_wind")]]
  method <- check_normality(co2_data, wind_data, country)
  correlation_value <- cor(co2_data, wind_data, method = method)

  correlations[correlations$Country == country, "Correlation"] <- correlation_value
  correlations[correlations$Country == country, "Method"] <- method
}

print(correlations)
```

Source: Developed by the author in RStudio.

When generating correlation coefficients using the print command, it is evident that Spearman's correlation analysis was used for all countries, which indicates the normality of the data for all countries.

Figure 5: Generated pie analyses with correlation methods for VO1

```
> print(correlations)
  Country Correlation   Method
1 Belarus  -0.4812201 spearman
2  Russia  -0.2179980 spearman
3  Norway  -0.9219593 spearman
4   Spain   0.8209398 spearman
5 Germany   0.6593407 spearman
```

Source: Developed by the author in RStudio based on data from OWD 2024.

In the last step, we use the corrplot command to create a visualization of the correlation coefficients for the monitored countries (see Results).

Figure 7: Method for creating a correlation visualization using the corrplot command

```
cor_matrix <- matrix(correlations$Correlation, nrow = 1, ncol = length(countries))
colnames(cor_matrix) <- paste0(countries, "_CO2")
rownames(cor_matrix) <- "Correlation_with_Wind"
# Vizualizace korelační matice
corrplot(cor_matrix, method = "color", addCoef.col = "black", tl.col = "black", tl.srt = 45,
         title = "Correlation between CO2 and Wind for each Country", mar = c(0,0,2,0))
```

Source: Created by the author in RStudio.

For the second research question, we will also use content analysis and transfer the edited data to the analytical program RStudio, where we will perform a correlation analysis in the same way as for the first research question and subsequently generate a visualization of the correlation coefficients.

The only difference between the methods in the first and second research questions is the correlation methods used, as in the first VO all data were normal, so we used only Spearman's correlation analysis, but in the second research question the data were both normal and non-normal, so we used both Spearman's and Pearson's correlation analysis.

Figure 8: Generated pie analyses with correlation methods for VO2

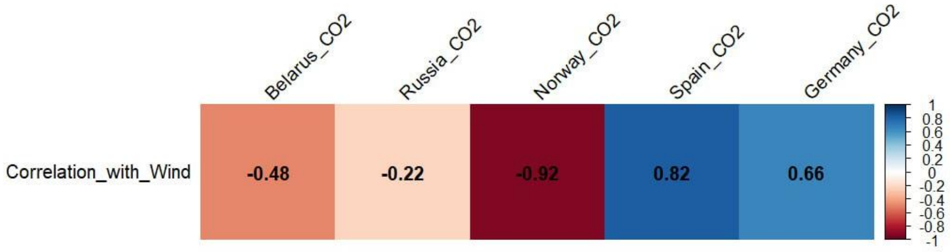
```
     Country Correlation   Method
1    Czechia   0.2358572  pearson
2     Poland   0.9107534  pearson
3    Hungary   0.4005402 spearman
4    Ireland  -0.1784496  pearson
5   Portugal   0.7559871  pearson
6 Lithuania  -0.2056883 spearman
7      Italy   0.6079961  pearson
8     Greece   0.2923768 spearman
9    Denmark   0.9908565  pearson
```

Source: Developed by the author in RStudio based on data from OWD 2024.

Results

Based on the research questions, a visualization of correlation coefficients is created in the analytical program RStudio. The first visualization includes data on the percentage of installed wind energy capacity in given countries from all over the world and the percentage of CO2 production in these countries. We have chosen Belarus, Russia, Norway, Spain and Germany as the selected countries in the years 2010 to 2022.

Figure 9: Visualization of correlation coefficients for VO1

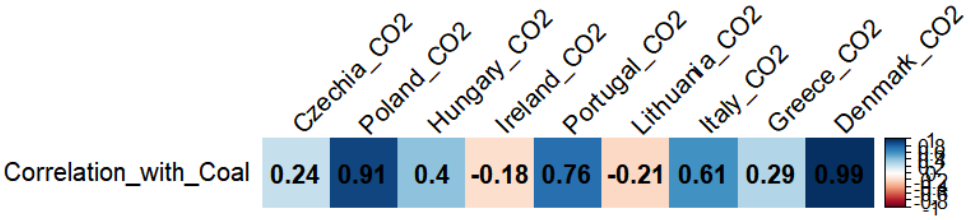


Source: Developed by the author in RStudio based on data from OWD 2024.

These results show the correlations between CO2 emissions and wind energy use in different countries. Norway has the highest negative correlation (-0.92), followed by Belarus (-0.48) and Russia (-0.22). On the other hand, Spain (0.82) and Germany (0.66) have high positive correlations. These data show how wind energy use affects CO2 emissions in different countries.

The second visualization of correlation coefficients worked from data regarding the percentage of angular energy use in given countries out of the total angular energy use in Europe and the percentage of CO2 emissions production in given countries out of the total CO2 emissions production in Europe in the years 2008 to 2022.

Figure 10: Visualization of correlation coefficients in VO2



Source: Developed by the author in RStudio based on data from OWD 2024.

These results show the correlations between CO2 emissions and coal consumption in different European countries. The highest positive correlations are found in Poland (0.91) and Denmark (0.99), indicating a strong dependence of CO2 emissions on coal. The negative correlations are found in Ireland (-0.18) and Portugal (-0.21), indicating that CO2 emissions in these countries are not so dependent on coal. The other countries have the following correlations: Czech Republic (0.24), Hungary (0.4), Lithuania (0.61), Italy (0.29) and Greece (0.61), indicating a slight to moderate dependence between CO2 emissions and coal consumption.

Discussion

VO1: There is a relationship between CO2 levels and wind energy use in the EU between 2010 and until 2022?

The correlation analysis between CO2 emissions and installed wind power capacity for individual countries brings interesting results. For Belarus, Russia and Norway, all negative correlation strengths were measured (Belarus -0.481, Russia, -0.218, Norway -0.922), where in Russia the influence of wind power capacity on CO2 production is very weak. In Belarus, this influence is slightly stronger, but still not very strong. While in Norway we can observe a very strong influence of wind power capacity and CO2 production. On the other hand, in Spain and Germany we can observe a positive correlation (Spain 0.821, Germany 0.659), where in Spain a very strong positive correlation was measured, which means that in this country with increasing wind power capacity, CO2 production increases. In Germany we can observe the same phenomenon, but with less strength.

Overall, we can say that these relationships vary across countries, which may be due to various local factors and policies that may play a crucial role in this case.

One important factor why these results are so different in individual countries may stem from the already mentioned works by Kuang et al. (2022) and Kaffine et al. (2020), which dealt with the intermittency of wind energy and its impact on CO2 emissions. Based on their works, I tried to expand knowledge on this issue with this work.

VO2: Is there a relationship between CO2 levels and energy use from coal-fired power plants in the EU between 2008 and 2022?

Correlation analysis was used to examine the relationship between coal energy use and CO2 production. The most visible phenomenon is that seven out of nine countries studied showed a positive correlation coefficient, which in itself may indicate the possibility of a positive relationship between coal energy use and CO2 production, but the research found that in Ireland and Lithuania the correlation coefficient was in negative units. Although in both cases it is a weak negative correlation (Ireland -0.178, Lithuania -0.206), this suggests that in these countries there is a possibility of a negative impact of coal energy use on CO2 levels. These results can be attributed to several factors, such as alternative energy sources, efficient use of produced energy, etc. On the other hand, strong and very strong positive correlations were found in Poland, Denmark and Portugal (Poland 0.911, Denmark 0.991, Portugal 0.756), indicating that in these countries the use of angular energy has a positive effect on CO2, which is in line with public expectations, as angular energy is often associated with high CO2 emissions.

However, it is important to mention that different correlation methods were used for the correlation (see Data and Methods) due to differences in normality it was necessary to use Pearson correlation analysis and Spearman correlation analysis, which differ in that Spearman correlation analysis takes into account the order of values and Pearson correlation analysis takes into account linear relationships between variables. This may lead to different results.

In this study, I follow up on the research of Iqbal et al. (2022) and; which dealt with the relationship between the use of renewable energy sources and CO2 emissions. Iqbal et al. (2022) suggests that the growth of renewable energy production may have different impacts on CO2 emissions depending on individual factors and management effectiveness. At the same time, Thakuri et al. (2021) examine the relationship between CO2 production and economic growth, providing insights into policies and measures to reduce CO2 emissions. These studies provide context for our analysis of the relationship between energy use from coal-fired power plants and CO2 emissions in EU countries, allowing us to better understand the factors influencing CO2 emissions in the energy sector.

Conclusion

The first research question examined the relationship between carbon dioxide emissions and installed wind power capacity in the European Union countries from 2010 to 2022. Correlation analysis revealed that there are different relationships between the two variables in different countries. For example, in Spain and Germany we observed a positive correlation, while in Belarus, Russia and Norway we recorded a negative correlation. These differences suggest that local factors and policies may play a key role in the impact of wind power capacity on CO2 production in individual countries.

In the second part of our analysis, we looked at the relationship between coal use and CO2 levels in the EU between 2008 and 2022. Here again, we found mixed results across countries. While we identified a positive correlation in Poland, Denmark and Portugal, we found a weak negative correlation in Ireland and Lithuania. These results suggest that coal use has a different impact on CO2 emissions depending on the specific conditions in the countries concerned. Overall, our analysis has provided valuable insights into the relationship between renewable and non-renewable energy use and CO2 emissions in the European Union. This study extends the findings of existing research and highlights the importance of further investigating this issue in the context of combating climate change and finding sustainable energy solutions.

However, it should be noted that our analysis has certain limitations. One of the main limitations is the possible inaccuracies in data collection and the use of different methods, due to the different normality of these data. Furthermore, due to the complex factors in the energy sector, some relationships may be distorted or insufficiently taken into account. Despite these limitations, this work provides useful insights for further research in the field of energy and the environment. Its results could serve as a basis for the formulation of policies and measures aimed at reducing CO2 emissions and promoting sustainable development in the energy sector.

In conclusion, this work provides important information on the relationship between the use of different types of energy and CO2 emissions in the European Union.

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