The Scientific Temper (2024) Vol. 15 (2): 2349-2355 E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.50 https://scientifictemper.com/

RESEARCH ARTICLE

Analysis of renewable energy and economic growth of Germany

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Abstract

The study aims to investigate the effect of energy use, renewable energy consumption, nuclear energy consumption and air transport freight on CO_2 emissions in Germany. Auto-regressive distributed lag (ARDL) technique was used to establish the short and long-term correlations between the dependent (CO_2) and independent variables (Energy use, nuclear consumption, renewable consumption, air transport freight) on a time series data from 1970 to 2021. The results demonstrated the dependence of energy use on non-renewable energy sources by revealing a significant and positive relationship between short and long-term energy use and CO_2 emissions. Similar to energy use, nuclear energy use and air transport freight was also found to be positively correlated with CO_2 emissions. On the other hand, despite the fact that there is a strong negative connection between carbon dioxide emissions and renewable energy, the results reveal that the correlation between the two is not statistically significant. The study aims to investigate the effect of important economic factors on Germany's CO_2 emissions in order to move further in a sustainable manner. The data reveals an astonishing increase in the usage of nuclear energy for power generation between 1965 and 1985, which was followed by a fall in 2012 as a result of the Fukushima tragedy and growing social unease in Germany, which ultimately led to the phase-out of nuclear power. Nonetheless, BAU projections revealed that even with 200 nuclear power plants, CO_2 emissions would still be reduced to 278 by 2070, in part because of the additional power produced by other energy sources.

Keywords: CO_2 emissions, ARDL, Renewable energy consumption, Nuclear consumption, Air transport.

Introduction

One of the most important concerns of mankind today is perhaps climate change. This is clear from the fact that the world is no longer wasting time on theoretical debates and has turned its attention to concrete regulations and environmental laws. Therefore, it has become a matter of tremendous interest to spot and solve the challenges pertaining to reduction in carbon dioxide emission levels. Environmental degradation brought on by human activities that release CO_2 includes ecological problems, global warming, climate change and environmental pollution. According to BP statistics, the G7 nations contributed approximately 25% of global CO_2 emissions in 2019 and slightly less in 2020 to 23.2%. The world's most industrialized economies play a crucial role and their policies and practices are frequently imitated by other nations (B. Li and N. Haneklaus. 2022). We will examine the impact of macroeconomic variables on Germany's CO_2 emissions because it is one of the greatest energy consumers in the world and ranks third in the G-7 countries for overall CO_2 emissions, after the United States and Japan (M. Blesl. *et al*. 2006).

Environmental issues are having a growing impact on German energy policy. The government has set the objective of lowering greenhouse gas (GHG) emissions by at least 55% by 2030 and by 85% by 2050 compared to 1990 emission levels as part of the German Climate Action Plan 2050 (P. Markewitz., *et al*. 2019). The government has promoted initiatives for energy efficiency and renewable energy. The eco-tax was created in 1999 with the intention of promoting energy efficiency, renewable energy use, and conservation. The German Renewable Energy Act (EEG), which went into effect in 2000, established a feed-in tariff (FIT) system for all renewable technologies, which led to an astonishing increase in renewable energy capacity (C. Eui,

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How to cite this article: Singh, A., Kumar, N. (2024). Analysis of renewable energy and economic growth of Germany. The Scientific Temper, **15**(2):2349-2355.

Doi: 10.58414/SCIENTIFICTEMPER.2024.15.2.50

Source of support: Nil

Conflict of interest: None.

Received: 25/04/2024 **Accepted:** 10/05/2024 **Published** : 15/06/2024

C. Marcantonini, and A. D. Ellerman, 2013). However, only an energy shift is not sufficient to reduce GHG emissions significantly. In order to meet the ambitious ideals set by the German government, all sectors, including energy, industry, transport, agriculture and homes, will need to drastically reduce their GHG emissions. For a more comprehensive analysis, we have taken into account a number of sectors, including consumption of renewable energy, nuclear energy and air transportation along with energy use.

As per popular belief, clean energy fuels have a direct impact on the reduction of carbon dioxide levels through production as well as consumption. In this paper, we have emphasized on consumption, so renewable energy consumption is a significant regressor in our analysis. Renewable energy must be able to supply the necessary energy for economic activity and lessen environmental issues brought on by the use of fossil fuels (Y. Fang, 2011). It is worthwhile to mention that clean fuels not only require energy innovation at its pinnacle but also political and social commitment. Therefore, renewable energy consumption's impact may not be as direct and immediate as it seems. Trade is a crucial component of economic growth, which in turn implies that air travel is a crucial component as well. Despite its significance for the advancement of the nation and the creation of jobs, its unfavorable impact on GHG emissions is a serious concern. In fact, 915 million tonnes of CO_2 were created by flights globally in 2019, accounting for 12% of all transport-related CO_2 emissions. This leads us to the inclusion of air transport freight as an essential variable in the study. In an effort to build alternative sources of energy and to avoid the price fluctuations associated with oil import, nuclear power plants have been set up in several countries. Nuclear energy is proposed to offer a significant advantage in terms of reducing CO_2 emissions and curbing the effects of global warming (Y. Wolde-Rufael and K. Menyah, 2010). Hence, the nuclear consumption of Germany has also been taken into account in this study. The use of recent statistics, such as the BP statistics on G7 nation's CO_2 emissions, adds credibility and relevance to the discussion. The mention of Germany's position in global CO_2 emission provides a focused context for the study.

Review of Literature

Chang explored the relationships between energy use, carbon dioxide emissions and economic growth in China. The results of the study indicated that rising economic activity increases energy use and CO_2 emissions (C.C. Chang., 2010). A similar study on Russia's CO_2 emissions, energy use, and economic growth was analyzed by (H.T. Pao., *et al*. 2011). They used the causality test and the co-integration technique to analyze the data between the period of 1990 and 2007. Empirical findings indicated that emissions appear to be elastic in terms of energy use but inelastic in terms of output in the long run (A. Singh., *et al*. 2022) used ARDL analysis on data from 2007 to 2018. The study looks at how economic and environmental factors affect logistic performance in India. The logistics performance index (LPI) is found to be positively impacted by foreign direct investment (FDI) and negatively impacted by the use of fossil fuels, both in the short and long term. While greenhouse gas emissions show a positive correlation with LPI, GDP per capita has a negative correlation, raising worries about the environment. The global economy suffered as India's logistic performance rating fell from 35^{th} to 44^{th} in the world. The report makes suggestions for how to enhance logistics and explains why India

Some of the other studies focussed on factors different from energy use. Apart from energy consumption, Baek also investigated the effects of nuclear energy and income on CO_2 emissions in 12 major nuclear-generating countries. The research demonstrated that nuclear energy typically reduces CO_2 emissions (J. Baek, 2015). Related research by Al-mulai examined the impact of nuclear energy use on GDP growth and CO_2 emissions in 30 nations worldwide. But unlike the previous research, the study's results revealed that nuclear energy use has no long-term impact on CO_2 emissions, but it has a positive long-term impact on GDP growth (U. Al-mulali., 2014)

Some research also studied the relationships of renewable energy use (K. Menyah and Y. Wolde-Rufael, 2010) investigated the relationship between nuclear and renewable energy use and carbon dioxide emissions in the US from 1960 to 2007. The research showed no correlation connecting renewable energy to CO_2 emissions, but it discovered a unidirectional causality between the consumption of nuclear energy and CO_2 emissions. (S. Kumari and N. Kumar., 2023) concludes that while renewable energy boosts the green economy, helps agriculture, and lowers CO_2 emissions, it also highlights the need for better nuclear waste management to avoid environmental risks (A. Singh., *et al*. 2023). The study assesses GDP, nuclear energy consumption, and CO_2 emissions in the United States, France, and Japan from 1965 and 2020 in order to validate the environmental Kuznets curve (EKC) theory. It is demonstrated that nuclear energy greatly lowers CO_2, SO_2, and NOx emissions using the Fourier ARDL and FBTY causality tests. The report recommends boosting the generation of nuclear and tidal energy and making sure that radioactive waste is disposed of safely in order to reach the UN's 2050 net-zero carbon targets.

Similar research was conducted, which studied the causal association between renewable energy use and economic growth in Turkey from 1990 to 2010. The result revealed that there is a unidirectional causal relationship linking economic growth to renewable energy use (O. Ocal and A. Aslan, 2013). Sebri investigated related research for the BRICS countries between 1971 and 2010 using a multivariate approach. The research showcased that based on the ARDL estimations, empirical data demonstrates that there are long-run equilibrium relationships between the variables (M. Sebri and O. Ben-Salha, 2014). Similar techniques like ARDL and VAR methodology was used to examine the relationship between CO_2 emissions, economic growth, energy consumption and renewable energy consumption in Germany for the years 1975 to 2014 and suggested that the government should create and implement appropriate support programmes to encourage investment in new renewable energy technology by (S. khoshnevis Yazdi and B. Shakouri, 2018).

Different factors from energy use, nuclear energy use, and renewable energy use were analysed in some of the other research. (R. Waheed., *et al*. 2017) Studied the impact of Pakistan's agricultural and forest production on carbon dioxide emissions in addition to renewable energy use. The research showcased that the use of renewable energy and forests have negative and significant effects on CO2 emissions, whereas agricultural production has a positive impact on CO_2 emissions. (Y.Cai., *et al*. 2018) Examined the nexus between clean energy usage, economic growth and CO_2 emissions. The result revealed that in Canada, France, Italy, the US, and the UK there was no correlation between real GDP per capita, clean energy consumption and CO_2 emissions. However, when real GDP per capita and CO_2 emissions are the dependent variables, co-integration occurs in Germany and when CO_2 emissions are the dependent variable, co-integration occurs in Japan.

Methodology

The study establishes a relationship between CO_2 emissions and energy use, renewable energy consumption, nuclear energy consumption and air transport freight over the period 1970–2021 in Germany.

For the purpose of this study, we have used secondary data that was acquired from the World Bank Development Indicators (WDI). Equation 1 establishes the relationship of CO_2 emission with energy use, nuclear consumption, renewable consumption and air transport freight in the context of Germany during the period 1970-2021.

$$\text{InCO}_2 = f\ (\text{In Energy, InNuclear, InRenew, InAir}) \qquad ....(1)$$

The variables are described in Table 1 and in, the natural log, is used in the equation above.

$$\Delta \ln CO_2 = \alpha_0 + \sum_{i=1}^{n_1} \alpha_{1i}\, \Delta\, ln\, ENERGY_{t-i} + \sum_{i=1}^{n_2} \alpha_{2i}\, \Delta\, ln\, NUCLEAR_{t-i} + \sum_{i=1}^{n_3} \alpha_{3i}\, \Delta\, ln\, RENEW_{t-i} + \sum_{i=1}^{n_4} \alpha_{4i}\, \Delta\, ln\, AIR_{t-i} + \beta_1\, ln\, ENERGY_{t-1} + \beta_2\, ln\, NUCLEAR_{t-1} + \beta_3\, ln\, RENEW_{t-1} + \beta_4\, ln\, AIR_{t-1} + \mu_t \qquad .... (2)$$

In equation 2 the short-run relationship is represented by α_1 to α_4 whereas the long-run relationship is represented by β_1 to β_4 where α_0 is the drift component and μ_t is the error term and n_i is the optimal lag.

$$\Delta \ln CO_{2_t} = \beta_0 + \sum_{i=1}^{n_1} \beta_{1i}\, \Delta\, ln\, ENERGY_{t-i} + \sum_{i=1}^{n_2} \beta_{2i}\, \Delta\, ln\, NUCLEAR_{t-i} + \sum_{i=1}^{n_3} \beta_{3i}\, \Delta\, ln\, RENEW_{t-i} + \sum_{i=1}^{n_4} \beta_{4i}\, \Delta\, ln\, AIR_{t-i} + \theta ECM_{t-1} + \mu_t \qquad .... (3)$$

In order to create an error correction model, the co-integration of the variables was first tested, whereas θ is the speed of adjustment of the long-run equilibrium.

The description of the variable is shown in Table 1 where ENERGY, NUCLEAR, RENEW and AIR are the independent variables affecting CO_2 emission. We discovered that the ARDL technique was best suited for our research since some variables were stationary at the first difference and some at a level.

Results and Discussion

A popular statistical test to determine whether a particular time series is stationary or not is the augmented Dickey-Fuller test (ADF test). In time series analysis, the unit root test is used to determine if a time series is stationary or not. The null hypothesis states that time series have a unit root, whereas the alternative hypothesis states that time series are stationary. Therefore, we require the probability values to be smaller than 0.05 in order to reject the null hypothesis. The outcome of the unit root test is shown in Table 2. The results proved the stationarity of the dependent variable CO_2 at a level as well as 1^{st} difference, whereas the independent variables were stationary at 1^{st} difference.

For the purpose of examining co-integration, Pesaran, Shin and Smith (PSS) created the ARDL bounds test. (A. Montenegro., 2019) The ARDL model is the most suitable for our study since it permits having a mixture of variables at a level and first difference. Another advantage that ARDL test offers is that it is relatively more efficient in the case of small and finite sample data sizes (M. Belloumi, 2014). The ARDL bound test is used to evaluate the long-term connection between the dependent and independent variables prior to performing ARDL co-integration. The upper bound and lower bound are the two essential values that the bound test

Table 1: List of variables

Variables	*Description*
CO_2	Carbon dioxide emissions (Million Tonnes)
Energy	Energy use (kg of oil equivalent per capita)
Nuclear	Nuclear consumption (EJ)
Renew	Renewable consumption (EJ)
Air	Air transport, freight (million ton-km)

Source: [WorldBank Database, 2020]

Table 2: ADF unit root test

Variables	*Level t-statistics*	*Level probability*	*1st difference t-statistics*	*1st difference probability*
CO_2	-4.278871	0.0070	-8.039970	0.0000
Energy	-3.318208	0.0748	-7.844101	0.0000
Nuclear	-2.700536	0.2408	-4.932591	0.0011
Renew	-1.581440	0.7860	-1.615187	0.0995
Air	-1.279795	0.8816	-9.082132	0.0000

Table 3: Auto-regressive distributed lag bond test for co-integration

Variable	*F statistics*	*Co-integration*	
F (CO_2, energy, nuclear, renew, air)	4.445385***		
Critical value (%)	1	5	10
Lower bound	3.29	2.56	2.20
Upper bound	4.37	3.49	3.09

*Significant at 10% level, **significant at 5%, ***significant at 1%

Table 4: Auto-regressive distributed lag short-run estimates

Variables	*Probability*	*t-statistic*	*Co-efficient*
Energy	0.0000***	7.733957	0.892228
Nuclear	0.1056*	1.655687	0.038417
Renew	0.1581	1.438348	0.039372
Air	0.0002***	4.112279	0.135124

*Significant at 10% level, **significant at 5%, ***significant at 1%

characterizes. The lower limit assumes that all variables are at level, while the upper bound presumes that all variables are at first different. The null hypothesis is rejected and co-integration is shown to exist if the upper bound value is less than the F statistic.

Table 3 displays the results of the ARDL bound test; the findings reveal that the dependent and independent variables exhibit considerable co-integration because the F statistic is significantly higher than both the upper bound and lower bound statistic.

The findings of the ARDL short-run test are shown in Table 4. Energy use (0<0.05) and air transport (freight) (0.002<0.05) are significant and have a positive correlation with CO_2 emission, whereas nuclear consumption also has a positive relation with CO_2 emission and is significant at 10% (0.10>0.05). On the other hand, renewable energy has no significant correlation with CO_2 emission in the short run.

Table 5 describes the results of the long-run ARDL test. Energy use, is statistically significant and is positively correlated with carbon dioxide emission. Similarly, nuclear energy is positively correlated with CO_2 emissions and is significant at 10%. Moreover, air transport (freight) is again significant and has a positive correlation with CO_2 emission. On the other hand, renewable energy, an important variable of our study, is not statistically significant and has a negative correlation with carbon dioxide emissions.

Table 6 illustrates the results of the diagnostics tests that were performed to validate our findings. The Jarque-Bera test, which has achieved widespread acceptability among econometricians, is one of the most well-known tests for determining the normality of regressors. (T. Thadewald and H. Büning., 2007) Since normality is the most common presumption when using statistical procedures, we applied the Jarque-Bera test, and the findings indicate that variables are normally distributed.

Table 5: Auto-regressive distributed lag long-run estimates

Variables	*Probability*	*t-statistic*	*Coefficient*
Energy	0.0046**	3.000507	0.639761
Nuclear	0.1056*	1.655687	0.038417
Renew	0.3594	0.927247	0.028450
Air	0.0002***	4.112279	0.135124

*Significant at 10% level, **significant at 5%, ***significant at 1%

Table 6: Diagnostic tests

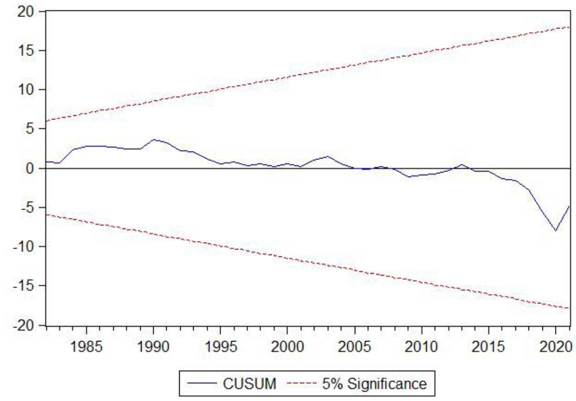
Jarque-Bera normality test JB stat	0.2346	0.8893
Ramsey RESET test, Log likelihood ratio	1.0537	0.2985
Breusch-Godfrey serial correlation, LM test	2.2290	0.3281
Heteroskedasticity Breusch-Pagan-Godfery test, Obs R-squared	15.3637	0.0814

Table 7: Granger causality test

Direction of causality	F-statistics	Probability
Energy - CO_2	1.76577	0.1827
CO_2 - Energy	6.13381	0.0044**
Nuclear - CO_2	0.61963	0.5427
CO_2 - Nuclear	4.48486	0.0167**
Renew - CO_2	1.76303	0.1832
CO_2 - Renew	2.27442	0.1146
Air - CO_2	2.59037	0.0861*
CO_2 - air	0.18345	0.8330
Nuclear - energy	4.08311	0.0235**
Energy - nuclear	2.11688	0.1322
Renew - energy	5.07704	0.0103**
Energy - renew	0.28825	0.7509
Air - energy	6.70181	0.0028***
Energy - air	0.96116	0.3902
Renew - nuclear	2.2363	0.1186
Nuclear - renew	2.90893	0.0649*
Air - nuclear	5.03021	0.0107**
Nuclear - air	1.21720	0.3056
Air - renew	5.13433	0.0098***
Renew - air	0.81349	0.4497

Homoscedasticity is a crucial presumption in statistical analysis. In order to determine if the data are homoscedastic or heteroscedastic, the heteroskedasticity Breusch-Pagan Godfrey test has been used; the results show that the dataset is homoscedastic.

Further Ramsey RESET test was used, and the outcome demonstrates that the model is free from specification error. Specification error means that at least one of the model's fundamental characteristics or presumption is erroneous.



*Significant at 10% level, **significant at 5%, ***significant at 1%

Figure 1: CUSUM test

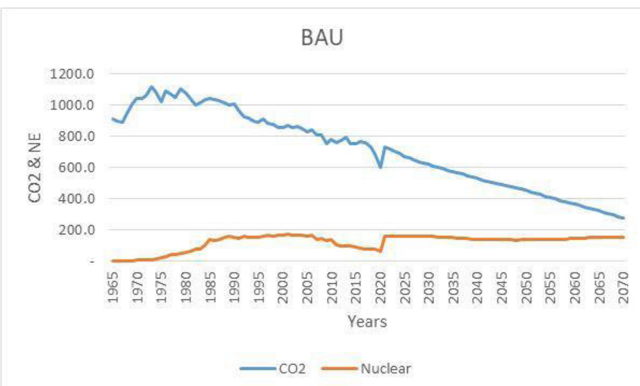


Figure 2: The business usual estimates

As a result, model estimation could produce inaccurate or deceptive results. Lastly, the Breusch-Godfrey Serial Correlation LM test demonstrated that our model's error component is not serially correlated.

Table 7 shows the results of the Granger causality test, the test is applied to time series data to determine whether there is any pronounced predictive power from one variable to the other. In essence, it aids in determining if a variable is helpful or not and whether it is capable of predicting other factors or not. It describes a one-to-one relationship between variables. As per our results, CO_2 - energy use, CO_2 - nuclear consumption, CO_2 - air, energy use - nuclear consumption, energy use - renewable energy consumption, energy use - air transport (Freight), renewable energy - nuclear consumption, nuclear consumption - air transport (Freight), renewable energy - energy use have unidirectional causal relationships.

Figure 1 demonstrates the result of the cumulative sum of the recursive residual stability test (CUSUM). Brown *et al.* invented the CUSUM test in 1975. It is a common statistical tool for analyzing and tracking structural changes in time series models (S. Otto and J. Breitung., 2022). The Figure 1 implies that the model is stable because our graph is within the bounds of 5% significance level.

BAU Estimates

The analysis a trend of sharp increase in the use of nuclear energy for power generation between the years 1965 to 1985. However, the trend started declining from the year 2012 mainly because of the 2012 Fukushima accident and the concerns in German society regarding nuclear accidents were deep, so the government had to completely phase out nuclear power generation. However, the BAU estimates from 2022 to 2070 show that even if the nuclear power generation would have maintained the 200 mark then also the CO_2 emission would have dropped to the mark of 278 by the year 2070. It's also because of the increase in power generation through other sources of renewable energy (Figure 2).

Conclusion

CO_2 emission is a major contributor to climate change and global warming. Substantial increase in CO_2 emission over the years has altered the proportions of our atmosphere and has given rise to global temperatures. The negative effects of this are currently being felt throughout the planet in the form of abrupt changes in weather patterns, extremely high temperatures, rising sea levels and melting ice caps. In this era of widespread recognition of the current issue, countries all over the world are issuing laws and taking precautions, but before one can be sure that these actions are effective, one must first determine whether or not they are even addressing the proper cause. In this paper, we analyzed whether or not the theoretically stated variables had an impact on Germany's CO_2 emissions. One can make some inferences from the empirical testing carried out in this paper.

The focus of the study is to find out whether CO_2 emissions are affected by energy use, renewable energy consumption, nuclear consumption, and air transport (freight) in Germany from the period 1970 to 2021. The results show a substantial and positive correlation between short and long-term energy use and CO_2 emissions, demonstrating the dependence of energy use on non-clean energy sources. The amount of energy used nationwide directly affects carbon dioxide emissions. Similarly there is a positive association between air transport (freight) and CO_2 emissions, indicating that the expansion of the aviation industry has contributed to increased emissions.

Consumption of nuclear energy is positively correlated with CO_2 emissions. It is obvious that Germany's CO_2 emissions will not decrease by switching to nuclear energy. As a result, the country's policy of using nuclear energy as a clean fuel has not been successful. On the contrary, we observe a rise in CO_2 emissions due to other factors such as energy use, industry, population, etc. Although there is a negative correlation between carbon dioxide emissions and renewable energy, which is a significant variable in our analysis, the test findings show that this correlation is not statistically significant. This suggests that just implementing policies to increase the use of renewable energy has little effect on carbon dioxide emissions. The aforementioned two findings are quite important since they show that, in the case of Germany, the energy industry has no impact at all on CO_2 emissions. Significant CO_2 emissions are not being caused by energy generation or consumption. Other economic sectors like transportation, industrialization, etc, instead influence CO2 emissions. As a result, the nation needs to change its focus on the source of CO_2 emissions. In a complicated economic system, it is exceedingly difficult to comprehend the underlying causes of CO_2 emissions. We can never be certain that our efforts to conserve the environment will be successful if we don't understand the true cause. As a result, ongoing efforts are made in this area, and our work has been essential in understanding some of the real variables influencing Germany's CO_2 emissions. The data demonstrates a strong rise in the usage of nuclear energy for power generation between 1965 and 1985, which was followed by a fall in 2012 as a result of the Fukushima tragedy and growing social unease in Germany, which ultimately led to the phase-out of nuclear power. Due in part to enhanced power generation from other renewable energy sources, BAU projections show that even with 200 units of nuclear power generation, CO_2 emissions will still be reduced to 278 by 2070. Further research can be done on managing the waste disposable generated by nuclear energy.

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