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Analysing the long run relationship between CO_2 emissions and Energy use of United Kingdom

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ABSTRACT

In this study, the time series data of the United Kingdom from 1965 to 2021 for energy usage, total reserves, manufacturing, GDP and total carbon emission have been examined using autoregressive distribution lag (ARDL) model. The results revealed that energy usage, manufacturing and GDP have a positive relation with CO_2 emission both in the short run and long run raising environmental concerns on the contrary only total reserves have a negative relation in the short and long run. United Kingdom increasing energy efficiency have been a top priority in the recent era, in order to achieve the target of net zero carbon emission by 2050, government need to promote policies for energy mix which would increase the usage of other renewable energy as the challenges remain for manufacturing and transportation industry because the overall emission from these sector remains largely unchanged despite advancements in fuel efficiency because the results indicates that a percentage increase in energy usage increase the CO_2 emission by 0.23% whereas 1% increase in manufacturing leads to 0.25% increase in the CO_2 emission.

Key words: *ARDL, CO2 emission, GDP, Energy mix, SDGs*

Introduction

Over time, the UK has significantly reduced its carbon dioxide (CO_2) emissions as shown in Fig. 1. Between the early 1990s and 2019, emissions had decreased by about 43%, largely as a result of a move away from coal-based energy production, improved energy efficiency, and the expansion of renewable energy sources. The energy industry has significantly reduced its emissions. This reduction was greatly aided by the closure of coal-fired power stations and their replacement with natural gas and renewable energy sources like wind and solar. A challenge has been the transportation industry. The overall emissions from this sector remained largely unchanged because of a rise in road traffic, despite advancements in fuel efficiency and the use of electric vehicles. The United Kingdom government has established challenging goals for emissions reduction. The goal is to achieve net-zero emissions by 2050, which is legally required. The UK has introduced a number of policies, including carbon pricing and subsidies for renewable energy, to achieve this.

The United Kingdom's energy mix has evolved over time, Fig. 2 shows the total energy usage of UK.

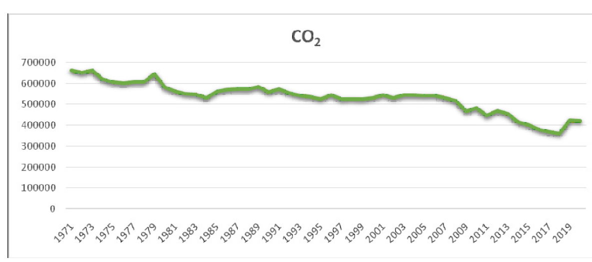

Fig. 1 CO_2 emission

While natural gas, nuclear power, and renewable energy sources have gained popularity, the amount of coal used to generate electricity has significantly decreased. The UK is now a global leader in offshore wind energy because to the significant increase of wind power in particular. In the UK, increasing energy efficiency has been a top goal. This covers metrics for building, appliance, and industrial process energy efficiency. To promote more energy-efficient housing, initiatives like the Energy Performance Certificate (EPC) have been introduced. Energy production has become more decentralized in the UK, where more homes and businesses are using solar energy and small-scale wind power to generate their own electricity. This trend to decentralized energy production has helped to cut down on transmission losses. Although there have been oscillations in energy use in the household and industrial sectors, there has been an overall trend towards increased energy efficiency. Government incentives and policies have contributed to the promotion of sustainable practices and energy efficiency.

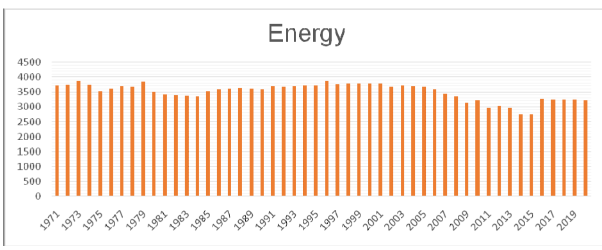

Fig. 2. Energy Usage

Emissions reduction in the transport industry is still a difficult task. It will take significant infrastructural investments to make the switch to electric vehicles and lessen reliance on fossil fuels.It will take time and effort to increase the housing stock's energy efficiency in the UK, particularly renovating older structures. In this study, we looked at the connections between CO_2 emissions, economic expansion (GDP, manufacturing value), total reserves and energy use. A multivariate model is used to investigate the causation, short and long sighted interdependence between CO_2 emission, economic growth (GDP, Manufacturing), total reserves and energy usage. The goal of the study is to identify the factors that are beneficial to environment sustainability so that we can advance in a more sustainable way.

Literature Review

A significant number of studies show that, despite the fact that economic growth does result in an increase in energy consumption, carbon emissions are not permanently reduced as a result. Some scholars use econometric models to look at the short- and long-term dynamic interactions between factors like carbon emissions, financial growth, suburbanization, and international trade in order to offer direction for the sustainable development of a region or a nation. According to the environmental Kuznets curve (EKC) theory, there is an inverse U-shaped relationship between environmental pollutants like CO_2 and GDP (Jebli *et al*., 2016; Leal and Marques, 2020; Rafiq *et al.,* 2016; Dong *et al*., 2017; Shahbaz *et al.,* 2019).

Time series data for the three major nations of the USA, France, and Japan were studied from 1965 to 2020 using the Fourier ARDL, Fourier bootstrap Toda-Yamamoto, and wavelet coherence methods. According to this analysis, France crossed the breakeven threshold in 1978, demonstrating that CO_2 levels decreased as nuclear energy use increased (Singh *et al*., 2023). The South Asian EKC hypothesis was also confirmed, demonstrating the beneficial effects of LPG use on the environment (Murshed, 2021).

GDP and CO2 emissions are inversely correlated, according to research on 31 developing countries with subpar clean energy development Aye *et al.* (2017). While few studies (Teng *et al*., 2021; Ahmed *et al*., 2019; Ahmed *et al*., 2020; Odugbesan and Adebayo, 2020; Pablo *et al.,* 2016; Wasti *et al*., 2020) found a positive link between GDP and CO2 emissions. The most modern econometric approaches, like as ARDL, Wavelet coherence, and Fourier analysis, have been used in several research to analyse the causal relationship and unidirectional connectivity between energy, GDP, and CO_2 emissions. Yang and Zhao (2014), Adebayo *et al.,* 2020; Adebayo *et al*., 2021; Khobai and Roux (2017), Wu *et al*., 2022, Adebayo, 2020; Gao and Zhang, 2021; Faisa *et al.*, 2016, Jafari *et al.*, 2015, Wang *et al*., 2019; Aydoan and Vardar, 2020; Kirikkaleli *et al*., 2020; Kirikkaleli and Adebayo. 2021.

The study found that using biofuels instead of fossil fuels reduces greenhouse gas emissions by 70%. The economic potential of biofuels was studied between 2001 and 2022 using bibliometric analysis. The research revealed that while the US, China, India, and Europe have the largest biofuel markets, many other developed and developing countries still have smaller and less developed markets for sustainable biofuels (Hasan and Coworkers, 2023).

Methodology

To test our hypothesis and accomplish our objective, we used secondary time series data that we obtained from the World Bank Development Indicators (WDI). Equation 1 was created to analyse the relationship between CO_2 emissions, GDP, energy use (EU), manufacturing value (MV), and total reserves (TR) in the context of the United Kingdom from 1965 to 2021.

$$\ln CO_2 = f\,(\text{lnGDP, lnEU, lnMV, lnTR}) \;\; \ldots (1)$$

Here, ln is the natural log in the equation above, and Table 1 defines the variable description has definitions of the variables.

$$\Delta \ln CO2_t = a_0 + \sum_{i=1}^{n_1} a_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{n_1} a_{2i} \Delta \ln EU_{t-i} + \sum_{i=1}^{n2} a_{3i} \Delta MV_{t-i} + \sum_{i=1}^{n3} a_{4i} \Delta \ln TR_{t-i} + \beta_1 \ln GDP_{t-1} + \beta_2 \ln EU_{t-1} + \beta_3 \ln MV_{t-1} + \beta_4 \ln TR_{t-1} + \mu_t \ldots\ldots\ldots(2)$$

The letters a1 to a3 in the equation above reflect the short-run relationship, b1 to b3 represent the long-run relationship, and a0 the drift component. While ni is the optimal lag and t is the error term.

$$\Delta \ln CO2_t = \beta_0 + \sum_{i=1}^{n_1} \beta_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{n2} \beta_{2i} \Delta \ln EU_{t-i} + \sum_{i=1}^{n3} \beta_{3i} \Delta \ln MV_{t-i} + \sum_{i=1}^{n3} \beta_{4i} \Delta \ln TR_{t-i} + \theta ECM_{t-1} + \mu_t \ldots\ldots\ldots\ldots(3)$$

In the equation above, the letters a1 to a 4 stand for the short-run relationship, b1 to b4 for the long-run connection, and a0 for the drift element. While t is the error term and ni is the ideal lag.

Results and Discussion

The study is conducted on time series data for 57 years so ADF unit root test was applied to check the stationarity of the variables, the results indicated that the variables were stationary at first difference, ARDL model is applicable if variables are stationary at level or first difference or a mixture of both and as the variables were stationary at first difference ARDL model was well suitable for this study. The table below illustrates the results of ADF unit root test.

Table 1. ADF unit root test

Variables	I(0) t-stats	I(0) p-value	I(1) t-stats	I(1) p-value
CO2	-2.897	0.1713	-8.379	0.0018***
GDP	-1.591	0.78	-7.015	0.002***
EU	-2.703	0.239	-7.567	0.018***
MV	-1.488	0.822	-7.525	0.003***
TR	-2.830	0.1931	-8.618	0.0098***

***, ** &*denotes 1%, 5% & 10% significance level.

The long-term relationship between the dependent and independent variables is assessed using the Auto Regressive Distributed Lag bond (ARDL) bound test. The upper bound and lower bound are two critical variables that the test displays. The lower bound assumes that all the variables are equal, while the upper limit assumes that there is a first difference for all of them in this situation.

The null hypothesis is rejected and co-integration is shown to exist if the upper limit value is less than the F statistic. ARDL bound test is used to check the cointegration between the variables, the finding reveals that the dependent variable CO_2 and the independent variables GDP, manufacturing, energy usage and total reserves are cointegrated as the F statistic is 4.26 which is greater than 3.49 the upper bound and 2.56 the lower bound at 5% significance level. Table 2 illustrates the results of the ARDL bound test.

Table 2. ARDL bound test

Variables	F-Statistics		
F (CO_2, GDP, EU, MV, TR)	4.264781**		
Critical Value	1%	5%	10%
Lower Bound	3.26	2.56	2.2
Upper Bound	4.47	3.49	3.09

***, ** &*denotes 1%, 5% & 10% significance level.

Table 3 The results of the ARDL short run estimates are indicated in Table 4 indicating that energy usage and GDP is significant at 1% and is positively correlated with CO_2 emission, a 1% increase in the GDP will increase CO_2 by 1.12% whereas one percentage increase in energy usage will increase the CO_2 emission by 0.23% on the other hand manufacturing also has a positive relation and is significant at 10%, in all the independent variable only total reserves is negatively correlated with CO_2 emission indicating that a percentage increase in the reserves leads to 0.04 reduction in the CO_2 emission.

Table 4 displays the results of ARDL long run estimates where the results of ARDL long run esti-

Table 3. ARDL short run

Variables	Probability	t-Statistics	Coefficients
GDP	0.0001***	4.5845	1.1222
MV	0.0701*	1.8598	0.2589
EU	0.0049***	2.9732	0.2321
TR	0.0239**	-2.3450	-0.0483

***, ** &*denotes 1%, 5% & 10% significance level

mates where the results indicates that GDP, manufacturing and energy usage are significant at 1%, 10%, and 1% respectively and has a positive relationship with CO_2 emission hence it would be advisable to use more of green energy both for manufacturing process and energy use which would also impact the GDP on the other hand total reserves is significant at 5% and has a negative relation with the CO_2 emission.

Table 5 displays the results of diagnostic test Jarque-Bera normality test was employed to check whether the residual are normally distributed or not and the result reveal that the residuals are normally distributed (0.20 > 0.05). Ramsey Reset test was used to check the specification error and the result revealed that there was no specification error in the model (0.40 & gt; 0.05). Breusch-Godferyserial correlation, LM test revealed that there exist no serial correlation among the error components in the model (0.38 & gt; 0.05). Lastly the outcomes of heteroscedasticity Breusch-Pagan-Godfery test demonstrates that the data is homoscedastic.

Table 4. ARDL long run

GDP	0.0000***	4.5845	1.1222
MANUFACTURING	0.0701*	1.8598	0.2589
ENERGY	0.0049***	2.9732	0.2321
RESERVES	0.0216**	-2.3880	-0.0589

***, ** &*denotes 1%, 5% & 10% significance level

Granger causality test is used for the time series data to predict whether one variable has potential prediction impact on the other variable. The results reveals that there exist unidirectional causation between CO_2 emission-GDP, total reserves- manufacturing and CO_2 emission-reserves at 10% significance level whereas manufacturing-CO_2 and GDP-reserves have a unidirectional causuallinkage at 1% and 5% respectively. The Granger causality test results are shown in Table 6.

Table 6. Granger causality test

Direction of Causality	F-statistics	Probability
CO_2-GDP	3.16670	0.0507*
Manufacturing-CO_2	5.07605	0.0098***
GDP-reserves	3.22392	0.0482**
Reserves-manufacturing	2.89367	0.0647*
CO_2-reserves	3.02068	0.0577*

***,**&*denotes 1%, 5% & 10% significance level

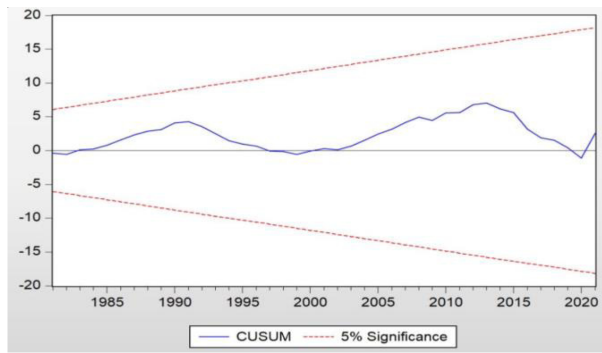

Fig. 3 CUSUM test

The stability of the model was checked by the cumulative sum of the recursive residuals stability test (CUSUM) and as the statistics were found to be between the critical bounds the model was found stable as shown in Fig. 3.

Conclusion

This study uses data from 1965 to 2021 to examine the relationships between carbon emissions, economic growth (GDP, Manufacturing, Reserves), and energy consumption of the United Kingdom. The findings reveal that energy use, GDP and manufacturing are positively related whereas total reserves have a negative relation with CO_2 emission both in the short run and long run respectively. The short

Table 5. Diagnostic tests

JB Normality Test	2.02	0.66
Ramsey RESET test	10.25	0.318
Breusch-Godfery serial Correlation	16.68	0.122
Heteroskedasticity B.P.G. test, Observed R-squared	5.46	0.325

and long run impact of GDP, energy usage and manufacturing on CO_2 emission is unfavourable that is a concern for the environment. Estimates of the linkages between economic expansion, CO_2 emissions, and energy consumption reveal that the United Kingdom has a wide range of options for establishing its energy policy toward alternative and renewable energy sources in anenvironmentally friendly and long-term manner. They could diversify their energy strategies in this direction, reducing environmental pollution while steadily and reliably increasing the energy supply over time. By supporting the development and widespread use of alternative and renewable energy technologies, it may also play a leading role in ensuring that future generations inherit a more habitable and cleaner environment.

Conflict of Interest- None

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