CO2 MITIGATION: SOLAR AND WIND ENERGY OVERTAKING HYDROPOWER EVIDENCE FROM 20 SELECTED COUNTRIES

Abdullaeva Dilfuza Rozakulovna
Tashkent State University of Economics,
Professor Assistant at the department of World Economy

ABSTRACT

The purpose of this research is to make a deeper investigation into the impact of Renewable Energy consumption and CO_2 emissions. Unlike in previous studies, types of renewable sources of energy in this research were depleted and considered separately. Namely, the top 20 most wind and solar-powered countries were selected and the research was made on how these two types of renewable energies assist in the CO_2 mitigation process by running panel data regression with 3 control variables: wind and solar energy taken as a single control variable,   hydropower and GDP per capita for the period 2000-2018. The findings suggest, that a 1% increase in the usage of wind and solar power for electricity generation decreases CO_2 emissions by 0.133 metric tons per capita, similarly a 1% increase in hydroelectric sources for electricity generation decrease CO_2 emissions by 0.028metric tons per capita. Meanwhile, a 1 % rise in GDP per capita increases CO_2 output by 2.635 metric tons per capita.

Keywords: *RE, CO2 emissions, GDP, Solar Energy, Wind Energy*

Introduction

While 13% of the world population does not have access to electricity that can provide very basic lighting, and charge a phone or power a radio for 4 hours per day, per capita consumption of it varies more than 100-fold across the world **Error! Reference source not found.**(Ritchie, Hannah; Roser, 2020) An average American citizen consumes more than ten times the energy of the average Indian, 4-5 times that of those who live in Brazil, and three times more than China. Since energy is the backbone of an economy, and its contribution to economic growth is self-contradictory the question how should countries with different levels of GDP and CO_2 emissions approach the issue of CO_2 reduction has been the focus of scholarly interest for the past 20 years. The question who is responsible for global climate change arises many more questions than answers. Should countries emitting the most CO_2 today or the ones which emit the most CO_2 per person or the countries   which emitted the most in total reduce its output?

Although main CO2 emitters are developed countries, the negative influence of greenhouse gases is seen in low-income agrarian nations. Since agriculture is a major activity in this region at the economic and social levels, it makes this industry vulnerable to climate change. (Ben Jebli, Farhani and Guesmi, 2020) Food security, is however, threatened by a rising speed of climate change, growth in world population   and income. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changing precipitation patterns increase the possibility of short-run crop failures and long-run production downturns. In spite of the gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security. Populations in the developing world, which are already vulnerable and food insecure, are likely to be the most seriously affected. (*Climate change : Impact on agriculture and costs of adaptation*, 2009). Considering the mentioned above, the purpose of research is to identify, whether all the countries can follow SDGs, and think of CO2 mitigation. Not all the countries can mitigate CO2 emissions without any threat to economic development, and even more, the real threat is targeted at developing countries, where agriculture is the main source of income. Meanwhile, the greatest numbers of CO2 emissions are displayed by industrialized countries.

All power production plants affect the environment and the ecosystems on Earth. Solar and wind systems are becoming more popular worldwide and are no longer specific to coastal, mountainous, desert or arid regions. So, the significance of studying the ecological impact is essential for the sustainability of these systems. This impact on the environment varies according to the level of development of a country and its geographical location. Relying upon the abovementioned, I explore the impact of greenhouse gas emissions, per capita GDP, the share of hydropower for electricity generation, share of solar and wind power energy for electricity generation for the top 20 most solar and wind energy using countries. The empirical results show that while GDP has a positive effect on CO2 emissions, hydropower and solar-wind based energy for electricity generation have negative effects.

LITERATURE REVIEW

Extensive investigations over the topic of RE consumption and economic growth, FDI, population growth, nuclear energy and urbanization have been carried out since sustainable development has been on the international agenda. Literature studying RE nexus CO2 can be divided into two main strands:

EKC (Environmental Kuznets Curve) emissions and economic growth.

EKC was first offered by Grossman and Krueger in 1991 which made a major contribution to the analyses of economic growth and environmental pollution. As a result, a great number of researchers started to analyze the validity of it using a number of variables and data sets by different econometric models and provided vague empirical outputs concerning the validity of EKC hypothesis.

For instance, (Khoshnevis Yazdi and Ghorchi Beygi, 2018) studied the effects of energy consumption, economic growth, RE, finance markets developments, trade openness, and urbanization growth on CO2 emissions. To do that they used the Pooled Mean Group approach. Further, a Granger Causality test was conducted in the EKC model with a data set of 25 African countries. The period 1985–2015 was tested. The outcome of the analyses was as following: RE consumption and trade openness decreased CO2 emissions, thus supporting the EKC hypothesis for the selected African countries within the given period.

The presence of bidirectional causality between economic growth and financial development and CO2 emissions were indicated by Granger's causality outputs (Shafiei and Salim, 2014) through the observed results show that non-RE consumption increases CO2 emissions, whereas RE consumption decreases CO2 emissions. Along with that, they find the existence of an environmental Kuznets curve between urbanization and CO2 emissions, implying that at higher levels of urbanization, the environmental impact decreases. Besides that (Pata, 2018)in his research over Turkey for the period 1974-2014 also supports the significance EKC for that country which establishes the link between EKC and GDP per capita. His findings conclude that the turning point of GDP per capita should be between 13523–14077 US Dollars so that it could reduce environmental pollution. (Aydoğan and Vardar, 2020) also supported EKC.

In contrast, (Zoundi, 2017) fails to validate EKC hypothesis. In his panel cointegration analysis with a set of robustness tests to assess the short and long-run impacts of RE on CO2 emissions, as well as the Kuznets Environmental Curve hypothesis for 25 selected African countries, over the period 1980-2012 he finds no evidence of a total validation of EKC predictions.

Exploring the relationships among per capita carbon dioxide (CO2) emissions, gross domestic product (GDP),renewable, non-RE production and foreign trade for China

covering the period 1980-2014 (Chen *et al.*, 2019) find that there is a long-run relationship among those variables. Moreover, they find that China does not have the EKC of CO2 emissions under the influence of economic growth, non-RE production and foreign trade. The addition of RE production variable, validates the existence of the inverted U-shaped EKC hypothesis in the long-run.

Emissions, economic growth and renewables

(Xu, Chou and Zhang, 2019) in their analyses show that the nation's economic input and its income level have a positive effect on hydrogen-based RE, which indicated that the economic growth has promoted living standards, inspired environmental awareness, and influenced the use of alternative energy and RE. (Waheed *et al.*, 2018) study the effects of RE consumption, agriculture production and forest on carbon dioxide (CO2) emission in Pakistan by using annual data from 1990 to 2014 and employ the Autoregressive Distributed Lag model to examine their long-run and short-run impacts on CO2 emission. They find that in the long run, RE consumption and forest have negative and significant effects on CO2 emission, which indicates that CO2 emission can be reduced by increasing RE usage and forest area. However, agricultural production positively and significantly affects CO2 emission in the long run which implies that agriculture production is a major carbon source in Pakistan as well. Another research was made by (Ito, 2017) in which a panel data of 42 developed countries over the period 2002-2011 was analyzed. He attempted to empirically examine the linkage between CO2 emissions, renewable and non-RE consumption, and economic growth. The findings claimed that non-RE consumption leads to a negative impact on economic growth for developing countries and that RE consumption positively contributes to economic growth in the long run.

Investigation of the causal relationship between economic growth and RE consumption in BRICS countries for the period 1971 – 2010 was carried out by (Sebri and Ben-Salha, 2014) concluding that there does exist Granger Causality test between economic growth and RE consumption, suggesting a feedback hypothesis clarifying the role of RE in economic growth. Meanwhile, (Liu *et al.*, 2020) employ the 3SLS model to conduct an empirical study on the relations among real output, RE consumption, and CO2 emissions of BRICS countries (except Russia) in 1999–2014. By using ARDL bounds testing approach, Gregory-Hansen and Hatemi - J cointegration tests for Turkey from 1974 to 2014,**Error! Reference source not found.**(Pata, 2018) investigated the short and long-run dynamic relationship between per capita GDP, per capita carbon dioxide (CO2) emissions, financial

development, per capita total RE consumption, hydropower consumption, alternative energy consumption and urbanization. The effects of stock market growth and RE use on CO2 emissions was studied by providing evidence from G20 countries by (Paramati, Mo and Gupta, 2017)

A Granger causality test and panel cointegration techniques are used to investigate the dynamic causal links between per capita RE consumption, real GDP, agricultural value-added, and CO2 emissions for a panel of five North Africa countries between 1980 and 2011 by **Error! Reference source not found.**(Mehdi and Slim, 2017) Granger causality tests reveal bidirectional causality between CO2 emissions and agricultural in the short run, as well as unidirectional causality from agriculture to GDP, GDP to RE consumption, and RE consumption to agriculture. In the long run, there is bidirectional causality between agricultural and CO2 emissions; a unidirectional causality runs from RE to agriculture and emissions, as well as from out-put to agriculture and emissions. According to long-run parameter estimations, increasing GDP or RE consumption (including combustible and waste) increases CO2 emissions, whereas increasing agricultural value-added reduces CO2 emissions.

METHODOLOGY
 Data description
In this study the dataset consists of one dependent (CO2 emissions, in metric tons per capita) and three independent variables: Solar and Wind Energy in electricity generation, as a % share of total electricity production, Hydropower -Electricity production from hydroelectric sources (% of total) and GDP per capita based on purchasing power parity (PPP) in constant 2017 international dollars.
Observations included top 20 most solar and wind energy consuming countries for generation of electricity. These are Australia, Belgium, Brazil, Chile, China, France, Germany, Italy, Japan, Mexico, Netherlands, New Zealand, Poland, Portugal, Romania, Spain, Sweden, Turkey, United Kingdom, and the United States. Due to the availability of data an 18-year period, (2000-2018) was taken to investigate the dependence of CO2 on the three variables mentioned above.
As the GDP per capita based on PPP was available for the period 2000-2016, this data was balanced by selecting mean of the data for each country.
The output variable CO2 is widely researched among scholars. In extant literature, different types of renewables are put under a single variable and its effect is studied accordingly. This research depletes the renewables into two main categories and analyses the impact of each separately. This decision has been done for a few reasons:

first of all hydropower has historically been used on a large scale and together with nuclear makes up about 10% of total energy use (Ritchie, Hannah; Roser, 2020) The potential of the hydropower is almost totally employed. Moreover, most areas that are densely populated and are in greater need for energy, feel more need water resources for its primary use. Some developing countries undergo water shortage and this shortage is expected to rise with time.

Sources

Data for CO2 in metric tons per capita, Share of hydropower(H) and GDP per capita have been obtained from the World Bank, while the Share of Wind and Solar Energy in electricity generation was taken from www.enerdata.net. The Figure1 provides data on top countries which use Wind and Solar (WS) energy for electricity generation.
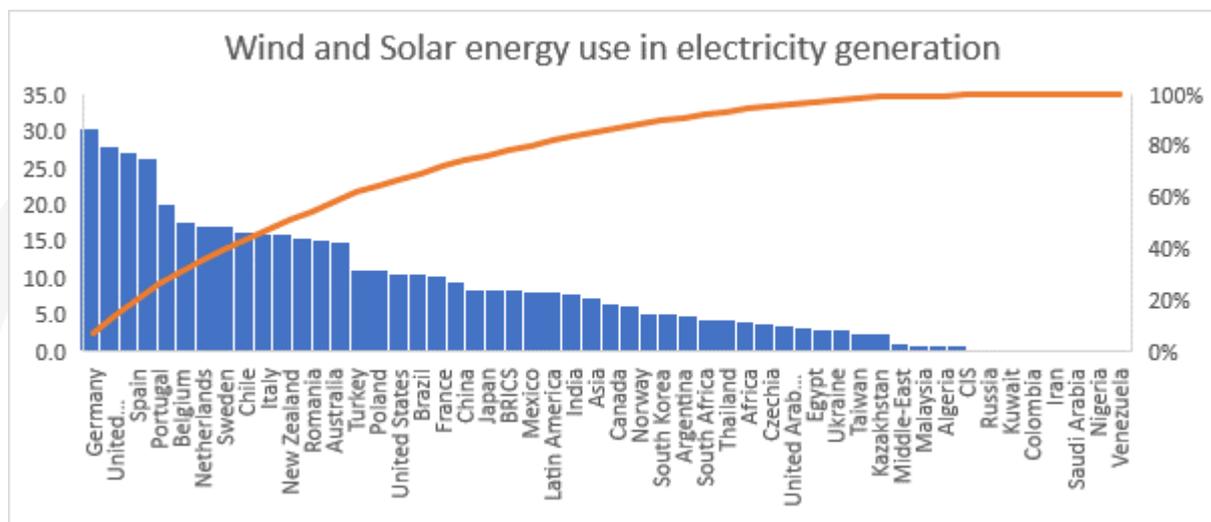

Figure 1.Wind and Solar Energy Use in Electricity Generation as % change between 2000-2020 www.enerdata.net

The data to identify most WS energy using countries was used by the % change of WS energy in electricity production throughout 2000-2020. As it can be seen from the chart, the most WS energy consuming country is Germany with 30.5 % increase in share of electricity production, followed by the United Kingdom with 28% change and Spain. The list is closed by Saudi Arabia, Nigeria and Venezuela with 0.1 % changes in the observed period.

Using the data on this graph, 20 top solar and Wind energy using countries have been selected, while the rest neglected as it would have been difficult to evaluate the contribution to CO2 mitigation of solar and wind power, the share of which was close to 0%.
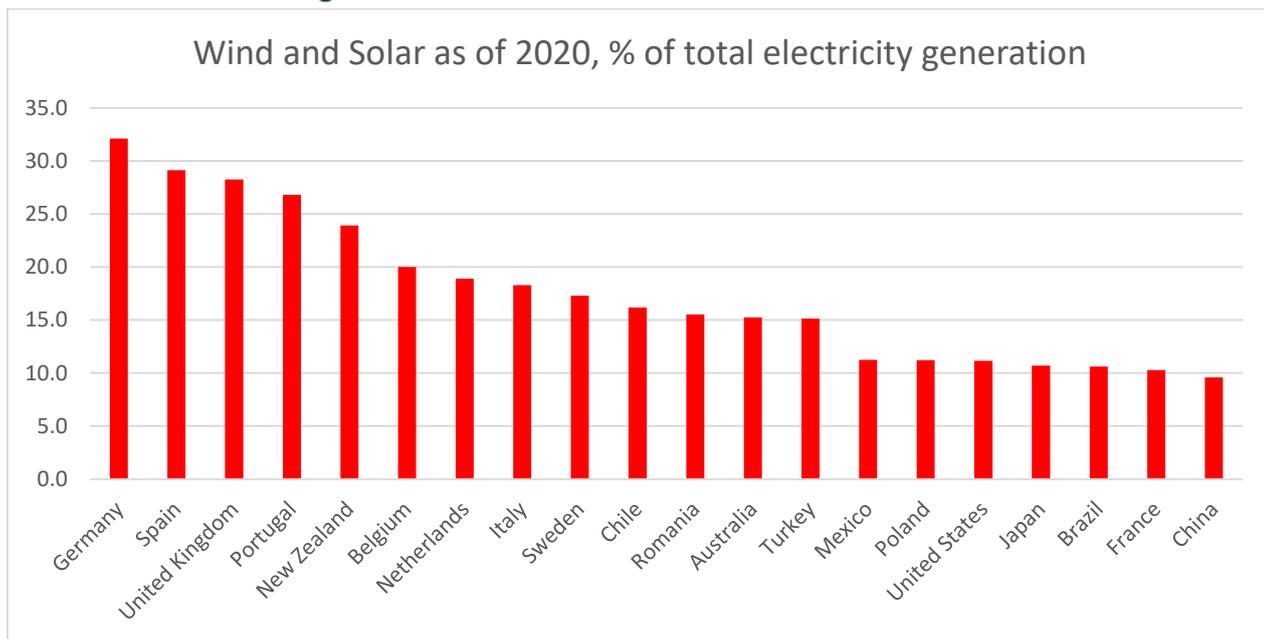
Figure 2. Wind & Solar Energy as of 2020, % of total electricity generation.
(www.enerdata.net)

In Figure 2, we can see if the change in WS use in electricity generation throughout 2000-2020 was similar to the WS use in electricity generation as of 2020. The outcome of the data has shown, that the top countries remained unchanged – Germany, Spain and the UK with around 30% of the share, while the closing list countries used about 10% of WS in the total production of electricity. Figure 3 visualizes the data for CO2 emissions for 20 selected countries between 2000-2018. As can be seen from the graph, the greatest emitters per capita are the UK, USA and Australia with around 18-20 mt tons per capita, whereas Germany produced under 10 mt tons. This is due to great efforts done by the German government to shift into green economy. The lowest CO2 emitters per capita are Brazil and Turkey, with just around 2-5 mt tons.

Using an add-in for Excel -XLSTAT, an association test for a panel data set of 20 countries with 3 independent and 1 dependent variable was made, indicated that we should reject the null hypothesis (assumption that rows and columns of the table are independent) and accept alternative hypothesis H_a, that there is a link between the rows and columns of the table.

Table 1 gives the data for R and adjusted R and F test. Adjusted R squared shows the percentage which can be predicted by this model. In this model, only 43,6% of the output can be predicted by the given independent variables. P-value obtained in this regression is less than 0.0001, which is enough to conclude that the results are valid. After running a panel data analyses, the model obtained is shown below

$$y_{it} = -0.133x1_{it} + 2.635x2_{it} - 0.028x3_{it} + \varepsilon_{it}$$

(1)

The subscripts i and y in equation *(1)* stand for a country and years accordingly, y_{it} is the amount of CO2 emissions per capita in metric tons, x1 – share of Wind and Solar energy use for electricity generation in %, x2 – GDP international logged naturally, x3 – share of Hydroelectric sources for electricity generation in % of the total and ε_{it} is the residual. The deviations of predicted results from the real ones are shown in the residuals column. The list of residuals is provided in the Appendix. When we add up all the residuals, the sum we get is equal to 0. According to our equation, we have the following results:

A 1% increase in the usage of Wind and Solar power for electricity generation decreases CO2 per capita emissions by 0.133 metric tons per capita, similarly a 1% increase in hydroelectric sources for electricity generation decrease CO2 emissions per capita by 0.028metric tons. Meanwhile, a 1 % rise in GDP per capita increases CO2 output by 2.635 metric tons per capita.

The given output proves out hypothesis that solar and wind energy, together with hydropower decrease emissions. There are many other factors in fact which may decrease the amount of CO2 emissions, like urbanization and use nuclear power plants. Obviously, urbanization can also be investigated separately analyzing its impact on the environment.

Table1 Panel Regression Output

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
CO2..Y..emissions.per.capita	380	0	380	1.702	20.472	7.443	4.064
Share.of.X1..wind.and.solar.in.electricity.production....	380	0	380	0.000	24.558	5.501	6.372
Ln.GDP..X2..international.2017	380	0	380	8.147	11.028	10.389	0.534
Electricity.production.X3..from.hydroelectric.sources....of.total.	380	0	380	0.050	87.244	19.229	20.770

Results for variable CO2..Y..emissions.per.capita:	
Goodness of fit statistics:	
rsq	0.468
adjrsq	0.436
Joint test of significance (F or Chi-square test):	

statistic.F	parameter.df1	parameter.df2	p.value.F
104.811	3	357	<0,0001

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
Share.of.X1..wind.and.solar.in.electricity.production....	-0.133	0.008	-17.119	<0,0001
Ln.GDP..X2..international.2017	2.635	0.273	9.655	<0,0001
Electricity.production.X3..from.hydroelectric.sources....of.total.	-0.028	0.011	-2.587	0.010

RESULTS AND DISCUSSIONS

The measure of economic growth - GDP - reflects the increase in the value of manufactured goods and services in a given country in a specific period (value of goods and services produced minus the value of goods and services used in production) **Error! Reference source not found.**(Campo and Sarmiento, 2013). It is worth remembering that the concept of "economic growth" is not the same as "economic development", which additionally includes qualitative changes accompanying economic growth, improving the competitiveness of a given economy. Regardless of whether energy consumption leads to economic growth or the opposite, most studies have considered the GDP as a representative for economic growth and a predictor for CO_2 emissions. Estimating environmental drawback brought by economic progress has been in the focus of scholarly interest since Paris agreement has been adopted, followed by SDG. Global warming, which is mainly the result of excessive CO_2 has become a global threat to humanity.

The rise of an average annual temperature has led to floods and droughts, resulting in deforestation, diminishing the areas for farming and many other negative impacts on agriculture. The study of the energy and GDP impact on CO_2 emissions has been growing since then.

CONCLUSION

Reducing the negative impacts of human economic activities is a global priority. Clean and safe energy is seen as a necessary mitigation approach to reducing the negative externalities of economic growth while retaining significant economic growth. Governments need to raise public awareness of environmental protection and reduction of CO_2 emissions by working with various platforms, such as television, the internet, and radio. This will help more families and individuals understand the importance of pollution control. Governments need to develop and enforce emission

reduction policies and energy conservation schemes, as well as attach corresponding measures to encourage production units to adopt green technologies and severely punish those who don't.

According to https://data.worldbank.org/indicator an average person in 2018 emitted 4.5 mt tons of CO_2 which is 0.6mt tons more compared to 1990's average. Our findings suggest that 1% increase in solar and wind energy use for electricity, mitigates CO_2 emissions by 0.133 mt tons per capita, that is almost 3% of 4.5 mt tons.

References

1. Aydoğan, B. and Vardar, G. (2020) 'Evaluating the role of renewable energy, economic growth and agriculture on CO_2 emission in E7 countries', *International Journal of Sustainable Energy*, 39(4), pp. 335–348. doi: 10.1080/14786451.2019.1686380.

2. Campo, J. and Sarmiento, V. (2013) 'The Relationship between Energy Consumption and GDP: Evidence from a Panel of 10 Latin American Countries', *Latin American Journal of Economics*, 50(2), pp. 233–255. doi: 10.7764/LAJE.50.2.233.

3. Chen, Y. *et al.* (2019) 'Exploring the effects of economic growth, and renewable and non-renewable energy consumption on China's CO_2 emissions: Evidence from a regional panel analysis', *Renewable Energy*, 140, pp. 341–353. doi: 10.1016/j.renene.2019.03.058.

4. *Climate change : Impact on agriculture and costs of adaptation* (2009) *Climate change : Impact on agriculture and costs of adaptation.* doi: 10.2499/089629535.

5. Ito, K. (2017) 'CO_2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries', *International Economics*, 151, pp. 1–6. doi: 10.1016/j.inteco.2017.02.001.

6. Ben Jebli, M., Farhani, S. and Guesmi, K. (2020) 'Renewable energy, CO_2 emissions and value added: Empirical evidence from countries with different income levels', *Structural Change and Economic Dynamics*, 53, pp. 402–410. doi: 10.1016/j.strueco.2019.12.009.

7. Khoshnevis Yazdi, S. and Ghorchi Beygi, E. (2018) 'The dynamic impact of renewable energy consumption and financial development on CO_2 emissions: For selected African countries', *Energy Sources, Part B: Economics, Planning and Policy*, 13(1), pp. 13–20. doi: 10.1080/15567249.2017.1377319.

8. Liu, J. L. *et al.* (2020) 'Do real output and renewable energy consumption affect CO_2 emissions? Evidence for selected BRICS countries', *Energies*, 13(4). doi:

10.3390/en13040960.

9. Mehdi, B. J. and Slim, B. Y. (2017) 'The role of renewable energy and agriculture in reducing CO2 emissions: Evidence for North Africa countries', *Ecological Indicators*, 74, pp. 295–301. doi: 10.1016/j.ecolind.2016.11.032.

10.   Paramati, S. R., Mo, D. and Gupta, R. (2017) 'The effects of stock market growth and renewable energy use on CO2 emissions: Evidence from G20 countries', *Energy Economics*, 66, pp. 360–371. doi: 10.1016/j.eneco.2017.06.025.

11. Pata, U. K. (2018) 'Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: Testing EKC hypothesis with structural breaks', *Journal of Cleaner Production*, 187, pp. 770–779. doi: 10.1016/j.jclepro.2018.03.236.

12. Ritchie, Hannah; Roser, M. (2020) 'Energy - Our World in Data', *OurWorldInData.org*.

13. Sebri, M. and Ben-Salha, O. (2014) 'On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries', *Renewable and Sustainable Energy Reviews*, 39, pp. 14–23. doi: 10.1016/j.rser.2014.07.033.

14. Shafiei, S. and Salim, R. A. (2014) 'Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: A comparative analysis', *Energy Policy*, 66, pp. 547–556. doi: 10.1016/j.enpol.2013.10.064.

15. Waheed, R. *et al.* (2018) 'Forest, agriculture, renewable energy, and CO2 emission', *Journal of Cleaner Production*, 172, pp. 4231–4238. doi: 10.1016/j.jclepro.2017.10.287.

16. Xu, R., Chou, L. C. and Zhang, W. H. (2019) 'The effect of CO2 emissions and economic performance on hydrogen-based renewable production in 35 European Countries', *International Journal of Hydrogen Energy*, 44(56), pp. 29418–29425. doi: 10.1016/j.ijhydene.2019.02.167.

17. Zoundi, Z. (2017) 'CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach', *Renewable and Sustainable Energy Reviews*, 72(October 2016), pp. 1067–1075. doi: 10.1016/j.rser.2016.10.018.