Journal of Energy and Economic Development,
Niroo Research Institute.
Vol. 1, Issue. 1, Summer 2022 , Pages 1-9
Journal homepage: http://jeedev.nri.ac.ir

Drivers of CO2 Emissions from Power Plants in Selected Fossil Fuel-Producing Countries

Vahid Ghorbani Pashakolaie[1*], Kioumars Heydari[2], Mohammad Sayadi[3]

1 Assistant Professor, Department of energy economics, Niroo Research Institute (NRI), Iran,

2 Assistant Professor, Department of energy economics, Niroo Research Institute (NRI), Iran,

3 Assistant Professor, Department of energy economics & Resources, Kharazmi University, Iran

Abstract. Fossil fuel-producing countries have access to low-cost primary energy sources, which could be converted into cheap secondary energies like electricity. Although, it is worth noting that this process always generates a high rate of emissions. Most of the energy-related emissions in fossil fuel-producing countries are caused by power plants. This study focuses on data from seven major fossil fuel-producing countries of the Middle East from 2000 to 2018. These countries include Bahrain, Iran, Oman, Qatar, Kuwait, Saudi Arabia, and the United Arab Emirates. The analysis is based on a dynamic panel data model using GMM techniques. The results show that switching from oil-fired power plants to natural gas-fired power plants does not reduce power plant CO_2 emissions. However, fuel switching could be an effective climate policy in cases where electricity is generated by burning low-quality oil products. Our analysis also indicates that by increasing the thermal efficiency of power plants, CO_2 emissions in fossil fuel-producing countries could be reduced. To conclude, we recommend incorporating power plant efficiency improvements into emission reduction efforts in fossil fuel-producing counties.

***Keywords*:** *Power Plant Emissions, Dynamic Panel Data, Thermal Efficiency, Fossil Fuel-Producing Countries, Fuel Switching*

INTRODUCTION

Carbon neutrality is a global goal, and under the Paris Agreement, the global average temperature increase will be well below 2°C and efforts will be made to limit it to 1.5°C above pre-industrial levels over the long term (Schleussner et al., 2016). To achieve the goal of a net-zero economy, innovative sectoral partnerships, and increased funding support were included in the Glasgow Agreement (Mountford et al., 2021). The most significant source of carbon

[*] *Corresponding author Email Address: vghorbani@nri.ac.ir*
https://doi.org/10.30503/jeedev.2022.283004.1011

emissions from human activities is the from burning of fossil fuels in for electricity generation. Approximately 80% of global energy is derived fromExtreme consumption of fossil fuels represent about 80% of the global energy (Alalwan et al., 2019). In fossil fuel-producing countries,Most of electricity is primarily generatedion in the fossil fuel countries comes fromby low efficiency fossil fuel power plants.

Therefore, decarbonizing the electricity sector is critical to achieving emission goals in fossil fuel-producing countries.

More efficient power plants produce fewer emissions because they burn less fuel per unit of electricity generated. Major technology retrofits would likely result in a significant reduction in GHG emissions (Campbell, 2015).

Main fossil fuel-producing countries generated 1537 million tons of CO2 in 2018 and are responsible for 5% of the world's total emissions (BP, 2020; Institute, 2020). In these countries, almost 35% of CO2 emissions are emitted from thermal electricity generation (IEA, 2020). Power plants that burn oil and low-quality petroleum products cause another environmental issue in fossil fuel-producing countries. This is because these power plants emit more emissions compared to gas-fired power plants. In fossil fuel-producing countries, cheap fossil fuel resources present a barrier to the penetration of non-fossil fuel sources, including renewable energies (Painuly, 2001).

In Middle Eastern fossil fuel-producing countries, power generation has low thermal efficiency. In the hot and humid regions, modern combined cycle turbines can achieve an efficiency of 50%. Despite that, in Middle Eastern fossil fuel-producing countries, the efficiency of gas-fired power plants barely exceeds 40%. As the thermal efficiency throughout the region is increased to a higher level, significant fuel savings and emission reductions will be possible (IRENA, 2019).

This paper evaluates how thermal efficiency impacts carbon emissions in major fossil fuel-producing countries. Natural gas is a relatively clean burning fossil fuel for power generation. Compared to petroleum products, burning natural gas results in fewer carbon emissions and generates an equal amount of electricity (EIA, 2020). Furthermore, the ratio of electricity generated from oil and petroleum products to gas-fired electricity generation is another key explanatory variable for (predicting/explaining) power plant emissions in fossil fuel-producing countries. This study uses the Generalized Method of Moments (GMM) model, the most common method for estimating dynamic panel data, as proposed by (Blundell & Bond, 1998).

The remainder of the article is organized as follows: Literature review presented in section two; Methodology described in section three; results presented in section four, and the conclusion given in section five.

1. LITERATURE REVIEW

Several scholars have argued that improving the efficiency of fossil fuel power plants could reduce CO2 emissions. EPA (2010) determined that carbon emissions per unit of electricity are likely linked to the thermal efficiency of fossil fuel power plants in the United States.

NETL (2008) suggested that if reducing emissions was the goal, improving heat rate efficiency could allow power plants to generate the same amount of electricity using less fuel, thus decreasing CO2 emissions. In conclusion, increasing efficiency from 32% to 36% resulted in a 2.5% reduction in the US CO2 emission rate in 2008. Similarly, Campbell (2013) suggested that to reduce emissions, the USA Congress could use tax incentives to encourage energy-efficient upgrades to power plants.

Song et al. (2018) indicated that developing natural gas-fired power plants would be an effective solution for a short-term GHG emission reduction in China. According to Rodrigues et al. (2020) the main drivers of the decrease in carbon emissions between 2000 and 2007 in the EU were changes in the fossil fuel mix, replacing coal with gas, and increasing electricity generation efficiency. By analyzing sample power plants, Alavijeh et al. (2013) concluded that increasing the efficiency of power plants could lower the emission factor of the power industry. Jorgenson et al. (2016) found that decreasing disproportionality among fossil-fuel power plants by focusing on those at the upper end of the distribution that burns fuels less efficiently might alleviate emissions from the power industry (Song et al., 2018).

J. Wang et al. (2021) showed that thermal power generation efficiency was a dominator in emissions reduction, followed by the use of renewable energies in electricity generation. The same results have been observed for coal emissions by Ali et al. (2021), Sharma and Kautish (2020), and Peng et al. (2021). Other researchers, such as Jindal and Nilakantan (2021) and N. Zhang and Choi (2013), focus more on innovation drivers in power plants.

However, some scholars have argued that improving efficiency may actually cause an increase in emissions. Jevon's writing is the source of this argument (Alcott, 2005). Jevons wrote that any improvement in engine performance accelerates the consumption of coal (Jevons, 2007).

Grant et al. (2014) found that while US power plant efficiency led to lower CO2 emission rates, it raised CO2 emission levels.

2. METHODOLOGY

Based on the dynamic nature of carbon emissions, the following model is proposed:

$$ln\,Pemi.c_{i,t} = \beta_0 + \beta_1\,ln\,Pemi.c_{i,t-1} + \beta_2 \ln GDP.c_{i,t} + \beta_3\,ln^2\,GDP.c_{i,t} + \beta_4 \ln Eff_{i,t} + \beta_5 \ln OGRatio_{i,t} + \beta_6 \ln Urban_{i,t} + \beta_7 \ln Trade_{i,t} + \varepsilon_{i,t} \quad (1)$$

$\ln Pemi.c_{i,t}$ Represents the per capita carbon emission of electricity generation of country i at time t, and $\ln Pemi.c_{i,t-1}$ is the first-order lag of dependent variable in logarithm form.

$\ln GDP.c_{i,t}$ Is the real GDP per capita in logarithm form and $ln^2\,GDP.c_{i,t}$ is the quadradic form of real GDP per capita. $\ln Eff_{i,t}$ Denotes electricity generation thermal efficiency index. $\ln OGRatio_{i,t}$ Shows the ratio of types of fuel used in power plants. In order to find out the emission drivers, demographic indicators such as urbanization trend and trade trend gas been included in the model (Farzanegan & Markwardt, 2018; Gholipour & Farzanegan, 2018). $\ln Urban_{i,t}$ Is trade volume (% of GDP), and finally $\ln Trade_{i,t}$ is urbanization trend (% of population).

$\beta_1, \dots, \beta_7$ Are the estimated coefficients. We expect $\beta_1, \beta_{2,}\ \beta_5,\ \beta_{6,}\ \beta_7$ to be positive and β_4 be negative. β_4 Is the most critical coefficient in this study. Positive β_4 refer to disadvantageous and negative β_4 refer to advantageous of thermal efficiency improvement for climate change. This study analyzed the model (Eq.1) using dynamic panel data GMM estimator (Arellano & Bond, 1991).

3. RESULTS

This study used seven country panel data from 2000 to 2018. Variables come from the International Energy Agency (IEA) and the World Bank. Power plant carbon emission is a dynamic nature variable and lag variable plays an important role. GDP per capita and power plant efficiency are crucial dependent variables (Y. Wang et al., 2019; K. Zhang et al., 2017).

Table1. Shows the descriptive statistics for all variables. Power plant CO2 emissions per capita refer to per capita emissions from all types of electricity and heat generation including coal, oil, and gas (IEA, 2020). Average logarithm of emissions in these countries is 1.9 tons of CO2.

GDP per capita is gross domestic product divided by midyear population (IEA, 2020). According to the gathered data, the maximum real GDP was earned by Qatar in 2011 by 69,679 dollars. In contrast, Iran earned the minimum amount in 2001 by 4,794 dollars.

Efficiency of thermal power plants is another explanatory variable. We utilized the index of thermal efficiency of electricity plants including CHP index (2000 = 100) (EIA, 2020). The highest and lowest efficiencies were reported in Oman in 2018 and United Arab Emirates in 2004, respectively.

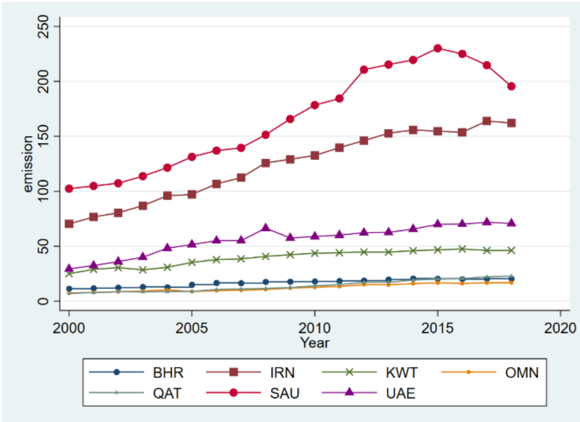
In fossil fuel-producing countries, another key factor that impacts emissions is the ratio of electricity generation from oil (petroleum product) to natural gas. As the top oil-fired electricity generator in fossil fuel-producing countries, Kuwait uses oil-fired electricity generation two times as much as gas-fired electricity generation, while this ratio is 0.51 for all seven countries studied.

Table 1. Descriptive statistics of the variables

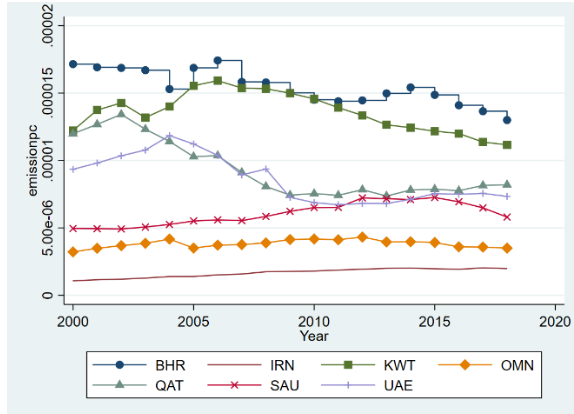
Panel-A:			Total Statistics			
Variables/Statistics	**Units**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
$\ln Pemi.c_{i,t}$	tCO2	133	1.9	0.74	0.09	2.8
$GDP.c_{i,t}$	Constant 2010 US$	132	31,037	19,329	4,794	69,679
$Eff_{i,t}$	Index	133	113.4	20.2	79.6	171.2
$OGRatio_{i,t}$	Ratio	127	0.51	0.83	0	3.72
$\ln Urban_{i,t}$	%	133	4.44	0.12	4.16	4.6
$\ln Trade_{i,t}$	%	132	4.54	0.37	3.66	5.25

Panel-B:			Country Statistics			
Country/Variables mean	$\ln Pemi.c_{i,t}$	$GDP.c_{i,t}$	$Eff_{i,t}$	$OGRatio_{i,t}$	$\ln Urban_{i,t}$	$\ln Trade_{i,t}$
Bahrain	2.73	21,808	107.64	0.003	4.48	4.98
Iran	0.49	5,997	98.53	0.261	4.24	3.85
Oman	1.34	17,404	122.62	0.075	4.33	4.65
Qatar	2.21	64,484	137.92	0.000	4.58	4.53
Kuwait	2.60	40,139	102.02	1.982	4.60	4.53
Saudi Arabia	1.79	19,649	114.47	1.085	4.40	4.33
United Arab Emirate	2.13	46,456	110.56	0.028	4.42	4.93

The total and per capita power plant emissions of these countries have been shown in Fig 1. The largest contributors of power plant emissions in these countries are Saudi Arabia and Iran. By comparing CO2 emissions per capita, countries dependent on fossil fuels have completely changed their order. Bahrain and Iran had the highest and lowest average power plant emission per capita in the world by 15.4 and 1.7 t/year CO2, respectively.



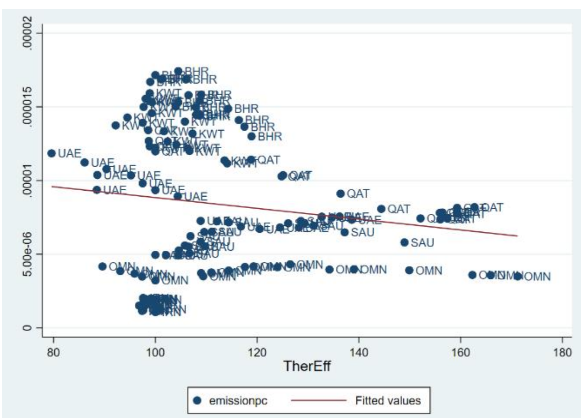
(a)-Total emission



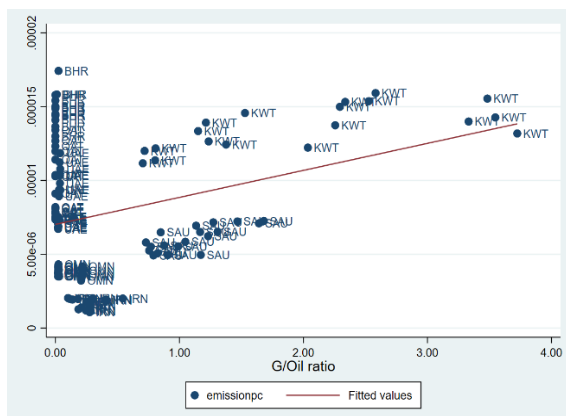
(b)- Per capita emission

Figure 1. Power plant emissions in selected fossil fuel-producing countries (IEA 2020)

Fig 2. Describes the predicted effects of selected dependent variables (power plant thermal efficiency and oil/gas-fired power generation ratio) on power plant CO2 emissions in the bivariate regression. Thermal efficiency and emissions are negatively correlated, meaning that with more thermal efficiency, less fuel is burned and therefore less emissions are released. In bivariate analysis, a positive correlation has been observed, indicating that more oil-fired power plants produce more emissions in fossil fuel-producing countries.



(a)-thermal efficiency



(b)-oil /gas-fired power generation ratio

Figure 2. Bivariate effect of selected dependent variables on CO2 emissions

In order to determine whether the bivariate relationships detected in Fig 2 can be explained by other relevant determinants, we conducted multi-variate regression analyses of the power plant emission factors. Table 2 shows the degree of co-movement between variables using the correlation matrix. According to the data, there will be no serious problem with multicollinearity.

Table 2. Correlations for the panel data set

	$\ln Pemi.c_{i,t}$	$\ln GDP.c_{i,t}$	$\ln Eff_{i,t}$	$OGRatio_{i,t}$	$\ln Urban_{i,t}$	$\ln Trade_{i,t}$
$\ln Pemi.c_{i,t}$	1.0000					
$\ln GDP.c_{i,t}$	0.5261	1.0000				
$\ln Eff_{i,t}$	-0.1259	0.2429	1.0000			
$\ln OGRatio_{i,t}$	0.3349	0.0548	-0.5704	1.0000		
$\ln Urban_{i,t}$	0.3451	0.3445	0.3300	0.3465	1.0000	
$\ln Trade_{i,t}$	0.4765	0.2142	0.2107	-0.2481	0.3048	1.0000

The stationary test was performed prior to using the dynamic panel model. The Im-Pesaran-Shin (IPS) stationary test indicates that all variables of the model are integrated of the same order (I (1)).

Table 3 presents the estimated results of dynamic panel data models. The coefficient of the lagged dependent variable is significantly positive in three models, indicating that previous year emissions significantly affect current year emissions. This is due to the lag in any carbon capture installation, as well as the lag in demand side and consumer behaviour adjustment.

GDP per capita is statistically insignificant, implying that GDP per capita is not a driver of power plant CO2 emissions in fossil fuel-producing countries. Which rejects the Kuznets curve hypotheses.

For model 2 and 3, the thermal efficiency coeffiecient is statistically significant in all models by one percent. This means that a one percent increase in thermal efficiecy could decrease power plant emissions by 0.7 percent. Accordingly, $\ln \mathrm{O/GRatio}_{i,t}$ has an insignificant statistical coefficient, meaning that compared to using gas to generate electricity, burning oil product, such as heavy oil and gasoline, does not lead to higher emissions in fossil fuel-producing countries.

$\ln Urban_{i,t}$ and $\ln Trade_{i,t}$ are siginificant in all models, suggesting that demographic factors are influential in power plant emissions.

Table 3. The results of panel dynamic panel data analysis model (Arellano and Bond estimation)

Independent Variables.	(1)	(2)	(3)
$\ln Pemi.c_{i,t-1}$	0.61*** (0.170)	0.41*** (0.164)	0.36*** (0.145)
$\ln GDP.c_{i,t}$	1.45 (1.43)	-0.36 (1.25)	-0.72 (1.26)
$\ln^2 GDP.c_{i,t}$	-0.062 (0.073)	0.03 (0.073)	0.04 (0.064)
$\ln Eff_{i,t}$	-0.027*** (0.093)	-0.72*** (0.093)	-0.706*** (0.098)
$\ln OGRatio_{i,t}$	-0.007 (0.01)	-0.004 (0.01)	-0.002 (0.009)
$\ln Urban_{i,t}$	-	2.38*** (0.41)	2.38*** (0.43)
$\ln Trade_{i,t}$	-	-	0.073*** (0.43)
Constant	-11.6** (6.91)	-13.5*** (3.39)	-12.7*** (3.68)

*** Significant on 1% confidence level; ** Significant on 5% confidence level; * Significant on 10% confidence level.

Validity and serial autocorrelation in residuals have been investigated by the Sargan and Arellani-Bond tests of over-identifying restrictions. According to the p-value of the Sargan test, the null hypothesis of no over-identifying restrictions cannot be rejected. Therefore, the Sargan test supports the validity of the GMM estimator.

The Wald test H_0 hypothesis (the independent variable has no explanatory power for the dependent variable) was rejected ($P<0.05$), so the entire model was assumed to be significant.

The Arellano-Bond autocorrelation test has been executed for 1^{st} and 2^{nd} degree aurocorrelation. The AR(1) was significant ($P>z = 0.020$) and AR(2) was insignificant ($P>z = 0.202$), implying that there is no second degree autocorrolation. The Sargan test H_0 hypothesis can not be rejected and therefore, overidentifying restrictions are valid ($Z=45.27$, $P>z =0.036$).

CONCLUSION

Using panel data of the seven major Middle Eastern fossil fuel-producing countries from 2000 to 2018, this study empirically analyzed the drivers of power plant CO2 emissions by using a dynamic panel data model.

The regression results showed that at the 1% level, the power plant thermal efficiency coefficient was highly significant. It is concluded that increasing the efficiency of power plants leads to lower levels of emissions. In other words, a one percent increase in thermal efficiency would decrease power sector emissions by 0.7 percent. Converting natural gas-fired power plants into combined cycle power plants is one of the most methodical ways to improve the thermal efficiency of power plants. To meet climate change targets in the Middle East, the policy implication is that conversion of simple cycle power plants to combined cycle power plants in fossil fuel-producing countries should be prioritized.

The oil-to-gas ratio coefficient is insignificant, meaning that compared to natural gas-fired power plants, burning oil products, such as heavy oil and gasoline, does not result in more emissions. Despite the insignificance of the oil-to-gas ratio coefficient, fuel switching is not totally inefficient. According to the research data, fuel switching is an effective remedy for climate change in countries where the quality of oil products is low. For instance, Iran's oil and gas-fired power plants emit 0.9 and 0.5 ton of CO2/MWh on average, respectively (EIA, 2020).

The results also show that there is no relation between GDP per capita and power plant emissions. A comparison of power plant emissions in fossil fuel and non-fossil fuel-producing countries should be considered in further researches. Future studies could assess the emission reduction potential of converting simple cycle gas-fired power plants into combined cycle power plants at the plant-level.

REFERENCES

Alavijeh, H. S., Kiyoumarsioskouei, A., Asheri, M. H., Naemi, S., Alavije, H. S., & Tabrizi, H. B. (2013). Greenhouse gas emission measurement and economic analysis of Iran natural gas fired power plants. Energy Policy, 60, 200-207.

Alcott, B. (2005). Jevons' paradox. Ecological economics, 54, 9-21.

Ali, Q. u. A., Khayyam, U., & Nazar, U. (2021). Energy production and CO2 emissions: The case of coal fired power plants under China Pakistan economic corridor. Journal of Cleaner Production, 281, 124974. doi:10.1016/j.jclepro.2020.124974

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. The review of economic studies, 58, 277-297.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of econometrics, 87, 115-143.

BP. (2020). Statistical Review of World Energy.

Increasing the efficiency of existing coal-fired power plants, Congressional Research Service Washington, DC, USA (2013).

Campbell, R. J. (2015). Increasing the efficiency of existing coal-fired power plants. Coal-Fired Power Plants: Efficiency Improvement Options, 77-111.

EIA. (2020). Natural gas and the environment.

EPA. (2010). AVAILABLE AND EMERGING TECHNOLOGIES FOR COAL-FIRED ELECTRIC GENERATING UNITS Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Coal-Fired Electric Generating Units. Energy.

Farzanegan, M. R., & Markwardt, G. (2018). Development and pollution in the Middle East and North Africa: democracy matters. Journal of Policy Modeling, 40, 350-374.

Gholipour, H. F., & Farzanegan, M. R. (2018). Institutions and the effectiveness of expenditures on environmental protection: evidence from Middle Eastern countries. Constitutional Political Economy, 29, 20-39.

Grant, D., Running, K., Bergstrand, K., & York, R. (2014). A sustainable “building block”?: The paradoxical effects of thermal efficiency on US power plants’ CO2 emissions. Energy Policy, 75, 398-402.

IEA. (2020). IEA, data and statistics. doi:https://www.iea.org/data-and-statistics

Institute, W. R. (2020). 4 Charts Explain Greenhouse Gas Emissions by Countries and Sectors. Retrieved from

IRENA. (2019). Renewable Energy Market Analysis: GCC 2019. Irena, 1-110.

Jevons, W. S. (2007). The coal question.

Jindal, A., & Nilakantan, R. (2021). Falling efficiency levels of Indian coal-fired power plants: A slacks-based analysis. Energy Economics, 93, 105022. doi:10.1016/j.eneco.2020.105022

Mountford, H., Waskow, D., Gonzalez, L., Gajjar, C., Cogswell, N., Holt, M., Gerholdt, R. (2021). COP26: Key Outcomes From the UN Climate Talks in Glasgow.

NETL, N. E. T. L. (2008). National Energy Technology Laboratory (NETL), 2008. Reducing CO2 Emissions by Improving the Efficiency of the Existing Coal-fired Power Plant Fleet.

Painuly, J. P. (2001). Barriers to renewable energy penetration; a framework for analysis. Renewable energy, 24, 73-89.

Peng, Y., Yang, Q., Wang, L., Wang, S., Li, J., Zhang, X.,.Wang, C. (2021). VOC emissions of coal-fired power plants in China based on life cycle assessment method. Fuel, 292, 120325.

Rodrigues, J. F. D., Wang, J., Behrens, P., & de Boer, P. (2020). Drivers of CO2 emissions from electricity generation in the European Union 2000–2015. Renewable and Sustainable Energy Reviews, 133. doi:10.1016/j.rser.2020.110104

Schleussner, C.-F., Rogelj, J., Schaeffer, M., Lissner, T., Licker, R., Fischer, E. M., Hare, W. (2016). Science and policy characteristics of the Paris Agreement temperature goal. Nature Climate Change, 6, 827-835.

Sharma, R., & Kautish, P. (2020). Examining the nonlinear impact of coal and oil-based electricity production on CO2 emissions in India. The Electricity Journal, 33, 106775.

Song, Q., Wang, Z., Li, J., Duan, H., Yu, D., & Liu, G. (2018). Comparative life cycle GHG emissions from local electricity generation using heavy oil, natural gas, and MSW incineration in Macau. Renewable and Sustainable Energy Reviews, 81, 2450-2459.

Wang, J., Song, C., & Yuan, R. (2021). CO2 emissions from electricity generation in China during 1997-2040: The roles of energy transition and thermal power generation efficiency. Science of The Total Environment, 145026.

Wang, Y., Zhang, Q., & Li, C. (2019). The contribution of non-fossil power generation to reduction of electricity-related CO2 emissions: A panel quintile regression analysis. Journal of Cleaner Production, 207, 531-541.

Zhang, K., Zhang, Z.-Y., & Liang, Q.-M. (2017). An empirical analysis of the green paradox in China: From the perspective of fiscal decentralization. Energy Policy, 103, 203-211.

Zhang, N., & Choi, Y. (2013). A comparative study of dynamic changes in CO2 emission performance of fossil fuel power plants in China and Korea. Energy Policy, 62, 324-332**.**