CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

ISBN 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106018

The Role of Renewable Power Generation in Sustainable Economic Growth and Climate Change Mitigation: An Asian Countries' Perspective

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As the global demand for electricity continues to grow, energy consumption for electricity production is increasing on a global scale. To address the growing power demand, the implementation of effective energy policies is crucial in alleviating the impact of energy consumption on climate change and ensuring the sustainability of the economy. From this perspective, this study analyses the role of renewable power generation (REPG) in sustainable economic growth and climate change mitigation in comparison with power generation from non-renewable energy sources (NREPG) based on the data from ten Asian countries. The study applies the fully modified ordinary least squares (FMOLS) and pairwise Dumitrescu-Hurlin causality tests. The results of both FMOLS and Dumitrescu-Hurlin causality tests show that REPG, including hydropower generation, has a significant positive impact on long run economic growth and makes a substantial contribution to reducing CO_2 emissions. NREPG, including coal power generation, has a significant long-term impact on GDP, but it is found to be unviable for climate change mitigation. Both REPG and NREPG have long term economic viability, but REPG is more favorable than NREPG in terms of CO_2 emissions. Therefore, REPG is identified to be a reliable source of power generation in maintaining a secure economy and minimizing the impact of climate change. Future power supply should focus on renewable energy sources. To foster renewable power production, REPG projects should be encouraged with attractive policies for project investments and implementation.

1. Introduction

Sustainable power supply is vital for maintaining economic development. In developing countries, sufficient electricity supply is the most fundamental factor for economic development (Morimoto and Hope, 2004). Despite its significance to economic development, power generation causes greenhouse gas (CO_2) emissions through the consumption of multiple energy sources. Power generation utilizes hydro, solar, wind, nuclear, geothermal, and biofuel (renewable energy sources) as well as oil, gas, and coal (non-renewable energy sources) (NEA/IEA, 2020). The role of power generation is controversial, as it balances the dual needs of maintaining a nation's economy and mitigating the impact of climate change.

Earlier studies have highlighted the role of aggregate power generation in fostering economies in different regions. Power generation had a long-run relationship with economic growth in Sudan in the period 1980-2013 (Awad and Yossof, 2015). Increased power generation stimulated economic growth in Spain over the period 1958-2015 (Jaime et al., 2021). There is a stronger connection between power production and GDP in some European countries in the period 2018-2020 (Szustak et al., 2022). In accordance with the growing awareness of environmental protection, power generation from renewable energy sources is also developing. Renewable energy is a clean or green energy source with low environmental pollutants, but there are some arguments regarding the role of REPG in economic growth. According to Susana et al. (2012), the share of REPG in total power production had a negative connection with GDP in Denmark, Portugal and Spain during 1960-2004. This finding discourages the implementation of REPG. Anam et al. (2021) show mutual effects between renewable power supply and GDP in twenty-five developing countries in the period 1990-2017. The result indicates that

Paper Received: 13 April 2023; Revised: 20 July 2023; Accepted: 09 August 2023
Please cite this article as: Thein E.E., Shimada K., 2023, The Role of Renewable Power Generation in Sustainable Economic Growth and Climate Change Mitigation: An Asian Countries' Perspective, Chemical Engineering Transactions, 106, 103-108 DOI:10.3303/CET23106018

REPG has a long-run effect on GDP. These studies only examine the economic impact of power generation and do not focus on its environmental impact.

Some studies examine the impacts of REPG on both economic growth and climate change. In Nigeria and South African countries, hydro, oil, and gas power had a positive contribution to economic growth in the period 1970-2010 (Okafor, 2012). Over the period 1966-2014 in Japan, electricity generated from hydro, gas, oil, and nuclear had a positive long-run effect on economic growth and negative effect on CO_2 emissions, while electricity generated from coal had a negative relation with economic growth and positive relation with CO_2 emissions (Villanthenkodath and Mohammed, 2023). This study supports power generation from hydro, gas, oil, and nuclear energy sources and discourages coal power production for supporting economic growth and climate change mitigation.

As power demand is globally increasing, the share of energy consumed by electricity production in total energy consumption has risen from 15.5 % in 2000 to 19.2 % in 2018 (IEA, 2019). Enhancing power supply to meet the growing demand requires energy policies that are vital for mitigating the environmental impacts of energy consumption and sustaining the economy (Villanthenkodath and Mohammed, 2023). In this regard, it is important to identify reliable energy sources for power generation to sustain economic growth and minimize CO_2 emissions. The impact of power generation from various energy sources on a country's economy and environment needs to be investigated. Despite the importance of power generation in energy policies, studies on the significance of power generation in connection with GDP and climate change impact in Asian countries are limited. This study examines the role of renewable power generation (REPG) in sustainable economic growth and climate change mitigation compared to that of non-renewable power generation (NREPG) in Asian countries.

2. Methodology

2.1 Method

This study investigates the impact of REPG on sustainable economic growth and its influence on climate change mitigation (measured by CO_2 emission) in comparison with that of NREPG based on the concept of Cobb-Douglas production function. REPG and NREPG are considered as production functions and added to the Cobb-Douglas production equation as shown in Eq(1). The analysis is based on a study conducted by Ahmed and Shimada (2019), which investigates the effects of renewable energy consumption on sustainable economic development.

$$GDP = f(REPG, NREPG, Labour, Capital\,) \tag{1}$$

Then, Eq(1) is rewritten as follows as Eq(2).

$$LogGDP_{it} = \alpha + \beta_1 LogREPG_{it} + \beta_2 LogNREPG_{it} + \beta_3 LogLabour_{it} + \beta_4 LogCapital_{it} + \varepsilon_{it} \tag{2}$$

Eq(2) examines the impacts of REPG on economic growth, where, subscripts i and t represent the country and time (year), GDP represents the country's economic growth, and REPG and NREPG denote renewable and non-renewable power generation (GWh). Labour (Total labour force) and $\mathrm{Capital}$ (fixed capital formation) are control variables. $\varepsilon_{\mathrm{it}}$ is the error term. To simplify the results, the study applies logarithmic functions.

Eq(3) investigates the impacts of REPG on climate change mitigation. $\mathrm{CO_2}$ represents greenhouse gas emissions as a proxy of climate change. GDP is a control variable that influences $\mathrm{CO_2}$ emissions.

$$LogCO_{2_{it}} = \alpha + \beta_1 LogREPG_{it} + \beta_2 LogNREPG_{it} + \beta_3 LogGDP_{it} + \varepsilon_{it} \tag{3}$$

The study measures the effects of power generation from various energy sources on GDP and $\mathrm{CO_2}$ emissions. Since long run panel data for nuclear, wind, and solar power generation are not available, these variables are not included in the analysis. Eq(4) and (5) examine the effects of power generation from various energy sources on GDP and $\mathrm{CO_2}$ emissions. In Eq(4), Hydro means the power generation from hydro (RE source) and $\mathrm{Oil, Gas, and\ Coal}$ represent power generation from oil, gas, and coal (NRE sources).

$$\begin{aligned} LogGDP_{it} = \alpha + \beta_1 LogOil_{it} + \beta_2\, LogGas_{it} + \beta_3\, LogCoal_{it} + \beta_2\, LogHydro_{it} + \beta_{\,5}\, LogLabour_{it} \\ + \beta_3\, LogCapital_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

$$LogCO_{2_{it}} = \alpha + \beta_1\, LogOil_{it} + \beta_2\, LogGas_{it} + \beta_3\, LogCoal_{it} + \beta_4 LogHydro_{it} + \beta_5\, LogGDP_{it} + \varepsilon_{it} \tag{5}$$

Eq(2) to Eq(5) are the main models used for the analyses. The study examines the existence of long-run cointegration among independent and dependent variables using the Pedroni cointegration test, Kao cointegration test, and fully modified ordinary least square (FMOLS) test and then, finds the causality among variables using the Dumitrescu-Hurlin causality test.

2.2 Data

The data used in the analyses and their respective sources are GDP and labour force (World Bank: World Development Indicators dataset), fixed capital formation (International Monetary Fund's investment and capital stock dataset 2021), power generation from various energy sources (World Energy Statistics Global database), and CO_2 emission from electricity and heat (Our World in Data). The sample dataset comprises ten Asian countries: China, India, Indonesia, Japan, Malaysia, Philippines, South Korea, Singapore, Thailand, and Vietnam, covering the period from 1990 to 2019. The study uses a strongly balanced dataset (10 countries x 30 y) for Eq(2) and Eq(3). Due to Singapore's lack of hydropower and coal power production and inadequate data availability of some countries, an unbalanced dataset is applied for Eq(4) and Eq(5).

3. Results and Discussion

To follow the procedures of the FMOLS test, the study firstly examines the presence of cross-sectional dependence in the panel data using the cross-section dependence (CD) tests. The panels include two dependent variables (GDP and $\mathrm{CO_2}$) and eight independent variables (REPG, NREPG, Hydro, Oil, Gas, Coal, Labour, and $\mathrm{Capital}$). The results of the CD test prove the existence of cross-section dependence in all panels at 1 % significance level. Secondly, the study checks the presence of non-stationary variables using the Levin-Lin-Chu unit root tests. The first differences of all panel variables are stationary at 1 % significance level. Thirdly, given the existence of cross-section dependence and stationary variables in the panel data, the study examines the cointegration among the dependent and independent variables in each equation (Eq(2) to (5)) using the Pedroni cointegration test and Kao cointegration test. Table 1 shows the results of Eq(2) and (3). The results of five Pedroni tests in Eq(2) and seven Pedroni tests in Eq(3) are significant. Consistent with these results, the Kao tests' results in both equations are significant, indicating the cointegration of all panels for each equation.

Table 1: The results of cointegration tests for Eq(2) and Eq(3)

	Eq(2)				Eq(3)			
Test categories	Statistics	P-value	Weighted Statistics	P-value	Statistics	P-value	Weighted Statistics	P-value
Pedroni residual cointegration tests								
Panel v-Statistic	3.010***	(0.001)	2.367***	(0.009)	−2.524	(0.994)	−2.676	(0.996)
Panel rho-Statistic	1.770	(0.962)	−1.928	(0.973)	−2.035***	(0.021)	−0.729	(0.233)
Panel PP-Statistic	−0.523	(0.301)	−0.644	(0.260)	−4.029***	(0.000)	−3.068***	(0.001)
Panel ADF-Statistic	−1.502**	(0.067)	−1.738***	(0.041)	−3.777***	(0.000)	−2.969***	(0.002)
Group rho-Statistics	2.962	(0.999)			−0.357	(0.360)		
Group PP-Statistics	−0.669	(0.252)			−3.336***	(0.000)		
Group ADF-Statistics	−2.704***	(0.003)			−3.641***	(0.000)		
Kao residual cointegration test	−4.378***	(0.000)			−2.921***	(0.000)		

Note: Null hypothesis; No cointegration. **<p-value 0.05 and ***<p-value 0.01.

Table 2 presents the results of Pedroni tests and Kao cointegration test for Eq(4) and (5). In Table 2, the results of five Pedroni tests in Eq(4) and six Pedroni tests in Eq(5) are significant and show the long run cointegration among the panels. Additionally, the Kao tests' results indicate the cointegration of all panels in each equation. Both Pedroni cointegration tests and Kao cointegration tests reveal a long run cointegration of all panel variables, electricity generation from multiple energy sources, economic growth, and CO_2 emissions. Then, the study proceeds the FMOLS test.

Table 3 illustrates the results of FMOLS test for equation (2) which investigates the long run impact of REPG on economic growth. The results prove a significant long-run positive relationship between REPG and economic growth. 1 % increase in REPG causes 0.05 % positive change in GDP. The economic impact of REPG is insignificant compared to that of NREPG, which has a coefficient of 0.21 %. The results of labour and capital are consistent with the concept of Cobb-Douglas production function. Labour productivity shows the largest impact on GDP in Asian countries.

Table 2: The results of cointegration tests for Eq(4) and Eq(5)

Test categories	Eq(4) Statistics	P-value	Weighted Statistics	P-value	Eq(5) Statistics	P-value	Weighted Statistics	P-value
Pedroni residual cointegration tests								
Panel v-Statistic	1.963***	(0.025)	2.057***	(0.020)	0.127	(0.449)	−1.257	(0.896)
Panel rho-Statistic	3.835	(0.999)	3.435	(0.999)	0.161	(0.564)	−0.165	(0.434)
Panel PP-Statistic	2.177	(0.985)	0.847	(0.802)	−3.198***	(0.000)	−3.894***	(0.000)
Panel ADF-Statistic	−2.388***	(0.009)	−2.074***	(0.019)	−3.397**	(0.000)	−4.277***	(0.000)
Group rho-Statistics	4.712	(1.000)			0.998	(0.841)		
Group PP-Statistics	0.283	(0.611)			−4.184***	(0.000)		
Group ADF-Statistics	−2.324***	(0.010)			−4.495**	(0.000)		
Kao residual cointegration test	−4.524***	(0.000)			−2.870***	(0.002)		

Note: Null hypothesis; No cointegration. **<p-value 0.05 and ***<p-value 0.01.

Table 3: Estimated results of panel FMOLS test for Eq(2)

Dependent variable	REPG	NREPG	Labour	Capital	Number of Observations
GDP	0.054***	0.214***	0.972***	0.253***	290
	(0.021)	(0.037)	(0.145)	(0.061)	

Note: Standard errors are in parentheses. *** <p-value 0.01 and ** <p-value 0.05.

Table 4 illustrates the impact of REPG on CO_2 emission. The result shows a long run negative significant impact of REPG on CO_2 emission. 1 % increase in REPG reduces CO_2 emission by 0.09 %. The NREPG has a positive relationship with CO_2 emission. 1 % increase in NREPG contributes to an increase of 0.5 % in CO_2 emission. The results indicate that REPG can be viable for reducing the impact of climate change, but NREPG raises CO_2 emission. GDP positively influences CO_2 emission. Economic growth causes increased electricity demand and consequently, contributes to climate change with increased CO_2 emission.

Table 4: Estimated results of panel FMOLS test for Eq(3)

Dependent variable	REPG	NREPG	GDP	Number of observations
CO_2	−0.086**	0.566***	0.497***	290
	(0.048)	(0.070)	(0.135)	

Note: Standard errors are in parentheses. *** <p-value 0.01 and ** <p-value 0.05.

The results presented in Tables (3) and (4) indicate the significant contribution of REPG to fostering the economy and mitigating CO_2 emission. Compared to REPG, NREPG has a large positive impact on economic growth. The increased NREPG will have a significant impact on climate change through increasing CO_2 emissions. The results reveal that investment in REPG can be beneficial to secure the economy and reduce CO_2 emissions.

Table 5: Estimated results of panel FMOLS test for Eq(4)

Dependent variable	Hydro	Oil	Coal	Gas	Labour	Capital	Number of Observation
GDP	0.030**	0.014	0.122***	0. 032	1.059***	0.414***	253
	(0.017)	(0.009)	(0.027)	(0.020)	(0.203)	(0.066)	

Note: Standard errors are in parentheses. ***<p-value 0.05 and **<p-value 0.10.

Table 5 expresses the estimated results of Eq(4) which examines the impacts of various power sources on economic growth. The results prove the long-run positive and significant impact of hydropower and coal power generation on GDP. A 1 % increase in hydropower generation increases GDP by 0.03 %. Like the results in Table 1, the contribution of hydropower (RE source) generation to GDP is smaller than that of coal power (NRE source) generation. Every 1 % increase in coal power generation contributes to an increase in GDP by 0.12 %. Oil power and gas power generation do not show any significant impacts on GDP.

Table 6 shows the long run impacts of power generation from various energy sources on CO_2 emissions. The result proves a long-run negative impact of hydropower generation on CO_2 emissions. A 1 % increase in hydropower generation mitigates CO_2 emissions by 0.05 %. Power generation from oil, gas, and coal (NRE sources) has a positive impact on CO_2 emissions. Every 1 % increase in coal power raises CO_2 emission by 0.36 %, which is the largest environmental impact, followed by gas power (0.15 %) and oil power (0.05 %). According to the results in Tables (5) and (6), renewable hydropower generation significantly contributes to economic growth and climate change mitigation. Coal power generation has large economic and environmental impacts. Power generation from oil and gas has a positive contribution to CO_2 emissions although both power sources do not show any significant economic contribution. In considering economic contribution and alleviating CO_2 emissions, hydropower is the most suitable source of power generation among various energy sources.

Table 6: Estimated results of panel FMOLS test for Eq(5)

Dependent variable	Hydro	Oil	Gas	Coal	GDP	Number of observations
CO_2	−0.046**	0.047***	0.145***	0.363***	0.533***	253
	(0.024)	(0.010)	(0.011)	(0.022)	(0.056)	

Note: Standard errors are in parentheses. ***<p-value 0.01 and 0.05, and **<p-value 0.10.

Table 7 presents the results of pairwise Dimitrescu & Hurlin panel causality tests. Causality tests are conducted to examine the causal relationship between variables in panel data. The tests determine whether the relationship between two variables is bidirectional causality (where both variables have mutual effects on each other), or unidirectional causality (where only one variable has effect on the other), or non-causality (Dimitrescu and Hurlin 2012). The causality tests reveal that REPG, including hydropower generation, has bidirectional causality with GDP. The results explain long term mutual support relationship between REPG and economic growth in Asian countries. Bidirectional causality between REPG and capital indicates that REPG and investment stimulate each other and ultimately, they contribute to long run economic growth. NREPG, including coal power, has bidirectional causality with GDP. This suggests that both REPG and NREPG have a long run contribution to economic growth, but from the environmental protection view, REPG is preferable to NREPG. Oil and gas power have unidirectional causality with GDP and do not show economic contribution in the long run. These findings are consistent with the results of the FMOLS test and discourage the use of oil and gas power production.

Table 7: Results of pairwise Dimitrescu & Hurlin Panel Causality tests

Null-Hypothesis	Values of Z-bar	P-value	Conclusion
REPG does not homogeneously cause GDP GDP does not homogeneously cause REPG	1.725** 9.729***	(0.084) (0.000)	Bidirectional causality between REPG and GDP
NREPG does not homogeneously cause GDP GDP does not homogeneously cause NREPG	5.525*** 3.884***	(0.000) (0.000)	Bidirectional causality between NREPG and GDP
Cap does not homogeneously cause REPG REPG does not homogeneously cause Cap	12.229*** 6.365***	(0.000) (0.000)	Bidirectional causality between Capital and REPG
GDP does not homogeneously cause Hydro Hydro does not homogeneously cause GDP	4.840*** 2.120***	(0.000) (0.034)	Bidirectional causality between GDP and Hydro
GDP does not homogeneously cause Gas Gas does not homogeneously cause GDP	0.777 2.410***	(0.437) (0.016)	Unidirectional causality between GDP and Gas
GDP does not homogeneously cause Oil Oil does not homogeneously cause GDP	5.114*** 0.541	(0.000) (0.588)	Unidirectional causality between GDP and Oil
GDP does not homogeneously cause Coal Coal does not homogeneously cause GDP	5.097*** 2.122***	(0.000) (0.034)	Bidirectional causality between GDP and Coal

Note: ***<p-value 0.01 and 0.05, and **<p-value 0.10.

Both FMOLS tests and Dimitrescu & Hurlin panel causality tests indicate that REPG, including hydropower generation, is viable for not only maintaining economic growth but also mitigating CO_2 emissions. The results strongly recommend the promotion and encouragement of renewable energy sources in power generation, particularly in Asian countries where NREPG still accounts for a significant portion of total power generation (over 70 % in 2019). Despite significant impact of coal power generation on increasing CO_2 emissions, countries like India (73.9 %), China (64.6 %), Indonesia (62.6 %), and Vietnam (48.7 %) heavily rely on coal power as a major source of electricity. These countries should gradually switch their power generation from non-renewable to renewable energy sources to sustain the natural environment and mitigate the impact of climate change. To facilitate the shift towards renewable power production, government encouragement and support are vital. There are several ways to foster investment in renewable power projects. Private public partnerships are effective for large-scale projects like hydropower and wind power which have high initial costs. Providing technical and financial subsidies, low interest funding, tax incentive and feed-in tariff schemes can attract both local and foreign companies to invest in renewable power projects. Carbon pricing mechanisms, as seen in China, Japan and South Korea, are also effective in stimulating renewable power production. Policymakers need to carefully consider country's specific situation and learn from the experiences of other nations when designing suitable plans. Raising public awareness of environmental protection is crucial for successful implementation of REPG projects. Since REPG's development is limited in some Asian countries and available data are inadequate for conducting long-run test, this study cannot assess the significance of wind power, solar power, nuclear power, and geothermal power to a country's economic and climate change issue. To achieve sustainable environmental and economic policies, further study is required to identify the specific role of each power source in balancing economic growth and climate change mitigation.

4. Conclusion

This study revealed that NREPG has a significant impact on the GDP of the countries but results in increased CO_2 emissions compared to renewable power sources. REPG demonstrates a remarkable positive effect on both GDP and CO2 emissions. To maintain a sustainable economy with minimal environmental impact, it is crucial to promote and support renewable power projects for future power generation, in both developing and developed countries. Coal power production is prevalent in Asian countries and contributes significantly to economic growth, but its substantial environmental impact highlights a reduction in coal power generation and its replacement with renewable energy sources. Governments should prioritize the implementation of proper policies that encourage renewable power production.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 2 0 K 1 2 3 0 8.

References

Ahmed M.M., Shimada K., 2019, The effect of renewable energy consumption on sustainable economic development: Evidence from emerging and developing economies, Energies, 12(15).

Anam A., Muhammad R., Muhammad S., Jiahai Y., 2021, Renewable electricity generation and economic growth nexus in developing countries: An ARDL approach, Economic Research-Ekonomska Istraživanja, 34(1), 2423-2446.

Awad A., Yossof I., 2015, electricity production, economic growth and employment nexus in Sudan: A cointegration approach, International Journal of Energy Economics and Policy, 6(1), 6-13.

Dumitrescu, E. I. and Hurlin, C., 2012, Testing for Granger non-causality in heterogeneous panels. Economic Modelling, 29(4),1450–1460.

Jaime, J.S., Isabel, S., Luis, P.P., 2021, Economic growth or electricity, what came first in Spain after 1958? Applied Economic Analysis, 29(86), 105-123.

International Energy Agency (IEA), 2019, World Energy Outlook 2019, <www.iea.org/reports/world-energy-outlook-2019> accessed 12.10.2022.

Morimoto, R., Hope, C., 2004, The impact of electricity supply on economic growth in Sri Lanka, Energy Economics, 26(1), 77–85.

Nuclear Energy Agency/ International Energy Agency (NEA/IEA), 2020, Projected Costs of Generating Electricity, <www.oecd-nea.org/jcms/pl_51110/projected-costs-of-generating-electricity-2020-edition> accessed 15.11.2022.

Okafor, H. O., 2012, Testing the relationship between energy consumption and economic growth: Evidence from Nigeria and South Africa. Journal of Economics and Sustainable Development 3(11),111–124.

Susana, S., Isabel, S., Carlos, P., 2012, The impact of renewable energy sources on economic growth and CO_2 Emissions - A SVAR approach, European Research Studies,15(4), 134-144.

Szustak, G., Dabrowski P., Gradon, W., Szewczyk, L., 2022, The relationship between energy production and GDP: Evidence from selected European Economies, Energies, 15(1), 50.

Villanthenkodath, M. A., Mohammed, S. P., 2023, Examining the impact of electricity production on economic growth and environmental quality in Japan: A disaggregated level analysis, Environmental Science and Pollution Research, 30(1), 849-868.