Determinants of Power Purchase Agreements and Levelized Cost of Electricity in Renewable Energy Projects

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ปัจจัยที่ส่งผลต่อสัญญาซื้อขายไฟฟ้าและต้นทุนเฉลี่ยต่อหน่วยของการผลิตไฟฟ้าในโครงการ
พลังงานหมุนเวียน

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กฤษณ์ ยอดประดิษฐ์ : ปัจจัยที่ส่งผลต่อสัญญาซื้อขายไฟฟ้าและต้นทุนเฉลี่ยต่อหน่วยของการผลิตไฟฟ้าในโครงการพลังงานหมุนเวียน. (Determinants of Power Purchase Agreements and Levelized Cost of Electricity in Renewable Energy Projects) อ.ที่ปรึกษาหลัก : อ. ดร.นราพงศ์ ศรีวิศาล

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Similar to the concept of concessions, governments worldwide encourage investment in renewable energy by providing a fixed price under the power purchase agreement (PPA) to the renewable energy developers. Depending on each renewable energy technology, the PPA usually corresponds to the levelized costs of electricity (LCOE) or the average lifetime costs of electricity produced by a power plant. Hence, these two parameters play an important role in boosting renewable energy development. Little is however known about the determinants of the PPA and LCOE. Therefore, the paper tries to shed some light on the determinants of the PPA and LCOE of wind and solar technologies with a global (totaling 26 countries) panel data over the period of 2015 to 2019 using a fixed-effects and a system generalized method of moments (sys-GMM) estimation model. We mainly find that the trend of PPA in a more mature wind technology has tapered off but still driven mainly by the technological costs and how risky the banks view the wind projects. Meanwhile, the trend of PPA in a less mature solar technology is still declining and affected by the additional demand shifted from conventional energy such as oil, natural gas, and coal towards renewable energy and the environmental pressure from high CO_2 emissions. The LCOE's of wind and solar energy are both in a downward trend and driven mainly by the reduction in technological costs, the additional demand from conventional energy players and the pressure from high CO_2 emissions with the solar LCOE also depending on the bank's perspective. Lastly, the investment environment through the FDI, inflation, and long-term interest rates can also affect the PPA and LCOE. Implications of our results are also mentioned.

Field of Study:	Finance	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....

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Krit Yodpradit

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1. INTRODUCTION

In the Paris Agreement, December 2015, governments worldwide committed to the reduction of CO_2 emissions to address climate change issues. The power sector accounts for 32% of global CO_2 emissions (IRENA, 2020). As a result, one of the driving forces for the transition towards a greener economy to reduce global warming is the development of renewable energy (RE). Due to a considerable amount of policy measures to support the RE adoption, the International Energy Agency (IEA) has observed the unexpectedly rapid growth in the RE industry and has consistently underestimated RE growth from 2000 to 2016 (IEA, 2017) as shown in Fig. 1.

As the RE market continues to flourish, a number of players have entered the industry. Consequently, the market becomes tighter, which is good in the eye of the governments as high competition leads to more RE adoption and lower emissions. However, the RE developers (RE corporates) find it difficult to squeeze profits out of the RE projects in a highly competitive market. The mechanism of profit-making in the RE market is simply revenues from the electricity sold under a fixed-price contract called a power purchase agreement (PPA) minus costs from the averaged lifetime costs of electricity produced, also known as levelized cost of electricity (LCOE). Every project has a different PPA and LCOE and thus a different profit profile. Cumulatively, a country also has a different profit profile in the RE industry.

Since the profit margin is becoming thinner in recent years as demonstrated in Fig. 2 by the dotted red line showing PPA is becoming relatively smaller than LCOE for offshore wind projects, suggesting more competition and reduced support schemes from governments in the RE industry, it is of an imperative advantage to see the determinants of PPA and LCOE. For instance, RE corporates can identify and formulate their strategy based on the trends, drivers, and barriers of the profit-making mechanism in the RE market. The benefits of this knowledge need not limit to RE enterprises. The government can utilize the outcomes for energy policy, Merger & Acquisition (M&A) corporations can make decisions to pursue projects in profitable countries, and even residents can decide whether to put solar panels on their roofs.

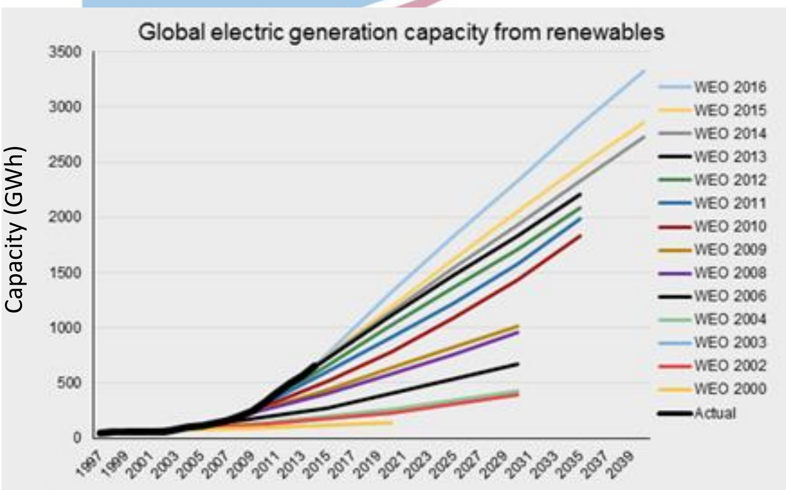

Fig. 1 Underestimated Growth Prediction of Wind and Solar Sectors (IEA, 2017)

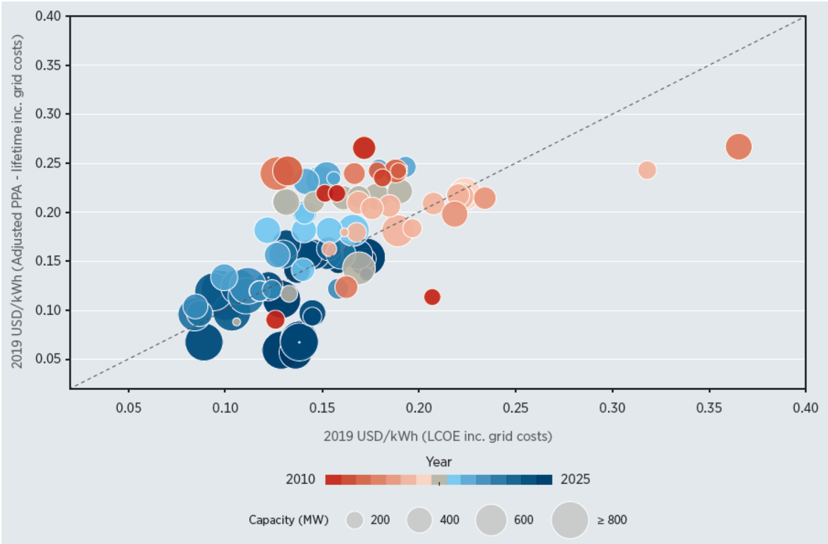

Fig. 2 Offshore Wind Project LCOE vs. Auction/PPA Pricing, 2010-2025 (IRENA, 2020)

In this paper, we attempt to shed some light on the determinants of PPA and LCOE in the RE market. Specifically, we carry out an econometric study to test how significant PPA and LCOE are affected by the market environment in 26 countries globally from 2015 to 2019 with 2 panels for wind and solar technologies. Our study considers the most relevant factors and develops hypotheses that influence PPA and LCOE.

2. LITERATURE REVIEW

A. BACKGROUND

Levelized Cost of Electricity (LCOE): LCOE is an economic measure that shows the averaged lifetime costs of electricity produced. It is typically used to compare across different power generation technologies with dissimilar characteristics such as useful lives, capital costs, project sizes, construction costs, operation and maintenance (O&M) costs, etc. As RE technologies have advanced, their costs have significantly decreased and their competitiveness over those of fossil fuel counterparts have become prominent, investors and policymakers are often interested in LCOEs to make an investment decision, to devise incentive schemes, and more importantly to understand the long-term economic trends of RE technology.

Power Purchase Agreement (PPA): When a RE project is created, the power seller (project developer) usually signs a long-term contract (to sell the electricity at a fixed and specified price over a certain period) with an obligated buyer called an off-taker (e.g. a utility or a corporate) often in the form of a PPA. The agreed price is usually determined at a higher price than the spot electricity price in the market as an incentive from the government or at a breakeven price (usually higher than LCOE to account for additional risks such as credit and transmission risks (Raikar and Adamson, 2019) with corporates. As more RE power plants are being built and sometimes even exceed the government's mandates in some countries, constant reduction of the agreed price has been observed (IRENA, 2020).

B. EXISTING LITERATURE OF ENERGY-RELATED DETERMINANTS

Past literature on RE development concentrated on a descriptive and survey (qualitative) approach to identify the drivers of RE diffusion (del Río and Gual, 2007; del Río, 2008; Lipp, 2007; Haas et al., 2011; Lesser and Su, 2008; Wang, 2016; Van Rooijen and Van Wees, 2006; Kumar et al., 2010; Jäger-Waldau, 2007). Only recently, the research has shifted towards a more econometric and statistical (quantitative) means to study RE development through the effectiveness of RE incentive mechanisms such as feed-in tariffs (FIT) and renewable portfolio standards (RPS) of policymakers (Jenner et al., 2013; Menz and Vachon, 2006; Alagappan, et al., 2011; Carley, 2009), RE consumption (Omri and Nguyen, 2014; Sadorsky, 2009; Salim and Rafiq, 2012; Apergis and Payne, 2010, 2011), and the role of financial intermediaries (Le et al., 2020; Tamazian and Rao, 2010; Jalil and Feridun, 2011; Brunnschweiler, 2010; Fangmin and Jun, 2011; Corsatea et al., 2014), and CO_2 emissions (Tamazian et al., 2009; Jaforullah and King, 2015; Sadorsky 2009; Van Rooijen and Van Vuuren, 2009; Menyah and Wolde-Rufael, 2010), and other factors (Marques and Fuinhas, 2011; Sovacool, 2009; Huang et al., 2007; Chang et al., 2009; Sadorsky 2009; Onno, 2019; Costantini and Mazzanti, 2012; Groba, 2014; Groba and Cao, 2015; Fang et al., 2018) towards the cumulative RE capacity or RE development. To the authors' knowledge, there has not been a research paper that has touched on in the vicinity of financial (or profit-making) aspect in the RE industry, specifically the determinants of PPA and LCOE.

Similar to such energy commodity, albeit not as volatile as oil, PPA and LCOE of renewable energy can be influenced by supply (more support policies from the public sectors that increase the PPA levels or lower prices of raw material for RE technology that reduce the LCOE) and demand (more RE developers trying to seize the PPAs with a high fixed price can decrease the overall PPA levels or the lender raising the loan margin to the developer can increase the overall cost and hence LCOE) in the market. Supply and demand for oil have been utilized to construct various predictive models for the oil price and its volatilities (Liu et al., 2016; Groen, 2014; Wang, 2015; Yin and Yang, 2016; Drachal, 2016; Chevillon and Rifflart, 2009; Naser, 2016; Wei et al., 2017; Kim and Vera, 2019; Kruse and Wegener, 2020; Chatziantoniou et al., 2021). Moreover, various macro-economic fundamentals have also been used as determinants to explain the movements of oil prices. Therefore, this paper will also take into consideration the concept of demand and supply from the energy commodity (oil) evidence in past literature to better describe the drivers of PPA and LCOE.

A vast amount of literature has particularly focused on the development and promotion of RE and has attempted to identify what drives and hinders it to suggest mostly to the public sectors what schemes to put forward to boost RE shares. Although private sectors can also strategically benefit from the indirect interpretation of previous papers; for instance, (Onno, 2019; Costantini and Mazzanti, 2012; Groba, 2014; Groba and Cao) have touched on the trade openness and competitive advantage of a country in the RE industry, this paper expands on the existing literature in that this paper introduces a new finance-wise concept of the profit-making mechanism through PPA and LCOE that aims at helping the public, private, and even residential sectors make strategic investment decisions.

3. HYPOTHESIS DEVELOPMENT

In RE, project developers can also boost profits by maximizing the selling fixed price of electricity under the power purchase agreement (PPA) and minimizing the average cost of electricity (LCOE) over the project's lifetime. PPA and LCOE of wind and solar technologies are different as each has different characteristics in terms of cost structures, technological advancements, and government support schemes, to name a few.

Broadly speaking, the observed reductions in PPA and LCOE are driven by the competitiveness in the RE market. The government gradually withdraws support policies (reducing the fixed price under a PPA), which are initially set as incentives to allure RE project developers, as its mandates towards the environment are fulfilled. The costs of RE projects, on the other hand, have significantly dropped as manufacturing processes and power plant efficiency have improved, and the operation and maintenance (O&M) and associated installed costs have been reduced. It should be noted that the price structures of

PPA and LCOE are different across countries and technologies. Therefore, the samples are divided into 2 panels (wind and solar technologies). In summary, the research question of this paper is: what are the determinants that could explain the downward trends of PPA and LCOE, and how significant are the impacts of these factors in each subgroup-year?

Loan Margin (LM): As illustrated by (Le et al., 2020; Tamazian and Rao, 2010; Jalil and Feridun, 2011; Brunnschweiler, 2010; Fangmin and Jun, 2011; Corsatea et al., 2014), financial development is statistically significant for RE development. Project finance in RE has proven to be more popular than traditional corporate finance and is usually characterized as high leverage (high debt) (Raikar and Adamson, 2019). The main source of debt comes from bank loans as a source of capital; therefore, the ease of developing a RE project depends partly on the loan lender margin that takes into account the associated risks of the project and is charged upon market borrowing rate. As the banks gain experience from their customers in RE projects recently, they become more comfortable and are willing to give the loan with a lower interest rate. A decrease in loan margins should directly lead to a drop in LCOE as the lower loan margins mean lower underlying risks of project. Lower loan margins will also cause an increase in PPA as the rational off-takers will adjust the PPA in response to the lower project underlying risks. Thus, we test the hypothesis: *H1 – A drop in loan margins charged by the bank leads higher PPA and lower costs (LCOE)*.

Cumulative Capacity (CAP): Following the logic from (Jenner et al., 2013), instead of annual change in RE power capacity, actual cumulative RE power capacity should be preferred to capture the long-term downward trends of PPA and LCOE. It is worth mentioning that the power capacity of a power plant is technically the maximum capacity of energy per unit of time it can generate. The cumulative capacity can also be viewed as the development of RE technology. An increase in RE capacity translates to higher RE supply as more project developers are added to the market. According to the law of supply and demand, the added developers are seen as an increase in the RE supply. Consequently, this will bring down the PPA. On the other hand, regarding the cost side, when more project developers are added to the system, more demand towards the RE resources such as RE equipment or lands. This can drive up the prices of equipment and land leasing prices as the RE manufacturers and land leasers who try to rationally maximize their profits will adjust the prices in response to the increase in the demand. As a result, this will bring up the LCOE. We test the hypothesis: *H2 – RE technological development leads to lower PPA and higher LCOE.*

O&M Costs (OMC) and Installed Cost (CAPEX): To capture the reduction in costs resulting from technological advancements over time, the operation and maintenance (O&M) costs and installed cost (CAPEX) of each RE technology are included. It should be noted that offshore wind farms, for instance, may have higher O&M costs and installed cost as higher-paid engineers need to travel to the wind farm located in the middle of the ocean to build and maintain the power plant, whereas these costs are lower in solar photovoltaic (PV) farms. We postulate that the reduction in OMC and CAPEX directly leads a decrease in costs (LCOE) as well as the PPA. The latter can be justified by the fact that the rational off-takers will adjust the PPA price in response to the reduced costs because they need not necessarily provide high incentives to induce investments in RE when the costs are already low. Hence, we test the hypothesis: *H3 – Reduction in OMC and CAPEX will lower LCOE and lower PPA*.

Consumption of Fossil Fuels (CFF): Burning fossil fuels (oil, coal, and natural gas) has been a cheaper way to generate electricity as it does not internalize the environmental and social costs and when embedded with such costs, the alternative RE can become more competitive than the traditional fossil fuels (Raikar and Adamson, 2019; Menz and Vachon, 2016; Marques and Fuinhas, 2011). Dependency on fossil fuels such as Saudi Arabia or Abu Dhabi that rely on oil production can discourage RE development and force the public sectors to boost incentives to induce more project developers. Having said that, Saudi Arabia or Abu Dhabi have started to diversify their energy portfolios and prepare for their greener futures (Marques and Fuinhas, 2011). We conjecture that higher consumption in conventional energy, fossil fuels, translates to relatively lower consumption in alternative energy such as RE and the lack of investments in RE. Hence, fewer project developers are introduced to the market, which translates to lower RE supply (higher PPA). On the other hand, the equipment manufacturers or landowners will rationally their prices in response to the decrease in demand towards RE equipment and lands (lower LCOE). We test the hypothesis: *H4 – High fossil fuel consumption leads to higher PPA and lower LCOE.*

Prices of Fossil Fuels (PFF) and Volatility of Prices of Fossil Fuels (VPFF): When the prices of oil, coal, and natural gas rise, businesses are motivated to move towards another alternative source of energy due to higher production costs and higher volatility (risks) of fuel prices. We posit that an increase in prices of fossil fuels and their volatilities should positively influence the investment climate in the alternative RE, boosting more supply (more project developers) into the RE market. With a similar logic presented earlier, this leads to lower PPA and higher LCOE. We test the hypothesis: *H5 – High fossil fuel prices and their volatilities could lead lower PPA and higher LCOE.*

CO_2 Emissions (CO2): CO_2 contributes the most to greenhouse gases that cause climate change. The popular effort to fight global warming and reduce the amount of CO_2 has pushed the use of the conventional (dirty) energy industry towards RE as the world is becoming more digitalized and more than ever dependent on power from electricity (IRENA, 2020). Furthermore, it has been found in (Tamazian et al., 2009; Jaforullah and King, 2015; Sadorsky 2009; Van Rooijen and Van Vuuren, 2009; Menyah and Wolde-Rufael, 2010) that countries with a high level of CO_2 emissions tend to possess already high RE consumption and investments as their governments are committed to the Paris Agreement and determined to slash the amount of CO_2. In other words, an increase in the level of CO_2 emissions induces an influx of project developers to the market through the government's incentives (e.g. tax credits). This will increase the RE supply. With a similar concept of the law of supply and demand presented earlier, it can be inferred that higher level of CO_2 emissions leads to lower PPA and higher LCOE. Thus, we test the hypothesis: *H6 – High CO_2 emissions lead to lower PPA and higher LCOE.*

It is worth mentioning that the impact of environmental commitment on RE supporting policies is also expected. As observed from (Jenner et al., 2013; Menz and Vachon, 2006; Alagappan, et al., 2011; Carley, 2009), it is still debatable whether policies are really effective let alone a high degree of complexity introduced by a number of different policy characteristics. RE support policies come in many types and shapes that are barely comparable across countries. The mere consideration of the number of incentives might lead to a misleading conclusion. Therefore, we opt to exclude the RE supporting mechanisms from our model.

Lastly, we control for macro-economic factors that could potentially affect the demand and supply of PPA and LCOE and account for differences in capital levels and usage. First, real per capita GDP is used to represent the country's income as it becomes standard in econometric analysis across countries to include economic growth (Marques and Fuinhas, 2011; Sovacool, 2009; Huang et al., 2007; Chang et al., 2009; Sadorsky 2009). Second, electricity demand is taken into consideration. Third, foreign direct investments are included as domestic RE demand can be greatly affected by foreign capitals especially where nations' economies depend closely upon one another. Forth, inflation is used to reflect the escalation of prices of goods and services, which can either foster or deteriorate investors' confidence towards RE. Fifth, long-term interest rates, which could encourage or impede investments from private sectors in RE projects, are used as another control variable.

4. DATA AND METHODOLOGY

A. DATA

Data are collected from several independent databases: Bloomberg New Energy Finance (BNEF), World Bank (WB), British Petroleum Statistical Review of World Energy (BP), and Bloomberg. The definition, data frequency, unit, period of collection, and source associated with dependent, explanatory, and control variables are shown in Table 1. We use data from 2015 to 2019 of two RE technologies (wind and solar). The reason we analyze wind and solar sectors is due to the abundance of the database in the wind and solar and that is likely to increase result validity. Then, we omit the project or country with incomplete information. This process leaves us with 26 countries worldwide (23 nations for wind and 21 nations for solar technology, shown in Table 2).

It should be noted that the meaning of LCOE data is from the actual average cost of electricity in each particular year while that of PPA is all the capacity available on the commercial operation date (COD) of RE power plants. In other words, the PPA of a solar project that is signed in 2015 with the COD in 2016 will be counted in 2016. Because each RE technology has a different construction period (e.g. 1-5 years), it should be kept in mind that the measurement error in the dependent variable arises but should not affect the regression process, nonetheless.

Table 1 Variables: Definition, Frequency, Unit, and Source

Variable	Definition	Data	Frequency	Unit	Source
Dependent Variable					
$LCOE_{i,t}$	Levelized cost of electricity	Logarithm of LCOE	Annual	\$/MWh	BNEF[1]
$PPA_{i,t}$	Power purchase agreement	Logarithm of PPA	Annual	\$/MWh	BNEF
Explanatory Variable					
$LM_{i,t}$	Loan Margin	Logarithm of term loan lenders margin	Annual	bps	BNEF
$CAP_{i,t}$	Cumulative Capacity	Logarithm of RE electricity generation	Annual	GWh	BNEF
$OMC_{i,t}$	O&M Cost	Logarithm of operation and maintenance cost	Annual	k\$/MWh/yr	BNEF
$CAPEX_{i,t}$	Installed Cost	Logarithm of installed cost	Annual	M\$/MWh	BNEF
$CFF_{i,t}$	Consumption of fossil fuels	Logarithm of consumption of oil, coal, natural gas	Annual	EJ	BP[2]
$PFF_{i,t}$	Prices of fossil fuels	Logarithm of real prices of oil, coal, natural gas	Annual	\$	BP
$VPFF_{i,t}$	Volatility of prices of fossil fuels	Logarithm of 1M standard deviation of real prices of oil, coal, natural gas	Annual	\$	Bloomberg
$CO2_{i,t}$	CO_2 emissions	Logarithm of per capita CO_2 emissions	Annual	Mtonnes	BP
Control Variable					
$GDP_{i,t}$	Income	Logarithm of real GDP per capita	Annual	\$	WB[3]
$ED_{i,t}$	Electricity Demand	Logarithm of electricity demand	Annual	TWh	BP
$FDI_{i,t}$	Foreign direct investment	FDI/GDP	Annual	%	WB
$Inf_{i,t}$	Inflation	Inflation	Annual	%	WB
$Lint_{i,t}$	Long term interest rate	10Y local government bond rate	Annual	%	Bloomberg

Notes: [1] Bloomberg New Energy Finance, [2] British Petroleum Statistical Review of World Energy, [3] World Bank

Table 2 Country List

Wind	Solar
Argentina, Australia, Brazil, Canada, Chile, China, Denmark, France, Germany, India, Italy, Japan, Mexico, Netherlands, Panama, Peru, Poland, South Africa, Spain, Sweden, Turkey, UK, US	Argentina, Australia, Brazil, Canada, Chile, China, France, Germany, India, Italy, Japan, Malaysia, Mexico, Panama, Peru, South Africa, Thailand, Turkey, UAE, UK, US

In addition, BNEF does not directly provide the price per energy under the PPA of projects in countries outside the US. Hence, corporate auction prices are used as proxies of the PPAs for each country-year. The remaining data of PPA will be desk-researched manually case-by-case from the internet. Statistics (number of observations, mean, standard deviation, minimum and maximum) of dependent, explanatory, and control variables are illustrated in Table 3. Moreover, logarithmic transformation is used to correct for the skewed distribution of both dependent and explanatory variables and for the sake of intuitive interpretation (% change) of a variable.

Although good examples can be observed from (Omri and Nguyen, 2014; Le et al., 2020; Tamazian, 2009; Onno, 2019; Costantini and Mazzanti, 2012), common criticisms around existing literature's quantitative analysis have raised doubts about whether the results are robust and reliable and that can be improved are as follows: small and specific sample (countries and years), inclusion black-swan events, wide technology-type emphasis, and estimation models. This paper aims to resolve these issues by providing a worldwide perspective with the most recent data (at the time of writing) from 2015-2019 with the exclusion of such event as the 2020 financial crisis from the coronavirus pandemic to obtain a more solid trend in RE industry, by separately analyzing wind and solar technologies with a lion's share of 77% (IRENA, 2020), and by testing the validity and comparing the results between different estimators (that are suitable for panel dataset with large cross-sectional span but short duration (Le et al., 2020) to obtain robust and reliable results.

Table 3 Variable Statistics

Variable	Unit	Wind					Solar				
		Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
Dependent Variable											
$LCOE_{i,t}$	$/MWh	115	69.4	22.0	33.9	167.5	104	94.9	41.6	34.8	232.8
$PPA_{i,t}$	$/MWh	115	66.9	32.4	18.5	184.8	104	87.4	55.1	15.2	278.0
Explanatory Variable											
$LM_{i,t}$	bps	115	566	285	200	1,632	104	576	289	175	1,602
$CAP_{i,t}$	GWh	115	20,803	40,029	55	223,870	104	17,578	33,682	1	212,901
$OMC_{i,t}$	k$/MWh/yr	115	25.9	6.4	9.9	51.7	104	21.9	10.6	6.2	73.6
$CAPEX_{i,t}$	M$/MWh	115	1.7	0.4	0.9	2.8	104	1.3	0.6	0.5	4.1
$CFF\_Oil_{i,t}$	EJ	115	5.3	8.5	0.3	37.1	104	5.8	8.7	0.5	37.1
$CFF\_NG_{i,t}$	EJ	115	3.1	5.7	0.0	30.5	104	3.5	5.9	0.0	30.5
$CFF\_Coal_{i,t}$	EJ	115	5.8	16.5	0.0	81.7	104	6.3	17.2	0.0	81.7
$PFF\_Oil_{i,t}$	$	115	55.5	9.2	41.2	71.3	104	55.1	9.2	41.2	71.3
$PFF\_NG_{i,t}$	$	115	5.2	2.5	1.1	11.7	104	5.4	2.7	1.1	11.7
$PFF\_Coal_{i,t}$	$	115	69.9	16.3	51.4	111.7	104	72.0	17.9	51.4	111.7
$VPFF\_Oil_{i,t}$	$	115	1.9	0.4	1.1	2.5	104	1.9	0.4	1.1	2.5
$VPFF\_NG_{i,t}$	$	115	0.1	0.0	0.1	0.1	104	0.1	0.0	0.1	0.1
$VPFF\_Coal_{i,t}$	$	115	2.0	0.4	1.3	2.7	104	2.0	0.4	1.3	2.7
$CO2_{i,t}$	Mtonnes	115	1,032	2,079	33	9,826	104	1,138	2,160	51	9,826
Control Variable											
$GDP_{i,t}$	$	115	30,190	20,512	1,752	65,820	104	25,418	19,082	1,752	57,187
$ED_{i,t}$	TWh	115	818	1,535	29	7,503	104	891	1,597	48	7,503
$FDI_{i,t}$	%	115	3.1	6.7	-39.5	42.2	104	2.7	2.0	0.1	12.1
$Inf_{i,t}$	%	115	4.0	7.8	-0.9	50.6	104	4.3	8.1	-1.9	50.6
$Lint_{i,t}$	%	115	4.3	6.6	-0.2	54.4	104	5.1	6.7	-0.2	54.4

B. METHODOLOGY

Our analysis will be proceeded first by employing a fixed-effects (FE) estimator with the time trend and then adding the lagged term ($Y_{i,t-1}$) and removing the time trend to investigate possible persistency in PPA and LCOE using a two-step system generalized method of moments (sys-GMM) model. The FE and sys-GMM estimation models are shown below, respectively.

$$Y_{it} = \beta_1 LM_{it} + \beta_2 CAP_{it} + \beta_3 OMC_{it} + \beta_4 CAPEX_{it} + \beta_5 CFF_{Oil_{it}} + \beta_6 PFF_{Oil_{it}} + \beta_7 PFF_{NG_{it}} + \beta_8 PFF\_Coal_{it} + \beta_9 VPFF\_Oil_{it} + \beta_{10} VPFF\_NG_{it} + \beta_{11} VPFF\_Coal_{it} + \gamma C_{it} + \delta t + \eta_i + \varepsilon_{it}$$

$$Y_{it} = \alpha Y_{i,t-1} + \beta_1 LM_{it} + \beta_2 CAP_{it} + \beta_3 OMC_{it} + \beta_4 CAPEX_{it} + \beta_5 CFF_{Oil_{it}} + \beta_6 PFF_{Oil_{it}} + \beta_7 PFF_{NG_{it}} + \beta_8 PFF\_Coal_{it} + \beta_9 VPFF\_Oil_{it} + \beta_{10} VPFF\_NG_{it} + \beta_{11} VPFF\_Coal_{it} + \gamma C_{it} + \eta_i + \varepsilon_{it}$$

Where Y_{it} is the dependent variable (i.e. PPA and LCOE) for country i at year t; X_{it} is a vector of explanatory variables such as $LM_{it}, CAP_{it}, OMC_{it}, CAPEX_{it}, CFF_{it}, PFF_{it}, VPFF_{it}, and\ CO2_{it}$; C_{it} is a suite of control variables such as $GDP_{it}, ED_{it}, FDI_{it}, Inf_{it}, and\ Lint_{it}$; δt is the time trend to capture a time-variant component; η_i represents country-level fixed effects; $Y_{i,t-1}$ is the first lagged term of the dependent variable; and α represents the persistency of the dependent variable over time.

5. MAIN RESULTS

First, we test for the potential of multicollinearity problems by building a correlation matrix of explanatory variables for wind and solar panels shown in Table A1 and Table A2, respectively. The figures in Table A1 and Table A2 suggest a multicollinearity problem and hence some variables need to be dropped out. High correlations are observed among explanatory variables; for instance, natural gas consumption (*CCF_NG*) vs. oil consumption (*CCF_Oil*), coal consumption (*CFF_Coal*) vs. RE capacity (*CAP*), CO_2 emissions (*CO2*) vs. *CAP* vs. *CCF_Oil* vs. *CCF_Coal*, and electricity demand (*ED*) vs. *CAP* vs. *CCF_Oil* vs. *CCF_Coal* vs. *CO2*. The relationships between these highly correlated variables can easily be explained: countries with high energy consumption (i.e. high *ED*) tend to consume more fossil fuels (oil, natural gas, and coal) and produce a high amount of CO_2 emissions (high *CO2*). These countries also have a competing incentive to pursue renewable energy, observed by high renewable energy capacity (high *CAP*). In summary, we choose to drop out variables with a correlation of more than 0.85: natural gas consumption (*CCF_NG*), coal consumption (*CCF_Coal*), CO_2 emissions (*CO2*), and electricity demand (*ED*).

Without the 4 explanatory variables (*CCF_NG*, *CCF_Coal*, *CO2*, and *ED)* for the *PPA* and *LCOE* of wind and solar panels, we then perform Breusch-Pegan test with the null hypothesis of no significant unobserved individual effects shown in Table A3. It is found that all 4 panels indicate the existence of unobserved individual effects. We further perform the Hausman test to determine whether the data fit a random-effects or fixed-effects (FE) estimator better with the null hypothesis that the two estimators are consistent. As displayed in Table A3, the test suggests that the data in 3 panels (PPA of wind, PPA of solar, and LCOE of wind) fits the FE better whereas the data of LCOE of solar can be estimated by both random-effects and FE estimators. Therefore, we choose to build a FE model for all panels for the sake of consistency.

As brought up by (Marques and Fuinhas, 2011), a dynamic panel approach can more appropriately be used when there exists a persistency trend of the dependent variable since the dynamic estimators possess 4 main advantages: elimination of unobserved individual effects, allowing the lagged terms explanatory variables be used as instruments (solving the endogeneity problem), preventing the multicollinearity problem, allowing the determination of the persistency or trend of dependent variable

Table 4 Regression Results (Coefficients)

Explanatory Variables	FE Estimator				Sys-GMM Estimator			
	PPA		LCOE		PPA		LCOE	
	Wind	Solar	Wind	Solar	Wind	Solar	Wind	Solar
$Y_{i,t-1}$					0.293 (0.521)	0.809*** (0.182)	0.452** (0.210)	0.112 (0.205)
$LM_{i,t}$	-0.0286 (0.177)	-0.180* (0.122)	0.0424 (0.0569)	0.164*** (0.0592)	-0.330*** (0.119)	-0.244** (0.107)	-0.0178 (0.0580)	-0.0650 (0.0659)
$CAP_{i,t}$	-0.0374 (0.138)	-0.0886*** (0.0300)	0.129*** (0.0444)	0.0252** (0.0145)	0.00643 (0.0593)	-0.0355 (0.0287)	0.0157 (0.0246)	0.0233* (0.0150)
$OMC_{i,t}$	-0.503* (0.307)	0.00887 (0.158)	0.0233 (0.0988)	0.175** (0.0768)	-0.196 (0.238)	0.134 (0.129)	0.198* (0.119)	0.271*** (0.0973)
$CAPEX_{i,t}$	1.248*** (0.371)	-0.169 (0.189)	0.738*** (0.119)	0.576*** (0.0916)	0.860*** (0.325)	-0.0938 (0.187)	0.436** (0.195)	0.484*** (0.150)
$CFF\_Oil_{i,t}$	0.229 (1.167)	-0.193 (0.940)	0.318 (0.375)	-0.833** (0.455)	0.00174 (0.0412)	0.0639* (0.0372)	-0.0187 (0.0221)	0.0215 (0.0549)
$PFF\_Oil_{i,t}$	-0.748 (0.819)	-1.079* (0.722)	-0.453** (0.263)	-0.221 (0.350)	-0.632 (0.659)	-1.223*** (0.453)	-0.540** (0.256)	0.145 (0.542)
$PFF\_NG_{i,t}$	0.0879 (0.262)	-0.00740 (0.213)	0.165** (0.0841)	0.177** (0.103)	0.223 (0.278)	0.0689 (0.113)	0.152*** (0.0577)	0.00993 (0.0425)
$PFF\_Coal_{i,t}$	0.135 (0.414)	0.370 (0.356)	-0.0566 (0.133)	-0.0982 (0.172)	-0.0621 (0.408)	0.288 (0.225)	0.0211 (0.105)	0.0527 (0.215)
$VPFF\_Oil_{i,t}$	0.714 (0.771)	-0.566 (0.563)	-0.120 (0.248)	-0.411* (0.273)	0.208 (0.716)	0.224 (0.277)	-0.494*** (0.173)	-0.249 (0.229)
$VPFF\_NG_{i,t}$	-1.454 (1.941)	2.197* (1.557)	0.315 (0.624)	1.033* (0.755)	-0.362 (1.103)	0.875** (0.370)	1.283*** (0.324)	0.0158 (0.767)
$VPFF\_Coal_{i,t}$	0.181 (0.775)	-1.271** (0.660)	-0.159 (0.249)	-0.359 (0.320)	-0.360 (1.240)	-1.746*** (0.666)	-0.128 (0.344)	0.671 (0.749)
$GDP_{i,t}$	-0.331 (1.645)	0.260 (1.242)	-1.015** (0.529)	-0.258 (0.602)	-0.0897 (0.0906)	-0.0134 (0.0326)	-0.0568* (0.0345)	-0.0533* (0.0343)
$FDI_{i,t}$	0.00132 (0.00375)	0.0103 (0.0176)	-0.000511 (0.00120)	0.00605 (0.00853)	0.00489** (0.00241)	-0.000246 (0.0154)	0.000889** (0.000449)	0.0165* (0.0103)
$Inf_{i,t}$	0.00245 (0.0120)	0.0263*** (0.00939)	-0.000938 (0.00384)	0.00695* (0.00455)	0.00369 (0.00587)	0.00581 (0.00359)	-0.00181 (0.00211)	0.0126*** (0.00275)
$Lint_{i,t}$	0.0108 (0.00838)	0.00412 (0.00631)	-0.00256 (0.00269)	0.000667 (0.00306)	0.00184 (0.00755)	0.00491** (0.00248)	0.00163 (0.00180)	-0.000346 (0.00337)
Time trend	0.0337 (0.108)	-0.241*** (0.0927)	-0.0523* (0.0348)	-0.103** (0.0449)				
Obs	115	104	115	104	92	83	92	83
m2 (p-value)					0.765	0.857	0.103	0.181
Hansen test (p-value)					0.824	0.88	0.443	0.316

Notes: The m2 test for second-order autocorrelation of residuals has H0 of no second-order autocorrelation; the Hansen test for over-identifying restrictions has H0 of instrument validity; ***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively; standard errors are reported in parentheses.

over time. The system generalized method of moments (sys-GMM) estimator, suggested by (Blundell and Bond, 1998), is suitable for dynamic panel data such as the one that involves the previous value of a dependent variable as an explanatory variable. However, the sys-GMM model with a 1-period lagged term of the dependent variable is considered valid only when there are enough valid instruments and there is no second-order autocorrelation (Marques and Fuinhas, 2011).

The regression results of FE and sys-GMM estimation models are shown in Table 4 with the second-order autocorrelation and Hansen tests. The tests suggest that the 2 conditions to make the sys-GMM model with a 1-period lagged term of dependent variable valid are met: The Hansen test suggests that all 4 subpanels have valid instrumental variables; The m2 test suggests no second-order autocorrelations are detected. On the whole, both estimators exhibit consistent results. As illustrated in Table 5, the results of signs of significant variables are robust throughout the PPA and LCOE results for both estimators.

Table 5 Significance Level and Sign of Significant Explanatory Variables

Explanatory Variables	PPA				LCOE			
	Wind		Solar		Wind		Solar	
	FE	Sys-GMM	FE	Sys-GMM	FE	Sys-GMM	FE	Sys-GMM
$Y_{i,t-1}$				***(+)		**(+)		
Time trend			***(-)		*(-)		**(-)	
$LM_{i,t}$		***(-)	*(-)	**(-)			***(+)	
$CAP_{i,t}$			***(-)		***(+)		**(+)	*(+)
$OMC_{i,t}$	*(-)					*(+)	**(+)	***(+)
$CAPEX_{i,t}$	***(+)	***(+)			***(+)	**(+)	***(+)	***(+)
$CFF\_Oil_{i,t}$				*(+)			**(-)	
$PFF\_Oil_{i,t}$			*(-)	***(-)	**(-)	**(-)		
$PFF\_NG_{i,t}$					**(+)	***(+)	**(+)	
$PFF\_Coal_{i,t}$								
$VPFF\_Oil_{i,t}$						***(-)	*(-)	
$VPFF\_NG_{i,t}$			*(+)	**(+)		***(+)	*(+)	
$VPFF\_Coal_{i,t}$			**(-)	***(-)				
$GDP_{i,t}$					**(-)	*(-)		*(-)
$FDI_{i,t}$		**(+)				**(+)		*(+)
$Inf_{i,t}$			***(+)				*(+)	***(+)
$Lint_{i,t}$				**(+)				

Notes: ***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively.

6. RESULT DISCUSSION

Our results provide evidence of the time trend and persistency in terms of the lagged term, although not significant for wind *PPA*, that explain the continuous decline in *PPA* and *LCOE*. The significant effect of the time trend in the FE model suggests that the rate of decline of solar *PPA* (of 24.1% per year) is greater than that of solar *LCOE* (of 10.3%), which is also greater than that of wind *LCOE* (of 5.23%). This result from the FE model corresponds with the results from the sys-GMM model in that the lagged term contributes more to the change of solar *PPA* than wind *LCOE*. It should be noted that the coefficients of the lagged terms in the sys-GMM model are less than 1, which exhibits a decreasing trend of *PPA* and *LCOE*.

The results suggest that the lender’s loan margin charged on top of the reference interest rate to the RE companies is important to explain the movements of *PPA* and *LCOE* (except for the case of wind *LCOE*). **We fail to reject H1** – higher PPA and lower *LCOE* are driven by smaller loan margins, charged by the financial institutions.

The results also show that, except for the case of wind *PPA*, the cumulative capacity (i.e. the development of RE technology) drives down the *PPA* as more supply (project developers) enters the RE market and brings up the *LCOE* due to higher demand towards the RE equipment and land usage (e.g. the suppliers raise the equipment prices). Since *CAP* and *CO2* are highly colinear, **we fail to reject H2 and H6** – RE technological development and high CO_2 emissions lead to lower *PPA* and higher *LCOE*.

Next, we find that the reduction in costs, especially *CAPEX*, resulting from technological advancements over time can well explain the downward movements of *PPA* and *LCOE* (except for the case of solar *PPA*). The exception of *OMC* for wind *PPA* with the opposite sign can be explained by a slower decline (reaching a plateau) of O&M price due to the relatively older technology of wind compared to solar. Therefore, **we fail to reject H3** – Reduction in O&M and installed (CAPEX) costs in RE leads to lower LCOE and PPA.

The dependency on fossil fuels (seen from the *CFF*) can be a driver of investments towards RE. The results are evident only in solar *PPA* and solar *LCOE* that higher fossil fuel dependency, meaning lacking the RE supply (fewer project developers), leads to higher *PPA* and leading to lower *LCOE* due to lower demand towards the equipment from fewer developers. Thus, **we fail to reject H4** – High fossil fuel consumption translates to higher *PPA* and lower *LCOE*.

Prices of fossil fuels (oil, natural gas, and coal) and their volatilities can also affect the RE investment sentiment (and the *PPA* and *LCOE*). We find that different types of fossil fuels differently affect the *PPA* and *LCOE*. For instance, an increase in oil price leads to a reduction in wind *LCOE* while a rise in the price of natural gas leads to an increase in wind *LCOE*. Therefore, **the results remain inconclusive for H5** – High fossil fuel prices and their volatilities could influence RE investment climate and boost RE demand, leading to lower *PPA* and higher *LCOE*. Possible explanation for the opposite signs of the oil price and its volatility on LCOE and the volatility of natural gas price can be because most RE project developers are mainly the companies that already have some investment in conventional power plants. Hence, when the prices and volatilities of these fuels increase, the costs of the power plant also rise and the profits drop, deferring the investments in RE from these companies and reducing the demand towards RE (as opposed to increasing stated in the hypothesis developed earlier). Therefore, the signs of PPA and LCOE are the opposite to those in the hypothesis development.

In addition, the signs of significant control variables are as expected. For example, higher *FDI* means more capital towards the RE sector (higher supply of *PPA* and more RE demand), leading to higher *PPA* and *LCOE*. Likewise, higher inflation and long-term interest rates lead to bad investment sentiment (higher *PPA* and *LCOE*). The summary of results for H1 to H6 is illustrated in Table 6.

All in all, it is obvious that the decline in *PPA* and *LCOE* is mainly driven by the installed costs (*CAPEX*) for both wind and solar technologies. The *PPA* and *LCOE* can be further explained by the bank's loan margin (*LM*) and cumulative RE capacity (*CAP*). The impact of consumption of fossil fuel (oil) on the *PPA* and *LCOE* is evident only in solar with the former also being affected by oil price and the volatility of coal price. The price of natural gas and its volatility are found to influence the *LCOE* (but not the *PPA*). Furthermore, we find that investment sentiment (the *FDI*, inflation, and interest rates) plays a role in the decreasing trend of *PPA* and *LCOE*.

Table 6 Summary of Results for H1 to H6

Hypothesis	Variable	Result	Not Significant	Reject
H1	$LM_{i,t}$	Fail to reject	Wind LCOE	
H2	$CAP_{i,t}$	Fail to reject	Wind PPA	
H3.1	$OMC_{i,t}$	Fail to reject	Wind PPA, Solar PPA	
H3.2	$CAPEX_{i,t}$	Fail to reject	Solar PPA	
H4	$CFF\_Oil_{i,t}$	Fail to reject	Wind PPA, Wind LCOE	
H5.1a	$\mathrm{PFF\_Oil}_{i,t}$	Fail to reject	Wind PPA, Solar LCOE	Wind LCOE
H5.1b	$\mathrm{PFF\_NG}_{i,t}$	Fail to reject	Wind PPA, Solar PPA	
H5.1c	$\mathrm{PFF\_Coal}_{i,t}$	Reject	Wind PPA, Solar, PPA, Wind LCOE, Solar LCOE	
H5.2a	$\mathrm{VPFF\_Oil}_{i,t}$	Reject	Wind PPA, Solar PPA	Wind LCOE, Solar LCOE
H5.2b	$\mathrm{VPFF\_NG}_{i,t}$	Fail to reject	Wind PPA	Solar PPA
H5.2c	$\mathrm{VPFF\_Coal}_{i,t}$	Fail to reject	Wind PPA, Wind LCOE, Solar LCOE	
H6	$CO2_{i,t}$	Fail to reject	Wind PPA	

An implication of the knowledge of the determinants of *PPA* and *LCOE* being utilized can be when the government wants to lower the fixed price under *PPA* due to some budget constraint, it can focus on reducing the total installed costs of wind technology (e.g. reducing taxes on wind-turbine imports) while still maintains the attractiveness in wind energy investment to meet its CO_2 emissions target. On the other hand, RE developers can determine if a country is good for investing in a solar farm by finding if the country possesses relatively high *PPA* and low *LCOE*. For instance, the country should have a good investment environment, the banks should be confident in solar technology and willing to lend with lower margins, and the country should still be consuming a relatively high amount of oil (with a high price).

7. CONCLUSION

This paper proposes a fixed-effects model and a system generalized method of moments (sys-GMM model to identify the determinants of a fixed price under the power purchase agreement (PPA) and levelized costs of electricity (LCOE) or the average lifetime costs of electricity of wind and solar technologies. Our global panel data covers a total of 26 countries (23 nations for wind and 21 nations for solar) in the period of 2015 to 2019. We perform tests and show that our fixed-effects and sys-GMM estimators are unbiased and consistent with consistent results and expected signs. Based on the law supply and demand for renewable energy, we create 6 hypotheses of the relevant variables found in past literature. Depending on the technology, we find evidence that the results are largely or partly consistent with our 6 hypotheses.

In particular, we find that the trend of the more mature wind PPA has tapered off and is only explained the technological costs and how risky the banks view the wind projects, while the trend of the less mature solar PPA is still in a decline and affected by the demand from conventional energy such as oil, natural gas, and coal and the environmental pressure from high CO_2 emissions. Meanwhile, the LCOE's of wind and solar energy are both declining and driven mainly by the reduction of technological costs, the additional demand from conventional energy players and the pressure from high CO_2 emissions with the solar LCOE also depending on the bank's perspective. Lastly, the investment environment through the FDI, inflation, and long-term interest rates can also affect the PPA and LCOE. The implication of this paper can be extended to policy design by the government and making investment decisions by RE developers. Finally, future research topics where complex structures and characteristics of incentive policies of each country are incorporated may lead to a more comprehensive conclusion of the PPA and LCOE determinants and is worth exploring.

APPENDIX

Table A1 Correlation Matrix for Wind Panel

Panel Wind	*PPA*	*LCOE*	*LM*	*CAP*	*OMC*	*CAPEX*	*CFF_ Oil*	*CFF_ NG*	*CFF_ Coal*	*PFF_ Oil*	*PFF_ NG*	*PFF_ Coal*	*VPFF_ Oil*	*VPFF_ NG*	*VPFF_ Coal*	*CO2*	*GDP*	*ED*	*FDI*	*Infl*	*Lint*
PPA	1.00																				
LCOE	0.77	1.00																			
LM	-0.25	-0.12	1.00																		
CAP	-0.17	-0.18	-0.13	1.00																	
OMC	0.47	0.58	-0.07	-0.41	1.00																
CAPEX	0.57	0.69	-0.08	-0.40	0.82	1.00															
CFF_Oil	-0.16	-0.11	-0.10	0.82	-0.16	-0.23	1.00														
CFF_NG	-0.17	-0.14	-0.15	0.61	0.03	-0.09	0.93	1.00													
CFF_Coal	-0.09	-0.04	-0.02	0.91	-0.44	-0.36	0.66	0.36	1.00												
PFF_Oil	-0.30	-0.44	-0.15	0.05	-0.30	-0.39	-0.03	-0.03	0.00	1.00											
PFF_NG	0.19	0.24	-0.25	0.09	-0.25	-0.14	-0.05	-0.16	0.19	0.40	1.00										
PFF_Coal	-0.10	-0.07	-0.17	0.17	-0.26	-0.28	0.05	-0.06	0.23	0.59	0.67	1.00									
VPFF_Oil	0.23	0.12	-0.01	-0.15	0.07	0.17	-0.11	-0.04	-0.17	0.02	0.02	-0.43	1.00								
VPFF_NG	-0.31	-0.30	-0.10	0.04	-0.20	-0.24	0.01	0.02	0.00	0.35	-0.01	0.12	0.16	1.00							
VPFF_Coal	-0.16	-0.02	-0.09	0.01	-0.01	-0.03	0.00	0.00	0.00	-0.31	-0.15	0.08	-0.33	0.58	1.00						
CO2	-0.13	-0.08	-0.06	0.96	-0.36	-0.33	0.87	0.64	0.94	-0.01	0.10	0.17	-0.15	0.00	0.00	1.00					
GDP	0.18	-0.01	-0.66	-0.07	0.14	0.14	0.06	0.22	-0.25	0.11	0.14	0.07	0.10	0.02	0.00	-0.14	1.00				
ED	-0.15	-0.10	-0.09	0.96	-0.32	-0.31	0.91	0.72	0.90	0.00	0.06	0.15	-0.15	0.01	0.00	0.99	-0.08	1.00			
FDI	0.10	0.05	0.02	-0.08	0.03	0.08	-0.08	-0.07	-0.07	-0.21	-0.13	-0.18	0.05	-0.11	0.00	-0.08	0.02	-0.09	1.00		
Infl	-0.15	-0.10	0.57	-0.12	0.16	0.04	-0.11	-0.07	-0.07	0.00	-0.12	-0.09	-0.01	0.07	0.03	-0.09	-0.35	-0.10	-0.08	1.00	
Lint	-0.15	-0.10	0.69	-0.11	0.07	-0.02	-0.09	-0.09	-0.03	-0.06	-0.22	-0.14	0.01	0.00	-0.07	-0.06	-0.51	-0.08	-0.04	0.81	1.00

Table A2 Correlation Matrix for Solar Panel

Panel Solar	*PPA*	*LCOE*	*LM*	*CAP*	*OMC*	*CAPEX*	*CFF_ Oil*	*CFF_ NG*	*CFF_ Coal*	*PFF_ Oil*	*PFF_ NG*	*PFF_ Coal*	*VPFF_ Oil*	*VPFF_ NG*	*VPFF_ Coal*	*CO2*	*GDP*	*ED*	*FDI*	*Infl*	*Lint*
PPA	1.00																				
LCOE	0.60	1.00																			
LM	-0.25	0.15	1.00																		
CAP	0.03	-0.13	-0.17	1.00																	
OMC	0.69	0.77	-0.13	-0.18	1.00																
CAPEX	0.45	0.86	0.22	-0.14	0.64	1.00															
CFF_Oil	-0.05	-0.10	-0.09	0.70	-0.20	-0.05	1.00														
CFF_NG	-0.08	-0.07	-0.16	0.48	-0.13	0.00	0.92	1.00													
CFF_Coal	0.02	-0.11	0.03	0.82	-0.27	-0.14	0.66	0.34	1.00												
PFF_Oil	-0.29	-0.49	-0.09	0.17	-0.44	-0.47	-0.02	-0.01	0.02	1.00											
PFF_NG	0.31	-0.03	-0.19	0.17	0.03	-0.16	-0.07	-0.16	0.17	0.39	1.00										
PFF_Coal	0.02	-0.33	-0.09	0.23	-0.31	-0.33	0.00	-0.08	0.18	0.59	0.70	1.00									
VPFF_Oil	0.17	0.36	-0.02	-0.18	0.39	0.30	-0.05	0.00	-0.13	-0.04	-0.06	-0.49	1.00								
VPFF_NG	-0.27	-0.38	-0.09	0.09	-0.25	-0.35	0.01	0.02	0.00	0.34	0.00	0.14	0.13	1.00							
VPFF_Coal	-0.13	-0.19	-0.09	0.02	-0.13	-0.17	0.00	0.00	0.00	-0.31	-0.13	0.08	-0.32	0.58	1.00						
CO2	-0.01	-0.12	-0.02	0.85	-0.27	-0.11	0.87	0.63	0.94	0.01	0.08	0.12	-0.10	0.00	0.00	1.00					
GDP	0.00	0.01	-0.57	0.10	0.12	0.02	0.20	0.38	-0.19	0.08	0.08	0.02	0.10	0.01	0.00	-0.03	1.00				
ED	-0.03	-0.12	-0.05	0.86	-0.26	-0.10	0.91	0.70	0.90	0.01	0.04	0.09	-0.09	0.01	0.00	0.99	0.04	1.00			
FDI	-0.11	-0.12	0.00	-0.25	-0.08	-0.07	-0.21	-0.18	-0.18	-0.13	-0.31	-0.25	0.19	0.03	0.03	-0.21	-0.09	-0.21	1.00		
Infl	-0.19	0.20	0.57	-0.15	-0.08	0.21	-0.14	-0.11	-0.08	-0.01	-0.13	-0.14	0.05	0.06	0.02	-0.11	-0.29	-0.12	-0.15	1.00	
Lint	-0.21	0.13	0.66	-0.20	-0.10	0.20	-0.15	-0.15	-0.07	-0.04	-0.20	-0.15	0.05	0.00	-0.08	-0.11	-0.41	-0.13	-0.01	0.80	1.00

Table A3 Breusch-Pegan and Hausman Tests

Test	Subpanel			
	PPA Wind	PPA Solar	LCOE Wind	LCOE Solar
Breusch-Pagan test (χ^2)	47.8***	61.8***	40.8***	69.5***
Hausman test (χ^2)	27.6**	63.0***	29.7**	15.9

Notes: The Breusch-Pegan test has H0 of no significant individual effects; the Hausman test determines whether a FE or RE model should be used with H0 of two models being consistent; ***, **, and * denote significance at 1%, 5%, and 10% significance levels, respectively.

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