Analyzing Energy Transition Patterns in Asia: Evidence From Countries With Different Income Levels

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Energy transition as the issue of striving to use more environmentally friendly energy sources instead of fossil fuels is a crucial debate for scholars. A key point is how macroeconomic variables can accelerate the energy transition movement in different regions, which may lead to similarities in energy transition patterns among various regions. The main purpose of this study is to determine how energy transition patterns depend on economic variables in Asian economies, classifying based on their income level. To this end, we collected the related variables for 45 economies in Asia over the period 1993–2018 and conducted estimation using the generalized method of moments (GMM) approach. The major results revealed that economic growth has a positive relationship with the energy transition, while CO_2 emissions negatively influence energy transition. Furthermore, in both sub-sample groups (i.e., high and upper-middle-income and low and lower-middle-income groups) an increase in population lows the energy transition process. As an important recommendation, Asian economies with different income levels need different policies to improve and accelerate the energy transition movements. Especially in the developing and emerging economies that have higher economic growth rate and more energy demand, the governments need to implement various supportive policies for easing the access to electricity from green resources in line with the sustainable development goals (SDGs). This is more essential in the current low oil price era.

Keywords: energy transition, fossil fuel consumption, renewable energy consumption, asian regions, GMM estimator

INTRODUCTION

The issue of striving to use more environmentally friendly energy sources instead of fossil fuels (energy transition) is a crucial debate for scholars. Kaberger (2018) and Rasoulinezhad and Jabalameli (2019) argued that replacing fossil fuels with renewable energy for electricity generation and other economic purposes may be a crucial topic for the future of the world economy. Based on IEA (2019a) report on the importance of clean energy transition, there are not any other alternative scenarios of the energy transition for mankind to combat with the current and future global environmental pollution.

Countries in the form of the global community are trying to reach efficient agreements to transform fossil fuels to cleaner fuels and increase energy efficiency to achieve a carbon zero

economy target (Wiseman, 2018), however, this transition is not simple. Shell Energy Transition Report 2019 expresses that demand for fossil fuels would higher in 2030 than today, but the contribution of fossil fuels in the total energy system falls. Moreover, Regarding World Economic Forum (2018), the world needs an "effective energy transition" meaning a timely shift to address global energy-related challenges with creating value for firms and societies. Therefore, reaching an effective energy transformation is not an easy way for countries and needs in-depth studies to clarify different aspects of it.

Due to the complexity of energy transition process, different regions in the world experience different levels of energy transition based on their local energy consumption basket, geographical position, local economic ties with fossil energy, and so on. Singh et al. (2019) showed this fact by conducting the World Economic Forum's Energy Transition Index (ETI). They concluded that based on energy system performance and transition readiness of countries, there are different level of the energy transition in the world. The energy transition movement (renewable energy consumption divide on fossil fuels energy consumption) throughout 1990–2018 is illustrated in **Figure 1**. It can be seen that most regions have not experienced significant energy transformation progress in the last decades. Besides, the South Asian region has a reduction movement to 2010 and then it has experienced a smooth decrease till 2018.

Asia-Pacific is one of the most important regions in the world requiring a faster pace of energy transition. Mohammad (2019) believed that Asia's energy transition can contribute to cleaner earth in the future due to the large share of industrial production and population size in this region. Furthermore, Qiao (2019) expressed that due to the cost reduction of clean energy and improvement of the green energy efficiencies, Asian countries, particularly the South East ones have big opportunity to carry out their energy transition plans. The importance of energy transition in Asia has been also declared by United Nations: Economic and Social Council (2018) due to the increased trend of fossil fuel consumption and their high potential of industrial production. Among Asian countries, China and India drive the global renewable energy generation, which is undergoing a period of energy transition and economic transformation (Mamat et al., 2019). Many studies such as Jairaj and Kumar (2019) and Al-Shamma's et al. (2020) showed the importance of studying energy transition matters in regions and countries of Asia-Pacific. **Figure 2** presents the consumption of various energy resources for different regions over the period 1965–2018.

It can be seen that the Asia-Pacific is a pioneer in having a growth rate of energy consumption among different regions. Furthermore, the Middle East has an increased movement over the last decades. Jia et al. (2011) predict that, as a leader of Asian energy consumers, China will maintain sustained and rapid growth by 2020 and then gradually slow down, reaching 6.6 and 6.2 billion toe in 2050. In line with China, India, South Korea, and Malaysia (Sharvini et al., 2018) have been experiencing high rates of economic growth, leading to increased energy consumption in recent decades. This high level of using non-renewable energy resources has made Asian economies as significant emitters of CO_2. However, Asian economies are geographically located in areas with different climatic conditions such as tropical, humid, and so on, which provides easy access to a variety of renewable energy sources (Shukla et al., 2017).
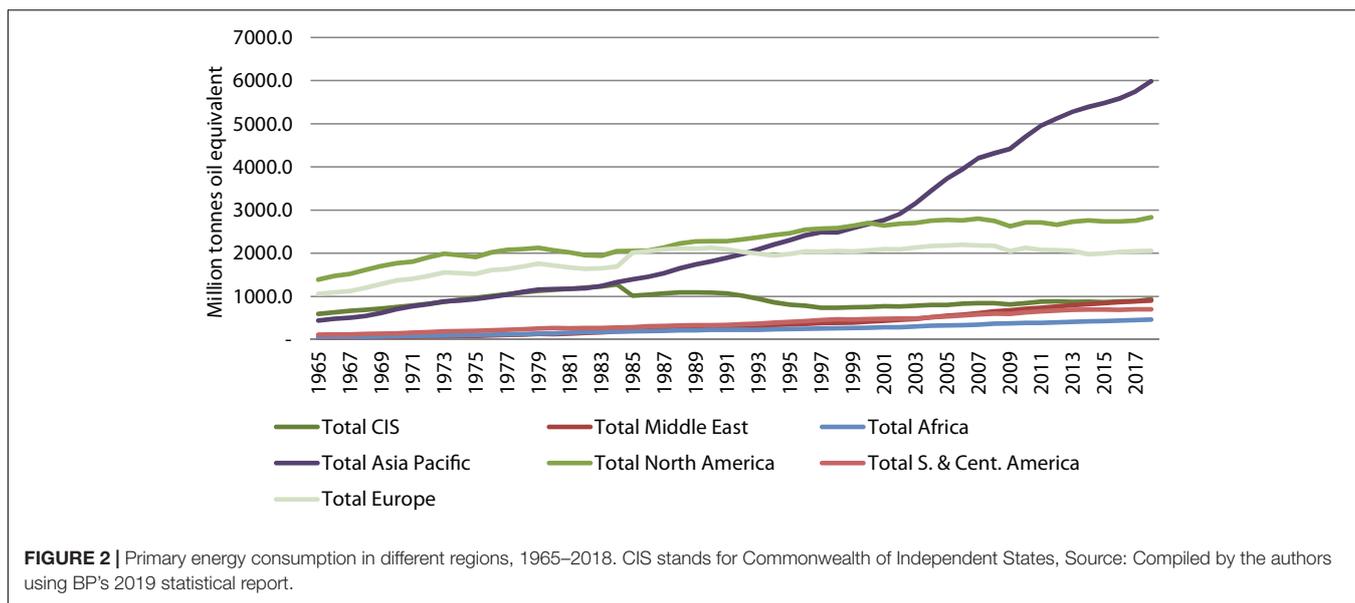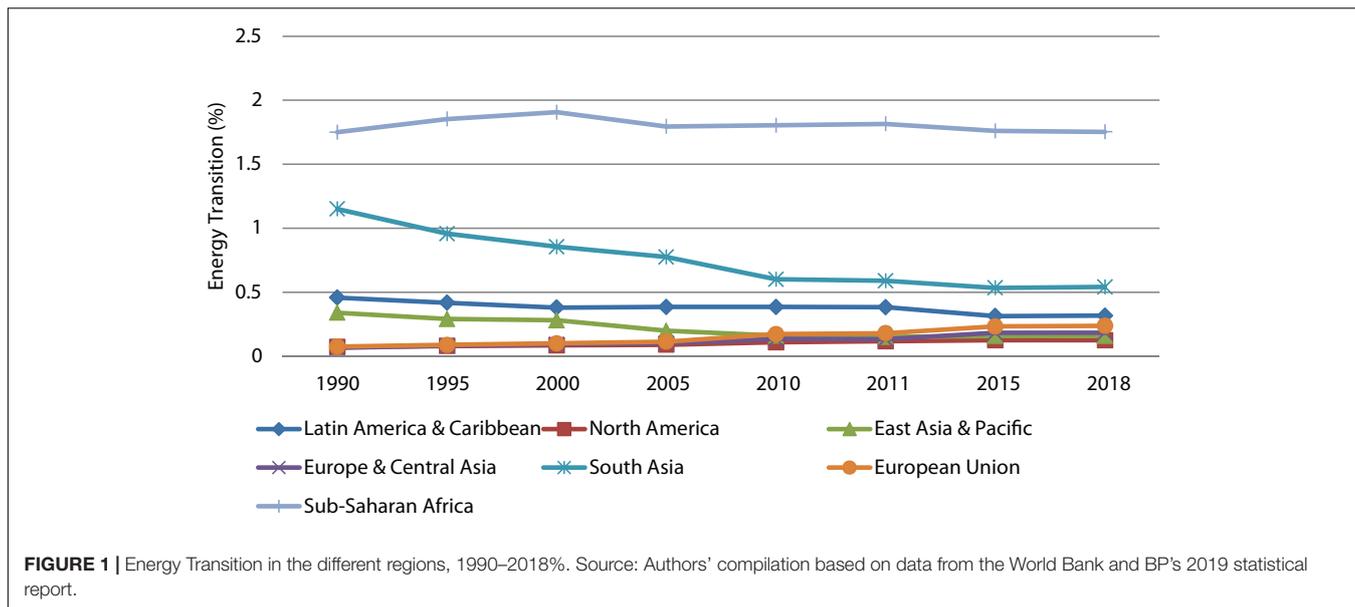
In terms of increased energy demand, the issue of global warming, and the potential for developing green energy resources in Asia, there is a question of how macroeconomic variables can accelerate or decelerate energy transition movement in different regions in Asia. Despite numerous studies such as Fattouh et al. (2019); Yuan et al. (2018), Sharvini et al. (2018); Aung et al. (2017), Saboori et al. (2017); Taghizadeh-Hesary et al. (2016)Taghizadeh-Hesary et al. (2017); Reddy (2016), and Hess and Mai (2014) focusing on energy consumption and energy transition in Asian countries, we did not find any serious academic research considering energy transition patterns among such countries. Hence, this point covers the major novelty of our research and the gap in the literature our findings may fill.

The rest of our paper is organized as follows. Section 2 represents a brief literature review. The theoretical background is discussed in section 3. Section 4 describes the data and model specifications. Section 5 reports empirical results and Finally, section 6 provides concluding remarks and policy recommendations.

LITERATURE REVIEW

The related literature can be divided into two different strands. First focuses on energy transition issues and the second investigates energy transition in Asia.

The first strand concentrates on energy transition in different countries. Verbong and Geels (2007) analyzed energy transition trends in the Dutch electricity system for the period 1960–2004. The authors revealed that an energy transition, with roots in the 1960s and 1970s, is occurring in the Dutch electricity system but is mainly driven by liberalization and Europeanization. Al-Mulali et al. (2015) studied the relationship between economic growth and renewable energy consumption with the environmental pollution in 23 European countries with the data for the period 1990–2013. The major results proved that there is a positive relationship between economic growth with CO_2 emissions, while renewable electricity generation from solar and wind has not statistically significant effect on CO_2 emissions. Sovacool (2016) discussed the speed of energy transition in different countries. He concluded that such speed is not similar among countries and depends on different factors, policies, geographical location, and energy flows in the region. Al-Mulali et al. (2016) tested the Environmental Kuznets Curve (EKC) (the U-Shape linkage between CO_2 emissions and income level) hypothesis in seven different regions throughout 1980–2010. Dogan and Ozturk (2017) investigated the impacts of fossil fuel energy consumption and non-renewable energy consumption on CO_2 emissions in the United States throughout 1980–2014. They found out the positive and significant impact of fossil fuel energy consumption on environmental pollution in the United States, while there is a negative relationship between green energy consumption and CO_2 emissions there. Leeuwen et al. (2017)

FIGURE 1 | Energy Transition in the different regions, 1990–2018%. Source: Authors' compilation based on data from the World Bank and BP's 2019 statistical report.

FIGURE 2 | Primary energy consumption in different regions, 1965–2018. CIS stands for Commonwealth of Independent States, Source: Compiled by the authors using BP's 2019 statistical report.

reviewed urban energy transition in the Netherlands with a focus on smart energy management. They concluded that the role of smart energy management as part of the integration of renewable energy into existing infrastructure is vital and can lead to the integration of state policies and the use of cleaner energy sources. Solarin et al. (2017) tried to analyze the existence of the EKC hypothesis in two emerging economies, i.e., India and China. The major results proved that GDP positively impacts on CO_2 emissions in these two countries. Stokes and Breetz (2018) analyzed politics in United States energy transition, particularly in the case of wind, solar, and biofuels. The findings depicted similar patterns across the electricity and transportation sectors. Osti (2018) considered different problems of transition to renewable energy sources on the small island

of Sardinia in Italy. He concluded that in this region, three myths of fossil fuels vs. renewables, competition regarding smart grid and storage system technologies, and energy sovereignty vs. energy interdependency should be solved to enhance the energy transition level of Sardinia in the future. Vainio et al. (2019) investigated achieving a sustainable energy transition in Finland with a focus on the importance of citizen's images. The major findings revealed that the sustainable energy transition was strongly supported in Finland, but different socio-economic groups preferred somewhat different images. Szabo et al. (2019) studied types of long-term pathways that exist for electricity sector development in Southeast Europe. They found that to avoid lock-in to carbon-intensive technologies, stranded costs should be carefully considered in decision-making on new

fossil fuel generation and gas network investment. Ozcan and Ozturk (2019) focused on the relationship between renewable energy consumption and economic growth in different emerging economies for the period of 1990–2016. The major findings showed evidence of the existence of the neutrality hypothesis due to the non-presence of the relationship between economic growth and renewable energy consumption. Vaillancourt et al. (2019) investigated the role of bioenergy in the low-carbon energy transition in Canada. Their results indicated a larger share of bioenergy in 2030 (up to a threefold increase in the most stringent greenhouse gas reduction scenario), with up to a fourfold increase in the total amount of feedstock used for bioenergy production. Sharif et al. (2019) conducted panel estimations to find out the relationship between fossil fuel and green energy consumption with carbon dioxide emissions for 74 countries from 1990 to 2015. The findings showed the direct and significant impact of fossil fuel energy consumption on CO_2 emissions, while the consumption of non-renewable energy resources can help the countries to lower CO_2 emissions.

The second strand of literature contains earlier studies focused on energy transition issues in different Asian countries. Pachauri and Jiang (2008) attempted to examine the household energy transition patterns in both India and China. They found that trends in energy use and the factors influencing a transition to modern energy are similar in both countries. Ngar-yin Mah et al. (2013) investigated the Japanese model of large smart grids for sustainable energy transitions. They argued that the Japanese model is characterized by a government-led, community-oriented, and business-driven approach with the launch of four large-scale smart-community demonstration projects. The Japanese government has demonstrated its high governing capacity in terms of leadership, and recombinative, institutional, enabling, and inducement capacities. Yildirim et al. (2014) studied the relationship between GDP per capita and energy consumption in the Association of Southeast Asian Nations (ASEAN) member states throughout 1971–2009. The paper concluded that the relationship is dissimilar among ASEAN member states. For instance, the conservation hypothesis is proved for Indonesia, while a bi-directional linkage was found out for the case of Thailand. Apergis and Ozturk (2015) tested the existence of the EKC for 14 Asian nations using the GMM approach. Their results proved the hypothesis for all Asian countries. Reddy (2016) used a bottom-up approach to investigate India's energy system transition. The main results revealed that significant resource savings can be achieved by 2030 through the introduction of energy-efficient and green technologies. In other studies, Ahmed et al. (2017) investigated the factors influencing on long-run CO_2 emissions in South Asia. Analyzing data throughout 1971–2013, the major results revealed that there is a uni-directional linkage from fossil fuel energy consumption and population growth to long-run CO_2 in this region. Gulagi et al. (2017) stimulated a 100% renewable energy transition model for India until 2030. They concluded that technology improvement can be an efficient instrument to reach a 100% energy transition in India. Chapman and Itoaka (2018) attempted to analyze the energy transition in Japan's liberalizing electricity market. They found that future

energy transition pathway projections will need to incorporate policy approaches and mechanisms as well as being cognizant of Japan's geographic and cost-competitive renewable energy resource deployment limitations. Kucharski and Unesaki (2018) investigated the role of Japan's energy institutions in the post-Fukushima period. The major results revealed that policy reforms can affect energy sector structure and performance and proved that significant structural and institutional changes are underway in Japan's energy transition.

Considering both strands of literature discussed above, to the best of our knowledge, there has not been any serious academic attempt to investigate energy transition-macroeconomic variables linkages in Asia-Pacific economies and compare them among different groups based on the income levels. Hence, our study aims to fill the literature gap.

THEORETICAL BACKGROUND

Energy sources, that is, renewables and non-renewables are mainly used for electricity generation. For instance, many Asian nations such as Malaysia is highly dependent on fossil fuels as oil, coal and natural gas are major contributors to its power generation (Sharvini et al., 2018). Furthermore, in China and India, the electricity sector is the major consumer of fossil fuels, particularly coal (Zou et al., 2016; Zhang et al., 2019). We can assume that only two economic sectors (industrial and household/residential sectors) consume electricity generated by energy sources. In other words, the demand for renewable and non-renewable energy comes from these two sectors only.

We start with the industry's energy demand. Eq. 1 represents the production function of industry, which is assumed to be in Cobb-Douglas form as in Rasoulinezhad et al. (2020):

$$Y_t^I = F\left(K_t, L_t, ET_t^I\right) = K_t^\alpha L_t^\beta \left(ET_t^I\right)^{(1-\alpha-\beta)} \quad (1)$$

Here, Y^I is the total output of industry, K is the capital input, L denotes the labor input, ET^I represents energy inputs of industrial production, which is considered as energy transition (share of renewables to non-renewables) in the industrial sector as written in Eq. 2. By considering constant returns to scale, α is the elasticity of production of capital, β is the elasticity of production of labor, and the elasticity of production of energy resources is equal to $1 - \alpha - \beta$.

$$ET_t^I = \frac{REC_t^I}{NREC_t^I} \quad (2)$$

Where REC^I and $NREC^I$ represent renewable energy consumption and non-renewable energy consumption in the industrial sector, respectively. It should be mentioned that we did not address energy resources as primary (contains original fuels such as oil, coal, natural gas, water, solar and wind) and secondary (like electricity) energies. Because these classifications can not represent an energy transition movement.

According to Hansen et al. (1995), firms are maximizing their profit as follows:

$$Max \ \pi_t = P_t^Y Y_t^I - r_t K_t - w_t L_t - e_t \left(P_t^E + T_t\right) ET_t^I \quad (3)$$

where π is the sector's profit, P^Y is the price of the final products, r denotes the interest rate of capital, w denotes the wage rate, e denotes the exchange rate, P^E denotes energy price and T denotes the transportation cost of energy resources.

By inserting Y^I from Eq. 1 into Eq. 3 and getting the first-order condition of profit (π) with respect to E^I, Eq. 4 will result:

$$\frac{\partial \pi_t}{\partial ET_t^I} = (1 - \alpha - \beta) \frac{P_t^Y Y_t^I}{ET_t^I} - e_t \left(P_t^E + T_t\right) = 0 \qquad (4)$$

The energy transition demand is represented in Eq. 5:

$$ET_t^I = (1 - \alpha - \beta) \frac{P_t^Y Y_t^I}{e_t \left(P_t^E + T_t\right)} \qquad (5)$$

As shown, industry's energy transition demand is a function of the elasticities of production of labor and capital, the real output of industry sector, the price of energy, the exchange rate, and the transportation cost of energy.

Next, we consider household energy demand using the following utility function:

$$U_t = \left(C_t, ET_t^H\right) = \frac{1}{1 - \gamma} (C_t)^{1-\gamma} + \frac{1}{1 - \delta} \left(ET_t^H\right)^{1-\delta} \quad (6)$$

As in Taghizadeh-Hesary and Yoshino (2018) C_t donates the consumption of non-energy goods and ET_t^H denotes the consumption of energy goods (representing the energy transition demand of households). Following Cymrot and Seiver (1982), households maximize their utility with respect to their budget, which is the constraint, as shown in Eq. 7:

$$S.T. \ P_t^C C_t + e_t \left(P_t^E + T_t\right) ET_t^H = Y_t^H \qquad (7)$$

Where P^C denotes the price of non-energy goods, P^E denotes the energy goods, which depends on energy prices denominated in US dollars, and T denotes the transportation costs, Y^H is the total income of the households.

To maximize the utility of households for defining the factors that determine energy demand, we develop the Lagrange function, as in Eq. 8:

$$\Gamma = U\left(C_t, ET_t^H\right) - \lambda \left\{P_t^C C_t + e_t \left(P_t^E + T_t\right) ET_t^H - Y_t^H\right\} \quad (8)$$

Obtaining the first-order conditions with respect to the ET^H, C, and λ results in Eqs. 9–11:

$$\frac{\partial \Gamma}{\partial ET_t^H} = \left(ET_t^H\right)^{-\delta} - \lambda \left\{e_t \left(P_t^E + T_t\right)\right\} = 0 \qquad (9)$$

$$\frac{\partial \Gamma}{\partial C_t} = C_t^{-\gamma} - \lambda \left(P_t^C\right) = 0 \rightarrow \lambda = \frac{C_t^{-\gamma}}{P_t^C} \qquad (10)$$

$$\frac{\partial \Gamma}{\partial \lambda} = Y_t^H = P_t^C C_t + e_t \left(P_t^E + T_t\right) ET_t^H \qquad (11)$$

Substituting λ from Eq. 10 in Eq. 9 and solving it for ET_t^H, we find that the household's energy transition demand is a function of the exchange rate, electricity tariff, transportation costs of

energy, and the income level of the household (in macro-level, the income level of the energy importer), as in Eq. 12:

$$E_t^H = f\left(e_t, \ P_t^E, \ T_t \ Y_t^H\right) \qquad (12)$$

The total energy transition demand is equal to the combined energy demand of households and industry (Eq. 13).

$$ET_t = ET_t^I + ET_t^H \qquad (13)$$

Therefore, the total energy demand (ET_t) is a function of different factors, as shown in Eq. 14:

$$ET_t = f(P_t^E, \ T_t, e_t, \ Y_t) \qquad (14)$$

where P^E is the electricity tariff, and T denotes the transportation costs of energy, e is the exchange rate, and Y_t is the total GDP of the energy importer, which depends on the income level of households (Y_t^H) and the total output of the industry (Y_t^I).

DATA AND MODEL SPECIFICATIONS

The empirical part of this study is based on balanced panel data of variables throughout 1993–2018 (the reason of choosing this period is the availability of data for the variables of the model) for high- and middle- and low-income countries in Asia-Pacific. Our samples are gathered based on the UN regional groups for the Asia-Pacific (un.org) including 55 different nations (see **Appendix 1**). However, due to the lack of data, we had to omit some countries and our finalized samples contained 45 countries. Based on the World Bank Atlas method (worldbank.org), the finalized samples were also divided into two different groups according to income level (to have a sufficient samples size for panel data estimation, we could not consider four income groups of high, upper-middle, lower-middle and low-income groups), that is, a high and upper-middle-income group (24 countries), a and low and lower-middle-income group (21 countries) (see **Appendix 2**).

Furthermore, based on the theoretical model, we employed energy transition (Renewable energy consumption/non-renewable energy consumption) as a dependent variable, and official exchange rate, GDP, population growth (due to the lack of data for energy prices in many countries for our samples, we choose population growth as a proxy for energy price, as the higher population growth rate will increase the energy demand and increase the energy prices), and CO_2 emissions as independent variables. Most of the data were extracted from the BP statistical review of BP, 2019 and the World Bank database. The primary descriptive statistics for 45 Asian countries are presented in **Table 1**.

As shown in **Table 1**, the average annual economic growth of all 45 countries is 4.6% over 1993–2018. Moreover, the maximum is 64.08% (Timor-Leste in 2004) and the minimum is -35.81% (Cambodia in 1993). It is interesting to note that countries with low and lower-middle incomes have the highest average economic growth over 1993–2018 (4.69% compared with 4.65% and 4.67% for countries with high and upper-middle incomes and all samples, respectively). Regarding energy transition, the

TABLE 1 | Descriptive statistics.

Samples	Variables	Unit	Mean	Maximum	Minimum	Std. Dev.
All samples	Economic Growth	%	4.67	64.08	-35.81	5.96
	Exchange rate	LCU per United States$	1185.36	40864.33	0.010	3708.33
	Energy transition	%	1.18	15.25	1.81E-05	2.18
	CO_2 emissions	Metric tons per capita	6.59	70.04	0.03	10.07
	Population growth	%	2.03	17.51	-1.75	1.85
High and upper-middle incomes	Economic Growth	%	4.65	54.15	-33.10	5.59
	Exchange rate	LCU per United States$	852.24	40864.33	0.010	3324.61
	Energy transition	%	0.38	8.72	1.82E-05	1.17
	CO_2 emissions	Metric tons per capita	10.72	70.04	0.28	11.81
	Population growth	%	2.23	17.51	-1.75	2.39
Low and lower-middle incomes	Economic Growth	%	4.69	64.08	-35.81	6.35
	Exchange rate	LCU per United States$	1566.06	22602.05	0.010	4073.03
	Energy transition	%	2.09	15.25	0.00	2.67
	CO_2 emissions	Metric tons per capita	1.88	24.62	0.03	4.03
	Population growth	%	1.82	8.79	-0.35	0.85

Source: Authors' compilation from Eviews 10.

average for countries with low and lower-middle incomes is 2.09%, which is higher than the means of this variable in counties with high and upper-middle incomes (0.38%).

Besides, **Tables 2–4** represent Pearson correlations between variables based on all samples, the high and upper-middle-income group, and the low and lower-middle-income group. According to **Table 2**, for 45 Asian countries, there is a negative relationship between energy transition and exchange rate, and CO_2 emissions and population growth, while economic growth and energy transition have positive linkage over the period.

For the case of the high and upper-middle-income group, it is clear that there is a negative relationship between energy transition and all regressors, while economic growth and population growth are positively linked with energy transition and exchange rate, and CO_2 emissions have a negative relationship with energy transition for the low and lower-middle-income group.

Based on our variables, our econometric equation with a generalized method of moments (GMM) panel approach can be written as in Eq. 15:

$$ET_{it} = \vartheta + \omega ET_{it-1} + \phi X_{it} + \eta_{it} + \varepsilon_{it} \qquad (15)$$

where *ET* indicates energy transition (dependent variable) and *X* denotes all explanatory variables η_{it} represents the country-specific effects, and ε_{it} is the error term.

For running the regressions, due to the limitations of data we are assuming that the electricity prices and transportations costs are constant. Instead, we are entering two control variables and can also represent these two omitted variables. The entered variables are population growth rate and CO_2 emission. According to Alimi and Mesagan (2018), growth in the population will increase energy consumption (energy demand) leading to an increase in energy prices and vice versa). Besides, longer distances between the origin of fossil fuels (energy exporters) and the importers' countries will result in higher transportation costs and higher CO_2 emissions. Next, some

preliminary tests should be conducted to derive reliable empirical estimations. As the first pre-estimation test, the variance inflation factor (VIF) is performed to ascertain whether there is any multicollinearity among the series. The second preliminary test is the Hausman test to check for the existence of heterogeneity, which clarifies the presence of random or fixed effects in our panel. Given that the economies of the Russian Federation and the selected sample have experienced various exogenous and endogenous shocks, the next pre-estimation test checks for cross-sectional dependency among the series. The second-generation unit root test is the last preliminary test and is used to ascertain whether the series are I(1) stationary or I(0) non-stationary. Furthermore, after running the GMM estimations, we conduct two different diagnostic tests. The first is the Arellano-Bond test for zero autocorrelation in the first-differenced errors, and the second is the Sargan test to verify the overidentifying restrictions.

RESULTS

Preliminary Tests

Before presenting empirical findings of GMM estimations, as previously mentioned, some preliminary tests should be conducted. **Table 3** reports the results of the VIF (checking multicollinearity among series) and Hausman (checking the nature of the panel data series) tests.

Based on the results in **Table 3**, we can conclude that there is low multicollinearity between the cross-sections. Besides, the findings of the Hausman test (Chi2) depict the panel data with random effects. Next, we test for the existence of cross-sectional dependence (CSD) in the series; the results are presented in **Table 4**.

The results of the CSD test indicate that cross-sections are present in all series among all samples, the high and upper-middle-income group, and the low and lower-middle-income group. This means that our samples, both in aggregated and

TABLE 2 | Pearson correlation results.

Samples	Dependent variable	Independent variables			
		Economic growth	Exchange rate	CO$_2$ emissions	Population growth
45 Asian countries	Energy transition	0.008	−0.78	−0.323	−0.111
High and upper-middle incomes group (24 countries)	Energy transition	−0.61	−0.79	−0.260	−0.198
Low and lower-middle incomes group (21 countries)	Energy transition	0.38	−0.153	−0.282	0.005

Source: Compiled by the authors using SPSS 19.

TABLE 3 | Results of VIF and Hausman tests.

Samples	Independent variables	Explanatory variables				
		LET	LGRO	LCO$_2$	LPOP	LEX
All samples	LET	-	1.28	1.13	1.20	1.31
	LGRO	1.40	-	1.09	1.39	1.28
	LCO$_2$	1.18	1.55	-	1.11	1.21
	LPOP	1.48	1.19	1.31	-	1.42
	LEX	1.31	1.08	1.42	1.24	-
	Mean VIF	1.34	1.27	1.23	1.23	1.30
	Chi2(5)	12.23				
High and upper-middle incomes group	LET	-	1.06	1.18	1.32	1.19
	LGRO	1.04	-	1.02	1.21	1.24
	LCO$_2$	1.31	1.02	-	1.43	1.29
	LPOP	1.82	1.23	1.02	-	1.31
	LEX	1.45	1.19	1.19	1.42	-
	Mean VIF	1.40	1.12	1.10	1.35	1.26
	Chi2(5)	12.18				
Low and lower-middle incomes group	LET	-	1.05	1.24	1.39	1.19
	LGRO	1.42	-	1.39	1.15	1.26
	LCO$_2$	1.51	1.23	-	1.11	1.36
	LPOP	1.31	1.20	1.38	-	1.02
	LEX	1.28	1.32	1.36	1.41	-
	Mean VIF	1.38	1.20	1.34	1.27	1.21
	Chi2(5)	11.30				

ET = energy transition, GRO = economic growth, EX = exchange rate, CO$_2$ = CO$_2$ emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: Compiled by the authors.

disaggregated groups, share the same characteristics. Generally, in situations in which there are low multicollinearity and CSD in the series, it is necessary to check the stationarity of variables. Here, we conducted the second-generation panel unit root test (Pesaran's 2007 CIPS test) with the null hypothesis of all series being I(1). The findings are reported in **Table 5**.

The findings of the aforementioned test reveal that all series considering all samples, the high and upper-middle-income group, and the low and lower-middle-income group are I(0).

GMM Findings

After performing all the necessary preliminary tests, the Arellano-Bond dynamic GMM estimation is conducted for the three groups (all samples, high and upper-middle-income group, and low and lower-middle incomes group). The results of the

GMM estimation for all 45 Asian countries (all samples) are reported in **Table 6**.

According to the results in **Table 6**, the economic growth of Asia-Pacific economies has a positive effect on the energy transition movement in this region. A 1% increase in economic growth level leads to an approximately 0.79% increase in the energy transition process. This finding is in line with Saidi and Hammam (2015); Adams et al. (2018), Hoon Kang et al. (2019), and Diaz et al. (2019) who found a positive linkage between economic growth and moving from fossil fuels to renewables. Our result is in contrast to Maji (2015) and Chen et al. (2019), who proved a mixture of negative and positive relationships between green energy usage and economic growth. Regarding CO$_2$ emissions, the estimation proves that this variable negatively affects the energy transition process. A 1% increase

TABLE 4 | Cross-sectional dependence test results.

Samples	Variables	CSD test	Corr.	Abs. (corr.)	Significant at 1% level
All samples	LET	6.17	0.313	0.313	Yes
	LGRO	9.73	0.491	0.491	Yes
	LCO_2	8.55	0.482	0.482	Yes
	LPOP	9.11	0.329	0.329	Yes
	LEX	8.72	0.319	0.319	Yes
High and upper-middle incomes group	LET	6.81	0.366	0.366	Yes
	LGRO	10.05	0.592	0.592	Yes
	LCO_2	7.90	0.429	0.429	Yes
	LPOP	10.32	0.628	0.628	Yes
	LEX	8.23	0.429	0.429	Yes
Low and lower-middle incomes group	LET	6.30	0.383	0.383	Yes
	LGRO	9.15	0.539	0.539	Yes
	LCO_2	8.64	0.428	0.428	Yes
	LPOP	9.28	0.613	0.613	Yes
	LEX	9.53	0.662	0.662	Yes

ET = energy transition, GRO = economic growth, EX = exchange rate, CO_2 = CO_2 emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: compiled by the authors.

in CO_2 emissions may decrease the energy transition process in Asia by nearly 1.7%. Our finding is in line with Ito (2015) and Bilgili et al. (2016), who found a negative linkage between these two variables. Besides, the effect of the exchange rate was found to be statistically insignificant, while population growth has a positive sign, meaning it has a positive effect on energy transition in Asia.

Table 7 reports the estimated coefficients of variables for the high and upper-middle-income group. The results prove the positive effect of economic growth on the energy transition process for this group. A 1% increase in the economic growth of these 24 nations leads to an almost 0.8% increase in

renewable energy consumption. This finding is in line with Teulon (2014) who argued that due to the developed economic structure in these kinds of countries, a higher economic

TABLE 6 | Estimation results for 45 Asian countries.

Explanatory variables	Coefficients	Significant at 1% levels
Constant	0.53	No
LGRO	0.79	Yes
LCO_2	-1.73	Yes
LEX	0.008	No
LPOP	0.882	Yes
No. of observations		1170
Range		1993–2018
Cross-sections included		45
Wald Chi2 (5)	723.14	Yes

ET = energy transition, GRO = economic growth, EX = exchange rate, CO_2 = CO_2 emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: Compiled by the authors.

TABLE 5 | Pesaran (2007) panel unit root test results.

Samples	Variables	Without trend	With trend
All samples	LET	0.301	1.529
	LGRO	0.319	−0.729
	LCO_2	0.288	−−0.818
	LPOP	−0.472	−0.929
	LEX	0.298	1.832
High and upper-middle incomes group	LET	0.392	1.616
	LGRO	0.361	−0.782
	LCO_2	0.291	−0.618
	LPOP	−0.515	−0.872
	LEX	0.310	−1.482
Low and lower-middle incomes group	LET	0.362	1.482
	LGRO	0.417	−0.832
	LCO_2	0.318	−0.792
	LPOP	−0.391	−0.892
	LEX	0.328	−1.449

ET = energy transition, GRO = economic growth, EX = exchange rate, CO_2 = CO_2 emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: Compiled by the authors.

TABLE 7 | Estimation results for the high and upper-middle income group.

Explanatory variables	Coefficients	Significant at 1% levels
Constant	0.04	Yes
LGRO	0.89	Yes
LCO_2	−2.17	Yes
LEX	−0.03	Yes
LPOP	−1.98	Yes
No. of observations		624
Range		1993–2018
Cross-sections included		24
Wald Chi2 (5)	551.83	Yes

ET = energy transition, GRO = economic growth, EX = exchange rate, CO_2 = CO_2 emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: Compiled by the authors.

growth accelerates financing green projects leading to more consumption of renewable energy sources. Furthermore, the rest of the variables were found to harm the energy transition. The estimation reveals that a 1% increase in CO_2 emissions, exchange rate, and population growth, may reduce the energy transition process in this group by approximately 2.1%, 0.03%, and 1.9%, respectively.

The GMM estimation for the low and lower-middle incomes group proves the positive effect of economic growth and exchange rate, while population growth and CO_2 emissions are found to have a negative effect on the energy transition process of this group. According to the results in **Table 8**, a 1% increase in economic growth and exchange rate leads to an increase of the energy transition of this group by approximately 0.9% and 0.07%, respectively, whereas a 1% increase in CO_2 emissions and population growth led energy transition to decelerate by nearly 1.5% and 2.8%, respectively. The magnitudes of impacts from CO_2 emissions and population growth are stronger than the impacts of economic growth and exchange rate. This finding is in line with Spencer and Mathur (2019) who expressed that emerging and developing nations with a lower income level need to link decarbonization policies (manage and lower CO_2 emissions) with their energy transition process.

As the final stage in the empirical estimations, we conducted diagnostic tests to verify the characteristics of the model. As

TABLE 8 | Estimation results for the low and lower-middle income group.

Explanatory variables	Coefficients	Significant at 1% levels
Constant	0.11	Yes
LGRO	0.96	Yes
LCO$_2$	−1.57	Yes
LEX	0.07	Yes
LPOP	−2.88	Yes
No. of observations		546
Range		1993–2018
Cross-sections included		21
Wald Chi2 (5)	616.38	Yes

ET = energy transition, GRO = economic growth, EX = exchange rate, CO$_2$ = CO$_2$ emissions, POP = population growth. (L) indicates variables in the natural logarithms. Source: Compiled by the authors.

TABLE 9 | Diagnostic test results for GMM estimation.

Samples	Statistics	AR(2)z	Chi2
All samples	Arellano-Bond test	−2.42**	–
	Sargan test	–	2781.11***
High and upper-middle incomes group	Arellano-Bond test	−2.18**	–
	Sargan test	–	3287.32***
Low and lower-middle incomes group	Arellano-Bond test	−2.01**	–
	Sargan test	–	3121.19***

** and *** indicate statistical significance at 1% and 5% levels, respectively. Source: Compiled by the authors.

TABLE 10 | Robustness check using FMOLS.

Samples	Independent variables			
	LGRO	LCO$_2$	LEX	LPOP
Full sample	0.07**	−0.13***	0.03	0.11**
High and upper-middle incomes group	0.12***	−0.10**	−0.17***	−0.29***
Low and lower-middle incomes group	0.06***	−0.25***	0.19***	−0.34***

ET = energy transition, GRO = economic growth, EX = exchange rate, CO$_2$ = CO$_2$ emissions, POP = population growth. (L) indicates variables in the natural logarithms. ** and *** indicate statistically significant at 1% and 5% levels, respectively. Source: Compiled by the authors.

shown in **Table 9**, the Arellano and Bond diagnostic test and Sargan test yield the following results.

The findings strongly reject non-autocorrelation, and the Arellano-Bond model assumptions are therefore satisfied. Besides, the Sargan test results prove that there are not any overidentifying restrictions, meaning that we can conclude that our three models are suitable.

Robustness Analysis

To check the GMM estimation results, reported in **Tables 6–8**, we used alternative panel data techniques, namely fully modified ordinary least squares (FMOLS), to check the robustness of our major findings. As shown in **Table 10**, estimation results do not significantly differ, which suggests our results are robust.

CONCLUDING REMARKS AND POLICY RECOMMENDATIONS

Based on annual data over the period 1993–2018, this study attempts to model energy transition in Asia-Pacific economies. To this end, we selected a sample of 45 countries and divided the sample based on the level of income to achieve better results. The high and upper-middle-income group included 24 countries and the low and lower-middle-income group included 21 countries.

Based on the empirical analysis using a GMM model, we determined similarities and dissimilarities in energy transition models among the sample groups. As for the similarities, economic growth has a positive relationship with the energy transition, while CO_2 emissions negatively influence energy transition in all sample groups. The results, regarding the economic growth-energy transition linkage, is in line with Saidi and Hammam (2015); Saad and Taleb (2017), Adams et al. (2018); Hoon Kang et al. (2019), Diaz et al. (2019) and Kouton (2020), who found a positive correlation between economic growth and moving from fossil fuels to renewables (energy transition). Our result is in contrast to Maji (2015) and Chen et al. (2019), who proved a mixture of negative and positive relationships between green energy usage and economic growth. Regarding the negative linkage between CO_2 emissions and energy transition, our finding is in line with Ito (2015), Bilgili et al. (2016) and Bilan et al. (2019), who found a negative

linkage between these two variables and that the negative impact of air pollution in terms of CO_2 emissions on green sources consumption does not depend on country income level. Reduction in air pollution can be an indicator of a reduction in fossil fuel consumption and an increase in using renewable energy sources. Moreover, a major motivation for transitioning to renewable energy is to reduce CO_2 emissions. Although the energy transition is not the only way for reducing CO_2 emissions. According to the United States Environmental Protection Agency (EPA), agricultural, forestry, and land use including crops, livestock and deforestation are responsible for 24% of the global carbon emissions (EPA, 2018). Regenerative agriculture sequesters carbon in the soil (the best indicator of healthy soil is its carbon content). This means in addition to shifting to renewable energy, for reducing CO_2 emissions transitioning from industrial agriculture to regenerative agriculture and preventing the deforestation are required.

The existence of differences among energy transition patterns of countries is in line with Chen et al. (2019) and Chen et al. (2020) who found out the dissimilar relationship between carbon dioxide emissions and renewable energy consumption across different regions.

Furthermore, in both sub-sample groups (i.e., high and upper-middle-income and low and lower-middle-income groups), increase the population leads to a decrease in the energy transition process. This result is in contrast with Salim and Shafiei (2014), who found a negative effect of population density on non-renewable energy consumption. The main reason for the negative effect is that the main energy source in Asia-Pacific is still fossil fuels. As dissimilarities, the results revealed that depreciation of the national currency in the high and upper-middle-income group may lead to an increase in renewable energy consumption in these countries, while this decreases energy transition movement in the low and lower-middle-income group. This happened because in the former group there are several exporters of renewable energy technologies such as China, Japan, Malaysia and while most countries in the latter group are the importer of green technologies and depreciation of the local currency makes the price of the imported renewable technology more expensive in the local currency as a result making the energy transition costlier and more difficult.

Based on IEA (2019b), the energy transition is a complexed process which needs interactions and cooperation among countries with different levels of development. Therefore, solving the complexity of energy transition requires global or regional cooperation and integration. According to Elshurafa et al. (2019), energy transition may take longer and has a heavy cost, so countries should make global or regional cooperation to facilitate these challenges in the way of energy transformation. This policy is in line with Kern and Smith (2008) who argued the necessity of energy transition management model to make integration in policies and plans to go to reach a higher level of energy transition which is a sign of economic development (Zahid et al., 2020). Another current challenge for energy transition development in Asia-Pacific is the Coronavirus (Covid-19) pandemic that hits demand for all fossil fuel resources and reduced the oil prices dramatically. According to the International Energy Agency

(IEA, 2020) as a consequence of global lockdown measures due to the Covid-19 crisis, 57% of global oil demand declined at an unprecedented scale in early 2020. Renewable energy projects will lose their competitiveness in low fossil fuel prices that will endanger the Paris agreement on climate change and the climate and clean energy-related SDGs.

Therefore in the post-Covid era proactive and efficient support and plans of government can keep the renewable energy sector and the energy transitions alive. Supportive plans such as the green credit guarantee scheme (Taghizadeh-Hesary and Yoshino, 2019) and policy and financial de-risking (Taghizadeh-Hesary and Yoshino, 2020) are necessary as renewable energy projects in the current timing find more difficulties in accessing to finance and investments.

Overall, we suggest that countries with different income levels have quite dissimilar energy transition patterns. Hence, they need different policies to improve energy transition movement. However, the inter-connected approach among countries in the field of energy transformation is a vital factor in success. Moreover, we recommend that Asia-Pacific countries need to alter their present energy policies [in line with Gulagi et al. (2020)] to enhance various policies for easing the access to electricity from green resources.

Notwithstanding its limitations, we believe that this study contributes to the existing literature on energy transition patterns. We recommend future research employs different control variables such as trade openness, interest rate, and inflation rate in econometric models, considering direct and indirect effects (following Taghizadeh-Hesary et al., 2013, 2019) and conducts causality tests to distinguish short- and long-run linkages between energy transition and independent variables.

DATA AVAILABILITY STATEMENT

The datasets analyzed in this manuscript are not publicly available. Requests to access the datasets should be directed to ER, e.rasoulinezhad@ut.ac.ir.

AUTHOR CONTRIBUTIONS

Both authors contributed equally to the manuscript and reviewed the final manuscript.

FUNDING

ACKNOWLEDGMENTS

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APPENDIX 1

TABLE A1 | Asia-Pacific group of the UN regional groups.

Afghanistan	Kyrgyzstan	Samoa
Bahrain	Lao People's Republic	Saudi Arabia
Bangladesh	Lebanon	Singapore
Bhutan	Malaysia	Solomon Islands
Brunei Darussalam	Maldives	Sri Lanka
Cambodia	Marshall	Syrian Arab Republic
China	Micronesia (Federated	Tajikistan
Cyprus	States of)	Thailand
Democratic People's	Mongolia	Timor-Leste
Republic of Korea	Myanmar	Tonga
Fiji	Nauru	Turkey*
India	Nepal	Turkmenistan
Indonesia	Oman	Tuvalu
Iran (Islamic Republic of)	Pakistan	United Arab Emirates
Iraq	Palau	Uzbekistan
Japan	Papua New Guinea	Vanuatu
Jordan	Philippines	Vietnam
Kazakhstan	Qatar	Yemen
Kiribati	Republic of Korea	
Kuwait		

Source: https://www.un.org/Depts/DGACM/RegionalGroups.shtml.

APPENDIX 2

TABLE A2 | Classification of samples based on income.

Low and lower-middle incomes	High and upper-middle incomes
Afghanistan	Bahrain
Bangladesh	China
Bhutan	Cyprus
Brunei Darussalam	Fiji
Cambodia	Iran (Islamic Republic of)
India	Iraq
Indonesia	Japan
Kiribati	Jordan
Kyrgyzstan	Kazakhstan
Mongolia	Kuwait
Myanmar	Lebanon
Nepal	Malaysia
Pakistan	Maldives
Papua New Guinea	Oman
Philippines	Qatar
Tajikistan	Republic of Korea
Timor-Leste	Samoa
Uzbekistan	Saudi Arabia
Vanuatu	Singapore
Vietnam	Sri Lanka
Yemen	Thailand
	Turkey
	Turkmenistan
	United Arab Emirates

Source: Authors' compilation from the World Bank.