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Research article

Does higher income lead to more renewable energy consumption? Evidence from emerging-Asian countries☆

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A R T I C L E I N F O

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A B S T R A C T

While some previous studies find a positive relationship between income or economic output and the share of renewables in energy consumption, others find a negative relationship. To bridge these seemingly contradictory findings, we test a non-linear relationship between income and the share of renewable energy sources in total energy consumption (REC%) in eight emerging-Asian countries. Using the feasible generalized least squares method and controlling for financial development and capital formation (two variables found in the literature to affect the use of renewable energy), we find a U-shaped relationship between income and the share of renewables in total energy consumption. In other words, at lower income levels, as income (Gross Domestic Product per capita) increases, REC% decreases. Once the income reaches a certain level, the relationship becomes positive. Financial development positively affects REC%. The implications and policy recommendations are presented in light of these findings.

1. Introduction

Consequences of climate change are already happening, and they are undoubtedly related to the increase in anthropogenic greenhouse gas (GHG) emissions [1]. If we continue emitting GHG the same way as in the last decades, we will likely suffer more severe and irreversible consequences on human beings and ecosystems [1]. Any meaningful effort to combat global warming must lessen reliance on fossil fuels. Renewable energy adoption can be a powerful contributor to improving environmental quality. Increasing renewable energy supply and demand is regularly stressed in the literature as a key instrument for lowering CO_2 emissions, enhancing environmental quality, ensuring energy security, and attaining long-term growth [2]. Growing concern about global warming is expected to increase renewable energy consumption [3]. Although drivers of the use of different kinds of non-renewable energy sources (oil, coal, etc.) have been extensively investigated, the study of factors affecting renewable energy consumption (REC) is an area that has received attention only more recently.

One of REC's most frequently studied drivers is income or Gross Domestic Product (GDP). On the one hand, it is expected that as income per capita increases, REC would increase because increased income enables countries to manage the expenses of developing and using modern renewable energy technologies [4] as they would have a higher ability to raise the necessary funds [5]. Moreover, governments of such countries would be better positioned to make sacrifices to encourage REC [6]. Citizens of wealthier countries are

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more likely to show environmental concern and may be more willing to use and invest in renewable energy [3].

On the other hand, economic growth may increase total energy consumption far more than renewable energy usage [7]. Especially in lower-income countries, investment in renewable energy is less likely to be a priority. Hence, as income increases, the new investment capabilities are more likely to be channeled to health or education [5]. In relatively poorer countries, the renewable energy consumed comes from traditional sources. As a result, with a higher income, the increased demand for energy will be satisfied by fossil fuel sources rather than relatively more expensive modern renewable energy sources [8].

As presented in detail in the next section, several papers focusing on developed economies have found a positive relationship between GDP per capita (GDPpc) and REC, and between GDPpc and the share of renewable energy sources in total energy consumption (REC%). However, other studies, analyzing mainly developing countries, found a negative relationship between these variables. This paper contributes to the existing literature by testing whether there is a U-shaped relationship between income per capita and the share of renewables in total energy consumption. That is, we hypothesize that at lower income levels, as income per capita increases, REC% decreases, but once the income reaches a certain level, the relationship becomes positive.

To test the hypothesized U-shaped relationship between income and REC%, we needed a set of countries that went from being relatively low-income to relatively high-income countries during the period for which we have available data regarding renewable energy consumption. Such data, for most countries, go back only around 30 years. Countries that satisfy this requirement are emerging countries in Asia. Moreover, the eight Asian economies we analyze made up 45.9% of the total world population in 2020 [9], and they are estimated to be among the top 25 fastest-growing economies in the period 2016–2050, while five out of the eight countries are estimated to be among the top ten [10]. Therefore, analyzing how income and other economic factors affect REC in these countries is important as these countries may become significant greenhouse gas emitters in the near future. For these reasons, they are the focus of our study.

The rest of the paper is structured as follows. The next section reviews the related literature and summarizes our contribution. Section 3 outlines the data, variables, and methodology used in this study. While Section 4 presents our results, the last section discusses the findings, proposes some policy recommendations, and suggests directions that can be taken for further research.

2. Literature review and our contribution

Following the works of Sadorsky [3,11], there has been a growing literature analyzing the socio-economic determinants of REC. In what follows, we first discuss the literature that focuses on the nexus between income and REC, our primary focus in this paper. Then, we briefly present the literature studying the nexus between REC and financial development and capital formation, respectively, our two control variables in the econometric analysis. Finally, we outline our contribution to the existing literature.

2.1. Income and REC

It has been well established in the literature that there exists a positive relationship between GDPpc and energy consumption (see for instance, Refs. [12-20], and [21]). Such a positive relationship was also found by the majority of studies analyzing the relationship between GDPpc and REC ([3,11,22–25] among others) as well as GDPpc and renewable energy production per capita [26]. While [27, 28], and [29] did not find any significant relationship between GDPpc and REC [30,31], found the relationship to be positive in a panel of middle and high-income countries. In the panel of low-income countries, however, the relationship was negative. Focusing on a set of 97 countries, Chen et al. [32] found a positive relationship between REC growth and GDP growth for only the developed countries in their dataset, while for the developing countries, the relationship is not statistically significant. Nevertheless, the positive relationship found in most studies does not necessarily indicate a stronger preference for renewable energy sources, as energy consumption from non-renewable sources may increase faster. Therefore, focusing on the effect of GDPpc on REC% (instead of the amount of consumption) would better picture the change in the energy mix.

In the case of studies that use REC% as their dependent variable, a positive effect of GDP on REC% is found in research focusing on either developed countries (Damette and Marques [33] in the case of 24 European countries; Li et al. [34] in OECD countries) or a large set of countries including both developed as well as developing ones (Yahya and Rafiq [35] for a panel of 85 countries). Several studies find a negative relationship between the two variables at hand. Those studies either focus on a panel of developing countries (21 African countries – Ergun et al. [8], 9 Balkan countries – Akar [36], 4 ASEAN countries – Kumaran et al. [37], 34 upper-middle-income developing countries – Shahbaz et al. [38]), a single developing country (Ghana – Kwakwa [39]) or panels of a large number of pre-dominantly developing countries (69 Belt & Road Initiative countries – Khan et al. [40], 102 countries Li et al. [7]). When dividing their set of countries into two groups (high and low income per capita), Akarsu and Gumusoglu [5] find the effect of income per capita on REC% to be positive in high-income countries. However, it is negative in low-income countries. Majeed and Hussain [41], on the other hand, find that a negative relationship exists in countries with lower levels of financial development, whereas a positive relationship exists in countries with a more developed financial system.

The empirical evidence presented above suggests that the relationship between income per capita and REC% is positive for relatively wealthier countries but negative for developing countries.

2.2. Financial development, capital formation, and REC

Due to the infrastructure requirements and start-up and operating costs, implementing renewable energy technologies is more costly than non-renewable ones [42]. Therefore, especially in developing countries, the financing of renewable energy projects is strongly linked to the financial sector development [43]. Financial development would allow the provision of more funds for capital investment in renewable energy technologies [6,42], making the funding of renewable energy investments more accessible for firms [44]. It would also enhance innovation in renewable energy technologies [45] and attract more foreign direct investment into such technologies [46]. Previous studies established a positive relationship between financial development and renewable energy capacities [47], electricity generation or consumption from renewable sources ([6,43,48]), overall REC [42], and also between financial development and the share of renewables in total energy consumption ([38–40,46,49]). On the other hand, Majeed and Hussain [41] found a U-shaped relationship between financial development and the proportion of renewable energies in overall energy usage. That is, at lower levels of financial development, the share of renewables in total energy consumption falls as financial development improves, while after a certain threshold level of financial development, the relationship becomes positive.

Capital formation, a key factor in long-run economic growth, may also contribute to the growth of renewable energy usage as a more developed infrastructure may allow faster growth of renewable energy usage [48]. Moreover, as energy and capital are complementary inputs in the production process, an increase in capital stock would bring a rise in REC [5]. Empirically, gross capital formation was found to affect REC positively ([24,50]) as well as REC% ([5]). Moreover, Saint Akadiri et al. [51] found a two-way causal relationship between capital formation and the proportion of renewable energy sources in overall energy consumption.

We control for financial development and capital formation based on the theoretical underpinnings and empirical evidence. For both variables, we expect to find a positive relationship with REC%

2.3. *Our contribution*

After reviewing the different findings concerning the effect of income on renewable energy consumption, one question emerges: Whether the relationship is positive for one type of countries and has always been positive, while at the same time, this relationship is negative for another type of countries and will continue to be negative in the future, or whether the sign of the relationship may change over time.

Obtaining a U-shaped relationship between GDPpc and REC% would reconcile at first seemingly contradictory findings in the literature: At early stages of development, a higher per capita income leads to a reduction in the share of renewables in the energy mix while as GDPpc reaches a certain level, higher income per capita will eventually lead to a more environmentally sustainable energy mix.

To the best of our knowledge, ours is the first study to test a U-shaped relationship between GDPpc and the share of renewables in total energy consumption for a set of countries. That means our paper is the first to analyze whether the relationship between income and REC might go from negative to positive while controlling for relevant variables. Only one other study by Zhao and Luo [52] tests and obtains such a U-shaped relationship in the case of a single country, China. Different than our study, their dependent variable is renewable energy generation. Moreover, they do not include any control variable in the estimation.

3. Data, variables, and methodology

3.1. *Data and variables*

Our objective is to investigate the relationship between the share of renewable energy consumption and income per capita in emerging-Asian countries. While doing so, we control for the country's financial development level and capital formation (as a percentage of GDP).

We follow the country classification by Morgan Stanley Capital International (MSCI) to determine which countries are emerging.[1] The necessary data is available for eight emerging markets in Asia: China, India, Indonesia, Korea, Malaysia, Pakistan, Philippines, and Thailand. As our measure of income per capita, we use real GDPpc, which is used in virtually all the studies mentioned in Part 2. For financial development, we use the Financial Institutions Development Index, developed by IMF, which considers the three dimensions of financial development, access, depth and efficiency [52]. Following [5,48], we use the expenditure on fixed assets and changes in inventories as a percentage of GDP as our measure of capital formation. The sample period selection is based on data availability, spanning from 1990 to 2015. The data are obtained from the World Development Indicators (WDI) –the World Bank's compilation of cross-country data,[2] and the International Monetary Fund (IMF) Data.[3] Table 1 presents a short description of the variables used in the analysis.

In the statistical and econometrical analysis, as is common practice, we use the logarithm of GDPpc, denoted by LGDPpc.

3.2. *Methodology*

We hypothesize that the relationship between GDPpc and REC% follows a U shape, i.e., it is negative for low values of GDPpc and positive for high values of GDPpc. Therefore, our basic model is as shown in equation (1) below.

[1] https://www.msci.com/market-cap-weighted-indexes.

[2] https://databank.worldbank.org/source/world-development-indicators.

[3] https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B.

Table 1
Description of the variables.

Variable code	Variable name	Source	Min	Max	Mean
REC%	Renewable energy consumption (% of total final energy consumption)	WDI (World Bank)	0.44	58.65	29.05
GDPpc	Gross Domestic Product per capita (in constant 2010 U.S. Dollars)	WDI (World Bank)	576	26064	4770
FD	Financial Institutions Development Index. It summarizes "how developed financial institutions are in terms of their depth (size and liquidity), access (ability of individuals and companies to access financial services), and efficiency (ability of institutions to provide financial services at low cost and with sustainable revenues)" (http://data.imf.org). The index goes from 0 to 1 and a larger value implies a higher financial development	IMF	0.206	0.812	0.423
GCF%	Gross capital formation (% of GDP)	WDI (World Bank)	14.12	46.66	28.82

$$REC\%_{it} = \beta_0 + \beta_1 LGDPpc_{it} + \beta_2 LGDPpc_{it}^2 + \beta_3 X_{it} + \varepsilon_{it} \tag{1}$$

where *REC%, LGDPpc, LGDPpc,*^{2} and *X* represent the share of renewables in the total energy consumption, the logarithm of GDPpc, the logarithm of GDPpc squared, and the control variables, respectively, while ε represents the error term.

The first step in the analysis is to investigate whether the panel data suffers from cross-sectional dependence (CD), i.e., the considered countries are correlated in the same cross-section, probably caused by some common factors affecting all the countries. We use Pesaran's CD test [53] to test whether there is cross-sectional dependence within the panel data.

The second step is to check for stationarity of the variables via a set of panel unit root tests: Levin et al. [54] (LLC), Harris and Tzavalis [55] (HT), Im et al. [56] (IPS), Breitung [57,58], and Pesaran's CIPS test [59]. In all the unit root tests, the null hypothesis (H0) of non-stationarity is tested against the alternative of stationarity. Variables are expected to be integrated of order 1; thus, we expect not to reject H0 for the variables in levels and to reject H0 for the variables in the first difference. The first four tests are called "first generation panel unit root tests", which in the presence of CD might be biased, while Pesaran's CIPS test is a "second generation panel unit root test" that takes into account common factors.

The next step is to check for cointegration among the variables, using Johansen Fisher [60], Kao [61], and Westerlund [62] cointegration tests. The null hypothesis in these tests states that the variables are not cointegrated. Maddala and Wu [60], using Fisher's result, propose a panel cointegration test for the full panel combining tests from individual cross-sections. The χ^2 values and the corresponding p-values for Johansen's cointegration trace test and maximum eigenvalue test are presented [60]. tests the presence of none cointegrated equation (CE), up to one, up to two, and up to three. If we cannot reject the presence of none cointegrated equation, the variables are not cointegrated. The Kao cointegration test presents the t-statistic and its corresponding p-values. The null hypothesis states no cointegration. The Westerlund test checks for the absence of cointegration based on an error-correction approach. Four panel cointegration tests are presented –two group-mean (G) and two panel tests (P), two computed with standard errors (t) and two with Newey-West adjusted errors (a)– with the bootstrapped p-values since they are robust in the presence of common factors in the time series. The underlying idea of the test is to check for the absence of cointegration by checking whether the individual panel members are error-correcting.

After confirming that the variables are cointegrated, we can estimate our model using feasible generalized least squares.

Feasible Generalized Least Squares (FGLS) is considered a robust estimation method that minimizes estimation bias and provides efficient estimations when we have auto-correlation, heteroskedasticity, and cross-sectional dependence [63,64]. This is crucial in our paper since it is likely that our dataset suffers from cross-sectional dependence. Moreover, as Shah et al. [64] stated, the FGLS estimator is consistent, asymptotically normal, and more efficient than ordinary least squares. In recent years, FGLS has been used in many different contexts (see for instance, Refs. [64-69]).

Three models are estimated: one without control variables (equation (2) below), and two more that include the control variables in steps (equation (3) and (4)).

$$REC\%_{it} = \beta_0 + \beta_1 LGDPpc_{it} + \beta_2 LGDPpc_{it}^2 + \varepsilon_{it} \tag{2}$$

$$REC\%_{it} = \beta_0 + \beta_1 LGDPpc_{it} + \beta_2 LGDPpc_{it}^2 + \beta_3 FD_{it} + \varepsilon_{it} \tag{3}$$

$$REC\%_{it} = \beta_0 + \beta_1 LGDPpc_{it} + \beta_2 LGDPpc_{it}^2 + \beta_3 FD_{it} + \beta_4 GCF\%_{it} + \varepsilon_{it} \tag{4}$$

For LGDPpc and REC% to have a U-shaped relationship, LGDPpc should have a significant negative effect on REC% (i.e., β_1 should be negative) and $LGDPpc^2$ should have a significant positive effect (β_2 should be positive). Moreover, we conduct the *U* test developed by Lind and Mehlum [70], where rejecting the null hypothesis (of a monotonous or inverted-U shape relationship) confirms the presence of a U-shape relationship between REC% and GDPpc.

The final step in the analysis is the exploration of causality between the independent variables and REC%, using the Dumitrescu and Hurlin [71] approach, which tests for Granger non-causality in heterogeneous panels. Bootstrap is used to allow for cross-sectional dependence. The null hypothesis of the test states that variable X does not Granger cause variable Y, while the alternative hypothesis states that there exists causality at least for some cross-sections. Wald statistics and their corresponding p-values are calculated.

4. Empirical results

The average share of renewables in the total energy consumption for the eight countries under study for the 26 years (1990–2015) is 29.05%. This number is well above the world average (see Table 2) and the average of several regions (EU, North America, East Asia & Pacific, for example) but below the average of Sub-Saharan countries.

As the primary goal of this paper is to study the nexus between REC% and GDPpc, it is illustrative to examine the relationship graphically.

Fig. 1 shows that for most countries, the relationship between GDPpc and REC% follows a U shape, but it also shows that the share of renewables is not uniform, as shown in Table 3 below. REC% goes from a low 1.10% in Korea to 49.98% in Pakistan. Likewise, GDPpc varies amply, with the lowest mean value corresponding to Pakistan (US$890) and the largest to Korea (US$17,356). Nonetheless, it must be noticed that most of the countries have low GDPpc; Korea is the exception. The country second to Korea in terms of the average GDPpc for the considered period is Malaysia, with a value of only US$7572. The highest values for the control variables are also observed for Korea, i.e., Korea's financial market is the most developed in our sample, and Korea has the highest average gross capital formation as a percentage of GDP. Despite the differences between the countries, Fig. 1 shows that the relationships between GDPpc and REC% at the country level are relatively similar.

After the descriptive analysis of the data, the first step is evaluating the cross-sectional dependence test. Table 4 below presents the results of the Pesaran test, which show that the null hypothesis of cross-sectional independence is rejected for all the variables, meaning that all units in the same cross-section are correlated. This is usually explained by some unobserved common factors that affect all the sampled countries, although it is likely that the countries are affected in different ways.

As mentioned in the previous section, the second stage in the analysis is to investigate the order of integration of the variables. Most of the tests in Table 5 below indicate that the order of integration of the variables is 1, i.e. the variables are I(1). Having proved the existence of CD, we should pay special attention to Pesaran's CIPS test. Its results show that all the variables are I(1) at 1% level because the statistic values for the variables in levels are all below -2.21 (the critical value at 10%). However, for the first differences, all the statistic values are above -2.57 (the critical value at 1%).

With all the variables integrated of order 1, we continue the analysis with cointegration tests. Most of the results in Table 6 reject the absence of cointegration between the variables, allowing us to continue our analysis with the estimation of the models.

Table 7 presents the results of the estimations. As stated in Section 3, for the relationship between LGDPpc and REC% to be U-shaped, the coefficient of LGPDpc should be negative and the coefficient of $LGDPpc^2$ should be positive. The estimates show that LGDPpc and REC% follow a U-shape relationship indeed: for low values of LGDPpc, REC% decreases, while for high values of LGDPpc, REC% increases, even when including the control variables. This finding explains why some studies such as [8,36] or [37] found a negative relationship between GDPpc and REC% while others such as [33] or [34] found a positive one. Regarding the control variables, as expected and previously found in the literature (see for instance, Refs. [40,46], or [49]), FD has a positive effect on REC%. That is, the more developed financial institutions are, the higher the share of renewables in a country. In the case of GCF%, contrary to previous studies such as [5] or [24], it does not significantly affect REC%.

The Utest shown in the lower part of Table 7, where the null hypothesis is rejected, confirms the U-shaped relationship between LGDPpc and REC%. As a consequence, a U-shape relationship is established. As part of the test results, the LGDPpc extreme point –minimum in our case– is also presented. For model 3, it implies that the GDPpc turning point is US$ 30,125, i.e., below this point, the share of renewables decreases, while for values above the turning point, the share increases.

To test whether the data suffers from high multicollinearity, we analyze the variance inflation factors (VIFs). All VIFs are under 10, and the average VIF is 5.81. Since Gujarati (2003) states that VIFs higher than 10 are problematic, we do not have a cause for concern. The inclusion of the variables in steps (not affecting the significance of the GDP variables) plus the relatively low VIFs found show that we do not have a problem of high multicollinearity [72].

The last step in the analysis is the causality investigation. As Table 8 shows, there is a one-way causal relationship going from LGDPpc and FD towards REC%, i.e., these two independent variables Granger-cause REC%.

Table 2
Average share of renewables in energy consumption.

	Average share of renewables
World	17.51
European Union	10.69
Latin America & Caribbean	28.99
North America	7.73
East Asia & Pacific	19.24
OECD members	8.73
Sub-Saharan Africa	71.72
South Asia	49.93
Eight countries under study	29.05

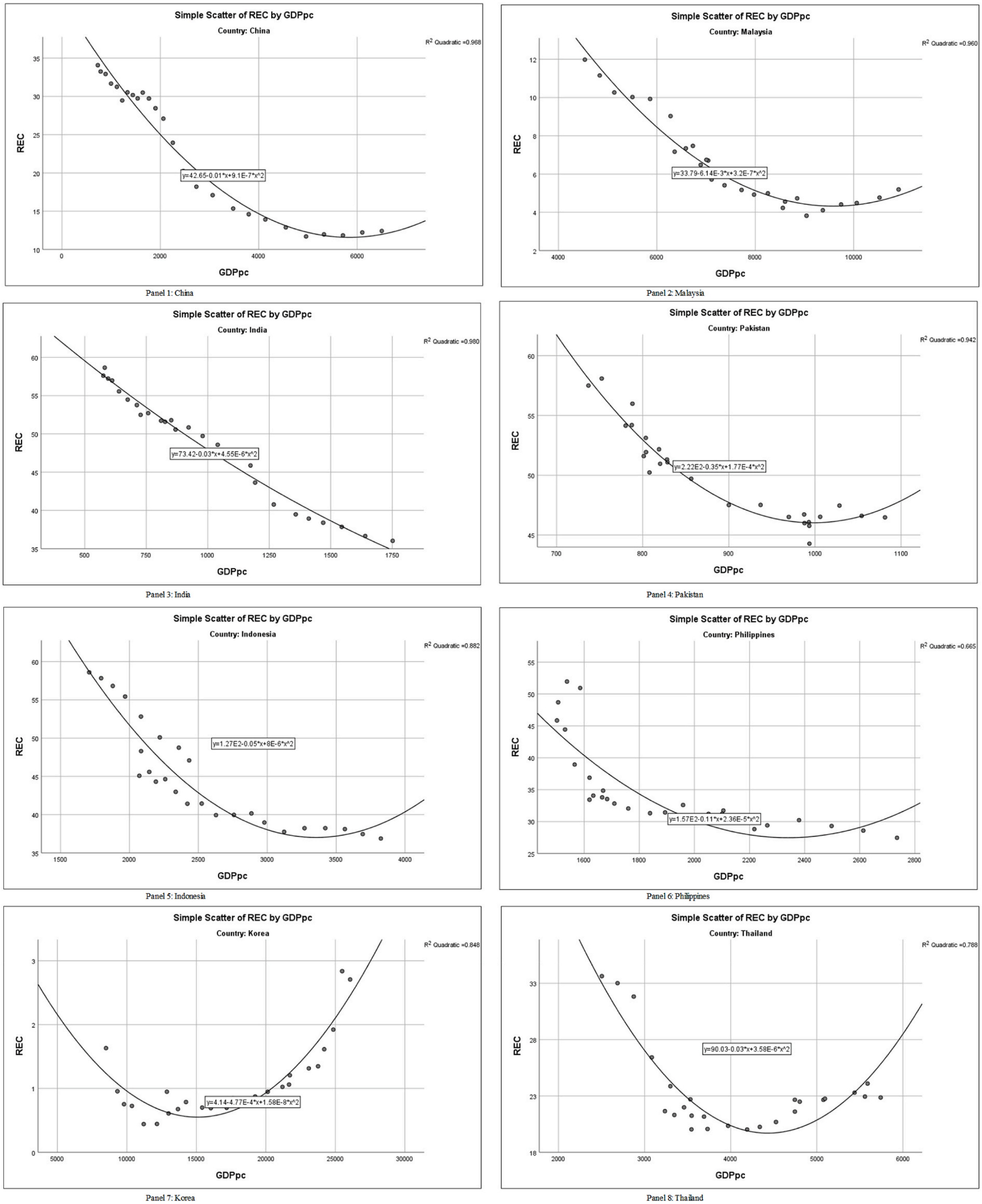

Fig. 1. Relationship between GDPpc and REC% by country. Panel 1: China, Panel 2: Malaysia, Panel 3: India, Panel 4: Korea, Panel 5: Malaysia, Panel 6: Pakistan, Panel 7: Philippines, Panel 8: Thailand.

Table 3
Means of variables by country.

	China	India	Indonesia	Korea	Malaysia	Pakistan	Philippines	Thailand
REC %	22.90	48.44	44.88	1.10	6.57	49.98	35.21	23.29
GDPpc	2789	1003	2562	17356	7572	890	1894	4090
FD	0.401	0.294	0.297	0.724	0.609	0.256	0.300	0.503
GCF%	40.10	31.88	28.77	33.79	28.51	17.46	20.52	29.54

Table 4
Pesaran cross-section dependence test.

Variable	CD-test	p-value
REC%	13.889	0.000
LGDPpc	26.069	0.000
FD	20.899	0.000
GCF%	4.774	0.000

Table 5
Unit root tests.

	LLC		HT		IPS		Breitung		CIPS
	Stat.	P-value	Stat.	P-value	Stat.	P-value	Stat.	P-value	Stat.
REC%	−3.127	0.001	0.943	0.907	0.009	0.503	4.504	1.000	−1.653
Δ REC%	−2.871	0.002	0.218	0.000	−5.700	0.000	−4.894	0.000	−4.314
LGDPpc	−0.949	0.171	0.989	0.993	4.680	1.000	8.824	1.000	−1.749
Δ LGDPpc	−4.716	0.000	0.221	0.000	−5.396	0.000	−3.787	0.000	−3.392
FD	3.305	1.000	0.999	0.997	4.702	1.000	4.435	1.000	−2.129
Δ FD	−5.193	0.000	−0.006	0.000	−7.086	0.000	−4.651	0.000	−4.426
GCF%	−1.941	0.026	0.847	0.150	−0.265	0.395	−1.613	0.053	−1.657
Δ GCF%	−5.497	0.000	0.031	0.000	−6.878	0.000	−6.024	0.000	−5.019

Notes: H0) X is not stationary. LLC: Levin-Lin-Chu, HT: Harris-Tzavalis, IPS: Im-Pesaran-Shin.
Pesaran's CIPS Critical values: -2.21 (at 10%), −2.33 (at 5%), −2.57 (at 1%).

Table 6
Cointegration tests.

Johansen Fisher Panel Cointegration Test				
Hypothesized	Fisher Stat.		Fisher Stat.	
No. of CE(s)	Trace test	P-value	Max-eigen test	P-value
None	138.4	0.000	91.35	0.000
At most 1	61.82	0.000	50.35	0.000
At most 2	26.7	0.045	19.21	0.258
At most 3	19.42	0.247	19.42	0.247
Kao Residual Cointegration Test				
	t-Statistic	P-value		
ADF	−3.342422	0.0004		
Residual variance	1.165095			
HAC variance	2.1136			
Westerlund panel cointegration test				
Statistic	Value	Rob.P-value		
Gt	−1.878	0.033		
Ga	−3.181	0.683		
Pt	−6.424	0.033		
Pa	−3.321	0.350		

Note: H0) No cointegration.

5. Conclusion and policy recommendations

This paper analyzed the nexus between income per capita, financial development, gross capital formation, and the share of renewables in total energy consumption in a panel of eight emerging-Asian countries. We found that the relationship between GDPpc and REC% is U-shaped. In other words, as GDPpc increases, REC% decreases at lower income levels, but once the income reaches a certain level, the relationship becomes positive. Moreover, we also found that financial development has a significant positive effect on REC%.

Table 7
GLS estimations.

Dependent variable: REC%	GLS					
	Model 1		Model 2		Model 3	
Variable	Coef.	Std.Err.	Coef.	Std.Err.	Coef.	Std.Err.
LGDPpc	−54.889***	2.544	−59.107***	2.535	−60.507***	3.379
$LGDPpc^2$	2.559***	0.147	2.810***	0.146	2.933***	0.213
FD			0.0583**	0.025	0.066***	0.020
GCF%					1.144	2.512
Constant	294.697***	10.873	309.648***	10.665	313.092***	13.323
Observations	208		208		208	
Groups	8		8		8	
Time	26		26		26	
Time effects	Yes		Yes		Yes	
Country effects	Yes		Yes		Yes	
Chi - square (p-value)	0.000		0.000		0.000	
Test for the presence of a U shape [H1) U shape]	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
Slope	−22.359	1.415	−23.385	2.722	−23.221	4.030
P > t	0.000	0.029	0.000	0.000	0.000	0.004
P-value of the overall test	0.029		0.000		0.004	
Extreme point LGDPpc	10.723		10.516		10.313	
Extreme point GDPpc	45,409		36,891		30,125	

Note: *, **, and *** denote 10%, 5%, and 1% significance level respectively.

Table 8
Granger panel causality tests results.

Null Hypothesis	Zbar Stat.	P-value	Causality
LGDPpc ↛ REC%	3.750*	0.100	Unidirectional LGDPpc→ REC%
REC% ↛ LGDPpc	2.706	0.300	
FD ↛ REC%	3.827***	0.000	Unidirectional FD→ REC%
REC% ↛ FD	1.371	0.600	
GCF% ↛ REC%	0.792	0.500	
REC% ↛ GCF%	2.576	0.200	

Notes: *, **, and *** denote 10%, 5%, and 1% significance level respectively. Bootstrap is used due to the presence of cross-sectional dependence. The symbol↛ means "Does not Granger-cause".

The causality tests also indicate a unidirectional causality from GDPpc and financial development towards REC%.

To the best of our knowledge, our study is the first one establishing a U-shaped relationship between income per capita and REC% for a panel of countries. As such, it establishes a bridge between seemingly contradictory findings in the literature.

Our results suggest that in countries where an increase in income per capita still leads to a lower share of renewables ([8,36,37,40]), as the economy grows further, the share of renewables will eventually increase. Hence, policies that would foment economic growth, such as increasing human capital, improving the country's infrastructure, or increasing the spending on R&D, would eventually positively affect REC%. As the country approaches the critical turning point, to dampen the negative effect of a higher share of non-renewable sources, policies fomenting a more efficient use of energy and campaigns increasing public awareness are recommended.

The negative relationship between income and REC% at lower income levels is likely due to the higher cost of renewable energy investments [38]. Therefore, policies that would reduce the relative cost of such investments, such as tax breaks, subsidies, and public loans at lower interest rates, are recommended.

The positive effect of FD on REC% suggests that improvements in the financial sector will allow countries to have a lower turning point in the U-shaped relationship between income and REC%. Hence, policies aimed at directly improving financial markets and institutions are recommended. Tadesse [73] argues that financial development leads to technological innovations, while Tamazian et al. [74] found that it helps reducing CO_2 emissions. The latter argue that FD can attract FDI and greater levels of investment in R&D, which might offer developing countries the chance to use new technologies to support more environmentally friendly production, which could increase the percentage of renewables in energy usage.

Moreover, Huang [75] and Law and Azman-Saini [76] found that FD can be boosted by high-quality institutions, which implies that enhancing the quality of institutions will develop a country's financial system, which in turn will increase REC% resulting in an environmental improvement. Therefore, another policy recommendation is to strengthen institutional quality. Similarly, policies that improve law enforcement and reduce corruption are recommended as both factors boost FD [77].

Our study is not without limitations. The most important one is related to our time span. Data on the use of renewable energy sources is available from 1990. If the information were available for a more extended period, we could include more countries in our study. That is, we would be able to include countries that transitioned from being in the relatively low-income group to the middle or high-income group earlier than the emerging-Asian countries. That would make our conclusions stronger.

The main finding of this paper brings a certain degree of optimism regarding a future reduction in energy-consumption-related GHG emissions. However, given the already present effects of climate change, the share of non-renewable energy sources in total energy consumption must decline at a faster rate. As such, analyzing which factors may allow countries to have a lower turning point in the U-shaped relationship between income and REC% is critical. This paper documents one such factor, financial development. Analyzing what other factors may lower this turning point would be an interesting topic for further research. In particular, the role of institutional quality and political stability are two factors that can be incorporated into future studies. Moreover, our study could be complemented by a comprehensive analysis of each country's different renewable energy sources.

Author contribution statement

Selim Jürgen Ergun: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

M. Fernanda Rivas: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

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