مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

Understanding the Dynamics of the Renewable Energy Transition: Determinants and Future Projections Under Different Scenarios

Fatih Yilmaz

November 2021

Doi: 10.30573/KS--2021-DP25

Acknowledgments

We would like to thank Fatih Karanfil, Jeyhun Mikayilov, Mari Luomi and Miquel Muñoz Cabré for their invaluable inputs in various capacities. We also thank the KAPSARC Seminar Series participants for their important contributions.

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

This publication is also available in Arabic.

Legal Notice

Key Points

This study provides a comprehensive econometric analysis of the determinants of the renewable energy (RE) transition. The analysis uses the recently developed renewable energy transition potential index and its components. The results show that:

Economic factors (e.g., economic size, growth and development) are positively associated with countries' RE transition performance.

The quality of human capital (e.g., population demographics, education and health quality) is also positively associated with this performance. In contrast, better energy access is negatively associated with countries' RE transitions. These associations are all statistically significant.

Access to private finance and environmental sustainability are also positively related to the RE transition performance, but these relationships are marginally statistically significant.

Finally, we use the econometric models to predict countries' RE transition paths by 2030 under different scenarios.

Introduction

The global energy system's current structure has severe environmental consequences that necessitate an urgent transformation toward more sustainable alternatives. Besides many available mitigation actions, such as enhancing energy efficiency, deploying nuclear energy, switching fuels and adopting carbon capture technologies, renewable energy (RE) has been the most widely applied one in many countries, especially for the power sector. The average country-level share of non-hydroelectric renewable energy (NhRE) in power generation rose sixfold over the last two decades, from less than 1% in 2000 to roughly 6% in 2018.[1] Despite its wide application, significant heterogeneity exists in the RE transition across countries. Some countries are moving faster, whereas others are lagging. This considerable heterogeneity across countries raises several critical questions that demand answers to explain the complex dynamics of the RE transition. Why do some countries move faster in their RE transition than others? What are the key factors that can explain this heterogeneity? Given their historical energy transition performances, can we predict countries' future RE transition trajectories? This study aims to shed light on these critical questions.

The RE transition is a multifactor, complex and long-term process. It requires investments of many trillions of United States (U.S.) dollars, the adaptation of new technologies and the development of necessary human capital. The support of local political actors and society's internalization of environmental sustainability are also necessary for a healthy RE transition. Although many studies provide partial results on the RE transition's critical determinants, they use diverse approaches. For example, they measure factors differently, analyze data from different developed or developing countries or consider different time periods. Thus, little consensus seems to have been achieved in the literature.[2] A recent work by Yilmaz (2021) takes a different approach. The paper extensively reviews two decades of academic literature and identifies 45 critical variables used to measure various determining factors of the RE transition. Using these critical variables, it constructs a composite index, the RE transition potential index (RETPI).[3] The RETPI comprises seven subindices: economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. Each subindex incorporates the most widely used indicators in the relevant context. As a forward-looking determinant index, the RETPI's primary objective is to measure countries' RE transition potentials. The index has been computed for 149 countries over the decades from 1990 to 2018. The current study uses the RETPI and its subindices to measure countries' RE transition potentials.

We proxy countries' RE transition performances by the share of NhRE in total electricity production.[4] The NhRE share is widely used in the literature (e.g., Bourcet 2020), where modern RE technologies, such as solar, wind and geothermal resources, are the focus. Focusing on contemporary RE technologies enables us to capture a wide range of climate mitigation actions as a part of the modern RE transition experiences across countries.[5] Secondly, we focus on electricity production because a significant portion of the global energy transition is taking place in the power sector. This sector is usually considered easier to decarbonize relative to other diffuse sectors, such as transportation. Moreover, the power sector alone is responsible for roughly one third of global carbon emissions (Crippa et al. 2019). Thus, increasing RE usage in electricity generation can help curb global emissions significantly.

Using the proxies for countries' RE transition performances and potentials, we estimate dynamic and static panel models with different specifications to identify the key determinants of the transition process. We lag the independent variables by one, three and five years to account for transition dynamics in the short, medium and long terms, respectively. We also control for global time trends and country fixed effects. We test the baseline results with further robustness checks, including different lag structures and year fixed effects instead of general trends. We also use region-year and income group-year fixed effects to account for transition dynamics that are specific to regions and income groups.

Our estimation results show that the RETPI is positively and statistically significantly associated with the usage of NhRE in power generation. The baseline model can explain a significant portion of the variation in the dependent variable (up to 57%). Among the RETPI's components, the economic factors subindex (i.e., country size, growth performance and development level) has a statistically significant and positive relationship with the NhRE share. We find similar results for human capital (i.e., population demographics, education level and health status) and environmental sustainability (i.e., lower carbon dioxide emissions and fossil fuel usage intensity) subindices. In some specifications, we find a positive, marginally statistically significant association between the financial development subindex (i.e., access to private finance) and the NhRE share. The energy access subindex (i.e., access to reliable electricity) has a statistically significantly negative association with the NhRE share. The energy security and institutional infrastructure subindices indicate no statistically significant associations with the NhRE share. These findings are robust to alternative specifications and various checks.

The results of our analysis generalize previous findings in the literature in a broader setting. Moreover, by using a more systemic approach, we complement and summarize previous findings. Our results are not based on a specific set of countries or time period and, more importantly, do not rely on limited proxies (e.g., Bourcet 2020). In contrast, prior studies use different variables to proxy for the main factors determining RE transitions, and they generate mixed results. For instance, studies generally find that economic factors are positively associated with RE usage (Bourcet 2020; Can Sener, Sharp, and Anctil 2018). However, this conclusion may vary depending on the type of proxy used for economic factors, such as economic size,[6] growth[7] or development.[8] Some studies find the opposite or insignificant relationships between economic factors and the RE transition (e.g., Marques and Fuinhas 2011a, 2011b).

The estimation results also confirm prior findings of a positive association between human capital and the RE transition (e.g., Pfeiffer and Mulder 2013; Romano et al. 2017; Zhao, Tang, and Wang 2013). Our results for the environmental sustainability subindex suggest that countries with greater environmental sustainability (or lower environmental concerns) tend to experience faster RE transitions. This result is also in line with the general findings in the literature (e.g., Marques and Fuinhas 2011b; Marques, Fuinhas, and Pires Manso 2010). Additionally, the literature suggests that the need to improve energy access is an essential motivation for governments to promote RE in power generation. Thus, countries with low energy access are expected to invest in and consume more RE (e.g., Glemarec 2012; Sokona, Mulugetta, and Gujba 2012). This hypothesis is supported by our findings regarding energy access. Despite the literature's strong findings on the positive association between financial development (e.g., access to private finance) and the RE transition (e.g., Anton and Afloarei Nucu 2020; Best 2017; Brunnschweiler 2010; Lin and Omoju 2017; Sadorsky 2010), our results suggest that the variables have only a marginally statistically significant positive association. Finally, previous studies suggest that energy security concerns and institutional quality have positive associations with the RE transition (e.g., Bayulgen and Ladewig 2017; Brunnschweiler 2010; Marques and Fuinhas 2011a, 2011b; Pfeiffer and Mulder 2013; Wu and Broadstock 2015). After controlling for other factors, however, we find no statistically significant relationships between these variables.

Among the estimated models, we use the models with the most predictive power to predict countries' future RE transition performances under reasonable scenarios. We consider fast, medium and slow transition scenarios in the analysis. These transition scenarios are developed according to trends in RETPI scores across income and region groups over the decade from 2009 to 2018. Moreover, we estimate one-, three- and five-year models for each scenario separately to provide predictions for the short, medium and long terms, respectively. Our results show that under reasonable assumptions, the current level of average NhRE share at the country level (i.e., roughly 6% as of 2018) could reach 22.2% by 2030 under the fast RE transition scenario. Under the slow RE transition scenario, it could reach 14.5% by 2030.

We also make separate projections for different income groups (i.e., developed OECD countries and the rest of the world). Developed OECD countries can increase their average NhRE share from its current level of 15.5% to between 41.5% and 48% by 2030. The developing world can raise its average NhRE share from 4.2% to between 10% and 18% by 2030. We also provide projections for the top 10 power-generating countries. For example, our predictions imply that Germany's NhRE share can reach between 58.5% and 65%. Thus, its target of generating 61.5% of its power from NhRE resources by 2030 is in the range of its RE transition potential. Overall, the predictions suggest that countries have the potential to achieve remarkable RE transitions in the coming decade. These transitions can greatly contribute to achieving their ambitious net-zero goals (IRENA 2019).

The rest of the paper proceeds as follows. The next section presents the details of our data. Section 3 discusses our econometric methodology, section 4 explains the estimation results and section 5 provides robustness checks for the baseline estimates. Section 6 develops the scenario analysis and discusses the projections. Finally, section 7 concludes.

Data

We utilize two main data sets in the analysis. For the determinants of the RE transition, we use data on the RETPI and its seven subindices developed by Yilmaz (2021). The RETPI covers a panel of 149 countries from 1990 to 2018.[9] The economic factors subindex covers countries' sizes, growth performance and development levels. The financial development subindex consists of different measures of access to private finance. The human capital subindex covers countries' population demographics, education quality and health status. The energy security subindex consists of different indicators of energy dependence. The energy access subindex consists of various indicators of access to reliable energy. The environmental sustainability subindex includes measures of carbon dioxide emissions and fuel consumption intensity. Finally, the institutional infrastructure subindex includes various measures of institutional quality, such as the rule of law, political stability and regulatory quality. The RETPI and its subindices take values between zero and one, with higher values implying higher RE transition potential.[10] To measure countries' RE transition performances, we use the share of NhRE in total power generation computed from Enerdata. NhRE includes only primary RE sources, such as onshore and offshore wind, solar and geothermal sources, and it excludes hydroelectricity.

Tables 1 and 2 show summary statistics for all of the variables used in the analysis and their cross-correlations, respectively. According to Table 1, the average NhRE share in the sample is 2%, and the average annual change is 0.2%. The three- and five-year average annual changes are relatively larger, at 0.5% and 0.9%, respectively. The NhRE share and its differences have statistically significant positive relationships with the RETPI and its components, as Table 2 shows. Table A1 in the Appendix presents the full list of countries included in the study and their income and regional groups. Following Yilmaz (2021), we define developed OECD countries as countries with long-standing OECD membership (i.e., more than 40 years), as in Kim and Loayza (2019).[11] Doing so allows us to create a more homogeneous group of high-income developed economies.

Table 1. Summary statistics.

Variables	Obs	Mean	Std. dev.	Min	Max
NhRE	4,367	0.018	0.051	0.000	0.509
NhREt - $NhRE_{t-1}$	4,216	0.002	0.009	-0.066	0.214
NhREt - $NhRE_{t-3}$	3,914	0.005	0.020	-0.118	0.272
NhREt - $NhRE_{t-5}$	3,612	0.009	0.029	-0.183	0.364
RETPI	4,150	0.55	0.17	0.00	1.00
EFI	4,337	0.37	0.09	0.00	1.00
FDI	4,191	0.15	0.09	0.00	1.00
HCI	4,375	0.38	0.25	0.00	1.00
EAI	4,379	0.53	0.29	0.00	1.00
ESI	4,302	0.40	0.10	0.00	1.00
EnSI	4,379	0.07	0.08	0.00	1.00
III	4,379	0.48	0.24	0.00	1.00

Source: Author's construction.

Notes: NhRE= share of non-hydroelectric renewable energy in power generation. RETPI= renewable energy transition potential index. EFI= economic factors subindex. FDI= financial development subindex. HCI= human capital subindex. EAI= energy access subindex. ESI= energy security subindex. ENSI= environmental sustainability subindex. III= institutional infrastructure subindex. All of the variables except for the differenced ones are at time *t*.

Table 2. Correlation matrix.

Variables	NhRE	$NhRE_t$ - $NhRE_{t-1}$	NhREt - $NhRE_{t-3}$	NhREt - $NhRE_{t-5}$
RETPI	0.2089*	0.1698*	0.2240*	0.2493*
EFI	0.2082*	0.1805*	0.2377*	0.2561*
FDI	0.1157*	0.0977*	0.1232*	0.1379*
HCI	0.2215*	0.1804*	0.2397*	0.2713*
EAI	0.1227*	0.1067*	0.1394*	0.1540*
ESI	0.1238*	0.0638*	0.0820*	0.0933*
EnSI	0.0071	0.007	0.0169	0.0303[a]
III	0.1956*	0.1433*	0.1946*	0.2265*

Source: Author's construction.

Notes: *p<0.01, [a]p<0.1. NhRE= share of non-hydroelectric renewable energy in power generation. RETPI= renewable energy transition potential index. EFI= economic factors subindex. FDI= financial development subindex. HCI= human capital subindex. EAI= energy access subindex. ESI= energy security subindex. ENSI= environmental sustainability subindex. III= institutional infrastructure subindex.

Methodology

We estimate the following panel model with fixed effects:

$$\Delta NhRE_{it}{}^{t-(t-k)} = \beta_0 + \beta_1 NhRE_{it-k} + \beta_2 ETDI_{it-k} + trend_t + trend_t^2 + f_i + u_{it},$$

where i is country and t is year. ΔNhRE is the change in the share of NhRE in power generation. This variable is a widely used proxy for countries' RE transition performances (e.g., Best 2017; Carley et al. 2017; Lin and Omoju 2017).[12] Instead of the level, we use the change in the NhRE share as the dependent variable. This approach removes the nonstationary trends in the dependent variable[13] but keeps the model simple, as in Best (2017) and Carley et al. (2017). More specifically, we consider changes over one, three and five years to account for transition dynamics in the short, medium and long terms.[14]

We estimate static and dynamic fixed effect specifications. Both specifications are frequently used in the literature, and Bourcet (2020) provides an overview of their use. Previous studies also use error-correction models and generalized method of moments estimators to infer strong associations (or potentially causal relations) between dependent and independent variables. In contrast, we perform an exploratory empirical analysis to identify strong associations between the indices and the RE transition in a simple econometric setting. We then use our model to predict future trends based on different scenarios.

In the dynamic specifications, we control for the level of the NhRE share lagged for one, three and five years. These lags account for the initial level of the RE share in each specification.[15] The deployment and effective usage of RE infrastructure may take time, creating a potential path dependency between current and historical levels of the NhRE share. In the static specifications, we restrict β_1 to equal zero, and the rest of the model remains the same. The key variables of interest are the RETPI and its subindices. Including the subindices in the analysis allows us to explore their relationships with the RE transition. We also include an annual linear time trend and its square to account for global RE transition trends.[16] Finally, all of the specifications include country-fixed effects to control for time-invariant unobserved heterogeneity.

We estimate the model with and without weights, where the weights are constructed according to countries' average total power generation over the sample period. We use weights because the RE transition experiences of countries with more power generation are more critical to achieving global climate goals. Nevertheless, we report the results with and without weights. We present and discuss the results in the following section, and several robustness checks are provided in section 5.

Estimation Results

The estimation results for the models with one-, three- and five-year lag specifications are presented in tables 3, 4 and 5, respectively. Each table shows the results for the RETPI and its components across static and dynamic specifications.

Table 3 shows that the RETPI is positively and statistically significantly associated with the change in the NhRE share. In other words, an increase in the RETPI score is associated with an increase in the share of NhRE in power generation. This positive relationship remains consistent across all of the static (columns 1 to 3) and dynamic (columns 7 to 9) specifications. The magnitudes of the coefficients do not change much across specifications. The dynamic term, the one-year lag of the level of the NhRE share, has a positive and statistically significant coefficient. Its magnitude is less than one, ensuring the stability of the model. The preferred specification is the dynamic model with time trends and weights in column 9. This specification has the highest explanatory power (R^2), as it can explain 34% of the total variation in the dependent variable.

Columns 4 to 6 and 10 to 12 present the results of models, including the RETPI's subindices. The results show that economic factors and human capital are statistically significantly positively associated with the change in the NhRE share in the short run. The environmental sustainability subindex has a marginally statistically significant positive effect only in the specifications shown in columns 4 and 10. Additionally, energy access is marginally statistically significantly negatively associated with the change in the NhRE share. This result implies that greater energy access discourages the further use of NhRE in power generation. The remaining two components of the RETPI, the energy security and institutional infrastructure subindices, have statistically insignificant effects across all of the specifications.

Table 4 shows the results for the medium term. The dependent variable is the three-year differenced share of NhRE, and the independent variables are also lagged for three years. The estimated coefficient of the RETPI remains statistically significant and positively associated with the dependent variable. The statistical significance levels, signs and magnitudes of the RETPI coefficients are consistent across the static and dynamic specifications. The medium-term models' coefficient estimates are slightly less than three times larger than the coefficient estimates in the short-term model. This difference is expected, given the longer time frame in the medium-term models. The coefficient of the dynamic term is still positive and less than one, but it is only statistically significant in some specifications. Among the components of the RETPI, the economic factors and human capital subindices have statistically significantly positive associations with the dependent variable. Energy access is statistically significantly negatively associated with the change in NhRE usage in power generation. The estimated coefficients of the financial development and environmental sustainability subindices are positive and statistically significant in some specifications. The energy security and institutional quality subindices have statistically insignificant effects in all of the specifications.

Table 3. Estimation results from one-year models.

	Static specifications						Dynamic specifications					
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
$NhRE_{t-1}$							0.0443***	0.0661***	0.0559***	0.0366**	0.0544***	0.0493***
							(0.0169)	(0.0178)	(0.0173)	(0.0169)	(0.0160)	(0.0160)
$RETPI_{t-1}$	0.0464***	0.0584***	0.0263**				0.0348***	0.0381***	0.0329***			
	(0.00697)	(0.00440)	(0.0125)				(0.00653)	(0.00540)	(0.00974)			
EPI_{t-1}				0.0191***	0.0137**	0.0128***				0.0164***	0.0136***	0.0138***
				(0.00436)	(0.00525)	(0.00487)				(0.00421)	(0.00422)	(0.00417)
FDI_{t-1}				0.00400	-0.000844	0.00508				0.00256	-2.57e-06	0.00282
				(0.00303)	(0.00573)	(0.00471)				(0.00320)	(0.00440)	(0.00402)
HCI_{t-1}				0.0213***	0.0333***	0.0271***				0.0150**	0.0222***	0.0218***
				(0.00736)	(0.00632)	(0.00855)				(0.00647)	(0.00459)	(0.00691)
EAI_{t-1}				0.00135	-0.0153**	-0.0100*				0.00267	-0.0101**	-0.00762
				(0.00699)	(0.00725)	(0.00595)				(0.00607)	(0.00476)	(0.00470)
ESI_{t-1}				0.00164	0.0147	0.0116				0.000764	0.00900	0.00840
				(0.00631)	(0.0112)	(0.0102)				(0.00560)	(0.00879)	(0.00854)
$EnSI_{t-1}$				0.00979**	0.0504	0.0442				0.00554*	-0.00303	0.00189
				(0.00400)	(0.0340)	(0.0329)				(0.00292)	(0.0214)	(0.0224)
III_{t-1}				-0.00405	0.000296	-0.00279				-0.00234	0.00540	0.00326
				(0.00577)	(0.00751)	(0.00677)				(0.00537)	(0.00607)	(0.00588)
Constant	-0.0235***	-0.0402***	-0.0167**	-0.0140***	-0.0206**	-0.0161*	-0.0179***	-0.0264***	-0.0219***	-0.0119***	-0.0181***	-0.0177***
	(0.00382)	(0.00323)	(0.00816)	(0.00467)	(0.00810)	(0.00866)	(0.00346)	(0.00370)	(0.00625)	(0.00384)	(0.00588)	(0.00661)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Weights	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
No. of observations	3,991	3,991	3,991	3,991	3,991	3,991	3,991	3,991	3,991	3,991	3,991	3,991
R^2	0.044	0.258	0.301	0.059	0.312	0.324	0.065	0.334	0.340	0.072	0.346	0.348
No. of countries	149	149	149	149	149	149	149	149	149	149	149	149

Source: Author’s construction.

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the country level are in parentheses. The time trend variable includes the annual time trend and its square. Weights are defined according to countries’ average total electricity production during the sample period. The dependent variable is the one-year change in the share of NhRE in power generation. RETPI: renewable energy transition potential index. EFI= economic factors subindex. FDI= financial development subindex. HCI= human capital subindex. EAI= energy access subindex. ESI= energy security subindex. ENSI= environmental sustainability subindex. III= institutional infrastructure subindex.

Table 4. Estimation results from three-year models.

	Static specifications						Dynamic specifications					
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
$NhRE_{t-3}$							0.0629	0.183***	0.137**	0.0356	0.124**	0.101*
							(0.0603)	(0.0640)	(0.0609)	(0.0633)	(0.0588)	(0.0580)
$RETPI_{t-3}$	0.144***	0.178***	0.0774**				0.130***	0.133***	0.0903***			
	(0.0211)	(0.0146)	(0.0333)				(0.0240)	(0.0163)	(0.0283)			
EPI_{t-3}				0.0579***	0.0506***	0.0442***				0.0553***	0.0502***	0.0468***
				(0.0102)	(0.0131)	(0.0107)				(0.00975)	(0.0110)	(0.00960)
FDI_{t-3}				0.0208**	-0.00176	0.0116				0.0193**	-0.00300	0.00650
				(0.00822)	(0.0140)	(0.0123)				(0.00946)	(0.0115)	(0.0113)
HCI_{t-3}				0.0608***	0.0991***	0.0801***				0.0558**	0.0785***	0.0713***
				(0.0226)	(0.0181)	(0.0260)				(0.0244)	(0.0151)	(0.0233)
EAI_{t-3}				0.00627	-0.0541**	-0.0393**				0.00811	-0.0418**	-0.0334**
				(0.0233)	(0.0223)	(0.0168)				(0.0230)	(0.0174)	(0.0149)
ESI_{t-3}				-0.00126	0.00234	-0.000804				-0.00153	-0.00377	-0.00452
				(0.0164)	(0.0211)	(0.0209)				(0.0159)	(0.0166)	(0.0175)
$EnSI_{t-3}$				0.0245***	0.162*	0.149				0.0219***	0.0593	0.0729
				(0.00849)	(0.0952)	(0.0924)				(0.00765)	(0.0635)	(0.0623)
III_{t-3}				-0.0143	-0.0149	-0.0191				-0.0130	-0.000963	-0.00677
				(0.0145)	(0.0193)	(0.0179)				(0.0152)	(0.0176)	(0.0171)
Constant	-0.0725***	-0.122***	-0.0471**	-0.0391***	-0.0340*	-0.0215	-0.0660***	-0.0915***	-0.0580***	-0.0378***	-0.0356**	-0.0286
	(0.0115)	(0.0107)	(0.0220)	(0.0138)	(0.0186)	(0.0231)	(0.0126)	(0.0112)	(0.0183)	(0.0128)	(0.0158)	(0.0204)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Weights	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
No. of obsarvations	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693	3,693
R^2	0.090	0.399	0.461	0.115	0.485	0.502	0.097	0.477	0.494	0.117	0.511	0.517
No. of countries	149	149	149	149	149	149	149	149	149	149	149	149

Source: Author's construction.

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the country level are in parentheses. The time trend variable includes the annual time trend and its square. Weights are defined according to countries' average total electricity production during the sample period. The dependent variable is the one-year change in the share of NhRE in power generation. RETPI: renewable energy transition potential index. EFI= economic factors subindex. FDI= financial development subindex. HCI= human capital subindex. EAI= energy access subindex. ESI= energy security subindex. ENSI= environmental sustainability subindex. III= institutional infrastructure subindex.

Table 5 shows the results of the long-term estimates, in which the five-year differenced NhRE share is the dependent variable. The independent variables are lagged for five years in all specifications in the table. As with the other models, the estimated association between the RETPI and the dependent variable is consistently positive and statistically significant across all specifications. As expected, these estimates are larger than the corresponding estimates for the short and medium terms. The estimated coefficients of the dynamic term are positive and less than one in all specifications, but they are only marginally statistically significant in some cases. As in the short and medium terms, the economic factors and human capital subindices are positively associated with the change in NhRE usage. The environmental sustainability subindex is also statistically significantly positively associated with the change in the NhRE share. However, it is only marginally statistically significant in the dynamic specifications. The financial development subindex is also positively associated with the change in the NhRE share. However, the relationship is only statistically significant in columns 4 and 10. The energy access subindex is statistically significantly negatively associated with NhRE usage. As before, the remaining two components of the RETPI, the energy security and institutional infrastructure subindices, are not statistically significant in any specification.

Overall, the results indicate a positive, statistically significant association between the RETPI and the RE transition. This finding is consistent across our different specifications. Among the RETPI subindices, economic factors and human capital have positive relationships and energy access has a negative relationship with the RE transition. Financial development and environmental sustainability have marginally significantly positive associations with the RE transition. The remaining two subindices, energy security and institutional infrastructure, have no statistically significant effects in any of the specifications.

Table 5. Estimation results from five-year models.

	Static specifications						Dynamic specifications					
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
$NhRE_{t-5}$							0.0872	0.333**	0.239*	0.0313	0.202*	0.157
							(0.164)	(0.132)	(0.122)	(0.172)	(0.117)	(0.112)
$RETPI_{t-5}$	0.244***	0.300***	0.118**				0.229***	0.234***	0.121***			
	(0.0357)	(0.0254)	(0.0512)				(0.0471)	(0.0273)	(0.0454)			
EPI_{t-5}				0.0967***	0.0889***	0.0681***				0.0945***	0.0856***	0.0685***
				(0.0163)	(0.0196)	(0.0159)				(0.0165)	(0.0164)	(0.0149)
FDI_{t-5}				0.0352***	0.0167	0.0287				0.0342**	0.0106	0.0200
				(0.0115)	(0.0193)	(0.0181)				(0.0140)	(0.0166)	(0.0167)
HCI_{t-5}				0.117***	0.154***	0.106**				0.114**	0.128***	0.0931**
				(0.0381)	(0.0272)	(0.0459)				(0.0467)	(0.0250)	(0.0420)
EAI_{t-5}				-0.00483	-0.0871***	-0.0752***				-0.00334	-0.0670**	-0.0649**
				(0.0360)	(0.0328)	(0.0283)				(0.0383)	(0.0272)	(0.0267)
ESI_{t-5}				-0.0154	-0.0352	-0.0189				-0.0153	-0.0299	-0.0188
				(0.0240)	(0.0333)	(0.0343)				(0.0237)	(0.0279)	(0.0299)
$EnSI_{t-5}$				0.0315***	0.293*	0.249*				0.0302***	0.186	0.168
				(0.0120)	(0.151)	(0.145)				(0.0115)	(0.114)	(0.109)
III_{t-5}				-0.0218	-0.0534	-0.0489				-0.0208	-0.0291	-0.0299
				(0.0213)	(0.0353)	(0.0337)				(0.0238)	(0.0333)	(0.0327)
Constant	-0.122***	-0.205***	-0.0675*	-0.0571***	-0.0236	0.00667	-0.115***	-0.161***	-0.0745**	-0.0565***	-0.0376	-0.00727
	(0.0192)	(0.0183)	(0.0343)	(0.0208)	(0.0320)	(0.0421)	(0.0241)	(0.0187)	(0.0296)	(0.0200)	(0.0289)	(0.0393)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Weights	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
No. of obsarvations	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395	3,395
R^2	0.121	0.444	0.514	0.157	0.542	0.563	0.125	0.516	0.546	0.157	0.563	0.574
No. of countries	149	149	149	149	149	149	149	149	149	149	149	149

Source: Author’s construction.

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Robust standard errors clustered at the country level are in parentheses. The time trend variable includes the annual time trend and its square. Weights are defined according to countries’ average total electricity production during the sample period. The dependent variable is the five-year change in the share of NhRE in power generation. RETPI= renewable energy transition potential index. EFI= economic factors subindex. FDI= financial development subindex. HCI= human capital subindex. EAI= energy access subindex. ESI= energy security subindex. ENSI= environmental sustainability subindex. III= institutional infrastructure subindex.

Robustness

We test our baseline results using a variety of specifications to ensure their robustness. First, we employ year fixed effects instead of a more general time trend. Doing so allows us to better account for the effects of global trends (e.g., the global financial crisis and the Paris Agreement) on RE transitions. Regional trends may also play an important role in countries' RE transition performances. These trends include the European Union's Green Deal agenda, fluctuations in global fossil fuel prices, and the effects of these prices on major oil-exporting nations. We control for regional trends in alternative specifications by interacting the year fixed effects with the seven main regions. Similarly, we interact a dummy variable for developed OECD countries with the year fixed effects to control for differences in trends in developed and developing countries. Table 6 shows the results of the listed robustness checks for the baseline models with the RETPI. According to the table, the baseline results remain statistically significant, and the positive association between the RETPI and the RE transition is robust.

Table 6. Estimation results from robustness checks.

	One-year specifications		Three-year specifications		Five-year specifications	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
	[1]	[2]	[3]	[4]	[5]	[6]
$NhRE_{t-1}$		0.0427**				
		(0.0196)				
$RETPI_{t-1}$	0.0537***	0.0427***				
	(0.0110)	(0.00940)				
$NhRE_{t-3}$				0.0770		
				(0.0636)		
$RETPI_{t-3}$			0.118***	0.103***		
			(0.0293)	(0.0270)		
$NhRE_{t-5}$						0.0932
						(0.130)
$RETPI_{t-5}$					0.155***	0.139***
					(0.0511)	(0.0474)
Constant	-0.0343***	-0.0290***	-0.0765***	-0.0701***	-0.0949***	-0.0876***
	(0.00757)	(0.00624)	(0.0209)	(0.0188)	(0.0352)	(0.0327)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects X Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects X Developed OECD fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Weights	Yes	Yes	Yes	Yes	Yes	Yes
No. of obsarvations	3,991	3,991	3,693	3,693	3,395	3,395
R^2	0.370	0.382	0.547	0.551	0.614	0.616
No. of countries	149	149	149	149	149	149

Source: Author's construction.

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors clustered at the country level are in parentheses. The time trend variable includes the annual time trend and its square. Weights are defined according to countries' average total electricity production during the sample period. The dependent variable is the one-, three- or five-year change in the share of NhRE in power generation. RETPI= renewable energy transition potential index.

Scenario Analysis

The previous analysis established a strong statistical association between the RETPI and RE transitions. Based on these results, we provide country-specific predictions of future transition trends under reasonable scenarios. We use the coefficient estimates from the dynamic models in these projections owing to their strong predictive power. More specifically, we consider the short-, medium- and long-term dynamic specifications for each scenario, as each specification has varying predictive power.

For the scenario design, we classify seven country groups according to income and geographic region. The developed OECD nations are considered as one group regardless of their location. The remaining countries are split into six regions: East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, South Asia and sub-Saharan Africa.[17] The scenarios are constructed according to the growth in countries' average RETPI scores in one-, three- and five-year intervals over the period 2009 to 2018.[18] We then identify the highest, median and lowest average performers in terms of RETPI growth in each of the seven groups. In the fast transition scenario, we assume that each country's RETPI grows at the highest rate in its group over the 12 years until 2030. Similarly, in the medium transition scenario, we assume that countries' RETPIs grow at their groups' median rates. Lastly, in the slow transition scenario, countries adopt the lowest RETPI growth rates in their respective groups over the next decade.

Table 7 summarizes the scenario design for each country group. Here, we provide an example to explain the table's interpretation. Among the developed OECD countries, Japan's RE transition potential (i.e., RETPI score) grew the fastest on an annual basis, with average annual growth of 0.6% over the last decade. The U.S. recorded the highest three-year average growth rate in the group, at 1.7%. Similarly, over the last decade, Ireland had the highest five-year average growth rate among the countries in the group, at 4.1%. We use these RETPI growth rates over one-, three- and five-year intervals to extrapolate the RETPI scores of other countries in the same group. The extrapolations span the next decade, and the rate chosen depends on the scenario. Using the extrapolated RETPIs and the estimated model coefficients, we predict countries' RE transition performances (i.e., the share of NhRE in power generation) until 2030.

Table 7. Scenario design.

Region	Fast transition scenario (max)			Median transition scenario (median)			Slow transition scenario (min)		
	1 yr	3 yr	5 yr	1 yr	3 yr	5 yr	1 yr	3 yr	5 yr
Developed OECD	0.6%	1.7%	4.1%	-0.1%	0.5%	1.4%	-1.0%	-1.0%	-0.8%
East Asia & Pacific	4.2%	10.9%	16.3%	1.5%	4.4%	7.5%	0.6%	2.1%	3.5%
Europe & Central Asia	1.2%	3.7%	7.5%	0.4%	1.8%	3.4%	-1.2%	-1.4%	-0.9%
Latin America & Caribbean	1.8%	5.2%	9.1%	0.7%	2.5%	4.9%	0.1%	0.6%	1.3%
Middle East & North Africa	1.6%	5.9%	9.5%	0.7%	2.0%	3.9%	-0.2%	-1.0%	-0.5%
South Asia	3.2%	9.2%	18.0%	1.6%	4.9%	8.9%	0.4%	1.1%	2.0%
Sub-Saharan Africa	3.9%	10.6%	20.1%	1.3%	3.3%	5.7%	-0.1%	0.3%	0.5%

Source: Author's construction.

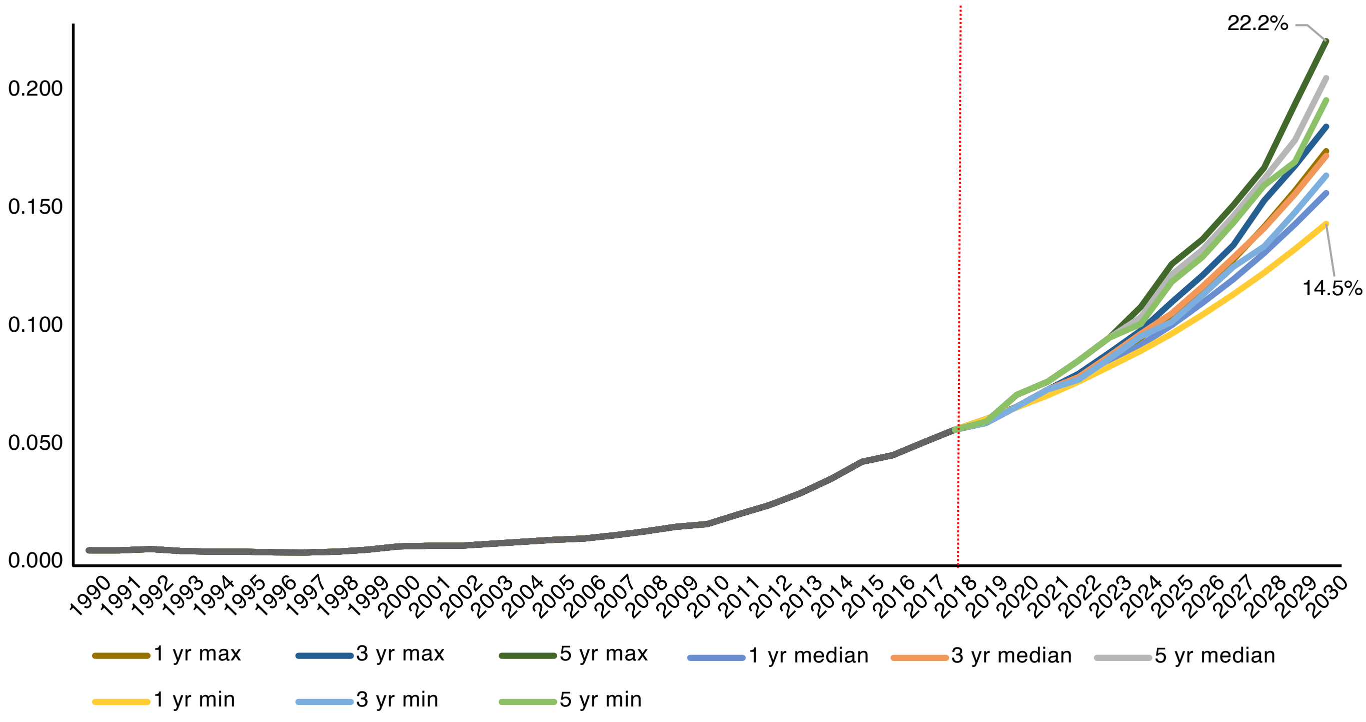
Note: Each scenario is designed according to the country groups' average RETPI growth performance in the decade from 2009 to 2018.

In the following subsections, we discuss our predictions for each scenario. We first consider average global RE transition trends across different income groups and regions. We then make country-specific predictions.

Global RE Transition Projections

Figure 1 summarizes our models' predictions for global RE transition trends. The figure provides the predictions for all three models (i.e., the one-, three- and five-year specifications) and transition scenarios (i.e., fast, medium and slow). Our original data end by 2018, meaning that all of the data for the years after 2018 reflect the model's predictions. According to the figure, the RE transition continues to follow an upward trend in the coming decade. In the fast transition scenario with the five-year specification, the average global NhRE share is expected to reach 22.2% by 2030. This share is the upper limit of our predictions. In contrast, the slow transition scenario with the one-year specification predicts an average NhRE share of 14.5% by 2030.

Figure 1. Global renewable energy transition projections, all models and scenarios.



Source: Author's predictions.

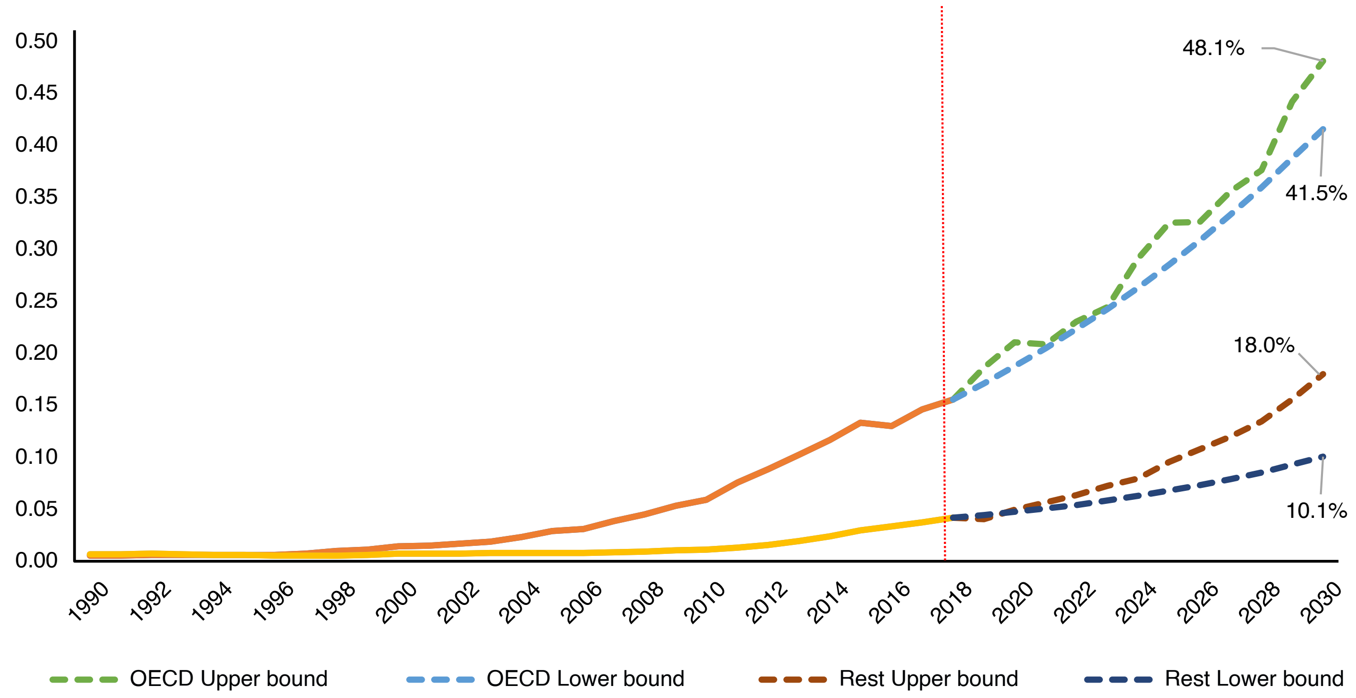
Note: All countries covered in the sample are included in the graph.

Global RE Transition Projections by Income Group

We divide the sample into developed OECD countries and the rest of the world. Figure 2 displays the prediction ranges (i.e., the upper and lower bounds) for these two main income groups. The figure shows that the gap between these two groups will widen further over the next decade.

The average upper bound prediction is 48% for developed OECD countries and 18% for the rest of the world. The average lower bound is 41.5% for developed OECD countries and 10% for the rest of the world. The predictions indicate that countries' NhRE shares will increase significantly by 2030 relative to their respective levels in 2018. However, the increase will be much more substantial for the developed OECD group.

Figure 2. Global renewable energy transition projections, by income (upper and lower bound predictions).



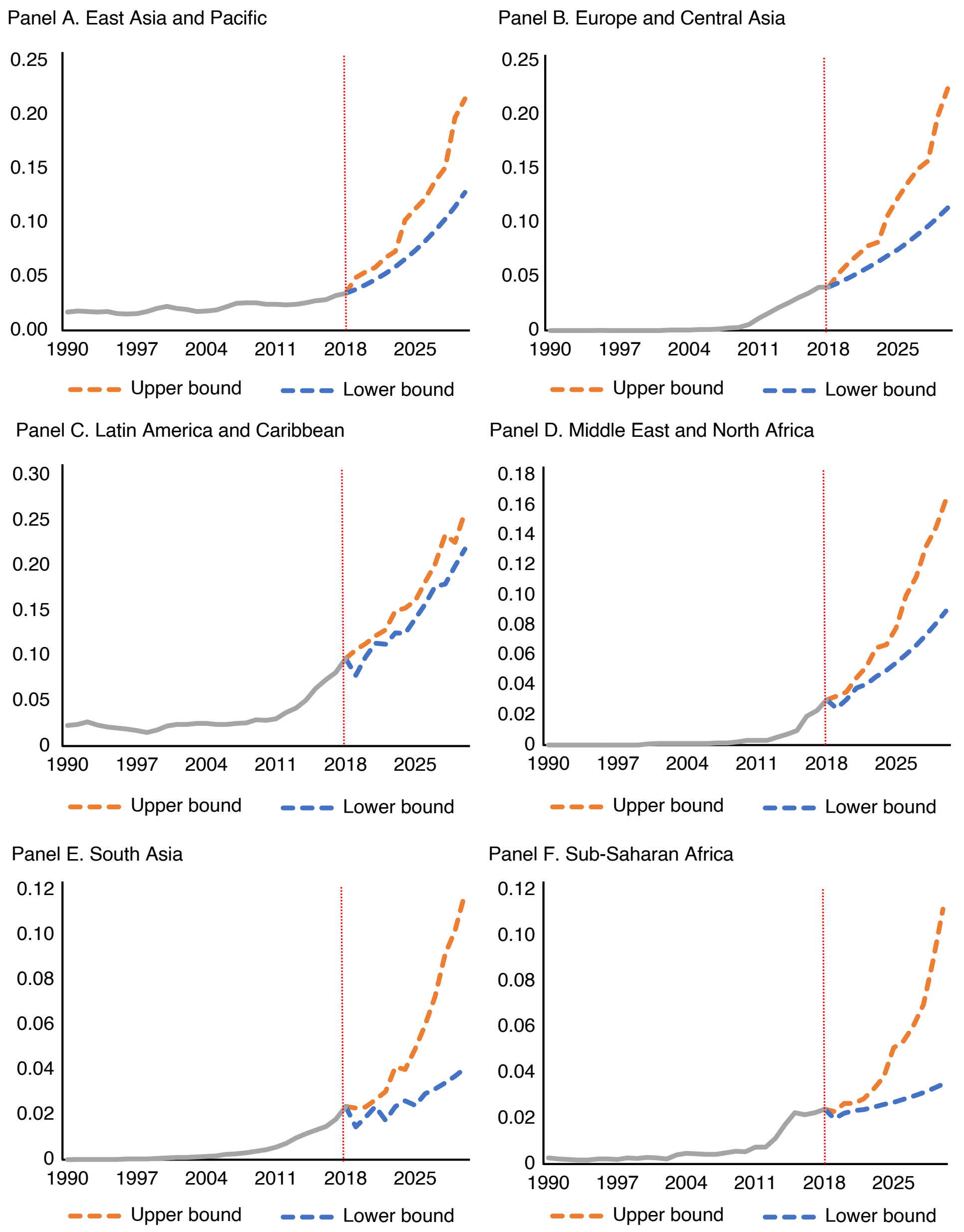
Source: Author's predictions.

Note: Data for OECD countries include only high-income members (see Table A1). Data for years after 2018 reflect model predictions.

Global RE Transition Projections by Region

Figure 3 shows regional average RE transition projections for the developing countries in our sample. The Latin America and Caribbean region (panel C) has the highest predicted lower and upper bounds of 22% and 26%, respectively. The East Asia and Pacific and Europe and Central Asia regions follow similar transition trends and have similar predictions (panels A and B, respectively). In line with the differences in their 2018 levels, the predictions for the Europe and Central Asia region have a slightly higher upper bound. Specifically, the upper bound prediction for Europe and Central Asia is 22%. The average NhRE share in the Middle East and North Africa region (Panel D) is expected to increase to 16.4% in the fast transition scenario, while it is predicted to increase to 9% in the slow transition scenario. The South Asia (panel E) and sub-Saharan Africa (Panel F) regions are predicted to have the lowest transition performance, with upper bounds of 12%.

Figure 3. Regional renewable energy transition projections (upper and lower bound predictions).



Source: Author's predictions.

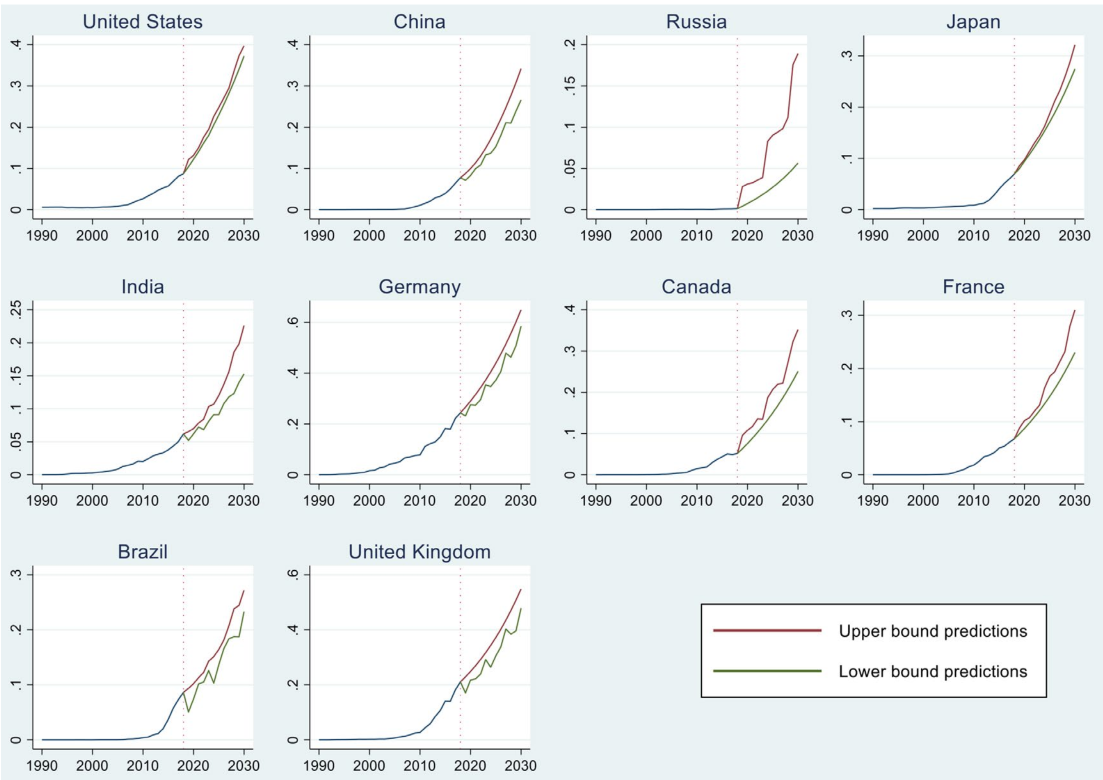
Notes: Graphs show the averages of country-level upper and lower bound predictions for each region. Only non-OECD countries are included. Data for years after 2018 reflect model predictions.

Country-Specific Projections

Figure 4 shows the model predictions for the top 10 energy-producing countries worldwide. These countries account for roughly 70% of total global energy production. The figure shows upper and lower bound predictions for the three specifications and scenarios (i.e., nine cases in total) for each country by 2030. Our predictions indicate that all 10 countries have significant potential to increase their NhRE shares multiple times over by 2030. Within this group, Germany has the highest expected NhRE share by 2030, with an upper bound prediction of 65%. The United Kingdom (U.K.) has the second highest upper bound prediction of 55%, and the U.S. is in third place, with an upper bound of 40%. The upper bound predictions for Japan, France and Canada range from 30% to 35%. Lastly, the emerging countries in the group, such as China, India and Brazil, have projected upper bounds between 23% and 34%.

Countries' RE targets take various forms, such as installed capacity, the RE share of the primary energy supply and the RE share of power generation. Among the countries mentioned above, we identify official NhRE electricity production targets by 2030 for Germany (61.5%), France (40%), Russia (4.5%) and Japan (15%). Germany's target is in the middle of our prediction range. France's target is above our prediction range, and Russia's and Japan's targets are below our prediction range. These results imply that Germany's target is achievable. In contrast, France's target seems to be above its potential, whereas Russia and Japan are aiming below their potentials.

Figure 4. Renewable energy transition projections for the top 10 power-producing countries (upper and lower bound predictions).



Source: Author's predictions.

Note: Data from years after 2018 reflect model predictions.

Conclusion

Climate change creates severe environmental challenges, and requires a significant transformation in the global energy system. With this vital agenda, many countries are revising their current policies and reconsidering their approaches to accommodate a smooth transition. Among different mitigation techniques, RE has been the most widely used technique in many countries, especially for the transformation of the power sector – i.e., the RE transition. Simple data facts show that some countries are experiencing faster RE transitions than others. This heterogeneity raises the essential question of the primary factors determining countries' RE transition performances. The relevant literature identifies several critical factors that may explain this heterogeneity. However, no systematic approach has been developed to provide a more complete explanation. To close this critical gap, we conducted an extensive econometric analysis of a panel of 149 developed and developing countries over the last three decades.

Our results show that the RETPI is positively and statistically significantly associated with countries' RE transition performances. This result implies that countries with greater RE transition potentials (i.e., higher RETPI scores) record stronger RE transition performances on average. Among the RETPI's subindices, the economic factors and human capital subindices are positively and statistically significantly associated with the RE transition. We also find that the environmental sustainability and financial development subindices are marginally statistically significantly positively associated with the RE transition. On the other hand, the energy access subindex is found to be statistically significantly negatively associated with the RE transition. The energy security and institutional infrastructure subindices have no statistically significant effects in any of the specifications. These results are robust to alternative specifications and controls.

Given the RETPI's strong predictive power for countries' future RE transition performances, we predicted country-specific RE transition paths. We considered fast, medium and slow transition scenarios. Our models predict that the global RE transition will increase exponentially, as the average NhRE share may reach 14.5% to 22% by 2030. The developed OECD countries will significantly contribute to this acceleration. Their average NhRE share is expected to reach 41.5% to 48% by 2030. Developing countries' average NhRE shares will also increase from 4.2% in 2018 to between 10% and 18% by 2030. Among the developed OECD countries, Germany and the U.K. are predicted to attain NhRE shares of nearly 60%. The U.S. is expected to achieve an NhRE share of around 40%, roughly more than four times its current level. Among developing countries, our predictions show that China, India and Brazil can achieve maximum NhRE shares between 23% and 34%. These results identify critical prospects for the future of the RE transition. By realizing their potentials, countries can achieve significant RE transitions in the next decade, which will significantly contribute to their global climate ambitions.

Although this study provided a strong analysis based on robust econometric techniques, it certainly has limitations. For instance, technological developments play an essential role in RE transitions. Breakthrough technologies (e.g., reducing RE investment costs faster than has been achieved over the last three decades or improving power storage capacity) are possible. Such technologies can undoubtedly accelerate the speed of the RE transition. Similarly, government policies to mainstream RE usage or deployment can also significantly contribute to the RE transition process. Our analysis only partially addresses these possibilities by accounting for global, regional and income group-specific trends over the last three decades. A better way to incorporate this potential would be to add policy and technology subindices to the RETPI. Doing so will become possible as more data with broader country coverage become available.

Endnotes

1 The NhRE share includes only contemporary RE technologies, such as wind, solar and geothermal.

2 For systematic reviews of the literature on the determinants of RE transitions, see Bourcet (2020), Can Sener, Sharp, and Anctil (2018) and Darmani et al. (2014).

3 Two other indices are available in the literature. Singh et al. (2019) developed the World Economic Forum's energy transition index, and the World Energy Council (2020) developed the trilemma index. These indices' methodological focuses are different from that of the RETPI in many ways, and their country and time-span coverages are not as comprehensive. More importantly, they do not focus solely on the determinants of the energy transition. Finally, these indices are not freely available to researchers. For a more detailed discussion of the differences between the RETPI and these indices, see Yilmaz (2021).

4 We measure this share in gigawatthours (GWh) of electricity production.

5 Electricity production from hydroelectric resources has traditionally been heavily exploited (Lin and Omoju 2017) and has distinct technical characteristics and resource requirements. It therefore has a different set of determinants from those considered in the construction of the RETPI (Burke 2010). Additionally, hydroelectricity production raises some social and environmental concerns (Pfeiffer and Mulder 2013).

6 For instance, many studies use different size measures, such as gross domestic product (GDP), population, land area and capital formation (Baldwin et al. 2017; Bayulgen and Ladewig 2017; Lin and Omoju 2017; Zeb et al. 2014). They find positive associations between these variables and the energy transition.

7 Przychodzen and Przychodzen (2020), Carley et al. (2017) and Baldwin et al. (2017) discuss the relations of GDP, population and capital formation growth with energy transitions. These studies usually confirm a positive relationship between these variables. On the other hand, Anton and Afloarei Nucu (2020) find a negative relationship between GDP growth and the RE share in the energy mix. Aguirre and Ibikunle (2014) conclude that the impact of population growth on the RE share in the energy mix is statistically insignificant.

8 For instance, Bayulgen and Ladewig (2017), Carley et al. (2017) and Aguirre and Ibikunle (2014) proxy economic development with GDP per capita. They find that it is positively associated with RE usage in electricity. Furthermore, other studies, such as those of Aker and Mbiti (2010) and Glemarec (2012), use infrastructure development measures to proxy for countries' development levels. These proxies include fixed-line telephone subscriptions, mobile phone usage and internet access. These studies find a positive relation between development and RE usage.

9 The data are strongly balanced. A small number of observations are missing for some countries because the relevant index scores could not be computed owing to missing data.

10 For further technical details about the RETPI and its subindices, see Yilmaz (2021).

11 Their study describes the methodology of a major World Bank research project identifying the key determinants of productivity growth. Although that project has a different focus than ours, their technical approach is relevant and useful for our purposes.

12 See Table 2 in Bourcet (2020) for a detailed list of the RE transition (dependent) variables used in the literature.

13 Our sample is unbalanced. Thus, we carry out Fisher-type unit-root tests (based on both the Dickey-Fuller and Phillips-Perron methodologies) for the dependent variable and the RETPI. We use a one lag, demean and trend structure. The test results indicate that the dependent variable clearly contains a unit root and that the RETPI is stationary. For further checks, we drop countries with missing RETPI scores (i.e., 20% of the sample) to obtain a balanced sample. We perform other panel unit-root tests (i.e., the Levin-Lin-Chu, Harris-Tzavalis, Breitung and Im-Pesaran-Shin tests) for this sample. The conclusion remains the same.

14 For instance, in the long-term model, the dependent variable is the five-year change (i.e., NhREt – NhREt-5).

15 For instance, in the five-year model, the lagged term is $NhRE_{it-5}$.

16 The squared term captures non-linearities in the global trend.

17 We exclude North America because only two countries located in this region, the U.S. and Canada, are part of the developed OECD group. Table A1 provides the country groups.

18 This 10-year interval covers various global events, such as the global financial crisis in 2009 and abundant capital flows to emerging economies. It covers the tightening global financial conditions in 2013 followed by the U.S. Federal Reserve's rate hike and the 2015 Paris Agreement. Many other technological transformations and new reforms occurred in this time period as well. Overall, the changes in countries' RETPI scores over the last decade reflect many positive and negative events. Thus, they can account for potential positive and negative events in the near future.

19 We also incorporate weights to account for countries' average total electricity consumption (instead of simple averages). Then, the upper bound estimate reaches 32.5%, and the lower bound is 27%.

20 Germany's national energy and climate plan may be found at this link. France's target is also discussed in its national energy and climate plan document, found at this link. Russia's energy strategy by 2030 is available at this link. Finally, Japan's 2030 target can be found at this link.

References

Aguirre, Mariana, and Gbenga Ibikunle. 2014. "Determinants of Renewable Energy Growth: A Global Sample Analysis." *Energy Policy* 69(C):374–84. DOI: j.enpol.2014.02.036

Aker, Jenny C., and Isaac M. Mbiti. 2010. "Mobile Phones and Economic Development in Africa." *Journal of Economic Perspectives* 24(3):207–32. DOI: 10.1257/jep.24.3.207

Anton, Sorin Gabriel, and Anca Elena Afloarei Nucu. 2020. "The Effect of Financial Development on Renewable Energy Consumption. A Panel Data Approach." *Renewable Energy* 147(P1):330–8. DOI: 10.1016/j.renene.2019.09.005

Baldwin, Elizabeth, Sanya Carley, Jennifer N. Brass, and Lauren M. MacLean. 2017. "Global Renewable Electricity Policy: A Comparative Policy Analysis of Countries by Income Status." *Journal of Comparative Policy Analysis: Research and Practice* 19(3):277–98. DOI: 10.1080/13876988.2016.1166866

Bayulgen, Oksan, and Jeffrey W. Ladewig. 2017. "Vetoing the Future: Political Constraints and Renewable Energy." *Environmental Politics* 26(1):49–70. DOI: 10.1080/09644016.2016.1223189

Best, Rohan. 2017. "Switching Towards Coal or Renewable Energy? The Effects of Financial Capital on Energy Transitions." *Energy Economics* 63(C):75–83. DOI: 10.1016/j.eneco.2017.01.019

Bourcet, Clémence. 2020. "Empirical Determinants of Renewable Energy Deployment: A Systematic Literature Review." *Energy Economics* 85(C):104563. DOI: 10.1016/j.eneco.2019.104563

Brunnschweiler, Christa N. 2010. "Finance for Renewable Energy: An Empirical Analysis of Developing and Transition Economies." *Environment and Development Economics* 15(3):241–274. DOI: 10.1017/S1355770X1000001X

Can Şener, Şerife Elif, Julia L. Sharp, and Annick Anctil. 2018. "Factors Impacting Diverging Paths of Renewable Energy: A Review." *Renewable and Sustainable Energy Reviews* 81(P2):2335–42. DOI: 10.1016/j.rser.2017.06.042

Carley, Sanya, Elizabeth Baldwin, Lauren M. MacLean, and Jennifer N. Brass. 2017. "Global Expansion of Renewable Energy Generation: An Analysis of Policy Instruments." *Environmental Resource Economics* 68(2):397–440. DOI: 10.1007/s10640-016-0025-3

Crippa, Monica, Gabriel Oreggioni, Diego Guizzardi, Marilena Muntean, Edwin Schaaf, Eleonora Lo Vullo, Efisio Solazzo, Fabio Monforti-Ferrario, Jos Olivier, and Elisabetta Vignati. 2019. "Fossil CO_2 and GHG Emissions of All World Countries." Luxembourg: Publications Office of the European Union. DOI: 10.2760/655913

Darmani, Anna, Niklas Arvidsson, Antonio Hidalgo, and Jose Albors. 2014. "What Drives the Development of Renewable Energy Technologies? Toward a Typology for the Systemic Drivers." *Renewable and Sustainable Energy Reviews* 38(C):834–47. DOI: 10.1016/j.rser.2014.07.023

Glemarec, Yannick. 2012. "Financing Off-grid Sustainable Energy Access for the Poor." *Energy Policy* 47(S1):87–93. DOI: 10.1016/j.enpol.2012.03.032.

International Renewable Energy Agency (IRENA). 2019. "Global Energy Transformation: A Roadmap to 2050." IRENA Technical Report.

———. 2020. “Global Renewables Outlook.” IRENA Technical Report.

Kim, Young Eun, and Norman V. Loayza. 2019. “Productivity Growth: Patterns and Determinants across the World.” World Bank Policy Research Working Paper Series, No. 8852. DOI: 10.1596/1813-9450-8852.

Lin, Boqiang, and Oluwasola E. Omoju. 2017 “Focusing on the Right Targets: Economic Factors Driving Non-hydro Renewable Energy Transition.” *Renewable Energy* 113(C):52–63. DOI: 10.1016/j.renene.2017.05.067

Marques, António C., and José Alberto Fuinhas. 2011a. “Drivers Promoting Renewable Energy: A Dynamic Panel Approach.” *Renewable and Sustainable Energy Reviews* 15(3):1601–8. DOI: 10.1016/j.rser.2010.11.048

———. 2011b. “Do Energy Efficiency Measures Promote the Use of Renewable Sources?” *Environmental Science & Policy* 14(4):471–81. DOI: 10.1016/j.envsci.2011.02.001

Marques, António C., José Alberto Fuinhas, and J. R. Pires Manso. 2010. “Motivations Driving Renewable Energy in European Countries: A Panel Data Approach.” *Energy Policy* 38(11):6877–85. DOI: 10.1016/j.enpol.2010.07.003

Pfeiffer, Birte, and Peter Mulder. 2013. “Explaining the Diffusion of Renewable Energy Technology in Developing Countries.” *Energy Economics* 40(C):285–96. DOI: doi:10.1016/j.eneco.2013.07.005

Przychodzen, Wojciech, and Justyna Przychodzen. 2020. “Determinants of Renewable Energy Production in Transition Economies: A Panel Data Approach.” *Energy* 191(C):116583. DOI: 10.1016/j.energy.2019.116583

Romano, Antonio A., Giuseppe Scandurra, Alfonso Carfora, and Mate Fodor. 2017. “Renewable Investments: The Impact of Green Policies in Developing and Developed Countries.” *Renewable and Sustainable Energy Reviews* 68(P1):738–47. DOI: 10.1016/j.rser.2016.10.024

Sadorsky, Perry. 2009. “Renewable Energy Consumption, CO_2 Emissions and Oil Prices in the G7 Countries.” *Energy Economics* 31(3):456–62. DOI: 10.1016/j.eneco.2008.12.010

———. 2010. “The Impact of Financial Development on Energy Consumption in Emerging Economies.” *Energy Policy* 38(5):2528–35. DOI: 10.1016/j.enpol.2009.12.048

Singh, Harsh Vijay, Roberto Bocca, Pedro Gomez, Steve Dahlke, and Morgan Bazilian. 2019. “The Energy Transitions Index: An Analytic Framework for Understanding the Evolving Global Energy System.” *Energy Strategy Reviews* 26:100382. DOI: 10.1016/j.esr.2019.100382

Sokona, Youba, Yacob Mulugetta, and Haruna Gujba. 2012. “Widening Energy Access in Africa: Towards Energy Transition.” *Energy Policy* 47(S1):3–10. DOI: 10.1016/j.enpol.2012.03.040

World Energy Council. 2020. “World Energy Trilemma Index.” In partnership with Oliver Wyman. https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2020

Wu, Lichao, and David C. Broadstock. 2015. “Does Economic, Financial and Institutional Development Matter for Renewable Energy Consumption? Evidence from Emerging Economies.” *International Journal of Economic Policy in Emerging Economies* 8(1):20–39. DOI: 10.1504/IJEPEE.2015.068246

References

Yilmaz, Fatih. 2021. “Understanding the Dynamics of Energy Transition: A Determinant Index Approach.” KAPSARC Methodology Paper.

Zeb, Raheel, Laleena Sahar, Usama Awan, Khalid Zaman, and Muhammad Shahbaz. 2014. “Causal Links Between Renewable Energy, Environmental Degradation and Economic Growth in Selected SAARC Countries: Progress Towards Green Economy.” *Renewable Energy* 71(C):123–32. DOI: 10.1016/j.renene.2014.05.012

Zhao, Yong, Kam Ki Tang, and Li-li Wang. 2013. “Do Renewable Electricity Policies Promote Renewable Electricity Generation? Evidence from Panel Data.” *Energy Policy* 62(C):887–97. DOI: 10.1016/j.enpol.2013.07.072

Appendix

Table A1. Country list, RETPI scores and ranks.

Rank	Country	Income group	Region	RETPI score
1	United States	Dev. OECD		1.00
2	Hong Kong	Rest	East Asia & Pacific	0.94
3	Singapore	Rest	East Asia & Pacific	0.92
4	Canada	Dev. OECD		0.90
5	Germany	Dev. OECD		0.88
6	Ireland	Dev. OECD		0.88
7	Japan	Dev. OECD		0.88
8	Australia	Dev. OECD		0.85
9	Finland	Dev. OECD		0.85
10	Netherlands	Dev. OECD		0.85
11	Austria	Dev. OECD		0.82
12	Sweden	Dev. OECD		0.82
13	United Kingdom	Dev. OECD		0.82
14	Switzerland	Dev. OECD		0.82
15	Norway	Dev. OECD		0.82
16	Korea, Rep.	Rest	East Asia & Pacific	0.81
17	Belgium	Dev. OECD		0.81
18	Denmark	Dev. OECD		0.81
19	New Zealand	Dev. OECD		0.80
20	China	Rest	East Asia & Pacific	0.80
21	United Arab Emirates	Rest	Middle East & North Africa	0.80
22	France	Dev. OECD		0.80
23	Estonia	Rest	Europe & Central Asia	0.80
24	Spain	Dev. OECD		0.79
25	Slovenia	Rest	Europe & Central Asia	0.78
26	Portugal	Dev. OECD		0.78
27	Czech Rep.	Rest	Europe & Central Asia	0.77
28	Italy	Dev. OECD		0.77
29	Cyprus	Rest	Europe & Central Asia	0.76
30	Lithuania	Rest	Europe & Central Asia	0.75

Rank	Country	Income group	Region	RETPI score
31	Israel	Rest	Middle East & North Africa	0.75
32	Slovak Rep.	Rest	Europe & Central Asia	0.75
33	Qatar	Rest	Middle East & North Africa	0.74
34	Greece	Dev. OECD		0.74
35	Poland	Rest	Europe & Central Asia	0.73
36	Latvia	Rest	Europe & Central Asia	0.73
37	Hungary	Rest	Europe & Central Asia	0.72
38	Russia	Rest	Europe & Central Asia	0.71
39	Bahrain	Rest	Middle East & North Africa	0.71
40	Georgia	Rest	Europe & Central Asia	0.71
41	Chile	Rest	Latin America & Caribbean	0.71
42	Bulgaria	Rest	Europe & Central Asia	0.70
43	Brazil	Rest	Latin America & Caribbean	0.70
44	Croatia	Rest	Europe & Central Asia	0.70
45	Mauritius	Rest	Sub-Saharan Africa	0.70
46	Malaysia	Rest	East Asia & Pacific	0.70
47	Saudi Arabia	Rest	Middle East & North Africa	0.69
48	Costa Rica	Rest	Latin America & Caribbean	0.69
49	Uruguay	Rest	Latin America & Caribbean	0.69
50	Argentina	Rest	Latin America & Caribbean	0.68
51	Oman	Rest	Middle East & North Africa	0.68
52	Kuwait	Rest	Middle East & North Africa	0.68
53	North Macedonia	Rest	Europe & Central Asia	0.68
54	Serbia	Rest	Europe & Central Asia	0.68
55	Trinidad & Tobago.	Rest	Latin America & Caribbean	0.67
56	Belarus	Rest	Europe & Central Asia	0.67
57	Vietnam	Rest	East Asia & Pacific	0.66
58	Panama	Rest	Latin America & Caribbean	0.65
59	Thailand	Rest	East Asia & Pacific	0.65
60	Turkey	Rest	Europe & Central Asia	0.65

Rank	Country	Income group	Region	RETPI score
61	Armenia	Rest	Europe & Central Asia	0.64
62	Mexico	Rest	Latin America & Caribbean	0.64
63	Romania	Rest	Europe & Central Asia	0.64
64	Lebanon	Rest	Middle East & North Africa	0.64
65	Bosnia	Rest	Europe & Central Asia	0.64
66	Jordan	Rest	Middle East & North Africa	0.63
67	Albania	Rest	Europe & Central Asia	0.63
68	Jamaica	Rest	Latin America & Caribbean	0.63
69	Tunisia	Rest	Middle East & North Africa	0.63
70	India	Rest	South Asia	0.63
71	Ukraine	Rest	Europe & Central Asia	0.62
72	Kazakhstan	Rest	Europe & Central Asia	0.61
73	South Africa	Rest	Sub-Saharan Africa	0.61
74	Moldova	Rest	Europe & Central Asia	0.61
75	Colombia	Rest	Latin America & Caribbean	0.60
76	Iran	Rest	Middle East & North Africa	0.60
77	Peru	Rest	Latin America & Caribbean	0.60
78	Morocco	Rest	Middle East & North Africa	0.60
79	Mongolia	Rest	East Asia & Pacific	0.60
80	Dominican Rep.	Rest	Latin America & Caribbean	0.60
81	Azerbaijan	Rest	Europe & Central Asia	0.59
82	El Salvador	Rest	Latin America & Caribbean	0.59
83	Ecuador	Rest	Latin America & Caribbean	0.59
84	Venezuela, RB	Rest	Latin America & Caribbean	0.58
85	Indonesia	Rest	East Asia & Pacific	0.58
86	Sri Lanka	Rest	South Asia	0.57
87	Algeria	Rest	Middle East & North Africa	0.57
88	Turkmenistan	Rest	Europe & Central Asia	0.57
89	Paraguay	Rest	Latin America & Caribbean	0.57
90	Philippines	Rest	East Asia & Pacific	0.56

Rank	Country	Income group	Region	RETPI score
91	Bolivia	Rest	Latin America & Caribbean	0.56
92	Uzbekistan	Rest	Europe & Central Asia	0.56
93	Namibia	Rest	Sub-Saharan Africa	0.55
94	Kyrgyz Rep.	Rest	Europe & Central Asia	0.55
95	Botswana	Rest	Sub-Saharan Africa	0.55
96	Cambodia	Rest	East Asia & Pacific	0.55
97	Egypt, Arab Rep.	Rest	Middle East & North Africa	0.55
98	Honduras	Rest	Latin America & Caribbean	0.54
99	Guatemala	Rest	Latin America & Caribbean	0.54
100	Gabon	Rest	Sub-Saharan Africa	0.53
101	Libya	Rest	Middle East & North Africa	0.53
102	Nicaragua	Rest	Latin America & Caribbean	0.52
103	Iraq	Rest	Middle East & North Africa	0.51
104	Ghana	Rest	Sub-Saharan Africa	0.51
105	Lao PDR	Rest	East Asia & Pacific	0.51
106	Nepal	Rest	South Asia	0.50
107	Tajikistan	Rest	Europe & Central Asia	0.48
108	Papua New Guinea	Rest	East Asia & Pacific	0.48
109	Myanmar	Rest	East Asia & Pacific	0.48
110	Congo, Rep.	Rest	Sub-Saharan Africa	0.48
111	Eswatini	Rest	Sub-Saharan Africa	0.48
112	Bangladesh	Rest	South Asia	0.47
113	Senegal	Rest	Sub-Saharan Africa	0.47
114	Lesotho	Rest	Sub-Saharan Africa	0.46
115	Sierra Leone	Rest	Sub-Saharan Africa	0.45
116	Kenya	Rest	Sub-Saharan Africa	0.45
117	Pakistan	Rest	South Asia	0.45
118	Mauritania	Rest	Sub-Saharan Africa	0.45
119	Cote d'Ivoire	Rest	Sub-Saharan Africa	0.44
120	Yemen, Rep.	Rest	Middle East & North Africa	0.43

Rank	Country	Income group	Region	RETPI score
121	Equatorial Guinea	Rest	Sub-Saharan Africa	0.43
122	Benin	Rest	Sub-Saharan Africa	0.43
123	Mozambique	Rest	Sub-Saharan Africa	0.43
124	Liberia	Rest	Sub-Saharan Africa	0.42
125	Sudan	Rest	Sub-Saharan Africa	0.42
126	Afghanistan	Rest	South Asia	0.42
127	Togo	Rest	Sub-Saharan Africa	0.42
128	Gambia, The	Rest	Sub-Saharan Africa	0.40
129	Zambia	Rest	Sub-Saharan Africa	0.40
130	Burkina Faso	Rest	Sub-Saharan Africa	0.40
131	Guinea	Rest	Sub-Saharan Africa	0.40
132	Haiti	Rest	Latin America & Caribbean	0.39
133	Zimbabwe	Rest	Sub-Saharan Africa	0.38
134	Angola	Rest	Sub-Saharan Africa	0.38
135	Mali	Rest	Sub-Saharan Africa	0.38
136	Nigeria	Rest	Sub-Saharan Africa	0.38
137	Madagascar	Rest	Sub-Saharan Africa	0.38
138	Cameroon	Rest	Sub-Saharan Africa	0.37
139	Eritrea	Rest	Sub-Saharan Africa	0.37
140	Tanzania	Rest	Sub-Saharan Africa	0.37
141	Uganda	Rest	Sub-Saharan Africa	0.36
142	Rwanda	Rest	Sub-Saharan Africa	0.35
143	Niger	Rest	Sub-Saharan Africa	0.35
144	Malawi	Rest	Sub-Saharan Africa	0.34
145	Guinea-Bissau	Rest	Sub-Saharan Africa	0.33
146	Congo, Dem. Rep.	Rest	Sub-Saharan Africa	0.31
147	Burundi	Rest	Sub-Saharan Africa	0.30
148	Central African Rep.	Rest	Sub-Saharan Africa	0.28
149	Chad	Rest	Sub-Saharan Africa	0.25

Source: Author's construction from Yilmaz (2021).
Note: Countries included in the study. Developed OECD is considered a separate region. Rep. is short for republic.

About the Author

Fatih Yilmaz

Dr. Yilmaz is a senior research associate in the Energy Transitions and Electric Power program. His current research agenda aims to enhance our understanding of the financial and economic consequences of the global energy transition towards renewables, and to design effective policies to balance financial risks and growth prospects.

Prior to joining KAPSARC, Dr. Yilmaz worked as an economist in the Structural Economic Research Department of the Central Bank of the Republic of Turkey, where he was actively involved in the research and the design of policies for the private and banking sectors. He has also worked as a consultant for the World Bank and took responsibilities in various consulting projects for the Canadian and Turkish Governments. As an academic, he spent a year as an assistant professor at the ADA University and worked as a graduate assistant at the University of Calgary and at the Western Illinois University, where he taught several courses in economics and econometrics.

Dr. Yilmaz has authored various academic and policy articles, and book chapters, in the past. He has been involved in the organization of conferences and workshops, and acted as a referee for many academic journals.

Index Data Sharing

The RETPI and subindex scores data are available upon request from the author.

About the Project

Energy transitions toward more sustainable systems are at the top of the policy agenda in many countries. Despite internationally coordinated efforts (e.g., the Paris Agreement), data shows that countries follow different transition paths, with some developed economies following a relatively fast transition and many developing nations lagging behind. Finance has emerged as a key driver of the process, among several other factors, such as policy action and technological advancements. There is an unprecedented need for investment in infrastructure, energy efficiency, research and development for mitigation technologies. This project aims to study the dynamics of energy transitions with a primary focus on the role of sustainable finance.

The project consists of five parts. The first part studies the key determinants of energy transitions with a focus on renewable energy, as it has been the most universally applied mitigation option. It constructs a composite index, the renewable energy transition potential index (RETPI), to better measure countries' renewable energy potential. The second and third parts highlight the sustainable finance instruments currently available and their effectiveness in enabling energy transitions. The final two parts attempt to understand the concept of stranded assets and their associated risks. These two parts also provide estimates on the potential size of stranded assets and a discussion on mitigation strategies.

The output of this project will improve our understanding of energy transition dynamics in terms of both managing the process and mitigating the associated risks. The project's findings will contribute significantly to the academic literature and policy discussions. More importantly, they will provide direct input into shaping Saudi Arabia's great ambitions for a more vibrant and diversified economy, as expressed in Saudi Vision 2030.

KAPSARC

مركز الملك عبدالله للدراسات والبحوث البترولية

King Abdullah Petroleum Studies and Research Center

www.kapsarc.org