King Abdullah Petroleum Studies and Research Center

Understanding the Dynamics of the Renewable Energy Transition: A Determinant Index Approach

Fatih Yilmaz

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Summary

Renewable energy is a key component of global energy transitions. To better identify its dynamics, this study constructs a composite index to measure countries' renewable energy transition potential. Based on two decades of academic research, we identify 45 main enabling factors of the renewable energy transition. We classify these factors into seven subindices: economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. We then aggregate the subindices into a composite index, which we call the renewable energy transition potential index. This index and its subindices are available for 149 countries for the period from 1990 to 2018.

1 Introduction

Transforming global energy systems toward sustainable alternatives (i.e., net-zero emissions) is the core goal of many countries' policy agendas. The global energy transition involves different mitigation activities that are all important and useful in different countries' contexts. For example, countries may increase their renewable energy (RE) usage, enhance their energy efficiency or switch fuels.[1] They may deploy nuclear alternatives or adopt carbon capture, utilization and storage technologies. Of these various options, RE has captured the most attention globally. According to the recent data, global share of RE in power generation has increased from less than 1% in 1990 to 7.5% in 2018.[2] In addition to this eightfold increase, many ambitious RE initiatives and projects have already been undertaken worldwide. These efforts will presumably boost the share of RE in the energy mix in the near future.

Despite RE's global importance and wide application, however, tools to assess countries' RE potential are lacking. Understanding countries' RE potential can help policymakers to better identify their RE opportunities. To fill this important gap, we construct a composite index, the RE transition potential index (RETPI). The RETPI combines 45 main enabling factors within seven categories, selected based on two decades of academic research, into one composite index. The seven categories are economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. The index covers 149 countries from 1990 through 2018.

A sizable academic literature examining the enabling factors of countries' RE transitions has emerged in the last two decades. These studies focus on the key determinants of RE infrastructure deployment, production and consumption. They have taken a broad focus, covering a variety of economic, social, political, financial, environmental and energy-related factors. However, no consensus has been reached on the relations between these factors and the RE transition. Recent systematic literature reviews, such as those of Bourcet (2020), Sener, Sharp, and Anctil (2018) and Darmani et al. (2014), identify various diverse approaches. For example, different studies measure factors differently, cover different developed or developing country samples, and span different periods. These different approaches may have led to the mixed results in the literature. The RETPI aims to consolidate these previous findings. To do so, we employ commonly used indicators in the literature and cover a broad set of countries over a long time span.

The RETPI specifically focuses on the determining factors of the RE transition to primarily provide a forward-looking picture of countries' RE opportunities. With this focus, it differs from the common indices in the literature, including the World Economic Forum's Energy Transition Index (WEFETI) (Singh et al. 2019), and the World Energy Council's (2020) Trilemma Index (WECTI). Whereas these two indices focus on countries' broad energy transition performances, the RETPI focuses on RE. Additionally, these other two indices consider both the determinants and the outcomes of the energy transition (e.g., the share of RE in power generation). In contrast, the RETPI concentrates solely on the determining factors of this process and, thus, measures countries' potential rather than their current performances. The RETPI's weighting methodology also significantly differs from the two indices. Whereas those indices rely on equal or pre-assessed weights to aggregate factors, the RETPI employs principal component analysis (PCA) to determine the weights for aggregation. These distinct approaches may have differing strengths and weaknesses.[3] However, the RETPI uses more objective criteria in its aggregation, as the weights are based on the correlations across the variables and are therefore data-driven. Moreover, the RETPI provides more comprehensive coverage, where it expands country coverage to all countries with populations over one million and time coverage to the last three decades.

The RETPI can be a useful tool for both policymakers and researchers. It summarizes countries' RE transition potential into a composite index. Thus, policymakers can assess their respective countries' transition potentials relative to their current performances and the performances of their peers. Furthermore, the subindices of the RETPI provide an overview of the underlying factors affecting countries' RE transition performances. With the RETPI, policymakers can carry out scenario analyses to explore the possible impacts of different policies on their countries' RE opportunities. Moreover, the process of creating the RETPI includes a massive data collection and a comprehensive literature review spanning the last two decades. Thus, we also provide an extensive literature review and a comprehensive data source for researchers.

The following section is a detailed literature review that gives context to the study. Section 3 discusses our rich data, variable selection and the imputation strategy applied for missing observations. Section 4 explains the methodology and construction of the RETPI. Section 5 discusses the index's main characteristics and its relationship with RE transition performance proxies, and Section 6 concludes.

2 Literature Review

This section begins with an extensive review of the literature on the main determinants of the RE transition, which we use to construct the RETPI. We then discuss similar indices, which are available in the literature.

Determinants of the renewable energy transition

The recent literature on the driving factors of the RE transition highlights the roles of several economic, environmental, energy security, political and regulatory aspects. Following the most recent systematic literature reviews (e.g., Bourcet [2020]; Darmani et al. [2014]; Sener, Sharp, and Anctil [2018]) in classifying key factors in the RE transition, we categorize them as economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. In the following subsections, we describe each category and review the relevant literature.

Economic factors

Economic factors generally determine countries' current and future energy demand and their capacities to deploy physical infrastructure. The literature focuses on a broad range of variables to account for the role of economic factors in explaining the RE transition. We categorize these variables into three subgroups: countries' size, growth and development levels. In theory, economic factors are generally positively related to the RE transition, but empirical evidence for the reverse association also exists. These contradicting results arise because an increase in energy demand may be met via supplying more RE or traditional fossil fuels (Bourcet 2020).

Studies often use gross domestic product (GDP) to measure the size of economies (e.g., Huang et al. [2007]; Zeb et al. [2014]). They find that GDP is generally positively related to RE usage and deployment in developing countries. However, this relationship is negative for developed economies (e.g., Marques and Fuinhas [2011a]; Marques and Fuinhas [2011b]; Marques, Fuinhas, and Manso [2010]). Population size (Baldwin et al. 2017), land (Bayulgen and Ladewing 2017) and gross capital formation (Lin and Omoju 2017) are also used in the literature to measure country size, which is usually found to be positively associated with the RE transition.

The growth of these variables (e.g., GDP, population and fixed capital stock) is also generally positively associated with increases in energy demand and RE usage. However, when energy demand increases drastically, RE sources may be insufficient, which can increase traditional resource usage. Studies find that RE can address increases in energy needs due to high economic, population and electricity demand growth (e.g., Baldwin et al. [2017]; Carley et al. [2017]; Przychodzen and Przychodzen [2020]). Thus, such types of growth may be positively associated with the higher usage of RE. However, 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 population growth has no statistically significant impact on the RE share in the energy mix. Overall, the effects of economic, population and capital stock growth on RE usage are mixed. These relationships are generally positive but may become negative if growth is excessive (Bourcet 2020).

One consistent finding in the literature is that economic development is positively related to the RE transition. More developed countries with higher incomes and better physical infrastructure tend to utilize RE more. In particular, many studies employ GDP per capita as a core measure of income and development. They find that it is positively related to a high share of RE in the energy mix (e.g., Aguirre and Ibikunle [2014]; Bayulgen and Ladewing [2017]; Carley et al. [2017]; Sadorsky [2009b]).[4]

Additionally, proxies for infrastructure development include fixed-line telephone subscriptions, mobile phone usage and internet access. These indicators are widely used in the development economics literature (e.g., Aker and Mbiti [2010]). They are directly and positively related to the diffusion and usage of RE (Glemarec 2012), predominantly in developing countries. In general, development is a broad concept and includes several other factors, such as the availability of private finance, human capital and regulatory frameworks. We describe these factors in more detail in the following subsections.

Financial development

Meeting the two-degrees Celsius above pre-industrial-level climate target will require transitioning to a low-carbon economy. To do so, trillions of dollars in investments are needed to replace the current energy infrastructure and deploy new RE infrastructure.[5] Such large-scale capital investments are beyond the capabilities of public resources. Domestic resources may provide some of the financing, but significant participation by private finance is also needed to meet the requirements.

Recent studies pay considerable attention to the linkages between financial development (i.e., access to private finance) and RE deployment or consumption. For instance, several recent studies find a strong positive relationship between financial development and RE investment and consumption (e.g., Anton and Afloarei Nucu [2020]; Best [2017]; Brunnschweiler [2010]; Lin and Omoju [2017]; Sadorsky [2010]). The literature stresses the importance of private finance channels to finance capital-intensive renewable infrastructure projects. These channels include private credit, access to international credit and debt markets, international trade and stock markets.

In addition to this direct link, the availability of finance can also enable the RE transition via indirect channels. For instance, financing small RE projects in primarily rural areas, where the grid infrastructure is limited or unavailable, can significantly improve energy access. In this way, such projects can speed up the RE transition (e.g., Ahlborg and Hammar [2014]; Haanyika [2008]). Similarly, energy-efficiency projects, such as retrofitting old buildings (e.g., Climate Transparency [2019]; Yilmaz et al. [2020]), can spur the RE transition by reducing energy resource waste.

Human capital

Human capital is a broad concept that generally covers education quality, population health and demography.[6] This concept is used to measure the size and productivity of labor in a country. Human capital may interact with the RE transition through various linkages. For example, it can affect productivity and technology adoption, political support for the RE transition and, more generally, energy demand. To explore these linkages, studies investigate the relationships between different aspects of human capital and the RE transition.

Many studies focus on the relationship between the education aspect of human capital and RE development (e.g., Apergis and Eleftheriou [2015]; Pfeiffer and Mulder [2013]; Zhao, Tang, and Wang [2013]). They provide empirical evidence that higher education is positively associated with the faster adaptation of RE technologies. Some studies investigate the relationships between population demographics (i.e., the percentage of women in a country, the age distribution and birth rates) and the RE transition. Romano et al. (2017) show that more women as a percentage of the population promotes more RE investment. Vainio et al. (2019) also confirm the importance of female leadership in accelerating the energy transition. To explain their findings, these studies argue that women usually have stronger environmental quality preferences and, thus, are more supportive of RE and related policies.

Both population growth and changes in the population's composition (e.g., aging) affect policy decisions. Such changes can affect policy attributions toward climate change (e.g., Harper [2013]) and a country's energy demand (e.g., Estiri and Zagheni [2019]). People's well-being interacts with the RE transition through various linkages, such as productivity and public health concerns owing to environmental pollution. In general, productivity and technological development increase with better public health, which supports economic growth (e.g., Arora [2002]). Thus, such development is associated with the RE transition (e.g., Ackah and Kizys [2015]). Moreover, environmental pollution and the resulting change in climate conditions leads to health concerns (e.g., IEA [2016]; WHO [2018]). Such concerns may also motivate a shift in the policy agenda toward RE usage (e.g., Caruso, Colantonio, and Gattone [2020]).

Energy access

Energy access is a serious issue in many developing countries, especially the least developed countries. Hence, it is closely monitored by various international institutions and academic studies (e.g., Bhatia and Angelou [2014]; ESMAP [2014]; IEA [2020]; Seuret-Jimenez, Robles-Bonilla, and Cedano [2020]; Yadava and Sinha [2019]). Here, we focus specifically on its relationship with the RE transition. The long distances between dispersed households in predominantly rural regions increase the cost of transmission infrastructure, hindering efforts to build fully inclusive electricity grid networks. In contrast, RE technologies offer promising alternatives, such as decentralized small grid alternatives and autonomous power generation (e.g., Glemarec [2012]; IRENA [2016]; Murphy [2001]). For instance, Ahlborg and Hammar (2014) explore the drivers and barriers to electrification in Tanzania and Mozambique by interviewing power sector actors and making observations. They conclude that improving households' grid access in mostly rural areas is generally infeasible owing to the high costs of doing so. Off-grid extensions in the form of RE technologies appears to be the only viable long-term solution. Overall, the opportunity to improve energy access via RE deployment may motivate governments to focus more on accelerating their RE transitions (Sokona, Mulugetta, and Gujba 2012).

Energy security

As oil and gas resources are concentrated in certain parts of the world, many countries depend on imports from resource-rich regions. Relying on fossil fuels creates significant dependencies for many countries, leading to essential energy security concerns. Reducing dependence on fossil fuel imports and becoming more self-sufficient is an important motivation for many energy-dependent countries to deploy RE (Marques and Fuinhas 2012). In contrast, fuel-exporting countries may have the opposite incentive, as low fuel costs can help to reduce global concerns about energy security. Local companies in these countries may lobby governments and manipulate oil prices to alleviate energy security concerns. The so-called lobbying effect is generally found to negatively impact RE usage (Pfeiffer and Mulder 2013). Overall, however, energy security concerns appear to be an important motivating factor for RE usage and thus, are positively associated with RE transition dynamics.

Environmental sustainability

The environmental consequences of the current energy system (e.g., higher air temperatures, natural disasters and greenhouse gas emissions) are tragic. Many countries have taken strict policy actions to mitigate these negative consequences, including setting official commitments via the Kyoto Protocol in 1997 and the Paris Agreement in 2015. The countries that ratified these commitments are required to reduce their greenhouse gas emissions significantly. Despite environmental concerns and international commitments, however, the relationship between environmental sustainability and RE transitions is inconclusive in the literature. Presumably, the association is expected to be positive, as countries with major environmental concerns, such as high greenhouse emissions, should use cleaner technologies more proactively (Aguirre and Ibikunle 2014; Sadorsky 2009a). However, some studies find that high carbon dioxide emission levels may discourage RE usage (Marques and Fuinhas 2011a; Marques, Fuinhas, and Manso 2010). One rationale for this finding is that current carbon dioxide levels may not be high enough (or perceived as high enough) to motivate a significant shift to RE. The political influences of different interest groups, such as traditionally carbon-intensive sectors (e.g., the metal industry) may play a significant role in these perceptions.

Institutional infrastructure

As discussed earlier, transforming the current energy system requires unprecedented capital investments in addition to a major shift in government policy. Significant participation by private investors is necessary for this process. Strong institutional quality is crucial to unlocking private resources, especially for long-term capital investment projects, such as RE deployment, and directing policies accordingly. Unlike traditional private investments, such as portfolio investments and other foreign direct investments by private entities, RE projects take a long time to complete. The investment returns from these projects are usually collected by supplying energy to the grid and end consumers for several years. Various regulations and incentive mechanisms (e.g., subsidies and feed-in tariffs) are used to enable these returns.[7] Thus, investors need to ensure that their contracts are well regarded and secured by strong institutions even if governments or ruling parties change. In line with these general expectations, studies find a positive relationship between institutional quality and private participation in long-term projects, such as RE projects (e.g., Bayulgen and Ladewig [2017]; Brunnschweiler [2010]; Wu and Broadstock [2015]). In other words, countries with strong institutional infrastructure tend to attract more private capital investment into RE, accelerating their RE transitions.

Alternative transition indices

Most indices developed in previous studies focus on one specific aspect of the energy transition, such as energy sustainability, energy security or environmental sustainability.[8] Although these indices provide valuable insights on their focus areas, they do not provide a comprehensive understanding of the RE transition. The RE transition is a multi-factor, complex, and long-term process, and most of its determinants are highly interlinked. For example, economic factors and finance, energy access and economic development, and environmental sustainability and institutional infrastructure are all clearly connected. Hence, focusing on specific aspects ignores the overall picture. Narula and Reddy (2015) provide a detailed discussion of the shortcomings and controversies of the widely used energy indices with specific focuses.

More recently, the literature's focus has shifted toward capturing countries' overall energy transition performances. Two indices, the WEFETI (Singh et al. 2019) and the WECTI (World Energy Council 2020), have received the most attention. The former emerged from the Global Energy Architecture Performance Index, and the latter emerged from the Energy Sustainability Index. Despite certain commonalities, the RETPI differs from these two indices in several important ways (Table 1). First, the RETPI focuses on the RE transition, whereas the two other indices focus on countries' overall transition performances. This approach allows the RETPI to rely on two decades of academic literature to better identify the critical determining factors and classify them into subindices.

Second, the RETPI focuses only on the determinants of the RE transition, providing a forward-looking index of countries' transition potentials. In contrast, the other two indices do not clearly distinguish between the determinants and enablers of overall energy transitions and their outcomes. The determinants of overall energy transitions are factors that directly or indirectly drive the transition process (e.g., economic factors, financial development and energy security). The outcomes are the results of the transition process (e.g., higher RE usage and achieving net-zero carbon emissions). Although the other two indices cover several essential factors, they mix determinants and enablers. It is unclear whether mixing the two can better capture a country's country situation or future potential.

Table 1. Comparison of the RETPI with the main transition indices.

Characteristics	RETPI	WEFETI	WECTI
Conceptual focus	Renewable energy transition	General energy transition	General energy transition
Indicator selection	Uses only determining factors	Mixed (determinants and outcomes)	Mixed (determinants and outcomes)
Weighting and aggregation methodology	Principle component analysis	Equal weights	Pre-assigned weights
Index coverage	Economic factors (size, growth and development), financial development, human capital (demography, education and health), energy access, energy security, environmental sustainability and institutional infrastructure	Economic development and growth, environmental sustainability, energy security and access, capital and investment, regulation and political commitment, institutions and government, infrastructure and innovative business environment, human capital and energy system structure	Macroeconomic environment, governance, stability for investment and innovation, energy security, energy equity and environmental sustainability
Country coverage	149	127	128
Time span	1990 - 2018	2017 - 2018	2000 - 2018

WEFETI: World Economic Forum's Energy Transition Index. WECTI: World Energy Council's Trilemma Index. Mixed implies the index uses both determinant and outcome variables.

Moreover, the indices also differ from each other in terms of their methodologies. The WEFETI weights factors equally, and the WECTI employs pre-assigned weights to each factor or factor group. The former claims that the main reason for not using more technical weights (such as PCA or regression weights) is due to the lack of empirical evidence on their superiority (Singh et al. 2019, 3). The latter chooses weights to balance scientific robustness and transparency (World Energy Council 2020, 64). Both approaches may have merits in practice. However, it remains unclear whether each factor is equally essential, or if their importance is precisely assessable based on expert opinion for a successful transition. These questions are critical, especially for the policymaking process. The RETPI follows more objective criteria (i.e., PCA) in its weighting approach.

It is also worth noting that there seems to be a tradeoff between indices' country and time coverage objectives and their indicator coverage. Many contemporary variables, such as the business environment, innovation, technology adaption and transition-focused policies, generally have limited availability. They tend to cover only recent years and a specific set of countries. By focusing on the years after 2017, the WEFETI covers more contemporary metrics that are largely unavailable for most countries before the year 2000. In contrast, the WECTI uses more general variables that are available for more countries over a longer period of time (2000–2018). Our strategy is to maximize both country and time coverage to utilize all countries' transition experiences. This strategy blends a large spectrum of transition experiences from countries in different income groups and regions.

3 Data

This study utilizes several datasets. We take power generation and energy data from Enerdata and country-level indicators from the World Bank's World Development Indicators (WDI) and World Governance Indicators (WGI). We choose our variables to maximize country and time coverage while conforming with the relevant literature's findings on key determinants of RE transitions.

We construct a rich data set spanning 1990 to 2018 covering the maximum possible number of countries. We exclude countries with average populations below one million. This criterion excludes small island countries that often have large data gaps. We impute some small gaps in the data, mainly in the early years, following standard statistical techniques. In the following subsections, we describe our variable selection strategy and discuss the imputation methodology.

Variable selection

We choose variables in seven main categories: economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. We employ widely used variables in the literature to capture the key determinants of the RE transition in each category. Table 2 presents a full list of the variables and their classifications into the seven categories. More specifically, our variable selection strategy adheres to three main principles:

- Determinant orientation: We use variables that can best be proxy determinants of the RE transition based on findings in the literature.
- Transparency and quality: We use reliable data that are available from international institutions, such as the World Bank, or academic sources, such as the Potsdam Institute for Climate Impact Research (PIK).
- Data maximization: We use the available variables for the maximum number of countries over the longest period of time.

Imputation

For our data imputation strategy, we first construct a reliable GDP series. As a baseline, we use the World Bank's WDI GDP series in current U.S. dollars. However, the series contains missing observations. We impute these observations using the growth rates obtained from PIK historical GDP data.[9] Utilizing the imputed GDP series and an almost entirely balanced population series,[10] we calculate the GDP per capita that is used in the imputation of the other variables.

More specifically, our imputation methodology follows a standard three-step procedure.

Step 1: Impute gaps between two years by averaging the values for those two years.

Step 2: Use the three-year average growth rate of a variable to impute missing observations in subsequent years.

Step 3: If gaps still exist, run the following regressions:

$$y_{it} = \propto_0 + \beta_1 gdp.pc_{it} + trend_t + trend_i^2 + f_i + e_{it},$$

$$y_{it} = \propto_0 + \sum_1^j \beta_j\, incomegroup_i + \sum_1^h \beta_h\, region_i$$
$$+ trend_t + trend_t^2 + u_{it},$$

Table 2. RETPI and variable descriptions.

Index	Group	Sub-index	Abbrevation	Description
Energy Transition Determinant Index (ETDI)	Economic Factors Sub-index (EFI)	Size Potential Sub-index (SPI)	*gdp*	GDP
			pop.	Population
			cap.form	Gross capital formation (constant 2010 US$)
			land	Land size
		Growth Performance Sub-index (GPI)	*gdp.gr*	GDP growth
			pop.gr	Popultion growth
			cap.form.gr	Capital formation growth
		Development Level Sub-index (DLI)	*gdp.pc*	GDP per capita
			fixed.tel	Fixed telephone subscriptions (per 100 people)
			internet	Individuals using the internet (% of population)
			mobile	Mobile cellular subscriptions (per 100 people)
			airtravel	Access to air travel - Air transport, passengers carried
	Human Capital Sub-index (HCI)	Demography Sub-index (DI)	*pop15.64*	Population ages 15-64 (% of total population)
			pop64+	Population ages 64+ (% of total population)
			pop.fem	Population female (% of total population)
			pop.urban	Urban population (% of total population)
			pop.prod	Production rate (Birth rate, crude [per 1,000 people] / Death rate, crude [per 1,000 people])
		Education Sub-index (EI)	*comp.sch*	Compulsory education, duration (years)
			sch.enroll	School enrollment, primary (% gross)
			inv.pup.teacher	Pupil-teacher ratio, primary (inverse)
		Health Sub-index (HI)	*health.exp*	Current health expenditure (% of GDP)
			physician	Physicians (per 1,000 people)
			inv.mortal	Mortality rate, infant (per 1,000 live births) (inverse)
			inv.tuber	Incidence of tuberculosis (per 100,000 people) (inverse)
			clean.water	People using at least basic drinking water services (% of population)
	Financial Development Sub-index (FDI)		*credit.to.gdp*	Domestic credit provided by financial sector (% of GDP)
			fdi	Foreign direct investment, net inflows (% of GDP)
			trade	Trade ([import+export]/of GDP)
	Energy Access Sub-index (EAI)		*acc.elec*	Access to electricity (% of population)
			acc.elec.rural	Access to electricity, rural (% of rural population)
			acc.elec.cooking	Access to clean fuels and technologies for cooking (% of population)
			elec.cons.pc	Electric power consumption (kWh per capita)
	Energy Security Sub-index (ESI)		*energy.imp*	Energy imports, net (% of energy use)
			inv.res.rent	Total natural resources rents (% of GDP) (inverse)
			inv.energy.dep	Energy depletion (% of GNI) (inverse)
	Enviromental Sustainability Sub-index (ENSI)		*inv.co2.gdp*	CO2 emissions (kg per 2010 US$ of GDP) (inverse)
			inv.co2.pc	CO2 emissions (metric tons per capita) (inverse)
			inv.co2.elec.heat	CO2 emissions from electricity and heat production, total (% of total fuel combustion) (inverse)
			inv.fossil.fuel	Fossil fuel energy consumption (% of total) (inverse)
	Institutional Infrastructure Sub-index (III)		*voice*	Voice and accountability
			pol.stab	Political stability, no violence
			govt.effct	Government effectiveness
			regulatory.qua	Regulatory quality
			rule.law	Rule of law
			corrupt	Control of corruption

Source: Author’s construction.

where i is country and t is year. The first equation includes the logarithm of GDP per capita, global linear and quadratic time trends, and country fixed effects (f). The second equation considers income (i.e., j income groups) and regional (i.e., h regional groups) differences and global time trends. The income groups are based on the high, upper-middle, lower-middle and low income groups defined by the World Bank. To better account for region-specific heterogeneity across countries, we employ the International Labor Organization's detailed regional grouping.[11]

In the indexation literature, studies follow similar imputation techniques, which generally rely on regional and income group trends or strong correlations between variables. For instance, Kim and Loayza (2019) construct a cross-country panel sample for the World Bank's productivity index. They use regional and income group trends to impute missing observations. They also employ regression models in their imputation if the independent variables have sufficiently high explanatory power (R^2). The World Energy Council (2020) employs a similar approach for the WECTI. They use income and regional averages to impute missing observations. In contrast, we do not directly apply the trends by income and regional groups in our imputation. Instead, we develop a richer regression setup that controls for linear and quadratic global time trends, as well as country-level fixed effects.

In practice, we run two models and use the model with the higher R^2 value for the imputation. As a baseline, we require the regression equations to explain at least 25% of the variation in the dependent variable (R^2). If they cannot do so, we stop the imputation process. Importantly, we do not directly use the predicted values in the imputation. Instead, we apply annual growth rates computed from the predictions to the latest available data in the series to extrapolate missing observations.[12] Lastly, we winsorize all of the variables at the 5% level to exclude potential outliers.[13] Table 3 shows the summary statistics of the variables used in the index construction.

Table 3. Summary statistics.

	Variable	Obs	Mean	Std. Dev.	Min	Max
1	gdp (in million $)	4,379	324,000	1,290,000	101	20,500,000
2	pop. (in million)	4,379	42.00	142.00	0.42	1,390.00
3	cap.form (in million $)	4,379	58,600	128,000	-	799,000
4	land (in million sq. km)	4,379	0.84	2.04	0.00	16.40
5	gdp.gr	4,379	0.07	0.16	-0.76	3.05
6	pop.gr	4,379	0.02	0.02	-0.19	0.19
7	cap.form.gr	4,339	0.05	0.13	-0.44	1.24
8	gdp.pc	4,379	9,343.94	14,600.07	95.19	103,059.20
9	fixed.tel	4,377	16.36	17.69	0.00	68.41
10	internet	4,379	20.43	27.55	0.00	98.64
11	mobile	4,379	48.24	51.36	0.00	210.05
12	airtravel	4,379	0.50	1.01	0.00	10.05
13	credit.to.gdp	4,379	56.62	47.90	0.00	260.86

14	fdi	4,191	3.61	5.06	-12.04	89.48
15	trade	4,379	78.02	36.61	11.09	226.04
16	pop15.64	4,379	61.48	7.07	46.98	78.75
17	pop64+	4,379	7.37	5.17	1.33	21.95
18	pop.fem	4,379	50.21	2.24	34.01	53.83
19	pop.urban	4,379	55.52	22.58	6.27	100.00
20	pop.prod	4,375	2.98	1.61	0.62	10.14
21	inv.pup.teacher	4,379	0.05	0.02	0.01	0.11
22	comp.sch	4,379	8.92	2.00	5.00	15.00
23	sch.enroll	4,379	70.33	32.30	5.16	156.56
24	clean.water	4,379	80.87	20.50	17.54	100.02
25	inv.mortal	4,379	0.04	0.05	0.00	0.33
26	inv.tuber	4,379	0.09	0.10	0.01	0.59
27	physician	4,379	1.56	1.39	0.00	5.29
28	health.exp	4,379	5.89	2.25	1.66	12.88
29	elec.cons.pc	4,379	3,354.13	3,624.91	23.67	17,765.72
30	acc.elec.cooking	4,379	59.22	37.55	0.00	100.00
31	acc.elec.rural	4,379	65.87	40.21	0.00	100.00
32	acc.elec	4,379	74.28	33.56	2.13	100.00
33	energy.imp	4,379	-23.06	144.03	-885.25	103.31
34	inv.res.rent	4,302	10.35	75.88	0.02	1,505.81
35	inv.energy.dep	4,379	5.15	4.25	0.02	10.00
36	inv.co2.gdp	4,379	3.04	2.22	0.22	17.52
37	inv.co2.pc	4,379	2.53	5.28	0.03	53.47
38	inv.co2.elec.heat	4,379	11.55	337.75	0.00	10,000.00
39	inv.fossil.fuel	4,379	397.38	1,953.58	0.01	10,000.00
40	voice	4,379	0.53	0.23	0.05	0.98
41	pol.stab	4,379	0.59	0.18	0.10	0.93
42	govt.effct	4,379	0.49	0.20	0.12	0.96
43	regulatory.qua	4,379	0.53	0.20	0.10	0.96
44	rule.law	4,379	0.52	0.21	0.14	0.99
45	corrupt	4,379	0.40	0.23	0.04	0.98

Source: Author’s construction.

4 Designing a RE Transition Index

This section describes our methodology and the index construction process.

Methodology: A principal component analysis approach

As discussed in Section 2, we group the RE transition determinants into seven main subindices that are then aggregated to create the overall RETPI. We construct the subindices and the RETPI using principal components analysis (PCA). We first apply PCA to the subindices and then apply it to the composite index. We invert the variables when necessary to ensure that each variable has a positive relationship with the RE transition based on the literature findings. Thus, a higher index value implies better RE transition potential.

We briefly outline the PCA methodology. PCA is a dimensionality reduction method that summarizes the information contained in several variables into principal components (i.e., a linear combination of those variables). The number of principal components can be as high as the number of selected variables. However, the first principal component usually accounts for the most variation (i.e., explanatory power). One rule of thumb for PCA is that the eigenvalue associated with a principal component should be greater than one to ensure the model's quality. A second rule of thumb is that the variables included in a PCA model should have a certain degree of sufficient commonality. This commonality is generally tested using the Kaiser-Meyer-Olkin (KMO) test. This test has a critical value of 0.5, above which the commonality is sufficient. Thus, for all of the PCA models employed in our analysis, we report the eigenvalue for the first principal component and the KMO test result.[14]

Construction of the RETPI

In this subsection, we discuss the construction of the overall RETPI and its subcomponents. We also present the factor loadings (weights) from the PCA and the results of necessary robustness tests.

Economic factors subindex

The economic factors subindex (EFI) includes size potential, growth performance and development level subindices. The size potential subindex (SPI) includes different size measures. We use GDP, population, gross capital formation and land to reflect economic, demographic, physical capital and geographic size, respectively. Similarly, the growth potential subindex (GPI) includes the growth of all of these size measures except land, which is mostly constant over time. Lastly, the development level subindex (DLI) covers various proxies measuring different aspects of economic development. These proxies are GDP per capita, fixed telephone subscriptions (per 100 people) and individuals using the internet (as a percentage of the population). They also include mobile cellular subscriptions (per 100 people) and total annual air passengers (as a percentage of the population). The PCA factor loadings for the EFI are:

$$EFI = 0.63 * z(SPI) - 0.39 * z(GPI) + 0.67 * z(DLI), \quad (1)$$

where $z(x) = \frac{X_i - \text{mean}(X)}{std(X)}$.[15] The EFI accounts for 45% of the total variation in its subcomponents. The principal component model's eigenvalue is 1.35, and the KMO tests for all of the variables (i.e., the subindices) are above the critical value of 0.50. Moreover, the PCA factor loadings for the subindices are:

$SPI = 0.55*z(gdp) + 0.43*z(pop.) + 0.54*z(cap.formation) + 0.47*z(land),$

$GPI = 0.65*z(gdp.growth) + 0.39*z(pop.growth) + 0.65*z(cap.form.growth),$

$DLI = 0.50*z(gdp.pc) + 0.43*z(telephone) + 0.50*z(internet) + 0.43*z(mobile) + 0.35*z(airtravel).$

The SPI, GPI and DLI capture 60%, 44% and 62% of the total variation in the control variables, respectively. Moreover, each model has an eigenvalue above one, and the KMO test for each variable is above the critical level.

Financial development subindex

The financial development subindex (FDI) contains three widely used variables in the literature to proxy financial development, particularly access to private finance. The first is domestic credit provided by the financial sector (as a percentage of GDP). The second is foreign direct investment net inflows (in current U.S. dollars as a percentage of GDP). Finally, we include the trade balance (total imports and exports as a percentage of GDP). The PCA factor loadings for the FDI are:

$$FDI = 0.39*z(credit.to.gdp) + 0.65*z(fdi) + 0.66*z(trade). \quad (2)$$

The FDI accounts for 50% of the total variation in the model's control variables. The model has an eigenvalue of 1.50, and the KMO value for each variable is well above 0.5.

Human capital subindex

The human capital subindex (HCI) has three subindices: demography, education and health. The demography subindex (DI) accounts for the main characteristics of a population (e.g., its size, age and production rate). It comprises the working population aged 15–64 years and the population over age 64, both as a percentage of the total population. It also includes the share of women in the total population and the urban population as a percent of the total population. Finally, it considers the population production rate (i.e., the ratio of births to deaths).

The education subindex (EI) describes a country's education level and quality. We include compulsory school education (in years), secondary school enrollment (primary, percentage of gross) and the pupil-teacher ratio (primary). We invert the pupil-teacher ratio to ensure that it is positively related to high-quality education.

Finally, the health subindex (HI) accounts for public health. It covers current health expenditures (percent of GDP), the number of physicians (per 1,000 people) and the infant mortality rate (per 1,000 live births). It also includes the incidence of tuberculosis (per 100,000 people) and people using at least basic drinking water services (percent of the population). The infant mortality rate and the tuberculosis incidence are inverted to ensure that they are positively related to better public health. The PCA factor loadings for the HCI are:

$$HCI = 0.57*z(DI) + 0.57*z(EI) + 0.59*z(HI). \quad (3)$$

The HCI accounts for 88% of the total variation in the variables for which the model controls. The model has an eigenvalue of 2.6, and the KMO test for each variable is well above 0.5 for all of the components. Moreover, the PCA factor loadings for the subindices are:

$DI = 0.47*z(pop15-64) + 0.59*z(pop64+) + 0.22*z(popfemale) + 0.40*z(pop.urban)$

$-0.48*z(pop.prod.rate),$

EI = 0.61∗z(inv.pupil.teacher) + 0.48∗z(compulsory.edu) + 0.63∗z(secondary.sch.enroll),

HI = 0.44∗z(clean.water) + 0.45∗z(inv.tuber) + 0.49∗z(inv.mortality) + 0.48∗z(physician)

+ 0.36∗z(health.exp.).

The DI, EI and HI capture 52%, 70% and 63%, respectively, of the total variation in their control variables. Each model's eigenvalue is well above one, and the KMO test results for the variables in each model are above the critical level.

Energy access subindex

The energy access subindex (EAI) aims to measure the ability of a country's population to access energy. The index includes electric power consumption (kilowatthours per capita) and access to clean fuels and technologies for cooking (percentage of the population). It also contains access to electricity (percentage of the population) and access to electricity in rural areas (percentage of the rural population). The PCA factor loadings for the EAI are:

EAI = 0.34∗z(elec.cons.pc) + 0.54∗z(access.to.elec.cooking) + 0.54∗z(access.to.elec)

+ 0.55∗z(access.to.elec.rural). (4)

The EAI accounts for 78% of the total variation in the model's control variables. The model has an eigenvalue of 3.11, and the KMO value for each variable is well above 0.5.

Energy security subindex

The energy security subindex (ESI) measures a country's energy security concerns or, more specifically, its dependence on fuel resources from other countries. It covers net energy imports (percentage of energy use), total natural resource rents (percent of GDP) and energy depletion (percentage of gross national income). Total natural resource rents are a country's total rents from natural resources, such as coal, oil and gas, in a given year. Higher total rents therefore imply less dependency on imported natural resources. Energy depletion is the ratio of the value of the remaining energy resources (coal, oil and gas) to the remaining reserve lifetime up to 25 years. Higher energy depletion implies more natural resource assets and, thus, less energy dependency. We invert both variables to align them with the nature of the index. Thus, a higher index value for a country implies more resource dependency (or greater energy security concerns). Overall, the PCA factor loadings for the ESI are estimated as:

ESI = 0.67*z(energy.import) + 0.30*z(inv.resource.rents) + 0.68*z(inv.energy.dep). (5)

The ESI accounts for 52% of the total variation in the variables for which the model controls. The model has an eigenvalue of 1.60, and the KMO value for each variable is well above 0.5.

Environmental sustainability subindex

The environmental sustainability index (ENSI) contains key measures of pollution. It includes carbon dioxide emissions (metric tonnes) per GDP (2010 U.S. dollars) and total carbon dioxide emissions (metric tonnes) per capita. It also includes total carbon dioxide emissions from electricity and heat production (as a percentage of total fuel combustion) and fossil fuel energy consumption (as a percentage of total energy consumption). All four variables are inverted so that the ENSI is greater when pollution is lower. The PCA factor loadings for the ENSI are:

ENSI = 0.61*z(inv.CO2.gdp) + 0.64*z(inv.CO2.pc) + 0.24*z(inv.CO2.elec.heat)

+ 0.39*z(inv.fossil.fuel). (6)

The ENSI accounts for 44% of the total variation in the model's control variables. The model has an eigenvalue of 1.76, and the KMO value for each variable is well above 0.5.

Institutional infrastructure subindex

The institutional infrastructure subindex (III) includes the WGI's voice and accountability, political stability, government effectiveness, regulatory quality, the rule of law and control over corruption. A higher value for each indicator implies better institutional quality. The PCA factor loadings for the III are:

III = 0.39∗z(voice.accountability) + 0.37∗z(political.stab) + 0.42∗z(govt.effectiveness)

+ 0.42∗z(regulatory.quality) + 0.43∗z(rule.of.law) + 0.42∗z(control.of.corrupt). (7)

The III accounts for 87% of the total variation in the model's control variables. The model has an eigenvalue of 5.25, and the KMO value for each variable is well above 0.5.

Composite RETPI

We obtain the composite RETPI by combining the seven subindices discussed above. The PCA factor loadings for the RETPI are:

RETPI = 0.41∗z(EFI) + 0.28∗z(FDI) + 0.50∗z(HCI) + 0.49∗z(EAI)+ 0.05∗z(ESI) – 0.24∗z(ENSI)

+ 0.45∗z(III). (8)

The RETPI accounts for 50% of the total variation in the control variables (i.e., the subindices) in the model. The model has an eigenvalue of 3.48, and the KMO value for each variable is well above 0.5. The RETPI and its subindices are rescaled to be between zero and one, following a standard linear transformation.[16] The rescaling simply makes the scores easier to interpret. It does not change the actual country rankings.

5 Discussion of the RETPI

The RETPI is designed to measure countries' RE transition potential given their historical performances on seven subindices and 45 variables. A country's potential may or may not directly map to its transition performance in a given year. In other words, although we expect a country's RE transition potential and performance to be positively related, they may not always have a direct mapping. Instead, a country may over- or underperform its potential. To further explore this relation, we first discuss the relationship between RETPI scores and the RE share, a widely used proxy for countries' RE transition performances. We then show these variables' trends over the last three decades and discuss the global picture based on the RETPI scores as of 2018.

Relationship between the RETPI and RE

In this subsection, we provide further empirical evidence of the relationship between the RETPI and countries' RE transition performances. Among different RE indications (e.g., RE production and consumption), we focus on contemporary RE resources, such as solar, wind and geothermal energy. Thus, we use the non-hydroelectric RE (NhRE) share in power generation as a proxy for countries' RE transition performances.[17]

Table 4 presents cross-correlations for the RETPI, its subindices and the NhRE share in total power generation. In line with prior studies, the NhRE share is positively correlated with the RETPI and its components. These correlations are statistically significant according to conventional levels, except in the case of the ENSI. However, the relationship is still positive. We also plot the relationship between the NhRE share and the RETPI in Figure 1. We observe a positive relationship between the variables, which appears to be quadratic. The quadratic relationship may imply that countries increase their transition speeds after reaching a certain RETPI level.

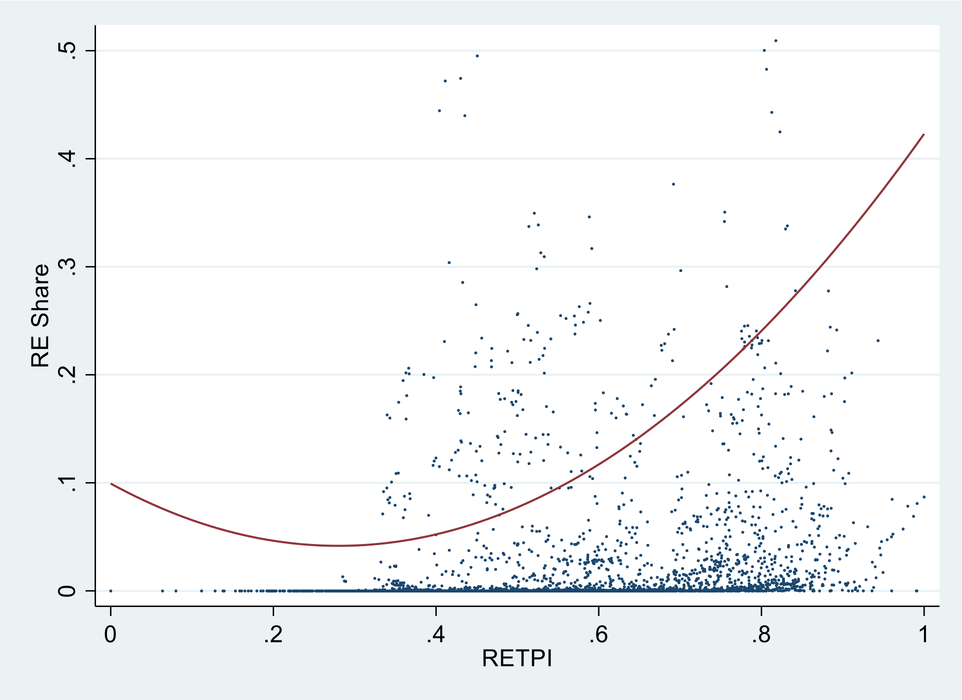
Table 4. Correlations between the NhRE share and the indices.

	RETPI	EFI	FDI	HCI	EAI	ESI	ENSI	III
NhRE	0.2089*	0.2082*	0.1157*	0.2215*	0.1227*	0.1238*	0.0071	0.1956*

Note NhRE = Non-hydro share of renewables in power generation; 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.

Source: Author's construction.

Figure 1. Correlation between the NhRE share and the RETPI.

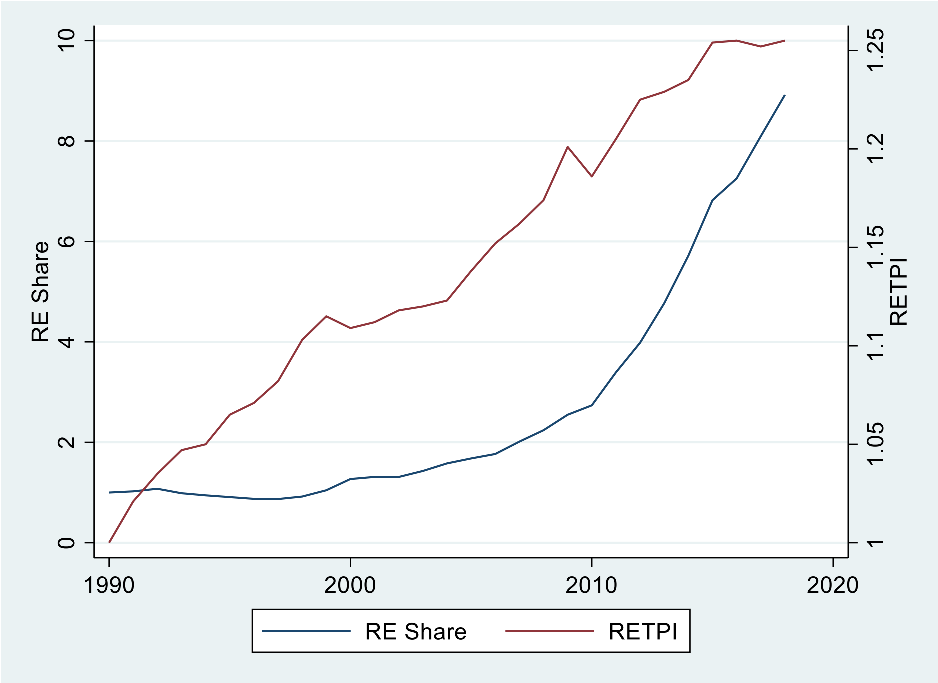


Note: The RE share includes non-hydro renewables in total power generation.
Source: Author's construction from RETPI and Enerdata.

For further visual reference, we plot the evolutions of the average RE share and the RETPI since 1990 in Figure 2.[18] According to Figure 2, the NhRE share and the RETPI trends follow similar growth dynamics, with a correlation of roughly 85%. We also plot the evolutions of the subindices in Figure 3, which provides valuable insights into the underlying factors that have driven the RETPI's evolution. First, Figure 3 shows that the RETPI has been mostly affected by developments in the economic, financial, human capital and energy access factors. These subindices, in line with the RETPI, have mostly trended upward during the sample period. On the contrary, the energy security, institutional infrastructure and environmental sustainability factors seem to be either mostly constant or gradually decreasing. Second, the trends in the economic and financial factors, especially, accelerated after the Global Financial Crisis of 2008. This acceleration may have been supported by the enormous capital flows from developed to developing economies. In contrast, the human capital and energy access factors have experienced near-linear growth over the last three decades.

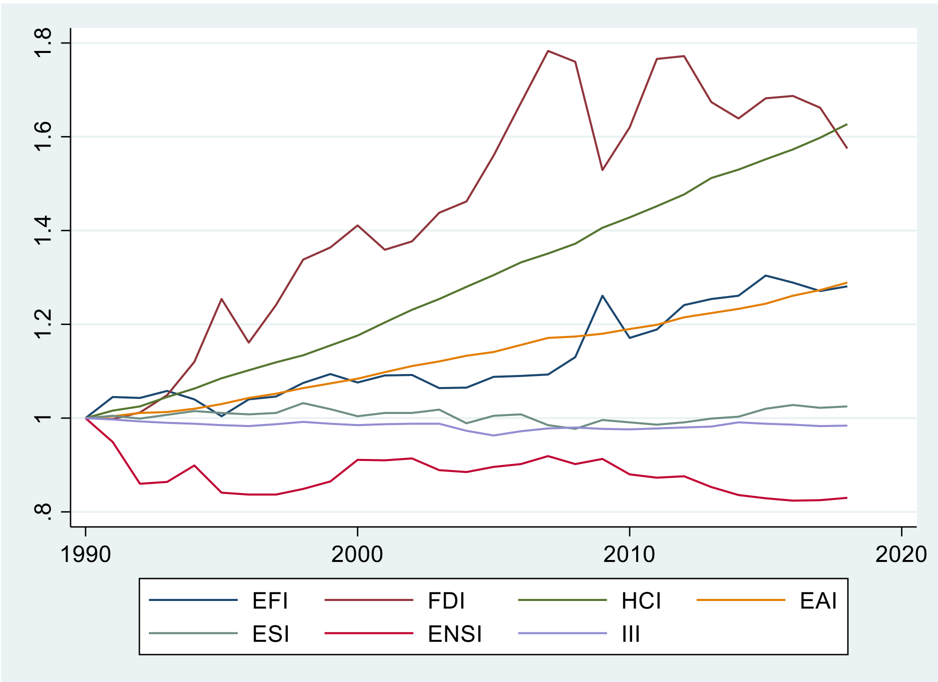
5 Discussion of the RETPI

Figure 2. Evolution of the RE share (NhRE) and the RETPI over time.



Note: The values of both variables are relative to their 1990 values. The RE share includes non-hydro renewables in total power generation.
Source: Author's construction from RETPI and Enerdata.

Figure 3. Evolution of the subindices over time.



Note: The values are relative to their 1990 values.
Source: Author's construction from REPTI.

RETPI 2018 rankings

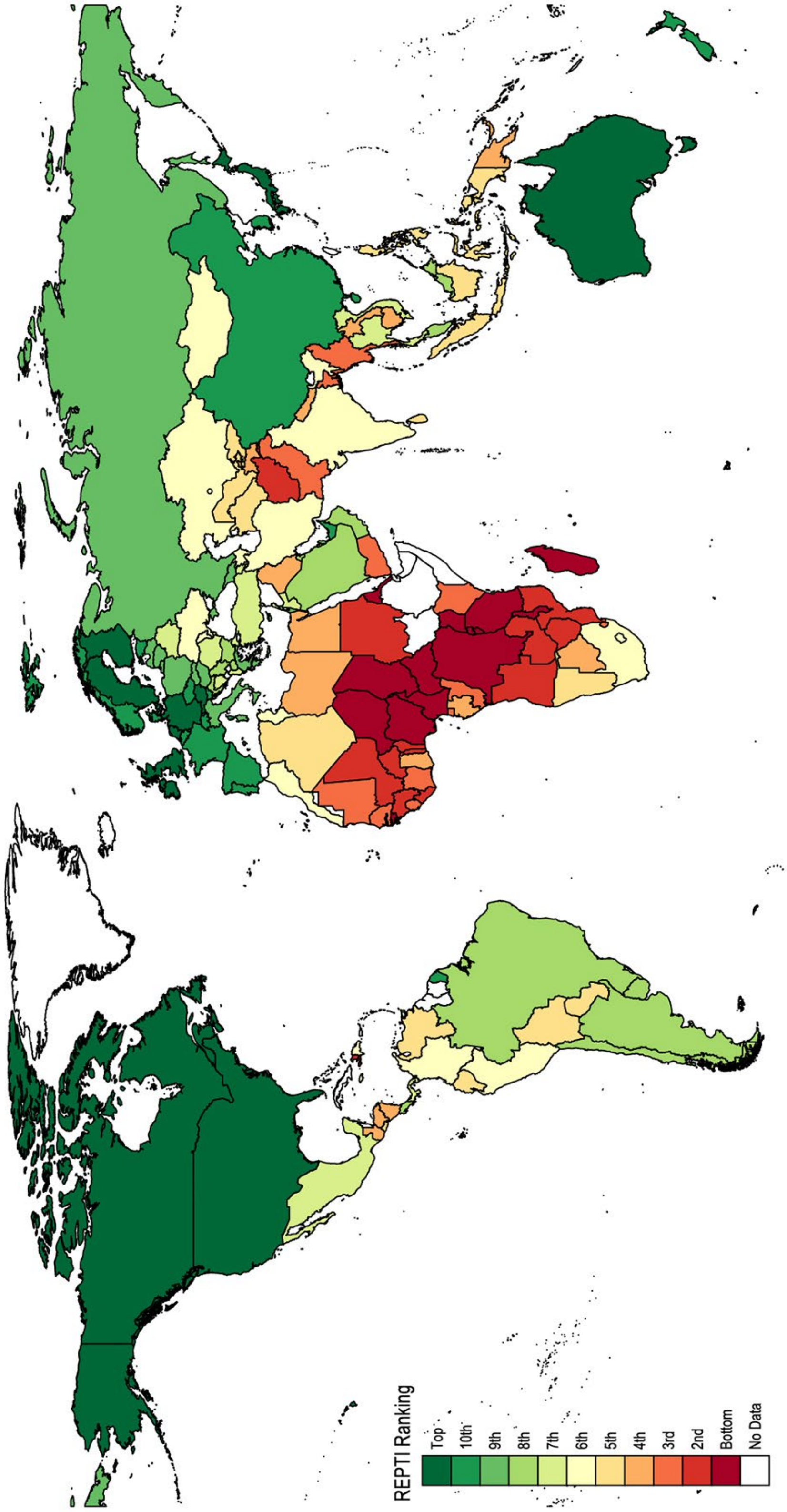
Table 5 shows the RETPI scores and rankings for 2018. The scores are also illustrated in a world heat map in Figure 4. The most recent RETPI scores are for 2018; they indicate which countries have the highest RE transition potential. They include the U.S. and Canada in North America and most European countries, particularly Germany, Austria, Switzerland and the Nordic countries. They also include Japan, Singapore and Hong Kong in Asia as well as Australia. In contrast, most African countries, particularly Western, Central and Eastern African countries, have the lowest RE transition potential.

Table 5. RETPI scores and rankings in 2018 by country.

R	Country	RETPI	R	Country	RETPI	R	Country	RETPI	R	Country	RETPI
1	United States	1.00	46	Malaysia	0.70	91	Bolivia	0.56	136	Nigeria	0.38
2	Hong Kong	0.94	47	Saudi Arabia	0.69	92	Uzbekistan	0.56	137	Madagascar	0.38
3	Singapore	0.92	48	Costa Rica	0.69	93	Namibia	0.55	138	Cameroon	0.37
4	Canada	0.90	49	Uruguay	0.69	94	Kyrgyz Rep.	0.55	139	Eritrea	0.37
5	Germany	0.88	50	Argentina	0.68	95	Botswana	0.55	140	Tanzania	0.37
6	Ireland	0.88	51	Oman	0.68	96	Cambodia	0.55	141	Uganda	0.36
7	Japan	0.88	52	Kuwait	0.68	97	Egypt, Arab Rep.	0.55	142	Rwanda	0.35
8	Australia	0.85	53	North Macedonia	0.68	98	Honduras	0.54	143	Niger	0.35
9	Finland	0.85	54	Serbia	0.68	99	Guatemala	0.54	144	Malawi	0.34
10	Netherlands	0.85	55	Trinidad and Tob.	0.67	100	Gabon	0.53	145	Guinea-Bissau	0.33
11	Austria	0.82	56	Belarus	0.67	101	Libya	0.53	146	Congo, D.R.	0.31
12	Sweden	0.82	57	Vietnam	0.66	102	Nicaragua	0.52	147	Burundi	0.30
13	UK	0.82	58	Panama	0.65	103	Iraq	0.51	148	Central African	0.28
14	Switzerland	0.82	59	Thailand	0.65	104	Ghana	0.51	149	Chad	0.25
15	Norway	0.82	60	Turkey	0.65	105	Lao PDR	0.51			
16	Korea, Rep.	0.81	61	Armenia	0.64	106	Nepal	0.50			
17	Belgium	0.81	62	Mexico	0.64	107	Tajikistan Papua New	0.48			
18	Denmark	0.81	63	Romania	0.64	108	Guinea	0.48			
19	New Zealand	0.80	64	Lebanon	0.64	109	Myanmar	0.48			
20	China	0.80	65	Bosnia	0.64	110	Congo, Rep.	0.48			
21	UAE	0.80	66	Jordan	0.63	111	Eswatini	0.48			
22	France	0.80	67	Albania	0.63	112	Bangladesh	0.47			
23	Estonia	0.80	68	Jamaica	0.63	113	Senegal	0.47			
24	Spain	0.79	69	Tunisia	0.63	114	Lesotho	0.46			
25	Slovenia	0.78	70	India	0.63	115	Sierra Leone	0.45			
26	Portugal	0.78	71	Ukraine	0.62	116	Kenya	0.45			
27	Czech Rep.	0.77	72	Kazakhstan	0.61	117	Pakistan	0.45			
28	Italy	0.77	73	South Africa	0.61	118	Mauritania	0.45			
29	Cyprus	0.76	74	Moldova	0.61	119	Cote d'Ivoire	0.44			
30	Lithuania	0.75	75	Colombia	0.60	120	Yemen, Rep.	0.43			
31	Israel	0.75	76	Iran	0.60	121	Equatorial Guinea	0.43			
32	Slovak Rep.	0.75	77	Peru	0.60	122	Benin	0.43			
33	Qatar	0.74	78	Morocco	0.60	123	Mozambique	0.43			
34	Greece	0.74	79	Mongolia	0.60	124	Liberia	0.42			
35	Poland	0.73	80	Dominican Rep.	0.60	125	Sudan	0.42			
36	Latvia	0.73	81	Azerbaijan	0.59	126	Afghanistan	0.42			
37	Hungary	0.72	82	El Salvador	0.59	127	Togo	0.42			
38	Russia	0.71	83	Ecuador	0.59	128	Gambia, The	0.40			
39	Bahrain	0.71	84	Venezuela, RB	0.58	129	Zambia	0.40			
40	Georgia	0.71	85	Indonesia	0.58	130	Burkina Faso	0.40			
41	Chile	0.71	86	Sri Lanka	0.57	131	Guinea	0.40			
42	Bulgaria	0.70	87	Algeria	0.57	132	Haiti	0.39			
43	Brazil	0.70	88	Turkmenistan	0.57	133	Zimbabwe	0.38			
44	Croatia	0.70	89	Paraguay	0.57	134	Angola	0.38			
45	Mauritius	0.70	90	Philippines	0.56	135	Mali	0.38			

Note: R = the country's ranking based on its RETPI score in 2018.
Source: Author's construction.

Figure 4. RETPI world heat map for 2018.



Source: Author's construction.

6 Conclusions

Over the last three decades, the global energy system has transformed significantly toward more sustainable alternatives. In most countries, RE is playing a major role in this transformation. Understanding the RE transition's central dynamics is therefore critical for designing effective policies. Thus, to contribute to these efforts, we constructed the RETPI. We carefully examined the relevant studies and the available indices in the literature to identify 45 key factors in RE transitions. We then grouped these factors into seven categories: economic factors, financial development, human capital, energy access, energy security, environmental sustainability and institutional infrastructure. Using PCA, we developed seven subindices for each of these categories and aggregated them into the RETPI. This composite index can be used to assess countries' RE transition potentials given their historical performances on critical enabling factors. The RETPI is available for 149 countries, from 1990 until 2018.

The RETPI is a useful benchmarking tool for policymakers and researchers. It explains the dynamics of RE transitions using three decades of historical data and, thus, indicates a country's transition potential relative to its peers. A higher RETPI is strongly and positively correlated with higher RE usage, a widely used proxy for the RE transition. Through its subindices, the RETPI also identifies the factors that must be improved to ensure a healthy RE transition experience. For instance, the RETPI scores for 2018 show which countries have strong RE transition potentials. They include the U.S. and Canada in North America; Germany, Ireland, Austria and the Nordic countries in Europe; Hong Kong, Singapore, Japan and South Korea in Asia; and Australia. In contrast, most African countries have low RE transition potentials. Among the subindices, economic factors, financial development, human capital and energy access contribute the most to the RETPI's acceleration. These factors appear to be lacking in most lagging countries.

This study reviewed a large amount of data and literature on the key determinants of the RE transition. Thus, it contributes to the development of further policy and academic studies. In particular, the RETPI and its subindices can be used to analyze individual countries' RE transition potential and performances and predict countries' future RE trends. However, the RETPI is merely an initial step in understanding the dynamics of the RE transition. Despite its comprehensive nature, it will require constant improvements and updates with different statistical methodologies and the additions of new variables or factors. For example, countries' transformation and diffusion of renewable technologies, climate policies and the availability of sustainable finance instruments may be incorporated in the RETPI. These improvements will contribute to efforts to establish more accurate benchmarking tools for assessing countries' RE transition potentials. Such efforts will be part of our future research.

Endnotes

[1] For instance, a recent transition concept, the circular carbon economy, was endorsed by the leaders of the G20, a group of leading rich and developing nations. This concept embodies all transition actions in the categories of reducing, removing, reusing and recycling, along with cross-cutting areas. As part of the reduce pillar, RE usage plays a major role in practice. Further details on the leaders' declaration can be found at https://www.mofa.go.jp/files/100117981.pdf.

[2] These figures are based on the author's calculations using data from Enerdata covering solar, wind and geothermal energy, the main sources of RE.

[3] For instance, following pre-assigned weights based on expert opinion, the WECTI weights environmental and energy-related factors more highly even though it is unclear whether these factors are stronger determinants of energy transitions. The WEFETI places equal weights on all factors, even though economic barriers may be more important than other determinants in some countries. Greco et al. (2019) discuss the strengths and weakness of these approaches more extensively.

[4] For a longer list of relevant studies, see Bourcet (2020) and Sener, Sharp, and Anctil (2018).

[5] Different estimates are available from various international institutions, but they agree that the investment needs are unprecedented. For instance, IRENA (2019) predicts total investment needs of around 110 trillion United States (U.S.) dollars to meet the stated goals by 2050. The OECD, the United Nations and the World Bank Group (2018) predict that annual investments of 6.9 trillion U.S. dollars are needed until 2030. The IFC (2019) points out that emerging markets will require climate-smart investments of around 23 trillion U.S. dollars through 2030. The New Climate Economy (2016) estimates that 90 trillion U.S. dollars in investments are necessary before 2030.

[6] For instance, the World Bank's Human Capital Index is constructed based on countries' education quality, health and population demography (e.g., Kraay [2018]).

[7] In a recent study, David and Venkatachalam (2018) discuss the key themes for successfully implementing private-public partnership projects in practice. They highlight the importance of the institutional quality in hosting countries.

[8] More specifically, the World Economic Forum's (2017) Energy Architecture Performance Index focuses on energy sustainability. The Index of Energy Security Risk (Global Energy Institute 2020) spotlights energy security risks. Finally, the Yale Center for Environmental Law and Policy's Environmental Performance Index's focus is environmental sustainability (Wendling et al. [2020]).

[9] Geiger and Frieler (2017) develop an elegant methodology to predict the GDP of 195 countries from 1850 through 2018. They kindly provide these data for researchers on the PIK's web page: https://dataservices.gfz-potsdam.de/pik/showshort.php?id=escidoc%3A2313888.

[10] Population data are mostly available for all the countries in our sample. We use the average population growth over the previous three years to impute the very few missing observations.

[11] We use the 20 regional groups from the International Labor Organization's regional specification. They are the Arab states, the Caribbean, Central Africa, Central America, Central Asia, Eastern Africa, Eastern Asia, Eastern Europe, Northern Africa, North America, Northern Europe, the Pacific Islands, South America, South-Eastern Asia, Southern Africa, Southern Asia, Southern Europe, Western Africa, Western Asia and Western Europe.

[12] In rare cases wherein a country is fully missing a variable, we use the predicted values directly in the imputation.

[13] We winsorize the yearly data for each of the four income groups.

[14] Jolliffe (2002) provides a more thorough discussion of PCA.

[15] Henceforth, the standardization z(x) is applied to all of the variables in the index construction.

[16] More specifically, the linear transformation function applied is $Y = \frac{X_i - \min(X)}{\max(X) - \min(X)}$.

[17] The NhRE share of power generation is measured in gigawatt hours of electricity production. Water resources have traditionally been highly exploited for electricity (Lin and Omoju 2017), and they have their own technical characteristics and resource requirements. They therefore have a different set of determinants from those considered in the construction of the RETPI (Burke 2010). Additionally, social and environmental concerns are associated with hydroelectricity production (Pfeiffer and Mulder 2013).

[18] All of the values shown in the figures are relative to the initial year, 1990. Thus, the changes in the values (growth) are relative to their respective values in 1990.

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About the Author

Fatih Yilmaz

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

Before joining KAPSARC, Fatih worked as an economist at the Structural Economic Research Department of the Central Bank of the Republic of Turkey, where he was involved in the research and design of policies for the real and financial sectors. He has worked as a consultant for the World Bank and spent a year as an assistant professor of economics at the ADA University. He has authored various academic and policy articles and has been involved in organizing conferences and workshops. He holds a Ph.D. degree in economics from the University of Calgary.

About the Project

Energy transitions toward more sustainable systems are top of the policy agenda in many countries. Despite internationally coordinated efforts (e.g., the Paris Agreement), data shows that countries follow different transitions paths, with some developed economies following a relatively fast transition and many developing nations lagging. Finance has emerged as a key driver of the process, among several 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 associated risks. They 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, it will provide direct input into shaping Saudi Arabia's great ambitions for a more vibrant and diversified economy, as expressed in Saudi Vision 2030.

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