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What motivates developing countries to diversify sources of renewable energy?

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Abstract

This paper investigates the determinants of diversification of nonhydro renewable energy sources using a substantially larger data set covering 117 developing countries over the period 1980 – 2011. We use a novel variable capturing diversification of nonhydro renewable energy sources (geothermal, solar, wind, waste and biomass) and explore several estimation techniques such as two-part model, negative binomial and Poisson pseudo-maximum likelihood. Results show that higher per capita income, implementation of policies promoting renewable energy, advances in technological innovation and improvement in human capital promotes diversification. Although the results are consistent with the literature, this study differentiates itself by including the nonlinear effect of income. Results show that nonlinear effect of income is evident across specifications suggesting non-monotonic changes in diversification as developing countries get more affluent. In addition, concerns related to energy security such as high dependence on foreign sources of fuel and increasing world market price for crude oil will push developing countries to diversify sources of nonhydro renewable energy. In contrast, local abundance of hydropower and availability of natural resource like oil impede diversification. Finally, we find robust evidence that Kyoto Protocol positively influence diversification of nonhydro renewable energy sources in developing countries but no conclusive results can be claimed for financial sector development. This suggests that progressive integration of diversified renewables in developing countries' energy mix can be hastened given relevant policy mix and favorable economic conditions.

JEL classification: O13, Q42, Q48

Keywords: diversification index, nonhydro renewable energy, Kyoto Protocol, technology diffusion

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1. Introduction

The reliance on fossil fuels to support economic activities for the past century has gravely threatened the Earth's climate system. According to the Intergovernmental Panel for Climate Change (IPCC) (2014) human influence on the recent climate change phenomenon is clear and this is largely attributed to the alarming and rising concentration of anthropogenic green house gas emissions in the atmosphere. Despite a growing number of climate change mitigation policies, annual carbon emissions have continued to increase at unprecedented levels and recent report shows that green house gas emissions particularly carbon emissions are highest in history (IPCC, 2014). The severity of threat associated with climate change on humans and the environment cannot be ignored. Scientist and policy makers around the world are making concerted efforts in averting catastrophic consequences from human induced climate change.

The issue of climate change has created an enormous challenge for developing countries to grow and prosper without further jeopardizing efforts in stabilizing the climate system (Seriño, 2017). It cannot be denied that increase energy access has contributed to the improvement of lifestyle of billions of people particularly from developing countries. However, in 2016 approximately more than 1 billion people still do not have access to electricity (Renewable Energy Policy Network for the 21st Century [REN21], 2018). Increasing diffusion of renewal energy in developing countries can contribute to providing access to energy for all, boosting energy security, economic growth and reducing emissions (REN21, 2018). In addition, the adoption of renewable energy in developing countries will not only slow down carbon emissions but will also offer opportunity for them to leapfrog developed countries as a result of harnessing energy from environment friendly sources before a lock in fossil fuel occurs (Popp, 2011; Watson and Sauter, 2011; Pfeiffer and Mulder, 2013).

Though conventional fossil fuels are still being the main source of energy worldwide, renewables are steadily becoming part of the global energy mix. According to World Bank (2018), the share of renewable energy consumption to total final energy consumption steadily increased from 16.91% in 2007 to 18.05% 2015. These renewable energy consumption comes from the traditional biomass and modern renewables such as solar, wind, geothermal, hydropower, wave and biofuels for transport. As of 2016, the share of modern renewables to total final energy consumption is approximately 10.4% (REN21, 2018). The combined share of renewable energy (modern and traditional biomass) to total energy consumption in 2016 is around 18.2% (REN21, 2018). Renewables have grown rapidly in recent years, accompanied by sharp reductions in cost for solar photovoltaics and wind power (International Energy Agency [IEA], 2018).

Renewable energy takes crucial role in transitioning to a less carbon-intensive economy and more sustainable energy system (IEA, 2018). Positive development in renewable energy surprisingly comes from developing countries. It used to be that in early 2000 the biggest share of investment in renewables comes from developed countries but in 2015 and for the first time in history developing countries surpassed developed countries in terms of investment in renewable energy (Frankfurt School, UNEP and BNEF, 2018). According to the 2018 report on Global Trends in Renewable Energy investment jointly published by Frankfurt School of Finance and Management, United Nations Environment Programme and Bloomberg New Energy Finance, developing countries led by China, Brazil and India made up the majority in investment in renewable energy amounting to as much as 63% of the global investment while the share of developed economies is just around 37%. China alone is responsible for over 40%

of global renewable capacity growth in 2017 making it the global leader in renewable energy growth (IEA, 2018). If developing countries will pursue the growth trajectory in renewable energy like China did, then this present an opportunity for sustainable development by growing further without increasing emissions. However, despite the enormous environmental and economic benefits associated with renewable energy, global renewable energy transition in developing countries is still progressing far too slowly and unevenly (REN21, 2018). China, India and Brazil accounted for more than half of the global investment in modern renewables excluding hydro (Frankfurt School, UNEP and BNEF, 2018) while others are lagging behind. To shed some light on this issue, this paper investigates various factors that enhances or impedes diffusion of renewable energy in developing countries.

Further integration of renewable energy into other developing countries requires transfer of these climate friendly technologies (Popp et al., 2011; Pfeiffer and Mulder, 2013). Although there are already commercially available renewable technologies, still they account only a limited share of the total energy generation. This could be because of several market, economic, institutional, technical and socio-cultural barriers that hinder developing countries in moving away from conventional energy sources (Verbruggen et al., 2010; Dulal et al., 2013). Correspondingly, several government policies like feed-in tariffs, tax credits, tradable certificates, investment incentives and production quotas play an important role in promoting the diffusion of renewable energy (IEA, 2014; Zhao et al., 2013). To aid policy decisions in accelerating deployment of renewable energy, we investigate the issue of renewable energy diversification. According to Brunnschweiler (2010) achieving a diversified and sustainable energy supply for the future is one of the major challenges for today's policymakers. Diversification of renewable energy sources has direct implications to energy security. When a county's energy system relies heavily from one source, it becomes vulnerable to energy shocks. Diversification of energy sources is an essential strategy for ensuring energy security.

Our study improves on the recent literature and takes a different approach by investigating what motivates developing countries to diversify sources of nonhydro renewable energy. Our contribution to the literature is threefold. First, we use a novel variable in capturing diversification. The usual practice in the literature is to aggregate the energy produced from different sources (see for example Brunnschweiler, 2010; Pfeiffer and Mulder, 2013; Zhao et al., 2013) or by counting the number of renewable energy sources (Seriño, 2018) to capture diffusion of renewable energy in developing countries. We capture diversification by creating a novel variable or index that will put weight to each source by using the share of energy produced from a particular source to the total renewable energy generated. The index takes a value of zero if a country has not invested in any nonhydro renewable technology and takes a value of 1 if the energy generated is coming only from one particular source. A value of more than one implies diversification. To the best of our knowledge, this is the first paper that uses this approach in measuring diversification. Second, we focus only on modern nonhydro renewable energy and exclude hydropower because hydropower is a mature technology (Pfeiffer and Mulder, 2013; Popp et al., 2011). In the last five years, the growth of renewable energy mostly come from nonhydro sources such as solar, wind, geothermal, biomass and waste (IEA, 2018). Third, we use a substantially larger data set covering more than one hundred developing countries spanning from 1980 to 2011. The empirical approach uses several methods such as negative binomial regression, two-part model and Poisson pseudo-maximum likelihood to account for large number of sample with zero observations and sample selection.

The remainder of the paper is structured as follows. Section 2 presents a brief literature review followed by the importance of energy diversification for energy security in Section 3.

Section 4 shows the empirical approach and the data used. Section 5 provides the results and discussions. Lastly, Section 6 presents the major highlights of the paper and concludes.

2. Literature Review

According to Marques et al. (2010) there are increasing number of papers on renewable energy but less attention has been given to the discussion on the determinants promoting renewable energy. Also, the available empirical work is much more concentrated in developed countries (see for example Menz and Vachon, 2006; Carley, 2009; Sadorsky, 2009; Marques et al., 2010; Ohler and Fetters, 2014; Upton and Snyder, 2017). However, investments in renewable energy from developing countries have been rapidly increasing in the recent years (REN21 2018; IEA 2018). As growth in renewable energy accelerates, integrating this into developing countries' energy system becomes increasingly important (IEA, 2018).

Menz and Vachon (2006) analyzed the effectiveness of different state policies for promoting wind power in the United States. Results show that state level policies are positively related with wind power development. Key limitations of their study include limited sample size and the possibility of omitted variable problem. Carley (2009) controls for these issues by including a time dimension and estimated a model of fixed effects with vector decomposition covering 50 states in the US for 9 years (1998 to 2006). However, results show that the policy instrument (renewable portfolio standard) is not a significant predictor of renewable energy but for each additional year that a state has a renewable energy policy, they are found to increase the total amount of renewable energy generation. For the European case, Marques et al. (2010) used panel data to investigate the factors driving renewable energy adoption among 24 European countries for the period 1990-2006 but they did not include policy variables in their analysis. This has been subsequently addressed by Marques and Fuinhas (2012), where they found evidence that policy measures promote a wider use of renewables. Zhao et al. (2013) employed the methods of panel data analysis in evaluating the effect of renewable electricity polices on renewable electricity generation covering developed, emerging and developing countries. The results suggest that policies play a crucial role in promoting renewable electricity generation but their effectiveness diminishes as the number of policy increases (Zhao et al. 2013). Also, Aguirre and Ibikunle (2014) emphasized that certain government-backed energy policies impede renewable energy investment implying failure in policy design. Despite some failures in policy design, Dulal et al. (2013) argued that the government's role is warranted in the generation of renewable energy, especially in Asia where the increase in population size should be met with dramatic increase in the energy supply.

Still focusing on the policy aspect, Polzin et al. (2015) examined the effectiveness of public policy to induce investments in renewable energy in OECD countries. The effectiveness of policy varies according to the type of renewable energy technologies. The same findings were highlighted by Kilinc-Ata (2016) when she evaluated the renewable energy policies adopted by European countries and US states. Johnstone et al. (2010) examined the effect of environmental polices not directly on renewable energy generation but on technological innovation focusing on renewable energy. They used patent data as a proxy for technological innovation on a panel of 25 countries and found that public policy plays a significant role in determining patent applications and that those different policies have varied effects on renewable energy sources. The work of Popp et al. (2011) is related to the study of Johnstone et al. (2010) in the sense that they also use patents in assessing the impact of technological change on investment in renewable energy capacity. They found evidence that technological advances in 26 OECD countries do lead to a greater investment in renewable energy, however the effect is only small.

It is worth noting that the majority of the literature discussed above focuses on developed countries. Only a handful of studies have been found to employ a more heterogeneous sample of developing countries (Brunnschweiler, 2010; Freitas et al., 2012; Pfeiffer and Mulder, 2013; Seriño, 2018). Though the literature of renewable energy in developing countries is limited, recent studies on this issue has been rapidly increasing. Brunnschweiler (2010) studied the role of financial sector in renewable energy development covering more than 100 developing and emerging economies. Results show that the influence of financial sector has significant positive effect on the amount of renewable energy generation in developing countries. This impact is even larger when only non-hydro renewables are considered such as wind, solar, geothermal and biomass (Brunnschweiler, 2010). Focusing only on major developing countries, Freitas et al. (2012) examined the diffusion renewable energy as influenced by Kyoto Protocol. Results suggest that the mechanisms of Kyoto Protocol may only be supporting the spread of existing technologies rather than the development of and diffusion of more sustainable variants of renewable energy technologies in the BRICS, i.e. Brazil, Russia, India, China and South Africa. However, the paper of Pfeiffer and Mulder (2013) contradicts the results of Brunnschweiler (2010) and Freitas et al. (2012). Although Pfeiffer and Mulder (2013) found a positive yet weak influence of the Kyoto Protocol on nonhydro renewable energy diffusion, no solid evidence was presented for the influence of financial sector development on the diffusion of renewable energy in developing countries. Recently, Seriño (2018) also claimed that financial development showed no robust evidence on its influence on nonhydro renewable energy adoption in developing countries but the influence of Kyoto Protocol was not incorporated in their analysis. This current paper improves on the recent literature and incorporate the influence of Kyoto Protocol on the diversification of nonhydro sources of renewable energy in developing countries.

3. Diversification of renewable energy for energy security

In business, it is important to have a diversified portfolio to help manage risks and volatility of investments. The saying “do not put all your eggs in one basket” is a common expression encouraging diversification. When a country’s energy supply relies heavily on one particular energy source it becomes extremely vulnerable to exogenous supply shock (van Hove, 1993). The energy crisis in 1970s had tremendous economic, political and social consequences not just in developed countries but also in developing countries. Since then, policy makers have paid increasing attention to energy security.

Li (2005) argued that diversification and localization of energy sources is essential for future energy system because it promotes sustainable development as well as energy security. Li (2005) stressed that the idea of diversified energy is good not just for the people but also for the environment. He cited several analogies in other fields pointing out the advantage of diversification. For example, bio-diversity is a good strategy to prevent the spread of pests and diseases, diversified portfolio will guarantee a better investment return and in governance, the success of democracy has diversification of ideas at its core. Similarly, for renewable energy diversifying its sources is viewed as an attractive option as it can helped stabilize energy supply.

The main disadvantage of renewable energy aside from its large capital cost is the reliability of energy supply. Most renewable energy relies on weather as its main source. For example, hydro power need rain to fill dams and keep the supply of water flowing, wind turbines need wind to turn blades, solar panels need clear skies and sunshine to generate electricity. These natural sources are somehow variable, unpredictable and inconsistent and when these sources are unavailable, the supply of energy will be affected. However, diversification of these renewable energy sources will help allow for a steady and reliable source of energy supply. For example, dry and sunny weather may not be good for generating hydropower but will be great for generating electricity from solar panels; stormy weather may reduce generation of solar energy but will be good for hydropower, wind energy and tidal energy. Therefore, diversifying sources of renewable energy is essential to achieve energy security through consistent and localized supply of energy (Li, 2005).

4. Data and Methodology

4.1. Data sources and diversity index

The dataset used in this study covers 117 developing countries for 32 years spanning from 1980 to 2011. This dataset is compiled using four different sources: International Energy Agency (IEA, 2014), World Bank's World Development Indicators (WDI) (World Bank, 2014), Energy Information Administration (EIA, 2014), and BP Statistical Review of World Energy (BP, 2014). Table 1 provides the data description and the source database for each variable. Table 2 presents the descriptive statistics of the variables used in the analysis.

Our analysis focuses on the diversification of nonhydro sources of renewable energy in developing countries. These nonhydro sources include wind, solar, biomass, waste and geothermal. Large hydropower is excluded in the current analysis because it is already a mature technology (Popp et al., 2011; Pfeiffer and Mulder, 2013). Our main source of data for the generation of renewable energy comes from IEA. Data from IEA on nonhydro power generation can be considered comprehensive, however, it may have underestimated the electricity generated as off-grid generation may not be included in the data set (Pfeiffer and Mulder, 2013).

Table1. Data descriptions of the variables used and their sources

Variable	Definition	Source
Dependent variables		
Diversity index	Takes a value of 1 if a country adopts only 1 renewable source and a higher value if more diversified. The index is weighted on the share of each renewable energy source. If a country did not invest in renewable energy, the value is zero	own computation
Independent variables		
GDP per capita	GDP per capita in constant 2005 USD (in logarithmic form)	World Development Indicator (WDI)
Energy import	Net energy imports in % of energy use	WDI
Population growth	Annual population growth in %	WDI
Patents	Total patent application taken in log form	WDI

Financial development	Domestic credit to private sector in % of GDP	WDI
Secondary enrollment	Secondary school enrollment % gross	WDI
FDI	Foreign direct investment, net inflows in % of GDP	WDI
ODA	Net official development assistance received in % of GNI	WDI
Crude oil price	Crude oil prices (West Texas intermediate)	BP
Kyoto protocol	Dummy variable taking value 1 from 1998 onwards and zero otherwise	International Energy Agency (IEA)
Renewable policy	Dummy variable taking value 1 from the year of implementation of a renewable energy policy	IEA
Hydro energy	Total hydroelectric power generated (in thousand kilowatt-hours) per capita	IEA
Oil production	Total oil production in thousands barrel / 1 million people	Energy Information Administration (EIA)
Coal production	Total coal production in thousand tons / 1 million people	EIA
Coastal	Dummy variable taking value 1 if a country has coast	Google map (Google, 2014)

Table2. Descriptive statistics for developing countries from 1980 to 2010

Variable	n	Mean	Std. Dev.	Min	Max
Dependent variables					
Diversity index	3946	0.37	0.31	0	2.89
Independent variables					
GDP per capita (in log)	4090	7.17	1.07	3.91	9.60
Energy import	2688	-41.92	195.54	-1982.88	99.96
Population growth	4727	1.81	1.35	-10.96	11.18
Patents	1473	6.25	1.93	0.69	13.17
Financial development	3708	3.01	0.87	-0.58	5.12
Secondary enrolment	2944	54.79	30.03	2.48	122.20
FDI	3849	3.69	11.79	-82.93	366.36
ODA	3654	9.29	12.95	-2.70	242.29
Kyoto protocol	4752	0.45	0.50	0	1
Renewable policy	4752	0.10	0.30	0	1
Hydro energy	4070	0.37	0.89	0	10.08
Oil production	3929	4281.3	14337.73	0	216634.1
Coal production	4144	289337.7	1012096	0	1.25e+07
Crude oil price	4752	37.66	25.00	14.39	100.06
Coastal	4752	0.78	0.42	0	1

Source: Author's calculations based on the data described in Table 1

One of the innovations of this study is to come up with an indicator of diversification. To do this, we use the share of renewable energy generated from each source to the total energy generated from all nonhydro sources. The diversity index takes a value of zero if a country has not invested in any nonhydro renewable technology and takes a positive value if a country has invested in any of the nonhydro renewable technologies. Technically, the diversity index takes a value of 1 if the energy generated is coming only from one particular source and if the country is more diversified then the index is greater than 1. If each source carries the same share of energy generated, the index converges to the total number of nonhydro sources adopted by developing countries. We propose, to estimate the diversity index as follows:

$$dre = \begin{cases} \dfrac{1}{\sum_{i=1}^{n}\left(\frac{nhre_{jt}}{NHRE}\right)^2} & if\ NHRE > 0 \\ 0 & if\ NHRE = 0 \end{cases} \tag{1}$$

where *dre* captures the diversity of a developing country's nonhydro renewable energy mix, *NHRE* is the net generation of nonhydro-electricity measured in billion kilowatt-hours and the $nhre_{jt}$ is the individual net energy generation from either of the nonhydro renewable energy sources (wind, solar, geothermal, biomass and waste) in country *j* in year *t*.

Pfeiffer and Mulder (2013) measures the variety of renewable energy technologies by calculating the energy mix and uses this variable as a measure of diversification. Our proposed calculation differs from Pfeiffer and Mulder (2013) because their index of diversification takes a value of zero if a country produces its energy from only one source and converges to one when a country is more diversified. We could have opted for this measure but this approach cannot accommodate zero observations or those developing countries that at a particular point in time that did not invest in nonhydro renewable energy. Figure 1 below shows that our data set has a substantial number of zero observations. Using Pfeiffer and Mulder's (2013) index will lead to a lot of missing observation because it will not compute for zero observation. However, our proposed index handles this problem. For example, assuming there are three countries named A, B and C. Country A and B produces energy from wind and solar while Country C has not invested in any renewable energy. The index requires the amount of energy generated from each source for us to do the calculation. For example, both country A and B produces 10 gigawatts (GW) total renewable energy. Country A produces 5 GW from solar and 5 GW from wind energy while country B produces 7 GW from solar and only 3 GW from wind. Applying our proposed formula for diversification, country A's diversity is 2, Country B is 1.72 and Country C is zero. This implies that if there is equitable generation of energy from various renewable sources, the diversity index converges to the number of renewable energy sources.

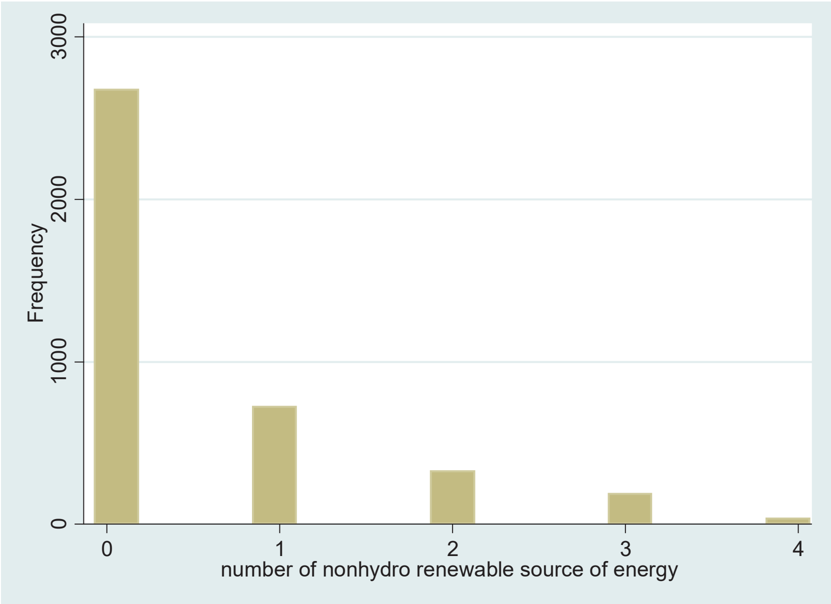

Figure 1. Number of nonhydro sources of renewable energy adopted by developing countries.

4.2. Determinants of diversification

The main dependent variable captures diversity in nonhydro renewable technology. Notably, our dependent variables contain a lot of number of zero observations or those countries that did not invest in nonhydro renewable energy (Figure 1). Following Seriño (2018), we specify our estimation regression in investigating the determinants that facilitates or impedes diversification of nonhydro renewable energy as follows:

$$dre_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 GDPsq_{it} + \beta_3 policy_{it} + \beta_4 kyoto_{it} + \delta \mathbf{Z}_{it} + u_i + v_t + \varepsilon_{it} \quad (2)$$

where dre_{it} is the index of diversification for country i at year t, GDP_{it} is the gross domestic product capturing income, $GDPsq_{it}$ is the squared of GDP to incorporate nonlinear effect of income , $policy_{it}$ is a dummy variable capturing the implementation of renewable energy-related policies, $kyoto_{it}$ is also a dummy variable capturing the potential impact of Kyoto Protocol on the diffusion of renewable energy in developing countries, and Z_{it} is the set of remaining independent variables, u_i is the country fixed effects used to capture time-invariant country heterogeneity, v_t is time fixed effects and ε_{it} is the remaining error. The covariates included in the analysis are further discussed as follows:

(1) Income as measured by GDP is positively correlated with adoption of renewable energy as suggested by various authors (see for example Aguirre and Ibikunle, 2014; Marques et al., 2010; Popp et al., 2011; Zhao et al., 2013, Seriño, 2018). We expect that countries with higher affluence have the ability to diversify renewable energy sources. This study differentiates itself from most literature by including the squared term of GDP to incorporate the nonlinear effect effect of income on renewable energy.

(2) Evidence on the influence of policy in stimulating adoption of renewable energy is abundant in the literature (see for example Menz and Vachon, 2006; Carley, 2009; Johnstone et al., 2010; Marques and Fuinhas, 2012; Zhao et al., 2013; Aguirre and Ibikunle, 2014; Polzin et al., 2015; Kilinc-Ata, 2016) Based on IEA's database, there several policy types related to renewable energy. This includes economic instruments,

information and education, policy support, regulatory instruments, research and development and voluntary approaches (IEA, 2014) . We used a dummy variable if any of those policies are implemented by developing countries.

(3) One of the first key steps in attempting to control global carbon emission was the adoption of Kyoto protocol in the late 1997. We control the impact of Kyoto protocol by introducing a time dummy from 1998 onward. This marks a greater environmental awareness which is not just confined to developed countries (Brunnschweiler, 2010; Johnstone et al., 2010; Popp et al., 2011; Aguirre and Ibikunle, 2014). Freitas et al. (2012) examined whether the Kyoto mechanisms have stimulated the diffusion of renewable energy technologies in the BRICS, i.e. Brazil, Russian, India China and South Africa.

(4) Energy imports capture how dependent countries are on external sources of energy. Bigger energy imports may stimulate investment on renewable energy as a measure for energy security (Aguirre and Ibikunle, 2014; Dong, 2012; Marques et al., 2010; Popp et al., 2011; Zhao et al., 2013).

(5) Population growth is an important indicator for energy demand. Most studies available in the literature did not include population growth in their analysis. The average population growth in developing countries is close to 2 (Table 2). Such high growth will put pressure on energy demand in the future.

(6) Popp et al. (2011) showed that diffusion of renewable technologies in developing countries can be facilitated by the degree of technological advancement. The number of patents is used as proxy for technological advancement (Johnstone et al., 2010).

(7) The role of financial development in stimulating renewable energy growth is a bit ambiguous in the literature. Brunnschweiler (2010) found out that financial sector development has significant positive effect on the amount renewable energy produced but Pfeiffer and Mulder (2013) showed no evidence from financial sector development on the diffusion of nonhydro renewable energy in developing countries. This paper will provide evidence on this aspect and may help clear the ambiguity of financial development.

(8) Human capital as proxied by secondary enrollment has important implications in the adoption of renewable energy (Pfeiffer and Mulder, 2013; Zhao et al., 2013).

(9) FDI and ODA are two external sources of funding which may potentially influence diversification of renewable energy in developing countries (Brunnschweiler, 2010; Pfeiffer and Mulder, 2013; Zhao et al., 2013).

(10) Another control variable is the amount of electricity generated from hydropower. Countries having large hydro power may not be as keen in investing in new renewable as opposed those who do not have (Popp et al., 2011; Pfeiffer and Mulder, 2013).

(11) Production of coal and crude oil are included in the analysis to control for conventional sources of energy (Marques et al., 2010). Countries abundant with these energy sources may be reluctant to invest in renewable energy. If renewable energy complements conventional sources, then an increase in coal and oil production is positively associated with renewable energy (Seriño, 2018).

(12) We include the in the analysis crude oil prices to control for global market fluctuations in fuel prices. If developing countries are price sensitive, then investments in renewable energy can augment their energy demands (Aguirre and Ibikunle, 2014).

(13) Natural endowment is captured by including a coastal dummy. This variable takes a value of 1 if a country has coastal area and 0 otherwise. This serves as a proxy of production potential of renewables.

(14) To account for heterogeneity of developing countries, regional dummy variables are included in the analysis.

(15) Lastly, we control for time variations by including year dummies in the regression.

4.3. Empirical approach

For the empirical approach, two-stage estimation technique is used to model the choice whether to adopt or not adopt nonhydro sources of renewable energy. And then conditional on adopting, we examine the factors influencing diversification of nonhydro sources of renewable energy. Take note, we have a large number of zero values in our dependent variable consisting almost 68% of the total observation (Figure 1). However, we assume that these zero observations are true zero or actual outcome. These zero observations reflect countries who have not invested in nonhydro renewable energy sources[1]. To address this issue, the two-stage estimation method using two-part model pioneered by Duan et al. (1983) is used. Two-part model is a methodological strategy designed to deal with large percentage of zero value observations (Pfeiffer and Mulder, 2013). The two-part model decomposes an observed random variable into two observed variables. The methodology consists of estimating in the first stage the observation with zero values and positive outcome and in the second stage we estimate the subset with positive outcome. We explicitly assumed that the decision to adopt a nonhydro renewable source and whether to diversify it or invest in different types of nonhydro resources are independent of each other.

The two-part model (2PM) consist of two equations, the first equation estimates the entire sample and the second equation focuses on the subset of the sample with positive outcomes. The positive outcomes refer to the computed diversity index. We specify the first stage equation as follows:

$$\Pr(dre_{it}^{*} = 1 |\, Z_{it}) = \Pr[dre_{it} > 0 \mid Z_{it}] = \Omega\,(\beta Z_{it} + \varepsilon_{it}) \qquad (3)$$

where dre^{*}_{it} takes a value of 1 if the index of diversification is greater than zero and zero otherwise. Z_{it} is the vector of control variables, β is the associated coefficient, Ω the standard normal distribution and ε_{it} is the remaining error term. In the second equation, we use the diversity index defined in equation 1 as the dependent variable. Diversifying sources of nonhydro renewable resources on the condition that a country invests on nonhydro renewable energy is defined as:

$$dre_{it} = \beta Z_{it} + \omega_{it} \qquad (4)$$

where dre_{it} captures how diversified is a particular country i at a given time t, Z_{it} captures our independent variables and ω_{it} is the remaining error. We estimate equations 3 and 4 using method of logit and ordinary least squares, respectively.

For robustness check, we use the method of negative binomial to model count observation. The negative binomial probability distribution is presented as follows:

[1] See for example Pfeiffer and Mulder (2013) and for further discussion on model selection with true zero and potential zero observation, please refer to Dow and Norton (2003).

$$\Pr(Y_i = j) = \frac{\Gamma\left(j+\frac{1}{\alpha}\right)}{\Gamma(j+1)\Gamma\left(\frac{1}{\alpha}\right)} (\alpha\lambda_i)^j [1 + \alpha\lambda_i]^{-(j+\frac{1}{\alpha})} \quad (5)$$

where $\alpha > 0$ is a nuisance parameter to be estimated along with β, Γ is the gamma function, i.e. a discrete probability density function for j. The negative binomial can be derived from a Poisson distribution in which the λ is distributed as a gamma random variable. The first two moments of the negative binomial distribution are given by

$$E(Y_i|X_i) = \lambda_i = \exp(X_i\beta) \quad (6)$$

and

$$Var(Y_i|X_i) = \lambda_i(1 + \alpha\lambda_i) \quad (7)$$

wherein the conditional variance exceeds the conditional mean of the distribution. The negative binomial model is employed as a functional form to deal with overdispersion problem (Greene, 2008).

In addition, we also explored the methods of Poisson pseudo-maximum likelihood (PPML) estimation technique as additional robustness check. PPML is suitable for modelling large proportion of zero observations. Santos Silva and Tenreyro (2010) did a pioneering work on Poisson pseudo-maximum likelihood (PPML) estimation technique. Using the usual OLS estimation will yield large bias given that the dependent variable has a large number of zero observations while PPML gives consistent estimates in the presence of large zero observations. This was based on the simulation conducted by Santos Silva and Tenreyro (2010). In addition, PPML also effectively handles heteroskedasticity by using robust covariance matrix.

5. Results and Discussions

5.1. Baseline results using two-part model estimation

The derived diversity index is used as the dependent variable in our baseline specification. By using this index, we use the share of electricity generated from each source to the total nonhydro electricity as weights for each nonhydro source. Table 3 presents the baseline results from different specifications while controlling for time and regional fixed effects. Results show the marginal effects from the two part model estimation[2].

While the effect of income on renewable energy has been well documented in the literature, none of the studies explored the nonlinear effect of income (Vachon and Menz, 2006; Marques et al., 2010; Pfeiffer and Mulder, 2013; Zhao et al., 2013; Aguirre and Ibikunle, 2014). Results shows that while income plays a positive significant role in explaining the diversification, the nonlinearity of its effect is strongly evident. Higher income makes developing countries more capable of diversifying nonhydro sources but the effect is non-monotonous. Our results showed evidence of U-shaped kind of relationship between income and diversification. This implies that as developing countries grow, diversification of renewable energy sources tends to decline, but as their economies become more affluent diversification increases. Results suggest that as countries develop demand for renewable energy is substituted

[2] Details of the two-part model estimation with the logit and OLS results can be found in Appendix A.

by conventional energy sources to fuel a growing economy but as their economies mature it will address environmental concerns through the use of cleaner sources of energy.

The nonlinear effect of income on diversification of renewable energy presents additional evidence on the relevance of environmental Kuznets curve (EKC). The EKC hypothesis that for a given society environmental problems will worsen until reaching its peak and then further increase in income will translate to a reduction in environmental problems as society takes initiatives in cleaning the environment (Stern 2004; Seriño and Klasen 2015; Irfany and Klasen, 2017). Table 3 shows that in model 3 and 4 the log of GDP per capita is negative but the squared term is positive. This associated sign reflects the environmental Kuznets curve suggesting that at initial stage of development countries choose to fuel economic activities with unclean energy but as the countries accumulate more wealth then they take care of the environment by using clean sources of energy.

The other determinants such as population growth, energy imports and oil price are positively correlated with diversification (Table 3). A growing population means rising energy demand. Countries that are more dependent on foreign energy sources are more likely to diversify nonhydro renewable energy. Similarly, higher world price for crude oil price facilitates diversification of nonhydro renewable energy sources. Developing countries are sensitive to price increases in fuel because this can influence higher inflation and hamper economic growth. Renewable energy presents an attractive option in dealing with energy security, hence, diversifying sources of renewable energy is a feasible action for dealing with fluctuations in oil prices. While Marques et al. (2010) and Aguirre and Ibikunle (2014) suggest that energy prices are not relevant factors in explaining the diffusion of renewable energy, we argued the opposite. Our results are consistent with Chang et al. (2009) and Seriño (2018) that increases in fossil fuel prices are associated with increases in renewable energy use.

The associated relationship of policy variable, number of patents for technological advancements and improved human capital through secondary enrollment are as expected (Table 3). Implementing policies that facilitates diffusion of renewable energy is positively correlated with diversification. However, Zhao et al. (2013) warn about policy crowdedness, wherein the effectiveness of policies diminish as more renewable energy policies are put in place. Technological improvements can facilitate diversification. This quite plausible because modern nonhydro renewable energy are technology dependent. This implies that adopting a variety of renewable energy requires a certain grasp of the related technology. This result is complemented by the evidence showing that accumulation of human capital as measured by secondary enrollment positively contributes to the diversification. Our results largely confirmed previous findings on the influence of policy (Johnstone et al., 2010; Zhao et al., 2013), technology (Popp et al., 2011), and human capital (Pfeiffer and Mulder, 2013) on renewable energy. However, the effect of financial development to diversification is not solid. Given that renewable energy requires a high level of financing, we would have expected robust results. Painuly and Wohlgemuth (2006) noted that absence of well-developed financial intermediaries and the consequent financing difficulties impede the development of renewable energy in developing countries. The paper of Pfeiffer and Mulder (2013) claimed that financial development has no influence on renewable energy diffusion in developing countries but Brunnschweiler (2010) and Freitas et al. (2012) argued the opposite. Further studies showed by done to clarify this issue.

Developing countries that are already generating renewable energy from hydropower do not show evidence of diversification. This suggest that developing countries are reluctant to invest in nonhydro sources if they have hydropower. This reflects the claim that countries with relatively low carbon intensity in their energy system are likely to diminish incentives in investing in other renewables (Popp et al., 2011; Pfeiffer and Mulder, 2013). Similarly, abundance of natural resources such as oil decreases the attractiveness in investing in other sources of energy. According to Popp et al. (2011) local oil production reduces concern of energy security, increases the relative price of other renewable energy and undermines support for reducing emissions making investment in renewable energy unattractive. However, the effect of coal production is inconclusive.

Table3. Average marginal effects from two-part model estimation (ATPM) with diversity index as dependent variable

Variables	(1) ATPM	(2) ATPM	(3) ATPM	(4) ATPM
Log GDP per capita	0.059**	0.103***	-1.745***	-1.856***
	(0.0290)	(0.0327)	(0.3751)	(0.6467)
Log GDP per capita_sq			0.123***	0.126***
			(0.0249)	(0.0425)
Energy import	0.003***	0.000	0.000	0.001***
	(0.0002)	(0.0003)	(0.0003)	(0.0003)
Population growth	0.114***	0.124***	0.116***	0.175**
	(0.0257)	(0.0246)	(0.0243)	(0.0376)
Oil price	0.009***	0.012***	0.012***	0.009***
	(0.0022)	(0.0027)	(0.0028)	(0.0032)
Policy on renewables	0.185***	0.080*	0.049	0.072
	(0.0440)	(0.0474)	(0.0480)	(0.0453)
No. of patents	0.084***	0.105***	0.114***	0.132
	(0.0098)	(0.0110)	(0.0112)	(0.0142)
Financial development	0.004	0.017	0.001	-0.095***
	(0.0251)	(0.0272)	(0.0262)	(0.0329)
Hydro energy		-0.104***	-0.113***	-0.295***
		(0.02184)	(0.0234)	(0.0409)
Oil production		-0.021***	-0.025***	-0.031***
		(0.0035)	(0.0036)	(0.0039)
Coal production		-0.021	-0.006	0.078***
		(0.0147)	(0.0148)	(0.0158)
Secondary enrolment				0.007***
				(0.002)
FDI				-0.015***
				(0.0056)
ODA				-0.012
				(0.0072)
Coastal dummy	0.245***	0.150***	0.117**	0.194**
	(0.0494)	(0.0534)	(0.0532)	(0.0862)
Regional dummies	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes
Observations	1,216	1,091	1,091	732

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

For external sources of funding such as foreign direct investment (FDI) and the official development assistance (ODA), the associated correlation with diversification is negative. While these two external sources of funding are important for technology transfers, neither of them facilitates the diversification of nonhydro renewable energy sources. The same findings were reported by Pfeiffer and Mulder (2013). This result adds to the huge literature on casting doubt about the effectiveness of aid in developing countries. Seriño (2018) presented some possible explanation citing that ODA variable is aggregated value and does not capture the energy specific projects. Similarly, FDI does not promote diversification of nonhydro renewable energy sources in developing countries because most FDI projects are related to conventional sources of fuel.

To control for regional fixed effects, the developing countries were divided into six regions following World Bank's regional aggregation, namely: (1) Latin America and the Caribbean, (2) Europe and Central Asia, (3) Middle East and North Africa, (4) Sub-Sahara Africa, (5) South Asia and (6) East Asia and Pacific. Aside from regional fixed effects, we also control for geographic locations of countries taking a value of 1 if a country has a coastline. This controls the geographic advantage of some countries in harnessing renewable energy and also captures the ease of access to trade. Results show that countries with coastal areas are more likely to diversify sources of renewable energy as compared to landlocked countries. We also incorporate in our specifications, year dummies to control for variations in renewable energy associated with time[3].

5.2. Does Kyoto Protocol facilitate diversification of renewable energy in developing countries?

The adoption of Kyoto Protocol in late 1997 marks a significant shift in global climate policy. We incorporate the potential impact of Kyoto Protocol on nonhydro renewable energy diversification by including a time dummy from 1998 onwards[4]. Although Kyoto Protocol did not place a heavy burden among developing countries on reducing emission, results in Table 4 consistently show a strong positive and significant effect of Kyoto Protocol on the diversification of nonhydro sources of renewable energy. This suggests that greater environmental awareness has led to a greater diffusion of renewable energy in developing countries. The probability of diversifying sources of renewable energy has been 0.2 points higher since the adoption of Kyoto Protocol in late 1997. These results align well with the previous findings in the literature (Brunnschweiler, 2010; Johnstone et al., 2010; Pfeiffer and Mulder, 2013; Aguirre and Ibikunle, 2014). Brunnschweiler (2010) found that most of the increase in renewable energy did not just come from hydropower but also a 27-fold increase in the electricity generated from nonhydro sources after the adoption of Kyoto Protocol.

Focusing on the coefficients of Kyoto Protocol in Table 4, it is observed that there are differences in the magnitudes of the estimates between two-part model and negative binomial. The difference can be explained by the type of data used in the estimation. For the negative binomial, the dependent variable is a count data capturing the number of nonhydro sources of renewal energy adopted by each country while for the two-part model, we used the computed diversity index. Though the magnitudes differ, the associated relationship is consistent across several specifications. This shows that Kyoto Protocol has a significant and positive influence

[3] Estimates of regional and time dummies are not shown to save space but are available upon request.
[4] We drop our time dummies when we introduce Kyoto Protocol in the specification to avoid collinearity since it also captures time effect.

on the diversification of nonhydro sources of renewable energy in developing countries. As to the other covariates, results are as expected and quite similar with the previous results.

Table 4. Effect of Kyoto Protocol on the diversification of nonhydro sources.

Variable	(5) ATPM	(6) ATPM	(7) ATPM	(8) NegBin	(9) NegBin
Log GDP per capita	0.108***	-1.669***	-1.602**	0.191***	-1.507**
	(0.0333)	(0.380)	(0.6873)	(0.0587)	(0.6781)
log GDP per capita_sq		(0.118***	0.109**		0.109***
		(0.0251)	(0.0454)		(0.0423)
Energy import	0.000	0.000	0.001***	0.002***	0.002***
	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0007)
Population growth	0.096***	0.086***	0.148***	0.039	0.173***
	(0.0240)	(0.0236)	(0.0374)	(0.0365)	(0.0628)
Oil price	0.003***	0.003***	0.001	0.003***	-0.002
	(0.0009)	(0.0009)	(0.0009)	(0.0010)	(0.0012)
Policy on renewables	0.117**	0.089*	0.119***	0.292***	0.313***
	(0.0466)	(0.0474)	(0.0453)	(0.0706)	(0.0735)
No. of patents	0.102***	0.109***	0.133***	0.208***	0.194***
	(0.0110)	(0.0111)	(0.0148)	(0.0192)	(0.0267)
Financial development	0.030	0.016	-0.095***	0.108**	-0.092*
	(0.0254)	(0.0243)	(0.0318)	(0.0476)	(0.0555)
Kyoto Protocol	0.260***	0.262***	0.137***	0.574***	0.326***
	(0.0367)	(0.0368)	(0.0421)	(0.0703)	(0.0838)
Hydro share	-0.087***	-0.096***	-0.280***	-0.377***	-0.983***
	(0.0209)	(0.0222)	(0.0415)	(0.0682)	(0.0973)
Oil production	-0.021***	-0.024***	-0.032***	-0.026***	-0.075***
	(0.0035)	(0.0036)	(0.0039)	(0.0065)	(0.0148)
Coal production	-0.019	-0.003	0.083***	0.018	0.150***
	(0.0151)	(0.0154)	(0.0149)	(0.0338)	(0.0439)
Secondary enrolment			0.008***		0.019***
			(0.0016)		(0.0027)
FDI			-0.013**		-0.031**
			(0.0057)		(0.0133)
ODA			-0.010		-0.084***
			(0.0066)		(0.0291)
Coastal dummy	0.132**	0.101*	0.217**	0.477***	0.419**
	(0.0530)	(0.0522)	(0.0908)	(0.1470)	(0.1777)
Regional dummies	yes	yes	yes	yes	yes
Constant				-4.359***	2.564
				(0.3925)	(2.7602)
Observation	1,091	1,091	732	1,086	727

Note: The dependent variable when using negative binomial regression is the number of nonhydro sources of renewable energy while the dependent variable when using two-part model is the derived diversity index of nonhydro renewable energy or simply the weighted number of nonhydro sources.
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Freitas et al. (2012), on the other hand, is a bit skeptical on the global influence of Kyoto Protocol in influencing diffusion of cleaner variants of renewable energy in developing countries. Their results suggest that mechanisms under Kyoto Protocol are not creating incentives for the use of sustainable variants of renewable energy but are merely encouraging increased capacity of existing technologies (Freitas et al., 2012). However, our results add to the strand of literature supporting evidence that global climate policy such as Kyoto Protocol can encourage developing countries to seek out cleaner sources of energy.

5.3. Extended analysis and robustness check

Instead of conducting two-stage estimation using the diversity index as dependent variable, we check the robustness of our results by pooling all the observation and run an OLS regression using similar specifications. Since many developing countries have yet to invest in renewable energy, our dependent variable, which is the diversity index, has a large proportion of zero observations. To deal with this problem, we follow the suggestion of Zhao et al. (2013) to use the method of Poisson pseudo-maximum likelihood (PPML) estimation technique. Using the usual OLS estimation will yield a large bias given that our dependent variable has more than 60% zero observations (Figure 1). In addition, PPML also effectively handles heteroskedasticity by using a robust covariance matrix[5]. The PPML approach gives consistent estimates regardless how the data is distributed (Santos Silva and Tenreyro, 2011; Zhao et al., 2013). We wanted to control for country fixed effects but as PPML fails to converge with the inclusion of too many country dummies we instead control for regional fixed effects. We also control for time dummies in regressions 10 to 11 and then in regressions 12 to 13 we include Kyoto Protocol.

Table 5 presents the estimation results using Poisson pseudo-maximum likelihood estimation. Results of PPML generally complement our previous findings. Higher income is associated with diversification and the nonlinear effect of income still holds. Higher dependence on external sources of energy as proxied by energy imports contributes positively to diversification of nonhydro sources of renewable energy. Higher crude oil prices and growing population is associated with increasing diversification. Diversification of nonhydro sources of renewable energy is further supported by the adoption of policies related to renewable energy, technological innovation as proxied by number of patents and improvement in human capital. In contrast, oil production and abundance of hydropower is negatively associated with diversification. As with our previous results, FDI and ODA do not support diversification. The effect of Kyoto Protocol is still positive and significant.

One surprising results for Table 5 is the influence of financial development on diversification. There is somehow no consensus in the literature as to the effect of financial development on renewable energy. While Painuly and Wohlgemuth (2006) cautioned that absence of well-developed financial intermediaries and the consequent financing difficulties may impede the development of renewable energy in developing countries, Pfeiffer and Mulder (2013) claimed that financial development has no influence on renewable energy diffusion in developing countries. Our result is also a bit puzzling because the baseline specification presented no conclusive evidence on the influence of financial development but our extended analysis showed significant positive correlation of financial development and diversification of

[5] Details of the PPML estimation could be found in Santos Silva and Tenreyro (2011).

renewable energy. Perhaps further empirical studies can be done evaluating the influence of financial development on renewable energy.

Table 5. Estimation results using the Poisson pseudo-maximum likelihood estimation.

VARIABLES	(10) PPML	(11) PPML	(12) PPML	(13) PPML
Log GDP per capita	0.102**	-2.077***	0.106**	-2.043***
	(0.0451)	(0.4686)	(0.0455)	(0.4833)
log GDP per capita_sq		0.133***		0.131***
		(0.0305)		(0.0313)
Energy import	0.000	0.001*	0.000	0.001*
	(0.0003)	(0.0007)	(0.0003)	(0.0007)
Population growth	0.076*	0.175***	0.050	0.153***
	(0.0413)	(0.0439)	(0.0434)	(0.0504)
Oil price	0.015***	0.013***	0.003***	0.000
	(0.0033)	(0.0036)	(0.0010)	(0.0011)
Policy on renewables	0.097	0.113	0.122*	0.129*
	(0.0652)	(0.0741)	(0.0651)	(0.0749)
No. of patents	0.066***	0.041***	0.063***	0.046***
	(0.0094)	(0.0128)	(0.0093)	(0.0125)
Financial development	0.291***	0.254***	0.287***	0.232***
	(0.0430)	(0.0551)	(0.0424)	(0.0531)
Kyoto Protocol			0.438***	0.444***
			(0.0617)	(0.0780)
Hydro energy	-0.330***	-0.724***	-0.315***	-0.724***
	(0.0684)	(0.0635)	(0.0685)	(0.0647)
Oil production	-0.004	-0.022**	-0.004	-0.022**
	(0.0038)	(0.0106)	(0.0038)	(0.0103)
Coal production	-0.017	0.091**	-0.015	0.084**
	(0.0235)	(0.0427)	(0.0231)	(0.0406)
Secondary enrolment		0.011***		0.013***
		(0.0024)		(0.0024)
FDI		-0.047**		-0.040**
		(0.0207)		(0.0177)
ODA		-0.020*		-0.016
		(0.0105)		(0.0110)
Coastal dummy	0.305***	0.897***	0.299***	0.898***
	(0.0911)	(0.1560)	(0.0923)	(0.1532)
Constant	-4.749***	3.397*	-3.914***	4.027**
	(0.4441)	(1.8648)	(0.3505)	(1.8910)
Regional dummies	yes	yes	yes	yes
Time dummies	yes	yes	no	no
Observation	1,908	1,242	1,908	1,242
R-squared	0.393	0.521	0.386	0.501

Note: Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Summary and Conclusion

In this paper, we investigate what motivates developing countries to diversify modern sources of renewable energy despite its huge upfront investment cost. In contrast to most studies in the literature that uses the amount of energy generated from renewable energy, we develop a new method capturing diversification by using the quantity of energy generated from each source as weights. To the best of our knowledge this is the first paper that uses this kind of measure for diversification. The analysis is focused only on the modern sources of renewable energy such as solar, wind, geothermal, biomass and waste excluding hydropower. Although there is a substantial number of developing countries not investing in nonhydro sources of renewable energy, we observed that there has been a rapid diversification of since the mid-1990s.

Based on a substantially larger data set, we assess a wider range of potential determinants of renewable energy diversification across 117 developing countries spanning from 1980 to 2011. Though we observed a rising trend in diversification, the dependent variable has still a lot of zero observation reflecting those countries that did not invest in any nonhydro sources. To address this methodological issue (large observation with zero values), we explore several empirical techniques such as two-part model, negative binomial and Poisson-pseudo maximum likelihood estimation. The two-part model is used to investigate whether to adopt or not renewable energy and conditional on adopting, do they diversify or rely only on source of renewable energy. The negative binomial model is used for count observation and Poisson pseudo-maximum likelihood estimation is used to model the aggregate electricity generated from nonhydro renewable sources giving attention to large number of zero observations.

We find that income has a non-monotonous effect on diversification. While most available studies in the literature do not include the nonlinear effect of income, our results show robust evidence that income has a significant nonlinear effect portraying a U-shaped kind of relationship with nonhydro renewable energy. This implies that as society develops demand for renewable energy is declining because it is replaced by conventional energy to fuel a growing economy but as the economy accumulates more wealth, it will address environmental concerns through the use of various sources of clean and renewable energy. Results shows the relevance of environmental Kuznets curve suggesting that greater environmental awareness comes with increasing affluence.

Holding other factors constant, countries that are more dependent on foreign energy sources are more likely to diversify nonhydro renewable energy. Energy security is a major policy agenda in developing countries. Diversification is one of the feasible approaches to localize energy supply and improve energy security. This result is complemented by the effect of higher world price for crude oil. Developing countries are sensitive to price increases in fuel because it can trigger higher inflation and hamper economic growth. Renewable energy presents an attractive option in dealing with energy security and diversifying its sources can help minimize the risks related to fluctuations in world market prices for oil.

Results show that the coefficient of policy variable, patents and secondary enrolment are as expected. This means that implementation of renewable energy policies, technological innovation and accumulation of human capital positively contributes to the diversification of nonhydro sources of renewable energy in developing countries. Several policies provide incentives for promoting the development of renewable energy, however, Zhao et al. (2013) cautioned about the potential crowding out effect of these several policies. The significant positive coefficient of patents suggests that diversification of nonhydro renewable energy is facilitated by the advances in technology. Similarly, improvement in human capital as proxied by enrollment in secondary education do facilitates diversification of renewable energy. However, financial development posted a mix result. There is also no consensus in the literature as the effect of financial development on renewable energy. While Brunnschweiler (2010) reported a robust effect, Pfeiffer and Mulder (2013) showed no evidence for any influence resulting from financial sector development.

On the other hand, abundance of hydro power impedes diversification. Maybe developing countries are less enthusiastic in utilizing other sources of renewable energy if hydro power is already part of their energy mix. Also, abundance of oil reduces incentives to diversify sources of nonhydro renewable energy because they don't have to worry about issues concerning energy security. In addition, abundance of oil will make renewable energy more expensive making it less attractive. There is also no conclusive evidence that shows FDI and ODA promotes diversification of nonhydro renewable energy. Lastly, the effect of Kyoto Protocol on the diversification is positive and significant. This suggests that global environmental awareness has led to a greater diffusion of renewable energy in developing countries. This can also be associated by the growing number of clean development mechanism (CDM) projects in developing countries because of Kyoto Protocol.

Our empirical investigations identified drivers and barriers to adoption of a more diversified sources of renewable energy. Results presents various dimensions where policy makers can promote renewable energy. Although there is rising trend of renewable energy adoption in developing countries particularly led by China, still it has a long way to go in integrating renewables in the energy system. According to REN21(2018), the share of modern renewable energy (excluding traditional biomass) to total final energy consumption is only around 10.4% in 2016 a little higher from its 2015 levels. This shows that there is progress in integrating renewable energy to the countries' energy system, albeit slow. Given the strong link between economic development and energy consumption, future growth of developing countries will heavily rely on massive energy use (Jakob et al., 2014). In the last decade, we are seeing continued economic growth from developing countries and this could be their opportunity to transform its economy and integrate a more diversified sources of cleaner energy. Our empirical analysis shows that one of the primary drivers of behind rising diversification is greater environmental concern. This is manifested by the positive and significant correlation of Kyoto Protocol on renewable energy diversification. By using cleaner sources of energy, developing countries can transition to a low-carbon economy while ensuring energy security and sustainability.

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Appendix A. Estimation using two-part model with diversity index as dependent variable.

Variables	Logit	OLS	Logit	OLS	Logit	OLS	Logit	OLS
Log GDP pc	0.022	0.101***	0.167	0.144***	-5.042**	-1.89***	-8.600	-2.03***
	(0.1538)	(0.0285)	(0.1883)	(0.0356)	(2.1088)	(0.4417)	(6.9972)	(0.3954)
Log GDP pc_sq					0.358**	0.132***	0.557	0.141***
					(0.1444)	(0.0280)	(0.4612)	(0.0255)
Energy import	0.013***	0.001***	0.004**	-0.000	0.004*	-0.000	0.013***	0.000**
	(0.0013)	(0.0002)	(0.0020)	(0.0002)	(0.0020)	(0.0002)	(0.0035)	(0.0002)
Pop growth	0.138	0.166***	0.207	0.173***	0.187	0.162***	0.879**	0.181***
	(0.1247)	(0.0297)	(0.1301)	(0.0297)	(0.1326)	(0.0282)	(0.3444)	(0.0439)
Oil price	0.045***	0.003**	0.070***	0.004**	0.072***	0.004**	0.067*	0.005***
	(0.0131)	(0.0016)	(0.0180)	(0.0018)	(0.0191)	(0.0018)	(0.0354)	(0.0019)
Policy on ren	0.772***	0.113***	0.176	0.100***	0.094	0.064*	0.569	0.043
	(0.2515)	(0.0356)	(0.3031)	(0.0388)	(0.3097)	(0.0385)	(0.4380)	(0.0469)
Patents	0.511***	0.005	0.664***	0.023**	0.699***	0.030***	1.017***	0.082***
	(0.0591)	(0.0092)	(0.0800)	(0.0095)	(0.0855)	(0.0090)	(0.1717)	(0.0132)
Finance dev	-0.039	0.018	-0.001	0.030	-0.067	0.018	-0.726**	-0.060**
	(0.1409)	(0.0211)	(0.1726)	(0.0232)	(0.1692)	(0.0208)	(0.3418)	(0.0296)
Hydro energy			-0.624***	-0.032*	-0.65***	-0.041**	-2.66***	-0.120**
			(0.1518)	(0.0162)	(0.1626)	(0.0178)	(0.3648)	(0.0563)
Oil prod'n			-0.104***	-0.01***	-0.12***	-0.02***	-0.20***	-0.03***
			(0.0235)	(0.0027)	(0.0249)	(0.0026)	(0.0456)	(0.0032)
Coal prod'n			-0.071	-0.021	-0.046	0.000	0.335**	0.090***
			(0.0927)	(0.0127)	(0.0965)	(0.0115)	(0.1504)	(0.0168)
Sec enrolment							0.087***	-0.000
							(0.0197)	(0.0015)
FDI							-0.060	-0.018**
							(0.0492)	(0.0068)
ODA							-0.123*	-0.002
							(0.0669)	(0.0079)
Coastal dummy	1.521***	0.009	1.013***	0.017	0.841**	-0.000	2.966***	-0.109
	(0.2800)	(0.0466)	(0.3211)	(0.0529)	(0.3301)	(0.0475)	(0.7434)	(0.1130)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes	yes	yes	yes	yes
Constant	-7.93***	-0.412*	-10.55***	-0.90***	8.546	7.00***	17.813	7.488***
	(1.4138)	(0.2378)	(1.5355)	(0.2688)	(7.6957)	(1.7118)	(26.6973)	(1.5401)
Pseudo R2/ R2	0.3882	0.2997	0.4341	0.3440	0.4389	0.3935	0.6165	0.5282
Observations	1,216	672	1,091	602	1,091	602	732	404

Note: Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1