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Explaining the Diffusion of Renewable Energy Technology in Developing Countries

Abstract

In this paper we study the diffusion of non-hydro renewable energy (NHRE) technologies for electricity generation across 108 developing countries between 1980 and 2010. We use two-stage estimation methods to identify the determinants behind the choice of whether or not to adopt NHRE as well as about the amount of electricity to produce from renewable energy sources. We find that NHRE diffusion accelerates with the implementation of economic and regulatory instruments, higher per capita income and schooling levels, and stable, democratic regimes. In contrast, increasing openness and aid, institutional and strategic policy support programs, growth of electricity consumption, and high fossil fuel production appear to delay NHRE diffusion. Furthermore, we find that a diverse energy mix increases the probability of NHRE adoption. Finally, we find weak support for a positive influence of the Kyoto Protocol on NHRE diffusion and no evidence for any influence resulting from financial sector development.

Keywords: renewable energy technologies, developing countries, electricity, technology diffusion, sample selection

JEL codes: O13, 014, Q42, Q48

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Explaining the Diffusion of Renewable Energy Technology in Developing Countries

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Article Outline

1 Introduction

The growth of global carbon emissions is nowadays largely driven by the increasing volume coming from within developing countries (IEA 2010). Consequently, in 2008 the aggregate energy-related CO_2 emissions of developing countries surpassed those of industrialized and transition countries for the first time in history (IEA 2010). The positive growth prospects for emerging economies make this trend likely to continue for the foreseeable future, especially given that – particularly in the initial stages of development – the demand for energy increases as the economy grows (Chow et al. 2003; Jakob, Haller and Marschinski 2012). Curbing the future increase of carbon emissions from developing countries is, therefore, indispensable to the achievement of ambitious climate targets (IPCC 2011).

Currently, the electricity sector constitutes a major source of energy-related CO_2 emissions, accounting for 41 percent of global CO_2 emissions (IEA 2010). This reality clearly makes the reduction of emissions from electricity generation an essential ingredient in any climate change mitigation strategies (IPCC 2011; GEA 2012). Alongside increasing energy efficiency, the rapid diffusion of renewable energy technologies (RET) is considered to be the second – though equally most effective – option for reducing carbon emissions while simultaneously meeting humanity's ongoing need for energy provision (GEA 2012). The widespread adoption of RET – including hydroelectric power, geothermal, solar, biomass and wind– would not only help to avoid the negative environmental and social effects associated with conventional (i.e., fossil fuel) energies, but also has the potential to create substantial additional socioeconomic benefits – such as, for example, reducing local air pollution and safety risks, increasing energy access and improving energy security (Martinot et al. 2002; GEA 2012; IPCC 2011; Owen 2006).

The research and development in RET is primarily done in industrialized countries (Dechezleprêtre et al. 2011; Popp et al. 2011). The key challenge for developing countries is, therefore, to secure the international transfer of these climate-friendly technologies. The adoption of RET in developing countries not only slows down global carbon emissions in the short term but also offers them the opportunity to "leapfrog" over developed countries, as a result of environmentally benign power production technologies being harnessed before a lock-in into conventional energy resources occurs (Popp 2011; Watson and Sauter 2011). Nevertheless, it is common knowledge that many governments and firms still continue to invest in old technologies even though the new ones are more cost-effective, which underlines that the diffusion of energy technologies is at least as equally costly and difficult as is their invention (Del Río González 2009; Jaffe and Stavins 1994; Jaffe et al. 2002; Popp et al. 2011). Against this backdrop, we thus study the adoption and diffusion of RET for electricity generation in developing countries.

The main contribution of this paper to the literature is twofold:

First, although investments in energy-saving or environmentally friendly technologies have received considerable attention in the field of environmental and energy economics,[1] to date few studies have focused specifically on the diffusion of RET, and these studies consider almost exclusively Organisation for Economic Co-operation and Development (OECD) economies. For example, Johnstone et al. (2010) use patent counts in a cross-section of 25 OECD countries to show that public policies encourage innovation in RET. Also using patent-based data, Popp et al. (2011) find that increased knowledge has a robust, albeit small, effect on renewable energy investments across 26 OECD countries. In contrast, we model and evaluate the adoption of RET across 108 developing countries between 1980 and 2010, assessing a wide range of potential drivers of, and barriers to, RET diffusion. As such, our study is related to recent work by Brunnschweiler (2010), who presents evidence of financial sector development having a positive effect on renewable energy development, with special attention given to non-OECD countries. Our study is different however, in that: we explicitly model the decision about whether or not to adopt RET; we focus

1 See Popp et al. (2010) for an excellent overview of this literature.

on non-hydro power; and we consider the potential role of additional possible drivers of RET adoption – including specific energy policies, the energy mix, trade and the official development assistance (ODA) provided.

Second, we first propose and then use an econometric approach to deal with two methodological problems in this area of study that have been somewhat overlooked so far. The main problem is the large number of zero-valued observations included in our dependent variable, because many countries do not yet, or have only recently begun to, invest in (non-hydro) renewable electricity production. Moreover, we might have a potential sample selection problem – the zero-valued observations may reflect either no investment in RET or the fact that off-grid electricity production is not included in the available data, and thus may differ systematically from the positive values of the potential outcome.[2] We deal with these two methodological issues by using two-stage estimation methods, in which we explicitly model the choice of whether or not to adopt RET as well as the decision about the amount of electricity to produce from renewable energy sources. To this end, we employ both the two-part model (2PM) of Duan et al. (1984) and Heckman's (1979) two-step selection model (TSM).

We find that the diffusion of non-hydro renewable energy (NHRE) technologies for electricity generation accelerates with the implementation of economic and regulatory instruments, higher per capita income and schooling levels and with stable, democratic regimes. In contrast, increasing trade intensity, higher levels of foreign direct investment (FDI) and ODA, institutional and strategic policy support programs, growth in electricity consumption and a high level of fossil fuel production appear to delay the diffusion of NHRE. Furthermore, we find that a large share of hydropower lowers the probability of NHRE being adopted but nevertheless stimulates the amount of NHRE electricity produced, while the opposite is true when there is a diverse energy mix. Finally, we find weak support for a positive influence of the Kyoto Protocol on NHRE diffusion and no evidence at all for any influence resulting from financial sector development.

The remainder of this paper is organized as follows: In Section 2 we present some stylized facts regarding the role of RET in global electricity production, and we discuss our data in relation to the existing literature dealing with the factors that determine technological adoption. In Section 3 we introduce and specify our empirical methodology. Section 4 presents the baseline results of our analysis. In Section 5 we provide additional results, with special attention given to the general drivers of technology adoption and to the role of the energy mix. Section 6 summarizes and concludes by offering some suggestions for possible future research in this field.

2 Data, Background and Stylized Facts

As a measure of RET adoption – our dependent variable – we use electricity generation measured in the amount of kilowatt-hours (kWh) per capita obtained from the following renewable re-

2 Off-grid electricity production from renewable sources is potentially important, given the installation of isolated photovoltaic (PV) of mini-hydro systems in remote rural areas.

sources: biomass, geothermal, solar, and wind. We exclude hydroelectric power generation from our definition, because large hydropower projects are increasingly viewed as being unsustainable sources of power generation due to their often serious negative environmental and social externalities.[3] Also, we exclude (traditional) biomass because of its negative impact on agricultural (food) production, as demonstrated by the rising price of grain as well as of other foodstuffs. We use data on electricity generation from non-hydroelectric sources provided by the United States Energy Information Administration (EIA) for the period 1980–2010. While the EIA data can be considered to be comprehensive, electricity generation may be underestimated, as off-grid activities do not seem to be included in the data. We use data for 108 developing countries (see Appendix, Table A1).

Table 1: Summary Statistics on Non-Hydroelectric Renewable Electricity (NHRE) Generation

	1980					2010				
Variable	**Obs.**	Mean	**Std. Dev.**	**Min.**	**Max.**	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Developing Countries										
NHRE SHARE	87	0.99	3.85	0.00	29.08	108	2.09	5.53	0.00	30.31
NHRE PER CAPITA	88	3.57	13.01	0.00	104.15	108	24.53	61.31	0.00	371.99
BRICS										
NHRE SHARE	4	0.35	0.70	0.00	1.39	5	2.20	2.65	0.14	6.64
NHRE PER CAPITA	4	3.91	7.82	0.00	15.63	5	51.90	65.89	6.80	167.44
Developed Countries										
NHRE SHARE	42	0.53	1.18	0.00	6.27	48	6.32	7.90	0.00	35.25
NHRE PER CAPITA	42	30.16	78.30	0.00	456.86	48	750.10	2106.26	0.00	14454.05

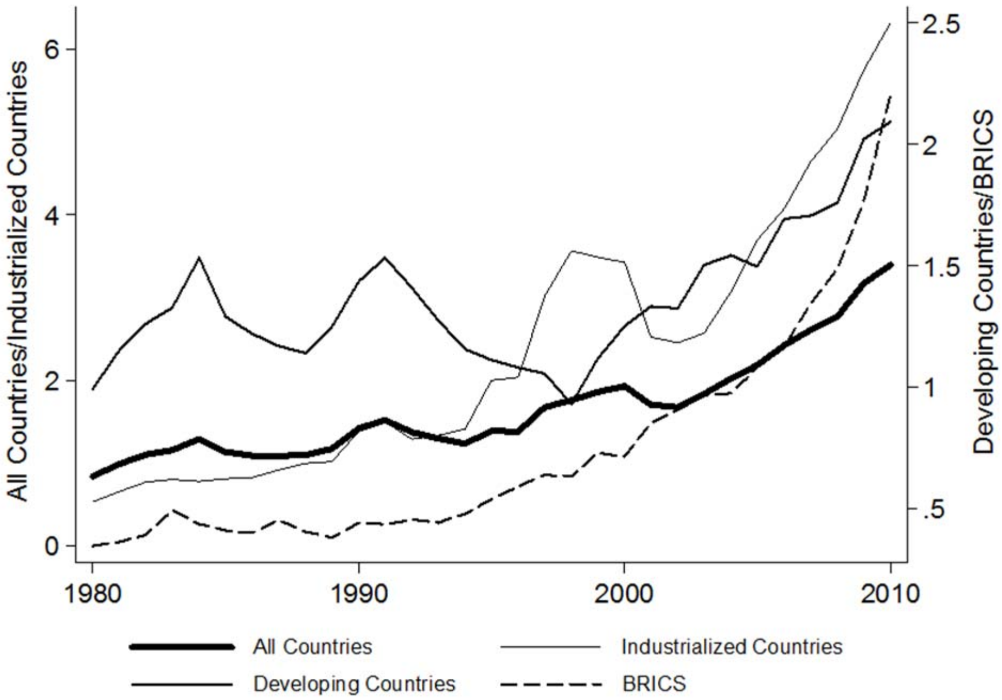
* Developing Countries' Statistics including the BRICS countries.
Source: Authors' calculations based on EIA (2012).

According to the 2012 report *Global Energy Assessment – Toward a Sustainable Future*, the contribution of RET (including hydropower) to the world's electricity generation in 2010 was roughly 3,800 terawatt-hours (TWh), equivalent to about 19 percent of total global electricity consumption. Renewable power capacity additions now represent more than one-third of all global power capacity additions (GEA 2012). Based on our data, Table 1 presents key statistics regarding the growth of NHRE between 1980 and 2010. It is evident that the share of NHRE in total electricity production in developing countries is small but rapidly increasing: since 1980 it has more than doubled, and now comprises over 2 percent. Moreover, Table 1 shows that while Brazil, Russia, India, China and South Africa (BRICS) initially lagged behind they are now leading the group of developing countries. Figures 1 and 2 below illustrate that NHRE, especially during the last decade, has experienced high annual growth rates, particularly in the BRICS countries. Finally, both

3 Unfortunately, our cross-country dataset does not allow one to consistently distinguish between large and small hydropower projects.

the relatively high shares and growth rates of NHRE in developed countries demonstrate that the RET adoption process is, as previously noted, (still) being led by rich countries.

Figure 1: Share of NHRE in Total Electricity Production in Industrialized Countries, Developing Countries and BRICS, 1980–2010

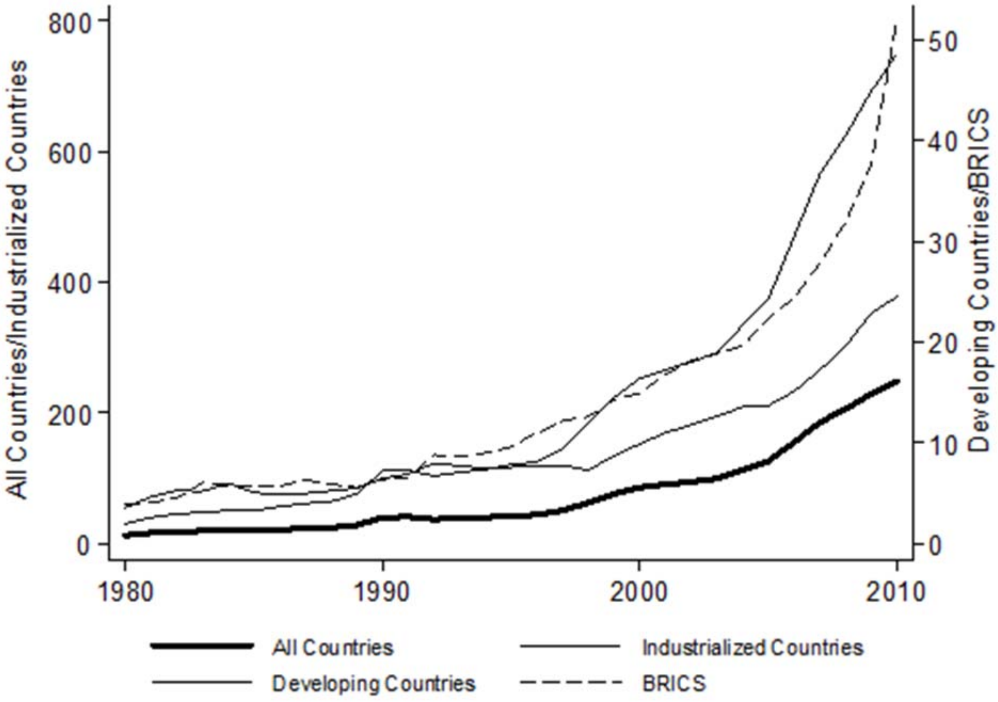


Source: Authors' calculations based on EIA (2012).

To identify the factors and barriers that may affect RET adoption, we make use of insights from both the broader economic literature as well as from the environmental and energy economics literature.[4] One of the main stylized facts regarding technological change is that new technologies often initially complement older technologies, and only subsequently – and often slowly – replace older technologies (see, for example, Dosi 1997; Gruebler et al. 1999; Mokyr 1990; Rosenberg 1982; Ruttan 2001; Stoneman 2002; Young 1993). The gradual nature of this technology diffusion can be explained from the fact that technologies differ not only in terms of their productivity (vertical dimension), but also with respect to other qualities (horizontal dimension). Consequently, agents face returns to diversity in that they explicitly attach value to using both new and old technologies at the same time.

4 For a review of the broader economic literature see, for example, Keller (2004) or Comin and Hobijn (2004). For a review of the technology adoption research in environmental and energy economics to date, see Popp et al. (2010).

Figure 2: NHRE Per Capita Production (Measured in kWh) in Industrialized Countries, Developing Countries and BRICS, 1980–2010



Source: Authors' calculations based on EIA (2012).

As regards the vertical dimension, broad historical evidence shows that new technologies tend to be initially inferior to more mature technologies due to the fact that they temporarily reduce expertise and, thereby, capital productivity. This leads to the gradual adoption of new technologies, and results in the coexistence of old and new technologies – with the productivity of the new technology increasing over time through learning (see, for example, Arrow 1962; Clarke et al. 2006; David 1975; Isoarda and Soriab 2001; Jovanovich and Lach 1989; OECD/IEA 2000; Parente 1994). In our analysis we capture this feature in a stylized way by controlling for the level of human capital, measured through secondary enrollment rates – therein assuming that the speed of learning for certain technologies is positively related to a more educated labor force in general. Data is taken from the World Bank's World Development Indicators (WDI).

The horizontal dimension of technological change refers to the fact that technologies differ in terms of required inputs (types of fuels or raw materials), plant location, plant size or managerial and organizational skills. A good example of this can be found in the electricity sector, where hydropower, unlike thermal power, is characterized by relatively high fixed costs but low variable costs (Von der Fehr and Sandsbråten 1997). These kind of considerations lead to a mix of interdependent and thus complementary technologies, with agents continually investing in the improvement of distinct pieces of the whole technological puzzle – instead of replacing the whole thing at once (see, for example, Antonelli 1993; Colombo and Mosconi 1995; Jovanovic and Stolyarov 2000;Milgrom et al. 1991; Mulder et al. 2003).

This "love of variety" may affect RET adoption for other reasons besides the return to technical diversity. For example, a dominant share being held by a competing technology can signal that underlying vested interests of particular subgroups exist in the economy, who may engage in efforts intended to keep the old technology in place – as (large-scale) RET adoption would reduce their expertise and rents (see, for example, Canton et al. 2002; Krusell and Ríos-Rull 1996; Mokyr 1992). To capture these mechanisms, we control our regressions for the diversity of a country's energy mix according to:

$$ENERGYMIX_{jt} = 1 - \sum_{i=1}^{M} \left(SHARE_{jt}^{E}\right)^2 \quad (1)$$

where $SHARE_{jt}^{E}$ is the share of each source of energy type E in country j in year t. The index takes a value of zero if a country produces its energy from only one source of energy, and converges to one the more diversified a country is. We include data in the index about energy production from coal, gas, nuclear and hydropower in quadrillion British thermal units (BTU), again taken from the EIA. We relate each source of energy to the total amount of energy produced from them, and exclude the shares of non-hydropower energy sources – in order to rule out any potential endogeneity problems.

Evidently, (changes in) the energy mix used for power production can influence NHRE diffusion in several different ways. First, if countries already make extensive use of nuclear power or hydropower, their relatively low carbon intensity is likely to diminish the incentives for investing in RET (Popp et al. 2011). Since the use of nuclear power is almost exclusively limited to developed countries, we control for this mechanism through the inclusion of a country's share of hydropower. Data is taken from the aforementioned EIA database. Second, on the basis of the assumption that energy markets function well, the actual energy mix reflects the relative costs of the competing energy sources, which obviously affects the attractiveness of RET. Unfortunately, country-specific prices for electricity produced from different sources are not available. For many developing countries no data on electricity prices is available, while for a relatively small subsample of them the only available data is overall electricity prices – which are clearly endogenous, since they include the price of renewable electricity production (ibid.). Instead, we include in our regressions the per capita production of coal and natural gas, assuming that they influence relative energy prices. Data is again taken from the EIA, and measured in quadrillion BTUs per 1 million people. Clearly, the local abundance of any energy resource endowment will drive down its domestic price. In addition, non-renewable resource abundance is expected to slow down the adoption of RET by reducing concerns about energy security and by undermining support for stringent emission reduction policies (ibid.).

Despite the absence of any binding agreements on reducing carbon emissions, developing countries are increasingly implementing policies to promote the adoption of RET. According to the IEA/IRENA Global Renewable and Energy Policies and Measures Database in late 2012, between 1980 and 2010 27 developing countries implemented such policies in the electricity sector. These included the use of economic and regulatory instruments (auditing, codes and standards), policy support (institutional creation, strategic planning), as well as voluntary approaches and support for information and education. The latter are less common policy practices in developing countries, with most attention going to economic instruments such as direct investments (e.g. in infrastructure), fiscal and financial incentives and market-based initiatives – like allowances for greenhouse gas (GHG) emissions or green certificates. In many cases, more than one of each type of policy has been implemented over time, while the renewable energy policies target biomass, geothermal, solar and wind – as well as the inclusion of multiple renewable energy sources.

The question of which type(s) of environmental regulation will have a measurable impact on technological change in support of more environmentally friendly production is empirically open (Del Río González 2009). In our regressions we first examine the effects of RET policy measures using an aggregate RET policy variable (RE policy), based on the IEA/ IRENA Global Renewable and Energy Policies and Measures database. This dummy variable takes a value of one if a country has implemented any of the above-described policies, measured from the first year of implementation onward; otherwise, it takes a value of zero. Second, we consider the most important policy measures in our country sample independently, in other words economic and regulatory instruments and policy support. Finally, we control for the potential impact of the Kyoto Protocol by including a time dummy from 1998 onward (given its adoption in late 1997).

In addition, we consider in our regression analyses the role of trade and FDI. In general, increasing trade linkages are expected to accelerate knowledge diffusion – via high-tech imports, joint ventures or increasing international competition (see, for example, Alcalá and Ciccone 2004; Coe and Helpman 1995; Comin and Hobijn 2004; Del Río González 2009). However, in the case of a highly regulated production factor like energy, trade might also induce countries to "race to the bottom" – whereby a country weakens regulations and/or decreases energy prices in order to exploit its comparative advantages (Copeland and Taylor 2004). Hence, the extent to which trade and FDI facilitate the international transfer of RET is expected to depend on a variety of local characteristics – including physical and human capital endowments, capital–skill complementarities, environmental stringency and (cultural) distance from the trading partner. We measure trade intensity as the sum of exports and imports of goods and services as a percentage of the gross domestic product (GDP), and FDI in terms of FDI net inflows as a percentage of GDP – with data taken from the WDI.

Due to the relatively high upfront costs of most RET, having access to finance is considered to be an important prerequisite for their adoption (Brunnschweiler 2010). In addition, we expect that ODA stimulates RET adoption, given the fact that one of the core areas of the ODA strategy for energy efficiency has for a long time been the push for the introduction of renewable energy usage (Martin 1996). To account for the role of access to capital, we include in our analyses the degree of local financial sector development, measured by the ratio of deposit money bank assets to central bank assets (ASSETS) – which reflects the importance of commercial banks as compared to central banks. We control per country for net ODA, as a percentage of gross national income (GNI). In both cases data is taken from the WDI.

Finally, RET are expected to increase with higher levels of economic development, because, among other things, the latter implies more private and public financial resources, increasing environmental awareness and growing electricity demand (Del Río González 2009; Plassmann and Khanna 2006; Popp et al. 2011). We therefore add to our control variables GDP per capita and growth of per capita electricity consumption, with the latter foreseen to capture expectations about future electricity demand. Data is taken from the WDI, with GDP measured in constant 2005 USD. Table 2 presents the descriptive statistics of the variables used in our study, while Table 3 summarizes the definitions of and sources for these variables.

Table 2: Summary Statistics, 1980–2010

Variable	Obs.	Mean	Std.	Min.	Max.
NHRE	3080	9.95	34.6	0.00	372.00
HYDRO SHARE	3056	43.50	35.9	0.00	100.00
COAL PRODUCTION	3080	0.0051	0.016	0.00	0.16
GAS PRODUCTION	3080	0.0089	0.037	0.00	0.61
RE POLICY	3348	0.074	0.26	0.00	1.00
ECONOMIC INSTRUMENTS	3348	0.056	0.23	0.00	1.00
REGULATORY INSTRUMENTS	3348	0.039	0.19	0.00	1.00
POLICY SUPPORT	3348	0.029	0.17	0.00	1.00
KYOTO	3348	0.42	0.49	0.00	1.00
GDP PER CAPITA	2958	1441.00	1584	54.50	10749.00
GROWTH IN ELECTRICITY CONSUMPTION	2962	3.24	12.3	-92.30	188.00
TRADE	2898	70.30	36.5	0.31	220.00
FDI	2757	2.79	5.82	-82.90	91.00
ODA	2686	7.83	11.2	-0.73	181.00
ASSETS	2643	12.90	30.6	-0.11	100.00
SECONDARY ENROLLMENT	2292	51.30	29.4	2.34	111.00
ENERGY MIX	2699	0.17	0.20	0.00	0.66
POLITY2	3000	-0.03	6.64	-10.00	10.00

Source: Authors' calculations based on data as summarized in Table 3.

Table 3: Definitions of Variables and their Sources

Variable	Definition	Data Source
NHRE	Per capita electricity generation from non-hydropower sources (kWh)	EIA
HYDRO SHARE	Share of hydroelectric power in total electricity generation	EIA
COAL PRODUCTION	Coal production in quadrillion BTUs/1 million people	EIA
GAS PRODUCTION	Gas production in quadrillion BTUs/1 million people	EIA
RE POLICY	Dummy variable taking value 1 from the first year of implementation of an RE policy (economic instruments, regulatory instruments, policy support) onward	IEA/IRENA
ECONOMIC INSTRUMENTS	Dummy variable taking value 1 from the first year of implementation of economic instruments for the promotion of RE onward	IEA/IRENA
REGULATORY INSTRUMENTS	Dummy variable taking value 1 from the first year of implementation of regulatory instruments for the promotion of RE onward	IEA/IRENA
POLICY SUPPORT	Dummy variable taking value 1 from the first year of implementation of policy support policies for the promotion of RE onward	IEA/IRENA
KYOTO	Dummy variable taking value 1 from 1998 onward	IEA/IRENA
GDP	GDP per capita in constant 2005 USD	WDI
GROWTH IN ELECTRICITY CONSUMPTION	Growth in electricity consumption measured in kWh per capita	EIA
TRADE	Sum of exports and imports of goods and services as a percentage of GDP	WDI
FDI	FDI net inflows as a percentage of GDP	WDI
ODA	Net official development assistance (ODA) received (% of GNI)	WDI
ASSETS	Deposit money bank assets as a percentage of total bank assets	WDI
SECONDARY ENROLLMENT RATE	Total enrollment in secondary education of the population of the age group that officially corresponds to the level of education shown	WDI
ENERGY MIX	Index that takes value zero if a country produces electricity from one source of energy (coal, gas, nuclear, hydropower), and converges towards one the more diversified a country is	EIA
POLITY2	Combined polity score that ranges from +10 (strongly democratic) to -10 (strongly autocratic)	Marshall et al. (2011)

Source: Authors' calculations.

Methodology

As noted, our dependent variable (NHRE per capita) features two important and interrelated characteristics. First, about 71 percent of the observations of our dependent variable are zero-valued, because a large proportion of countries did not invest in NHRE in certain years – often these were the early years, although sometimes they cover the whole sample period. Second, our dependent variable is heavily right-skewed (skewness: 5.83) and has considerable non-normal kurtosis (kurtosis: 45.42). Taking logs reduces the skewness (-1.19) and the kurtosis (4.89), and yields a dependent variable which is more normally distributed – this also, however, reduces the number of included observations considerably, because of the large number of zero-values.

To resolve these methodological issues, one possibility would be to follow an ad hoc approach and to limit estimation to non-zero-valued observations, or to arbitrarily add a small positive constant to the dependent variable – methods that have all been commonly used in the trade literature (cf. Linders and de Groot 2006). Instead, though, we have decided to apply a methodological strategy that is designed to deal with a large percentage of zero-valued observations. In this context, model selection very much depends on the kind of zeros appearing in our dataset. Frondel and Vance (2012) distinguish between exogenous censoring, true zeros and missing data. In the case of exogenous censoring, the dependent variable can be negative in principle but is only observed at zero or positive values. True zeros can be defined as actual outcomes that are fully observed and that can be characterized as corner solutions. Potential zero observations may arise because of missing data, and refer to latent variables that are only partially observed (Dow and Norton 2003). We may assume that the zero-valued observations of our dependent variable are true zeros, but we cannot rule out the possibility that some zero-valued observations are missing observations for the potential outcome, caused by the fact that off-grid electricity production is not included in the data. If these missing observations differ systematically from the positive values of the potential outcome, a sample selection problem has to be addressed (Ibid.).

For these reasons, we apply a two-stage estimation method, using both the two-part model (2PM) of Duan et al. (1984) and the two-step selection model (TSM) of Heckman (1979).[5] The 2PM allows for different mechanisms that generate both zero-valued observations and positive outcomes. The methodology herein consists of estimating a first equation for the sample of zero-valued and positive outcomes and a second equation for the subset of positive observations (Dow and Norton 2003). In our case, the underlying assumption of the 2PM is that the decision to invest in NHRE and the amount of NHRE produced are independent of each other. Equation 2 denotes the probability (PR) of a positive outcome of the dependent variable NHRE:

$$PR\left(NHRE^{*} = 1 \mid X_{jt}\right) = PR\left(NHRE > 0 \middle| X_{jt}\right) = \Phi\left(\beta X_{jt} + \varepsilon_{jt}\right) \tag{2}$$

where j denotes the country (j=1-108) and t the time period (t=1-30). The dummy variable NHRE* equals one if the outcome variable NHRE is larger than zero, and zero otherwise. The vector of

5 The Tobit model is the standard estimation method used in the case of exogenous censoring (Frondel and Vance 2012). An important underlying assumption of this censored regression model is that the same probability mechanism generates both the zero-valued observations and the positive outcomes of the data.

control variables is given by X_{jt}, while ε_{jt} is the disturbance term and Φ the standard normal distribution. In Equation 2 we use the log of NHRE as the dependent variable. The mean outcome, conditional on being positive, is defined as:

$$\ln(\text{NHRE}) = \beta X_{jt} + u_{jt} \quad (3)$$

with u_{jt} an error term and $NHRE > 0$.

In contrast to the 2PM, the TSM assumes that the decision to adopt NHRE and the amount of NHRE produced are not independent from each other. This assumption is valid in the case of sample selection and combines a first-stage selection model and a second-stage outcome regression. The TSM is also a probit estimator of having a positive outcome, and determines whether a country produces electricity from NHRE or not (see Equation 2). The outcome regression is an OLS estimator for positive observations, identifying how much electricity a country produces from non-hydroelectric sources:

$$E\left[\ln(NHRE)\middle|NHRE > 0, X_{jt}\right] = X_{jt}\beta + \rho\sigma_3\lambda(X\beta_2)\,. \quad (4)$$

In Equation 4, $\rho\sigma_3$ represents the inverse Mills' ratio coefficient, while λ denotes the inverse Mills' ratio that gives the probability that an observation is included in the sample. It is calculated for each observation in the sample (Heckman 1979; Dow and Norton 2003) according to:

$$\lambda(X\beta_2) = \phi(X\beta_2)/\Phi(X\beta_2) \quad (5)$$

with ϕ and Φ as before. By including the inverse Mills' ratio in the outcome equation the sample selection problem is solved.

In order to discriminate between the two methods, it is important to consider the distinction between the actual and potential outcomes of a variable (Dow and Norton 2003). The 2PM would be the preferred estimator if we were primarily interested in the determinants of actual rather than potential investments in NHRE and assumed no sample selection problem – in other words, if we assumed that zero-valued observations are true zeros and not missing data. The underlying reason is that in this case the interpretation of the TSM results tends to be complex since the TSM addresses the sample selection problem of potential outcomes (Ibid.). However, as previously argued, since we indeed expect a possible sample selection bias in our data, the TSM appears to be the appropriate one to use. The TSM is in principle also identified if the same regressors appear in the selection and outcome equation, due to the fact that the inverse Mills' ratio introduces nonlinearity in the functional form of the selection equation. However, the latter may cause the results to suffer from multicollinearity, implying large standard errors as well as a skewed *t*-statistic for the inverse Mills' ratio. Since the latter is commonly used to determine the appropriate model (Leung and Yu 1996), this may impede satisfactory discrimination between the TSM and the 2PM.

To overcome this problem, in the context of our study an exclusion restriction that determines the probability of adopting NHRE, but not the decision about how much NHRE to produce, is warranted. To this end, we use POLITY2 from the annual Polity IV time-s, a widely used combined polity score that ranges from +10 (strongly democratic) to -10 (strongly autocratic). In very general terms, democracy is determined in terms of the presence (or not) of institutions as well as of procedures that enable citizens to express their preferences about policies and leaders, the existence of institutional limitations on the power of the executive and the guarantee of political participation (Marshall et al. 2011). Our use of this index is based on the idea that a stable, democratic regime, sustained by high quality institutions, is positively correlated with a business-friendly environment and confidence in the enforcement and sustainment of (environmental) regulations and policies.[6] The literature has suggested various mechanisms that might explain this positive association, including the observations that political liberalization often enhances both economic liberalization and financial stability and that more open political systems allow policy-makers to better balance the interests of different groups in society, including private investors (De Haan et al. 2006; De Vanssay and Spindler 1994; Feng 2001; Pastor 1995; Seldadyo et al. 2007).

In this way a healthy institutional and business environment is clearly likely to increase the probability of RET being adopted, because it stimulates investment in general while at the same time not influencing the decision about how much electricity to produce from RET – the latter depends more on specific market conditions (see Section 2). This argument is supported by our data: the pairwise correlation between POLITY2 and the dummy for NHRE adoption is 0.36, while it is 0.16 between POLITY2 and the amount of NHRE produced. At the same time, the latter demands the careful comparison of results obtained from the various models. As will be elaborated upon in Section 4, it is reassuring that the main findings of our analysis are very robust across the use of the 2PM and the TSM, and with the exclusion restriction.

4 Baseline Results

In this section we present the results of the estimations of our 2PM and TSM models, which were carried out by following the methodology outlined in the previous section. For all specifications, we not only show the estimated coefficients but also the implied average marginal effects. In the probit model, marginal effects measure the effect of a one-unit change in the explanatory variables on the probability that a country adopts NHRE when all other control variables are set at their means. In contrast, the coefficients of the linear specification – the outcome equation with the amount of NHRE produced (in logs) as the dependent variable – cannot be simply interpreted as marginal effects in a two-stage model. Frondel and Vance (2010) show that the marginal effects of the actual outcome of the 2PM include the estimation results of both the probit as well as the linear specification. In a similar vein, Sigelman and Zeng (1999) argue that the effect of the explanatory variables is a compound of the effect on the selection and the outcome equation of the TSM when these variables appear in both equations. Hence, in order to identify the marginal effects as well as their level of significance in the log-linear part of both the 2PM and the TSM, we predict our dependent variable based on two parts. The first takes into account the decision to

6 Please note that we, unfortunately, could not make use of the World Bank's Doing Business data, since it has only been available as of 2004, and its rankings are thus only available for recent years.

adopt NHRE, while the second is the conditional expectation. The standard errors in the marginal effects are calculated by using bootstrap errors.

Table 3 presents pooled regression results for the probit and linear specification of the 2PM.[7] From columns 1 and 3 in Table 3 it can be seen that the probability of NHRE adoption decreases in a statistically significantly manner with an increase in the share of hydropower and higher per capita gas production, confirming our hypothesis that the relatively low carbon intensity of these countries is indeed likely to diminish the incentives for investing in RET (Popp et al. 2011). In contrast, the probability of NHRE adoption increases in a statistically significantly manner with a higher per capita income and with renewable energy policies in place. As regards the latter, the probability of investment in NHRE production has been about 0.1 points higher since the adoption of the Kyoto Protocol in late 1997 and 0.3 points higher for countries with RE policies as compared to those countries without ($p<0.01$). When we specify these RE policies (column 3), we find that countries that have implemented economic or regulatory instruments show a 0.27 and 0.52 points higher probability to invest in NHRE production respectively. Remarkably, the variable "policy support" has a negative marginal effect on the adoption decision. This suggests that, in contrast to the use of economic or regulatory instruments, giving attention to institutional creation and strategic planning has a counterproductive effect on the diffusion of RET – we will return to this issue below. Finally, the results show that the adoption decision is neither affected by per capita coal production nor by growth in per capita electricity consumption. The latter suggests that expectations about future electricity demand apparently do not underlie the decision to adopt RET.

As compared to the probit model, the linear specification in Table 3 (columns 2 and 4) comprises a relatively small number of observations – confirming that still only a limited number of countries produce renewable grid electricity from non-hydro sources.[8] In sum, we find a positive and statistically significant marginal effect for the impact of the share of hydropower on the amount of NHRE produced: a 1 percent increase in the share of hydropower implies about a 0.7 percent increase in NHRE production. In contrast, the relationship between the level of fossil fuel production and NHRE production is negative, although the effect becomes largely statistically insignificant in the second specification (column 4). A cautious conclusion may be that hydropower acts as a complement to NHRE once the latter has been adopted, while fossil fuel technologies act as substitutes for NHRE.

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7 We refrain from accounting for unobserved heterogeneity by using a fixed effects estimator, because of the methodological problems associated with this – such as the incidental parameters problem or the issue of perfect prediction of the selection variable (see Cameron and Trivedi 2005). By using a palatable number of country-specific control variables, as well as explanatory variables related to the (renewable) energy sector, we expect the capture of most of the heterogeneity across countries. We also tested for the joint relevance of year effects, but they are not significant in our specifications. Hence, our results are not driven by factors that affect NHRE production in all countries over time in an equal way. We tested the sensitivity of our findings by excluding the more developed BRICS countries.

8 The OLS estimates and the marginal effects of the linear model rest upon divergent samples – the first are based on a subsample of countries investing in RET, the latter are based on the complete sample (as we have to account for the decision to adopt RET). This is also the case for the TSM, as presented later in this section; see Frondel and Vance (2010) for a discussion of this.

In addition, with the exception of the role of the Kyoto Protocol, we find that the effect of renewable energy policies on the amount of NHRE produced is largely consistent with the effect of these policies on the decision to adopt RET: the use of economic and regulatory instruments positively influences the amount of NHRE produced, while the opposite is again true for policy support (institutional creation and strategic planning). More precisely, countries with renewable energy policies produce on average about 1.4 percent more NHRE than do countries without such policies, whereby the effect of regulatory instruments appears to be stronger than that of economic instruments. In contrast to the adoption decision, the Kyoto Protocol appears to have thus far played only a minor role in the choice about the amount of NHRE to produce. However, similar to the adoption decision, higher per capita income also stimulates the amount of NHRE produced, although the effect is small. In contrast to the probit estimation, in the linear model we find that growth in per capita electricity consumption has statistically significant negative marginal effects on the amount of NHRE produced. This finding is similar to that of Popp et al. (2011), who also found growth in electricity consumption to have a negative – although not statistically significant – effect on the presence of different non-hydropower sources of renewable energy. Apparently, if future electricity demand is expected to increase considerably, countries tend to focus on alternatives to non-hydro sources for the production of their electricity.

Next, in Table 4, we present the results of using the TSM, first without an exclusion restriction (Table 4a) and then with an exclusion restriction (Table 4b). Before discussing the regression results in more detail we should make a few general observations about the model results. First, we refrain from presenting the results of the selection equation as they are identical to those of the probit models presented in Table 3. Second, in the model without an exclusion restriction the differences between coefficients and marginal effects – both in terms of their magnitude and statistical significance – underscore the importance of taking into account the decision about whether or not to adopt NHRE when interpreting the results of the outcome equation. Third, the high condition numbers of the regressors in both specifications of the TSM without an exclusion restriction (Table 4a) indicate that the results of this particular model type are likely to suffer from a multicollinearity problem, thus yielding unstable estimates.[9] To reduce this problem, we base our model identification not only on the non-linearity of the inverse Mills' ratio but also define an exclusion restriction by including the variable POLITY2, as discussed in the previous section (Table 4b). Finally, it should be noted that in the specification without an exclusion restriction (Table 4a), the *t*-statistic of the inverse Mills' ratio (lambda) – which is generally used to discriminate between the 2PM and the TSM – is significantly negative in the first specification (column 1), and insignificant in the second one (column 2). As regards the first specification, this suggests a sample selection problem as unobservable factors that reduce the probability of NHRE being adopted also seem to reduce the amount of NHRE produced.

9 In both specifications of the TSM without an exclusion restriction (columns 1 and 2) the condition numbers are between 44 and 50, and therefore far above the threshold of 20 suggested by Leung and Yu (1996).

Table 4: Regression Results of the 2PM

	(1)		(2)		(3)		(4)	
	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect: 2PM	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect
HYDRO SHARE	-0.0028***	-0.0010***	0.023***	0.0066***	-0.0028***	-0.0010***	0.023***	0.0068***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	1.70	0.62	-7.60**	-1.92*	2.11	0.77	-6.76*	-1.51
	[0.30]	[0.30]	[0.04]	[0.09]	[0.20]	[0.20]	[0.07]	[0.18]
GAS PRODUCTION	-5.40***	-1.97***	-1.24	-2.68*	-5.69***	-2.09***	-0.69	-2.50
	[0.00]	[0.00]	[0.71]	[0.09]	[0.00]	[0.00]	[0.83]	[0.12]
RE POLICY	0.83***	0.30***	1.71***	1.38***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.74***	0.27***	1.14***	0.96***
					[0.00]	[0.00]	[0.00]	[0.00]
POLICY SUPPORT					-0.65***	-0.24***	-0.53	-0.33***
					[0.00]	[0.00]	[0.13]	[0.00]
REGULATORY					1.42***	0.52***	1.48***	1.74***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.29***	0.10***	0.15	0.18***	0.29***	0.11***	0.14	0.17**
	[0.00]	[0.00]	[0.31]	[0.01]	[0.00]	[0.00]	[0.35]	[0.01]
GDP PER CAPITA	0.00033***	0.00012***	0.00031***	0.00025***	0.00034***	0.00012***	0.00032***	0.00025***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0020	0.00071	-0.035***	-0.011***	0.0019	0.00070	-0.031***	-0.010***
	[0.39]	[0.39]	[0.00]	[0.00]	[0.41]	[0.41]	[0.00]	[0.00]
Constant	-0.96***		-0.053		-0.96***		-0.081	
	[0.00]		[0.78]		[0.00]		[0.67]	
Observations	2732	2732	957	2732	2732	2732	957	2732
Log likelihood								
R-squared			0.251				0.261	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01
Source: Authors' own calculations.

For these reasons, we focus our discussion on the results of the model with an exclusion restriction, as presented in Table 4b. In general, the marginal effects of the TSM outcome equation are largely similar to those of the 2PM OLS specification presented in Table 3.[10] In short, the TSM estimation results also suggest that the probability of NHRE being adopted increases as the importance of other clean energy resources (hydropower and natural gas) decreases, with the implementation of RE policies other than policy support and with higher per capita income. In addition, the positive and statistically significant results for the exclusion variable POLITY2 support the hypothesis that the probability of NHRE being adopted is higher in stable democratic regimes, being sustained by high quality institutions. As regards the decision about how much electricity to produce from non-hydro renewable energy sources, the TSM results also largely confirm our earlier findings: the amount of NHRE produced is positively related to the share of hydropower, to per capita income, to the implementation of RE policies other than policy support and to the Kyoto protocol (again with a stronger effect of regulatory instruments than of economic instruments); it is negatively related to growth in electricity consumption. In contrast to the 2PM, our TSM results confirm a statistically significant negative relationship between per capita coal production and NHRE production – suggesting that coal abundance decreases the attractiveness of the NHRE alternative, for example by (a combination of) raising the relative costs of NHRE, lowering energy security concerns and undermining support for stringent emission reduction policies.

In Section 2 we revealed that within the group of developing nations the BRICS countries feature particularly high annual growth rates for NHRE, and especially so during the last decade. It may therefore be the case that our results are driven primarily by developments in the BRICS countries. To control for this potential bias, we have re-estimated our 2PM and TSM models for a sample that excludes these countries. The results from this exercise are presented in Tables A2 and A3 in the Appendix, and show that, in general, our findings appear to be very robust even with the exclusion of the BRICS countries. In both models the main difference is that their exclusion considerably strengthens the negative impact of fossil fuel abundance on NHRE diffusion.

10 Note that the marginal effects of the 2PM should be interpreted as the impact on the actual outcome, while in contrast the marginal effects of the TSM relate to the potential outcome of our dependent variable.

Table 4a: Regression Results of the TSM without an Exclusion Restriction

	Without an Exclusion Restriction			
	(1)		(2)	
	Coefficient: Outcome	Marginal Effect: Outcome	Coefficient: Outcome	Marginal Effect
HYDRO SHARE	0.025***	0.021***	0.024***	0.022***
	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	-10.3**	-8.49***	-8.38**	-7.12**
	[0.01]	[0.01]	[0.03]	[0.02]
GAS PRODUCTION	4.44	-1.32	2.34	-1.07
	[0.32]	[0.72]	[0.55]	[0.77]
RE POLICY	1.07***	1.88***		
	[0.01]	[0.00]		
ECONOMIC INSTRUMENTS			0.84**	1.24***
			[0.02]	[0.00]
POLICY SUPPORT			-0.26	-0.67**
			[0.52]	[0.03]
REGULATORY INSTRUMENTS			1.05***	1.74***
			[0.01]	[0.00]
KYOTO	-0.12	0.18	-0.018	0.15
	[0.57]	[0.31]	[0.93]	[0.41]
GDP PER CAPITA	0.000054	0.00041***	0.00018	0.00038***
	[0.70]	[0.00]	[0.11]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	-0.037***	-0.035***	-0.033***	-0.032***
	[0.00]	[0.00]	[0.00]	[0.00]
POLITY2				
lambda	-1.53**		-0.86	
	[0.05]		[0.16]	
Constant	2.06*		1.12	
	[0.06]		[0.20]	
Observations	2732	2732	2732	2732
Uncensored observations	957		957	
Wald statistic	148.69		163.83	
rho	-0.63		-0.39	
sigma	2.45		2.23	
p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01				

Source: Authors' own calculations.

Table 4b: Regression Results of the TSM with an Exclusion Restriction

	With an Exclusion Restriction							
	(1)		(2)		(3)		(4)	
	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect
HYDRO SHARE	-0.0041***	-0.0015***	0.024***	0.019***	-0.0041***	-0.0015***	0.024***	0.020***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	0.10	0.037	-10.7***	-10.52***	0.63	0.23	-9.39**	-8.76***
	[0.95]	[0.95]	[0.01]	[0.00]	[0.71]	[0.71]	[0.02]	[0.01]
GAS PRODUCTION	-4.92***	-1.80***	5.45	-1.26	-5.45***	-2.00***	4.04	-1.44
	[0.00]	[0.00]	[0.15]	[0.72]	[0.00]	[0.00]	[0.27]	[0.69]
RE POLICY	0.72***	0.26***	1.01***	1.91***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.60***	0.22***	0.65**	1.21***
					[0.00]	[0.00]	[0.04]	[0.00]
POLICY SUPPORT					-0.59***	-0.22***	0.059	-0.57**
					[0.00]	[0.00]	[0.88]	[0.03]
REGULATORY INSTRUMENTS					1.38***	0.51***	0.77**	1.91***
					[0.00]	[0.00]	[0.02]	[0.00]
KYOTO	0.20***	0.071***	-0.21	0.053	0.20***	0.075***	-0.14	0.062
	[0.00]	[0.00]	[0.23]	[0.77]	[0.00]	[0.00]	[0.41]	[0.74]
GDP PER CAPITA	0.00030***	0.00011***	-0.000015	0.00040***	0.00031***	0.00011***	0.000076	0.00039***
	[0.00]	[0.00]	[0.85]	[0.00]	[0.00]	[0.00]	[0.31]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0038	0.0014	-0.038***	-0.033***	0.0037	0.0014	-0.034***	-0.031***
	[0.11]	[0.11]	[0.00]	[0.00]	[0.12]	[0.12]	[0.00]	[0.00]

POLITY2	0.046***	0.017***			0.044***	0.016***		
	[0.00]	[0.00]			[0.00]	[0.00]		
lambda			-1.97***				-1.47***	
			[0.00]				[0.00]	
Constant	-0.83***		2.56***		-0.83***		1.90***	
	[0.00]		[0.00]		[0.00]		[0.00]	
Observations		2676	2676	2676		2676	2676	2676
Uncensored observations			957				957	
Wald statistic			139.69				150.66	
rho			-0.76				-0.62	
sigma			2.59				2.38	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01
Source: Authors' own calculations.

More precisely, in the sample without the BRICS countries both the 2PM and the TSM document the negative influence of high per capita gas production on the probability of NHRE adoption, while the amount of NHRE produced is negatively influenced by both per capita coal and gas production. This finding supports the hypothesis that in many developing countries NHRE and fossil fuels are still primarily alternatives, rather than complements, to each other. These results at least confirm the observation that, in light of current technology options and market conditions, competition from lower cost conventional power production methods – notably gas turbine combined cycle systems – will continue to undercut RET (Chow et al. 2003; Owen 2006). In addition, our robustness check reveals that the exclusion of the BRICS countries also considerably strengthens the previously discovered negative impact of policy support on NHRE diffusion.

The negative relationship between policy support and NHRE diffusion is counterintuitive and demands clarification, especially given the fact that it appears to be robust across model specifications and samples. We think a plausible explanation for this puzzle lies in the reality that programs for institutional creation and strategic planning in developing countries do not take away from the fact that governments in these countries are often weak institutional players – due to low levels of human capital, a patronage-based human resource policy and the lack of effective democratic control mechanisms. In addition, effective policy formulation and implementation is frequently complicated by the fact that government entities in many developing countries depend to a large extent on a range of different donor organizations, each with their own priorities, programs and time horizons. As a result, a discrepancy often exists between official policies and programs at the senior policy level on the one hand and the actual behavior of officials in executive positions on the other. For example, Mulder and Tembe (2008) argue that the Mozambican government, under pressure from the World Bank, created by decree an electricity market regulator, but for a long time effectively blocked the implementation of this newly created institution by withholding funds from it. Our estimation results suggest that economic or regulatory instruments are much less prone to the effects of such mechanisms than strategic planning and the relatively intangible policy of supporting institutional creation. Moreover, the observed negative impact of the latter two on NHRE diffusion indicates that weaker governments tend to have more "policy support" programs – which can be well explained in cases where these programs are primarily backed by donors. In the next section we further examine this issue, by controlling for the role of ODA in explaining NHRE diffusion.

5 Extended Results

In this section we give further scrutiny to how NHRE diffusion in developing countries is influenced by a country's energy mix, as well as by more general drivers of technology adoption. As argued in Section 2, in addition to per capita production of coal and natural gas – which (implicitly) have a relative impact on energy prices and the carbon intensity of domestic electricity production – it may be important to control our regressions for the diversity of a country's energy mix.

The underlying reason for this is that the domination of the market by a certain technology (i.e., a lack of energy diversity) may (negatively) influence NHRE diffusion if it reflects the vested interests of a particular subgroup in the economy, who may engage in efforts to keep the old technology in place – as (widespread) RET adoption would reduce the extent of their expertise and rents. Alternatively, agents may prefer a mix of technologies because of the value of the implied complementary characteristics of them. To this end, we have developed an index that takes the value zero if a country produces its energy from one source of energy, and converges to one the more diversified a country is (see Equation 1). A higher index obviously reduces the chance of NHRE diffusion being hindered by strong vested interests. The estimation results for our 2PM and TSM models are presented in Tables 5 and 6 respectively.[11]

The results presented in Tables 5 and 6 also indicate that our baseline results, as presented in the previous section, remain largely unaffected by controlling for the role of energy diversity. The most important difference is that the negative impact of fossil fuel production on NHRE production is, as noted, now largely captured by our energy diversity index. According to the same logic, the inclusion of this index marginally weakens the positive impact of the share of hydropower on NHRE production while it slightly strengthens the positive impact of the share of hydropower on the probability of NHRE adoption. Finally, the inclusion of energy diversity somewhat reduces the influence of several policy variables, most notably the negative impact of policy support on NHRE diffusion.

11 Note that in this regression multicollinearity does not seem to be a problem, since we have a condition number below 20. Moreover, the coefficient of lambda suggests that we have a selection problem; as a result of this, the preferred model is a TSM with an exclusion restriction.

Table 5: Estimated Coefficients from the 2PM – The Role of the Energy Mix

	(1)		(2)		(3)		(4)	
	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect:	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect:
HYDRO SHARE	-0.0045***	-0.0017***	0.021***	0.0056***	-0.0045***	-0.0017***	0.021***	0.0058***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	-1.50	-0.56	-6.62	-3.07*	-1.02	-0.38	-5.12	-2.30
	[0.38]	[0.38]	[0.10]	[0.06]	[0.56]	[0.56]	[0.21]	[0.14]
GAS PRODUCTION	-6.90***	-2.55***	0.37	-2.99	-7.03***	-2.61***	1.61	-2.48
	[0.00]	[0.00]	[0.92]	[0.10]	[0.00]	[0.00]	[0.64]	[0.17]
RE POLICY	0.69***	0.25***	1.91***	1.40***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.59***	0.22***	1.28***	0.96***
					[0.00]	[0.00]	[0.00]	[0.00]
POLICY SUPPORT					-0.48**	-0.18**	-0.71*	-0.36***
					[0.02]	[0.02]	[0.05]	[0.00]
REGULATORY INSTRUMENTS					1.21***	0.45***	1.76***	1.87***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.28***	0.10***	0.062	0.15***	0.27***	0.10***	0.041	0.13**
	[0.00]	[0.00]	[0.70]	[0.01]	[0.00]	[0.00]	[0.80]	[0.02]
GDP PER CAPITA	0.00031***	0.00012***	0.00030***	0.00025***	0.00032***	0.00012***	0.00032***	0.00025***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0014	0.00052	-0.037***	-0.013***	0.0014	0.00051	-0.033***	-0.011***
	[0.56]	[0.56]	[0.00]	[0.00]	[0.57]	[0.57]	[0.00]	[0.00]
ENERGY MIX	0.80***	0.30***	-1.49***	-0.18	0.68***	0.25***	-1.71***	-0.32**
	[0.00]	[0.00]	[0.00]	[0.21]	[0.00]	[0.00]	[0.00]	[0.02]
Constant	-0.91***		0.36		-0.89***		0.36	
	[0.00]		[0.10]		[0.00]		[0.10]	
Observations	2439	2439	888	2439	2439	2439	888	2439
Log likelihood	-1312.57				-1298.86			
R-squared			0.245				0.259	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01

Source: Authors' own calculations.

Table 6: Estimated Coefficients from the TSM with an Exclusion Restriction – The Role of the Energy Mix

	With an Exclusion Restriction							
	(1)		(2)		(3)		(4)	
	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect
HYDRO SHARE	-0.0059***	-0.0022***	0.025***	0.018***	-0.0059***	-0.0022***	0.024***	0.019***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	-3.25*	-1.20*	-6.13	-10.05***	-2.74	-1.02	-5.18	-7.57**
	[0.07]	[0.07]	[0.16]	[0.00]	[0.12]	[0.12]	[0.22]	[0.02]
GAS PRODUCTION	-6.48***	-2.39***	8.74**	0.90	-6.81***	-2.53***	7.55*	1.59
	[0.00]	[0.00]	[0.03]	[0.84]	[0.00]	[0.00]	[0.06]	[0.72]
RE POLICY	0.58***	0.21***	1.50***	2.16***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.44***	0.16***	0.96***	1.33***
					[0.01]	[0.01]	[0.00]	[0.00]
POLICY SUPPORT					-0.41*	-0.15*	-0.34	-0.71**
					[0.05]	[0.05]	[0.40]	[0.01]
REGULATORY INSTRUMENTS					1.17***	0.43***	1.31***	2.17***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.18***	0.066***	-0.30	-0.08	0.18***	0.066***	-0.22	-0.06
	[0.00]	[0.00]	[0.11]	[0.59]	[0.00]	[0.00]	[0.23]	[0.70]
GDP PER CAPITA	0.00028***	0.00010***	0.000029	0.00037***	0.00028***	0.00011***	0.00012	0.00037***
	[0.00]	[0.00]	[0.71]	[0.00]	[0.00]	[0.00]	[0.11]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0036	0.0013	-0.039***	-0.035***	0.0035	0.0013	-0.035***	-0.031***
	[0.14]	[0.14]	[0.00]	[0.00]	[0.15]	[0.15]	[0.00]	[0.00]

ENERGY MIX	0.84***	0.31***	-2.61***	-1.59***	0.73***	0.27***	-2.40***	-1.76***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
POLITY2	0.049***	0.018***			0.048***	0.018***		
	[0.00]	[0.00]			[0.00]	[0.00]		
lambda			-1.77***				-1.29***	
			[0.00]				[0.00]	
Constant	-0.78***		2.71***		-0.76***		2.07***	
	[0.00]		[0.00]		[0.00]		[0.00]	
Observations		2385	2385	2385		2385	2385	2385
Uncensored observations			888				888	
Wald statistic			188.76				201.50	
rho			-0.71				-0.56	
sigma			2.51				2.32	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01
Source: Authors' own calculations.

Next we assess the role of more general drivers of technology adoption on the diffusion of NHRE in developing countries, including schooling, financial-market development, FDI, trade and ODA. The results are presented in Tables 7 and 8.[12] From these it can be seen that the addition of more general control variables implies a loss of about 40 percent of observations, as we do not have data for all countries over the whole sample period. At the same time, the results show that our baseline results are largely robust to this reduction in the sample size.

More precisely, the most important change to the baseline results is that controlling for general drivers of technology adoption reinforces the negative relationship between fossil fuel production and NHRE diffusion, as well as the negative relationship between the share of hydropower and the probability of NHRE adoption. Also, the previously found remarkable negative role of policy support gets somewhat stronger. In addition, the inclusion of the additional control variables somewhat weakens the role of per capita income, which is obviously a consequence of the positive relationship that exists between income and several of the general drivers of technology adoption – most notably schooling, financial-market development and trade.

As expected, in both models we find higher levels of education to have positive and significant marginal effects, supporting the hypothesis that higher levels of human capital stimulate the speed of learning with regard to the invention and implementation of new technologies. This result is in line with Popp et al. (2011), who found knowledge to have a robust but small effect on renewable energy adoption in developed countries. As regards the other potential general drivers of RET adoption, Tables 7 and 8 contain various surprising findings. First, there is no evidence that having access to finance has a statistically significant positive effect on NHRE diffusion, as measured by the ratio of deposit money bank assets to central bank assets (ASSETS). This result contradicts our hypothesis that having access to finance is an important prerequisite for RET adoption, given the relatively high upfront costs of most RET. It also contrasts with the earlier findings of Brunnschweiler (2010), who reports a positive association between the level of commercial banking and the amount of electricity generated from RET. These opposing conclusions are likely to result from the different specifications of the model, dependent variable and control variables. In contrast to Brunnschweiler (2010), we explicitly model the decision about whether or not to adopt RET; we focus on non-hydro power as our dependent variable; and we consider the role of specific energy policies, trade, and ODA in explaining NHRE diffusion.

In addition, we find that ODA has a negative impact on the NHRE adoption decision, while its impact on the amount of NHRE produced appears to be by and large statistically insignificant (albeit positive). This result contrasts with the observation that despite ODA flows being relatively low compared to private investment flows, they are still an important source of funding for technology transfer in countries that receive little FDI (Gupta et al. 2007). Since 1991, for example, the Global Environment Facility (GEF) – a joint program run by the United Nations Development Program, the United Nations Environment Program and the World Bank – has invested almost 2 billion USD in climate change projects, of which 90 percent has gone to energy efficiency, renewable energy, GHG reduction and sustainable transportation initiatives (de Coninck et al. 2008).

12 Note that the estimated condition numbers of the TSM models with an exclusion restriction are slightly above 30 for both specifications, indicating that these results may suffer from multicollinearity.

We can think of two possible explanations for this result. First, it may be the case that in the RET domain ODA primarily funds off-grid electricity production – for example, in the form of isolated PV or mini-hydro systems in remote rural areas – resulting in our dataset (which includes only grid-based electricity data) being unable to adequately capture the role of ODA. Second, it may be the case that ODA – because it has as its very objective the fight against the problems that prevail in the poorest countries – tends to favor countries with relatively weak governments. As such, donor-driven investment and attention given to RET adoption are insufficient in themselves to compensate for the fragile institutional environment existing in these countries – as a result, NHRE diffusion remains relatively slow. This second explanation aligns with the previously discussed finding that attention given to policy support tends to delay NHRE diffusion in developing countries.

Finally, we find that in both models increasing FDI lowers the probability of NHRE adoption as well as the amount of NHRE produced. Likewise, the marginal effects of TRADE are negative and significant in the 2PM probit and TSM selection models, suggesting that the probability of NHRE adoption is inversely related to higher trade intensity. These findings contradict the notion that trade and FDI facilitate the international transfer of RET by stimulating international knowledge diffusion – for example through high-tech imports, joint ventures or increasing international competition. On the contrary, our findings support the hypothesis that knowledge spillovers are a local rather than a global phenomenon (Keller 2004). This latter reality may be caused by the fact that many developing countries predominantly trade with neighboring countries holding comparable (and equally limited) physical and human capital endowments.

6 Conclusion

In this paper we have studied the adoption and diffusion of non-hydro renewable energy (NHRE) technologies for electricity generation. In contrast to most studies on renewable energy technologies (RET), which consider almost exclusively OECD economies, we have analyzed NHRE diffusion across 108 developing countries between 1980 and 2010, assessing a wide range of potential drivers of, and barriers to, RET adoption. For this purpose we have used the two-part model (Duan et al. 1984) and Heckman's (1979) two-step selection model, in which we have explicitly modeled the choice about whether or not to adopt NHRE as well as the choice about the amount of electricity to produce from renewable energy sources. The decision to use this two-stage estimation method was based on their ability to deal with a large number of zero-valued observations in our dependent variable as well as with a potential sample selection problem. The first methodological problem arises from the fact that many countries do not yet, or have only recently begun to, invest in (non-hydro) renewable electricity production. The sample selection issue arises from uncertainty about whether the zero-valued observations reflect no investment in NHRE or rather an absence of data, because off-grid electricity production is currently largely excluded from the available cross-country datasets.

We find that the implementation of economic and regulatory instruments, higher per capita income and schooling levels and stable, democratic regimes increase both the probability of NHRE adoption as well as the amount of NHRE produced. In contrast, the probability of adoption decreases with a greater abundance of alternative clean energy resources like hydropower and natural gas, as well as with increasing trade intensity and higher levels of foreign direct investment (FDI) and official development assistance (ODA). In addition, we found that having a large share of hydropower and higher per capita income contributes to increasing NHRE production, while fossil fuel abundance and growing electricity consumption appear to have a negative influence on the amount of NHRE produced. Furthermore, we find that having a diverse energy mix increases the probability of NHRE being adopted but reduces the amount of NHRE electricity produced, while institutional and strategic policy support programs tend to reduce both the probability of adoption and the amount of NHRE produced. Finally, we find weak support for a positive influence of the Kyoto Protocol on NHRE diffusion and no evidence for financial sector development having any influence. These results are largely robust to different model specifications, and do not appear to be influenced by the large emerging economies – in other words, Brazil, Russia, India, China and South Africa (BRICS).

In short, our results suggest that in many developing countries NHRE and fossil fuels are primarily substitutes, rather than complements, to each other. The finding that fossil fuel abundance decreases the attractiveness of the NHRE alternative may arise from the fact that high levels of fossil fuel production tend to increase the relative price of NHRE and to discourage energy security concerns and undermine support for stringent emission reduction policies (Popp et al. 2011). Further research is needed to assess which of these mechanisms prevail in which countries, and why. In addition, the robust negative relationship between growth in electricity consumption and the amount of NHRE produced provides evidence that the expected increase in future electricity demand leads countries to focus on alternatives to non-hydro renewable sources for their electricity production. Given the positive growth prospects for many developing countries, this finding obviously warns against being too optimistic with regard to the likelihood of there being a reduction in the current rapid growth rate of energy-related CO_2 emissions from within developing countries.

The negative relationship between policy support programs and NHRE diffusion lends credence to the hypothesis that these programs are often donor-driven and ineffective against the backdrop of weak institutional arrangements – circumstances which can often be found to exist in poor countries. This cautious conclusion is strengthened by our finding that ODA reduces the probability of NHRE adoption. It is likely that ODA is directed towards the poorest countries, and thus implicitly tends to favor those with relatively weak governments. Our results suggest that donor-driven investment and attention given to NHRE adoption are insufficient in themselves to compensate for the fragile institutional environment in these countries. Alternatively, it may be that ODA primarily funds off-grid electricity production, as a result of which our dataset might underestimate the impact of these initiatives because only grid-based electricity data is included. The further identification of these mechanisms remains an absolute necessity that future research will have to address.

Finally, it is well-known that the combination of uncertainty and some degree of irreversibility in investment slows down technology adoption because it creates an option value of waiting (see, for example, Balcer and Lippman 1984; Dixit and Pindyck 1994). In the context of competing technologies, uncertainty of course mirrors a degree of certainty about the alternative options. To some extent, consistent policies may change the sense of balance by reducing uncertainty about the future. Unfortunately, the current limitations regarding available data prevent the accurate assessment of this issue across developing countries. Even so, our research nevertheless still shows that the interplay between energy policies and technological competition in developing countries is a key issue to be faced on the road to reducing global carbon emissions.

Table 7: Estimated Coefficients from the 2PM – The Role of General Drivers of Technology Adoption

	(1)		(2)		(3)		(4)	
	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect
HYDRO SHARE	-0.0074***	-0.0028***	0.021***	0.0055***	-0.0077***	-0.0029***	0.020***	0.0054***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	-3.71	-1.40	-9.19**	-4.92***	-3.12	-1.19	-8.72*	-4.47***
	[0.11]	[0.11]	[0.04]	[0.00]	[0.19]	[0.19]	[0.06]	[0.00]
GAS PRODUCTION	-26.5***	-9.97***	-46.4***	-27.64***	-27.2***	-10.3***	-44.4***	-26.62***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
RE POLICY	0.71***	0.27***	1.66***	1.21***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.71***	0.27***	0.84**	0.73***
					[0.00]	[0.00]	[0.01]	[0.00]
POLICY SUPPORT					-1.00***	-0.38***	-0.12	-0.32***
					[0.00]	[0.00]	[0.79]	[0.00]
REGULATORY INSTRUMENTS					1.39***	0.53***	1.51***	1.62***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.24***	0.091***	0.49**	0.28***	0.27***	0.10***	0.50**	0.29***
	[0.00]	[0.00]	[0.02]	[0.00]	[0.00]	[0.00]	[0.02]	[0.00]
GDP PER CAPITA	0.00025***	0.000094***	0.00037***	0.00024***	0.00027***	0.00010***	0.00040***	0.00025***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0017	0.00065	-0.037***	-0.014***	0.0017	0.00066	-0.035***	-0.013***
	[0.58]	[0.58]	[0.00]	[0.00]	[0.58]	[0.58]	[0.00]	[0.01]
ASSETS	0.00044	0.00016	0.0013	0.00067	0.00045	0.00017	0.00094	0.00052
	[0.73]	[0.73]	[0.64]	[0.48]	[0.73]	[0.73]	[0.74]	[0.59]

NET FDI INFLOW	-0.033***	-0.012***	-0.081**	-0.043***	-0.028**	-0.011**	-0.070**	-0.037***
	[0.00]	[0.00]	[0.02]	[0.00]	[0.01]	[0.01]	[0.04]	[0.00]
ODA	-0.025***	-0.0095***	0.019	-0.0016	-0.024***	-0.0092***	0.022	0.00029
	[0.00]	[0.00]	[0.23]	[0.87]	[0.00]	[0.00]	[0.17]	[0.98]
SECONDARY ENROLLMENT	0.015***	0.0056***	0.0086	0.0088***	0.015***	0.0056***	0.0073	0.0078***
	[0.00]	[0.00]	[0.12]	[0.00]	[0.00]	[0.00]	[0.19]	[0.00]
TRADE	-0.0060***	-0.0023***	0.0051*	-0.00015	-0.0071***	-0.0027***	0.0035	-0.0010
	[0.00]	[0.00]	[0.06]	[0.90]	[0.00]	[0.00]	[0.20]	[0.39]
Constant	-0.50***		-0.79**		-0.45***		-0.67*	
	[0.00]		[0.04]		[0.00]		[0.07]	
Observations	1652	1652	649	1652	1652	1652	649	1652
Log likelihood	-809.48				-792.44			
R-squared			0.290				0.293	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01

Source: Authors' own calculations.

Table 8: Estimated Coefficients from the TSM with an Exclusion Restriction – The Role of General Drivers of Technology Adoption

	(1)		(2)		(3)		(4)	
	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect	Coefficient: Selection	Marginal Effect: Selection	Coefficient: Outcome	Marginal Effect
HYDRO SHARE	-0.0079***	-0.0030***	0.034***	0.017***	-0.0082***	-0.0031***	0.028***	0.018***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	-3.20	-1.21	-3.34	-9.91***	-2.55	-0.97	-5.79	-9.14***
	[0.18]	[0.18]	[0.57]	[0.00]	[0.29]	[0.29]	[0.26]	[0.00]
GAS PRODUCTION	-25.0***	-9.41***	2.21	-49.11***	-26.0***	-9.91***	-15.3	-49.44***
	[0.00]	[0.00]	[0.88]	[0.00]	[0.00]	[0.00]	[0.24]	[0.00]
RE POLICY	0.64***	0.24***	0.82**	2.04***				
	[0.00]	[0.00]	[0.02]	[0.00]				
ECONOMIC INSTRUMENTS					0.54**	0.20**	0.31	0.97***
					[0.01]	[0.01]	[0.45]	[0.00]
POLICY SUPPORT					-0.84***	-0.32***	0.68	-0.52
					[0.00]	[0.00]	[0.23]	[0.15]
REGULATORY INSTRUMENTS					1.41***	0.54***	0.79**	2.29***
					[0.00]	[0.00]	[0.05]	[0.00]
KYOTO	0.15*	0.057*	0.16	0.47*	0.18**	0.070**	0.26	0.50*
	[0.08]	[0.08]	[0.54]	[0.06]	[0.04]	[0.04]	[0.29]	[0.05]
GDP PER CAPITA	0.00021***	0.000078***	0.000074	0.00050***	0.00023***	0.000088***	0.00019**	0.00050***
	[0.00]	[0.00]	[0.47]	[0.00]	[0.00]	[0.00]	[0.03]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0025	0.00095	-0.040***	-0.035***	0.0025	0.00095	-0.037***	-0.034***
	[0.42]	[0.42]	[0.00]	[0.00]	[0.43]	[0.43]	[0.00]	[0.00]
ASSETS	0.00095	0.00036	0.00074	0.0027	0.00099	0.00038	0.00045	0.0018
	[0.46]	[0.46]	[0.83]	[0.22]	[0.46]	[0.46]	[0.88]	[0.44]

NET FDI INFLOW	-0.039***	-0.015***	-0.018	-0.097*	-0.034***	-0.013***	-0.035	-0.080***
	[0.00]	[0.00]	[0.66]	[0.09]	[0.00]	[0.00]	[0.33]	[0.00]
ODA	-0.026***	-0.0097***	0.087***	0.033*	-0.025***	-0.0095***	0.063***	0.030
	[0.00]	[0.00]	[0.00]	[0.09]	[0.00]	[0.00]	[0.00]	[0.15]
SECONDARY ENROLLMENT	0.014***	0.0054***	-0.019**	0.010**	0.014***	0.0054***	-0.010	0.0086
	[0.00]	[0.00]	[0.04]	[0.05]	[0.00]	[0.00]	[0.20]	[0.11]
TRADE	-0.0054***	-0.0020***	0.014***	0.0025	-0.0065***	-0.0025***	0.010***	0.0015
	[0.00]	[0.00]	[0.00]	[0.43]	[0.00]	[0.00]	[0.00]	[0.64]
POLITY2	0.032***	0.012***			0.030***	0.012***		
	[0.00]	[0.00]			[0.00]	[0.00]		
lambda			-3.10***				-2.00***	
			[0.00]				[0.00]	
Constant	-0.40***		2.42***		-0.35***		1.39*	
	[0.00]		[0.01]		[0.01]		[0.06]	
Observations		1637	1637	1637		1637	1637	1637
Uncensored observations			649				649	
Wald statistic			133.01				149.73	
rho			-0.99				-0.77	
sigma			3.12				2.60	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01

Source: Authors' own calculations.

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Appendix

Table A1: Country Sample

No.	Country Name	Income Level	No.	Country Name	Income Level
1	Afghanistan	LIC	55	Lesotho	LMIC
2	Albania	UMIC	56	Liberia	LIC
3	Algeria	UMIC	57	Libya	UMIC
4	Angola	LMIC	58	Lithuania	UMIC
5	Argentina	UMIC	59	Macedonia	UMIC
6	Armenia	LMIC	60	Madagascar	LIC
7	Azerbaijan	UMIC	61	Malawi	LIC
8	Bangladesh	LIC	62	Malaysia	UMIC
9	Belarus	UMIC	63	Mali	LIC
10	Benin	LIC	64	Mauritania	LMIC
11	Bhutan	LMIC	65	Mexico	UMIC
12	Bolivia	LMIC	66	Moldova	LMIC
13	Bosnia-Herzegovina	UMIC	67	Mongolia	LMIC
14	Botswana	UMIC	68	Montenegro	UMIC
15	Brazil	UMIC	69	Morocco	LMIC
16	Bulgaria	UMIC	70	Mozambique	LIC
17	Burkina Faso	LIC	71	Myanmar	LIC
18	Burundi	LIC	72	Namibia	UMIC
19	Cambodia	LIC	73	Nepal	LIC
20	Cameroon	LMIC	74	Nicaragua	LMIC
21	Central African	LIC	75	Niger	LIC
22	Chad	LIC	76	Nigeria	LMIC
23	Chile	UMIC	77	Pakistan	LMIC
24	China	UMIC	78	Panama	UMIC
25	Colombia	UMIC	79	Paraguay	LMIC
26	Congo-Kinshasa	LIC	80	Peru	UMIC
27	Congo-Brazzaville	LMIC	81	Philippines	LMIC
28	Costa Rica	UMIC	82	Romania	UMIC
29	Cote d'Ivoire	LMIC	83	Russia	UMIC
30	Djibouti	LMIC	84	Rwanda	LIC
31	Ecuador	UMIC	85	Senegal	LMIC
32	Egypt	LMIC	86	Serbia	UMIC
33	El Salvador	LMIC	87	Sierra Leone	LIC
34	Eritrea	LIC	88	Somalia	LIC
35	Ethiopia	LIC	89	South Africa	UMIC
36	Gabon	UMIC	90	Sri Lanka	LMIC
37	Gambia	LIC	91	Swaziland	LMIC
38	Georgia	LMIC	92	SyriaRepublic	LMIC
39	Ghana	LMIC	93	Tajikistan	LIC
40	Guatemala	LMIC	94	Tanzania	LIC
41	Guinea	LIC	95	Thailand	UMIC
42	Honduras	LMIC	96	Togo	LIC
43	India	LMIC	97	Tunisia	UMIC
44	Indonesia	LMIC	98	Turkey	UMIC

45	Iran	UMIC	99	Turkmenistan	LMIC
46	Iraq	LMIC	100	Uganda	LIC
47	Jordan	UMIC	101	Ukraine	LMIC
48	Kazakhstan	UMIC	102	Uruguay	UMIC
49	Kenya	LIC	103	Uzbekistan	LMIC
50	Korea, Dem. Rep.	LIC	104	Venezuela	UMIC
51	Kyrgyzstan	LIC	105	Vietnam	LMIC
52	Laos	LMIC	106	Yemen	LMIC
53	Latvia	UMIC	107	Zambia	LMIC
54	Lebanon	UMIC	108	Zimbabwe	LIC

* LIC denotes low-income countries, LMIC lower-middle-income countries, and UMIC upper-middle-income countries.

Source: Typology of income levels as defined by Beck et al. (2012).

Table A2: Estimated Coefficients from the 2PM – Excluding the BRICS Countries

	Excluding Brazil, Russia, India, China and South Africa							
	(1)		(2)		(3)		(4)	
	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect	Coefficient: Probit	Marginal Effect: Probit	Coefficient: OLS	Marginal Effect
HYDRO SHARE	-0.0037***	-0.0013***	0.019***	0.0044***	-0.0038***	-0.0013***	0.019***	0.0046***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	0.85	0.29	-19.6***	-5.98***	0.70	0.25	-20.2***	-6.27***
	[0.71]	[0.71]	[0.00]	[0.00]	[0.76]	[0.76]	[0.00]	[0.00]
GAS PRODUCTION	-14.7***	-5.11***	-36.2***	-17.78***	-14.9***	-5.25***	-35.3***	-17.17***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
RE POLICY	0.64***	0.22***	1.88***	1.24***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.67***	0.23***	0.91***	0.75***
					[0.00]	[0.00]	[0.00]	[0.00]
POLICY SUPPORT					-1.54***	-0.54***	0.092	-0.39***
					[0.00]	[0.00]	[0.86]	[0.00]
REGULATORY INSTRUMENTS					1.71***	0.60***	1.70***	2.10***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.31***	0.11***	-0.052	0.12*	0.32***	0.11***	-0.068	0.10**
	[0.00]	[0.00]	[0.75]	[0.06]	[0.00]	[0.00]	[0.67]	[0.05]
GDP PER CAPITA	0.00037***	0.00013***	0.00033***	0.00026***	0.00039***	0.00014***	0.00033***	0.00026***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0017	0.00060	-0.028***	-0.0084**	0.0013	0.00045	-0.026***	-0.0081**
	[0.46]	[0.46]	[0.00]	[0.01]	[0.59]	[0.59]	[0.01]	[0.02]
Constant	-0.96***		0.43**		-0.99***		0.42**	
	[0.00]		[0.03]		[0.00]		[0.04]	
Observations	2594	2594	848	2594	2594	2594	848	2594
Log likelihood	-1342.71				-1299.34			
R-squared			0.266				0.275	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01
Source: Authors' own calculations.

Table A3: Estimated Coefficients from the TSM – Excluding the BRICS Countries and with an Exclusion Restriction

	Excluding Brazil, Russia, India, China and South Africa – With an Exclusion Restriction							
	(1)		(2)		(3)		(4)	
	Coefficient: Selection	Marginal Effect:	Coefficient: Outcome	Marginal Effect	Coefficient: Selection	Marginal Effect:	Coefficient: Outcome	Marginal Effect
HYDRO SHARE	-0.0050***	-0.0017***	0.022***	0.015***	-0.0052***	-0.0018***	0.021***	0.016***
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
COAL PRODUCTION	0.29	0.10	-23.4***	-22.98***	0.095	0.033	-23.1***	-23.03***
	[0.90]	[0.90]	[0.00]	[0.00]	[0.97]	[0.97]	[0.00]	[0.00]
GAS PRODUCTION	-14.6***	-5.08***	-14.5*	-34.55***	-15.3***	-5.39***	-20.4***	-36.01***
	[0.00]	[0.00]	[0.08]	[0.00]	[0.00]	[0.00]	[0.01]	[0.00]
RE POLICY	0.49***	0.17***	1.35***	1.99***				
	[0.00]	[0.00]	[0.00]	[0.00]				
ECONOMIC INSTRUMENTS					0.54***	0.19***	0.51	1.03***
					[0.00]	[0.00]	[0.13]	[0.00]
POLICY SUPPORT					-1.63***	-0.57***	1.09*	-0.80
					[0.00]	[0.00]	[0.07]	[0.12]
REGULATORY INSTRUMENTS					1.81***	0.64***	0.99***	2.39***
					[0.00]	[0.00]	[0.00]	[0.00]
KYOTO	0.23***	0.078***	-0.42**	-0.11	0.23***	0.082***	-0.36**	-0.12
	[0.00]	[0.00]	[0.03]	[0.55]	[0.00]	[0.00]	[0.05]	[0.54]
GDP PER CAPITA	0.00035***	0.00012***	-0.000052	0.00043***	0.00038***	0.00013***	0.000044	0.00043***
	[0.00]	[0.00]	[0.59]	[0.00]	[0.00]	[0.00]	[0.61]	[0.00]
GROWTH IN ELECTRICITY CONSUMPTION	0.0035	0.0012	-0.032***	-0.027**	0.0030	0.0011	-0.030***	-0.027**
	[0.15]	[0.15]	[0.00]	[0.01]	[0.21]	[0.21]	[0.00]	[0.01]

POLITY2	0.042***	0.014***			0.043***	0.015***		
	[0.00]	[0.00]			[0.00]	[0.00]		
Lambda			-1.94***				-1.47***	
			[0.00]				[0.00]	
Constant	-0.84***		3.00***		-0.87***		2.39***	
	[0.00]		[0.00]		[0.00]		[0.00]	
Observations		2538	2538	2538		2538	2538	2538
Uncensored observations			848				848	
Wald statistic			144.60				159.29	
Rho			-0.75				-0.62	
Sigma			2.57				2.36	

p-values in brackets; * p<0.10, ** p<0.05, *** p<0.01
Source: Authors’ own calculations.

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