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WORKING PAPER SERIES

227, 2023

GREEN TAXATION AND RENEWABLE ENERGY TECHNOLOGIES ADOPTION: A GLOBAL EVIDENCE

Forthcoming: Renewable Energy Focus

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Abstract

There is substantial literature on the determinants of renewable energy consumption. This growing interest is related to the fact that renewable energy is not only one of the main drivers of greenhouse gas mitigation but also its contribution to the achievement of other sustainable goals. Despite this strategic role, the adoption level of renewable energy remains quite low. In this article, we address one of the determinants so far ignored by the literature, namely the environmental tax. This study, therefore, examines the effect of environmental taxes on the adoption of renewable technologies for 49 global samples between the 1996-2017 periods. The results through the FE Driscoll and Kraay, the Newey-West, the system GMM, and the quantile regression methodologies show that environmental tax increase the consumption of renewable energy. However, taking into account disparities in the level of development, the results suggest that the environmental tax spurs renewable energy technologies adoption in developed countries while it decreases renewable energy technologies adoption in developing countries. As policy implications, policymakers within this sample should consider the optimization of environmental taxation as a policy toward environmental protection. This would cause energy consumers to opt for renewable energy sources of energy to escape these taxes.

Key words: Green taxation; renewable energy; panel data; SDG7; environmental protection

1. Introduction

Renewable energy is widely used to describe the energy from a broad spectrum of resources that are self-renewing. It has become an incontestable concept in energy policy discussions and climate change mitigation. Since the adoption of the sustainable development goals (SDG) in 2015, especially in the SGD 7 of access to affordable, reliable, sustainable, and modern energy for all, the use of renewable energy has further gained momentum with development agencies and government strategizing on how to better invest in this source of energy. A record total of 260 Gigawatts (GW) RE-based generation was established globally in 2020 and is expected to reach 10 700 GW by 2030, with that capacity representing at least four times that which was added from other sources (IRENA, 2021). Furthermore, non-renewable energy electrical energy consumption installation capacity moved from more than 65% of total capacity in 2006 to less than 20% in 2020, while renewable electrical energy generation capacity increased from less than 40% to more than 80% within the same period. Despite these efforts, global investments in RE have remained concentrated in a few countries and regions while the rest languish in energy poverty. Between 2005 and 2019, the Asia-Oceania region attracted the highest percentage of investments in renewable energy (55%) while Europe and America closely followed with 20 and 16% respectively. At the same time, these regions are at the forefront of greenhouse gas emissions around the globe, whereas the optimal use of renewable energy should minimize the environmental impact due to its clean nature (Panwar et al., 2011; Adams and Fotio, 2022; Nchofoung and Asongu, 2022a).

Environmental degradation turns to affect economic growth and well-being and this effect could be both negative and positive. According to the environmental Kuznets curve hypothesis, there is an increase in CO2 emission at the early stages of growth up to a given economic development threshold where the sign reverses (Nkengfack et al., 2020; Dinga et al., 2021; Nchofoung and Asongu, 2022 b). One may therefore be wondering if Asia-Oceania, Europe, and America despite huge investments in renewable energy are still below the threshold emersion rate in their development trajectory. Nchofoung and Asongu (2022 a) however noted that if the emission of CO2 is taken in terms of growth rate, then these countries have witnessed a significant drop while continents like Africa are witnessing an upsurge in CO2 emission. These disturbing trends in CO2 emission from one region to another have forced policymakers both at the level of the national governments and international organizations to put into place other environmentally friendly measures that will limit environmental degradation and encourage the adoption of RE usage. In this respect, Wolde-Rufael and Mulat-Weldemeskel (2022) note that one of the most efficient measures that governments have been taking seriously is the adoption of the environmental tax to force individuals and firms to move towards environmental friendly measures. According to these authors, taxes have taken several forms depending on the economy under consideration, which could be in the form of energy taxes, transport taxes, pollution taxes, and extraction taxes.

The implementation of environmental tax has a varying effect on the economy, moving from positive to negative effects. Green taxation encourages economic activities that are environmentally friendly and discourages environmentally damaging activities. In whatever case, the principles of taxation should be respected which include equity, economic effect, and feasibility. In addition to these, the environmental impact should be considered (Milne, 2007). The theoretical origin can be traced back to the work of Pigou (1920) who posits that environmental tax should be equivalent to marginal damages and levied directly on the source of emission. Investigating the effects of this fiscal policy empirically, the tax has been found to work against the uneducated as it takes them off their employment leaving them to engage in small temporal employment while some are even discouraged to work (Yip, 2018). Besides these taxes has a varying effect on growth though the relationship seems to be causal as growth equally leads to more taxation (Abdullah and Morley, 2014). In this regard, Hassan et al. (2020) argue that environmental taxes enhance economic growth in rich economies, which is not always the case in other economies. Environmental tax greatly enhances environmental sustainability as individuals adopt environmentally friendly measures to escape this fiscal pressure (Morley, 2012). In this respect, therefore, individuals or industries that pay huge sums to the States because of their sources of energy used, their polluting habits, or their involvements in other activities that are not environmentally friendly would make them want to develop strategies on how to escape such taxes. One of the strategies that empirical studies have identified is that individuals and firms turn to innovation (Karmaker et al., 2021). These innovations which mostly involve energy innovation could result in the adoption of renewable energy technology that curbs environmental pollution (Alvarez-Herranz et al., 2017). Therefore, demand-pull factors are more effective in driving renewable energy innovations than other types of policy initiatives, and policies that target a unique technology is efficient than those that target multi-technology ones (Pitelis et al., 2020). One of these unique technologies could be the adoption of solar, wind, or thermal technologies for the efficient production of renewable energy. However, the investments required for these technologies are always huge and require the availability of adequate financial systems for them to be effective. These financing could result from financial globalization (Fotio et al., 2022) or national governments, or the domestic financial sector (Kim and Park, 2016; Shahbaz et al., 2021). It is therefore a reasonable analogy to establish that technological innovation and financial development can be effective in the implementation of renewable energy technologies. The objective of this study is therefore to establish the effect of environmental taxation on renewable energy adoption.

The study focuses on a global scale firstly because the fight for renewable energy adoption is a global fight that falls within the remit of the SDGs. In this regard, every nation is involved in policies that could help in meeting this agenda. Besides, environmental degradation in one part of the world has a global propelling effect. Secondly, given the heterogeneity around the adoption of renewable energy, there is a need to consider a comparative study to understand the problem statement. The contribution of this study is therefore on several fronts. Firstly, the study deals with two concepts that are dominating policy debates today in both the national and international agencies. While renewable energy has been identified as a way out of global warming, as the use of fossil fuels will be greatly reduced, green taxation has equally been identified as an efficient fiscal policy in promoting the concept of a green economy. However, empirical studies have neglected the link between these two concepts. The closest study in literature is Wolde-Rufael and Mulat-Weldemeskel (2022), however, the authors elaborated on how renewable energy and environmental tax affect CO2 emission and the causalities between them. Secondly, the study carries out comparative analyses between regional groupings and income groups. This is important in that richer countries have more revenues available for investment in renewable energy than poorer countries. Besides, countries with natural resources abundance will pollute differently from other countries, and taxes on resource extraction would be realized in these groups of countries than in other countries. Finally, this study applies various econometric techniques and specifications to investigate the effect of green taxation on renewable energy technology adoption. Such a combination is important since it helps to account for the complex reality with econometric biases and ensure that the estimates are efficient and robust the estimates.

The rest of this paper is therefore situated around a literature review (section 2), empirical strategy (section 3), results and discussions (section 4), and finally a conclusion and policy implications (section 5).

2. Review of related literature

The theoretical foundation of this work can be traced back to the Work of Pigou (1920). In his book titled the "economics of welfare", he integrated the effect of social cost into economic analyses which laid the foundation for "economic externalities". He, therefore, argues that environmental tax should be equivalent to marginal damages and levied directly on the source of emission. According to Pigou's point of view, therefore, the polluter should always bear the cost of externalities, and this cost should be levied as taxes (environmental tax). Kapp (1960) however challenged the Pigouvian view and argue that the polluter could always make a negotiation with the victim. Given this, in the Pigouvian context, individuals would opt for energy sources that pollute less to avoid bearing the cost of pollution in the form of taxes. This can only be the adoption of renewable energy which is environmentally friendly.

Several empirical works have stemmed from the said theory. In this study, we present two strands of the empirical literature. Firstly, the determinants of renewable energy adoption are presented and secondly, the effect of an environmental tax on macroeconomic outcomes is highlighted.

In the first strand of debate, the drivers of renewable energy are summarized in Table 1. The study, scope, analytical approach, and main results are discussed.

Table 1: A Synopsis of the literature on the determinants of renewable energy

Study	Scope	Analytical approach	Main results
Ergun et al. (2019)	21 African countries between 1990-2013	random-effects generalized least squares regression	human development and economic growth increase RE and foreign direct investment reduces
Akintande et al. (2020)	five most populous countries in Africa between 1996-2016	Bayesian model averaging technique	size of the population, urbanization, energy use, electric power consumption and human capital all increase the consumption of RE
da Silva et al. (2018)	Sub-Saharan African countries for a period covering 1990–2014	panel-ARDL model	economic growth and aid for energy development enhance renewable energy adoption while population growth has a negative nexus with it
Aguirre and Ibikunle (2014)	China and India between 1972-2011	multivariate vector error correction model (VECM)	Countries reduce RE energy adoption when under pressure to meet energy supply. Besides, failure in policy design impedes RE development while environmental concerns enhances renewable energy adoption
Chen et al. (2021)	97 countries covering the period between 1995 and 2015.	GMM and Panel threshold models	countries in high democracies witness an enhancing effect of economic growth and trade openness on renewable energy while a negative effect is realized in low democracies
Papież et al. (2018)	26 EU countries in the period between 1995 and 2014	the best subset regression and the LARS method	energy mix, economic growth and energy supply concentration enhance RE while abundance in fossil fuel sources reduces RE adoption
Zhao et al. (2022)	Pakistan	multi-Criteria Decision Analysis (MCDA), the Fuzzy-analytical hierarchical and the Data Envelopment Analysis (DEA)	development of wind energy projects will help meet local energy requirements and limit the use of fossil fuels
Olanrewaju et al. (2019)	five most populous and biggest economy in each of the five regions of Africa between 1990 to 2015	fixed and random effects models	recommended countries to charge high taxes for fossil fuels adoption and subsidize the use of RE energy as a strategy in promoting RE adoption and enhance environmental sustainability
Rafiq et al. (2014)	India and China during the period 1972 to 2011	multivariate vector error correction model (VECM)	direction of causality between output and RE generation differs between these countries and equally depends on the time horizon
Przychodzen and Przychodzen (2020)	27 transition countries between 1990–2014	Simple regression and ANOVA techniques	economic growth, unemployment and external debt enhance RE why deteriorating energy market competiveness reduce RE adoption
Marques and Fuinhas (2011)	27 European countries between 1990-2006	Dynamic Panel approach	The initial level of RE, social awareness and fossil fuel prices determines RE adoption
Amuakwa-Mensah and Näsström (2022)	global panel of 124 countries between 1998-2012	Two-step system-GMM	Improvement in the banking sector performance enhances RE
Amoah et al. (2022)	32 African countries between 1996-2019	GMM and instrumental variables techniques	corruption harms the share of renewable energy consumption in total final energy consumption
Shahbaz et al. (2022)	China between 1980-2018	Time series econometric techniques	Fiscal decentralization enhances RE demand while income inequality reduces demand
Polcyn et al. (2022)	European countries between 2000-2018	Fixed effect, random effect and the GMM techniques	Economic growth and CO2 emission per capita boost RE consumption while total labour force, gross capital formation and production based CO2

			reduce it.
Asongu and Odhiambo (2021 a)	Sub-Saharan African countries between 2004-2014	GMM and Quantile regression techniques	financial development stimulates renewable energy consumption while income inequality counteracts the underlying positive effect
Asongu and Odhiambo (2021 b)	Sub-Saharan African countries between 2004-2014	Quadratic Tobit Regressions	The effect of income inequality on RE consumption depends on the established threshold of income inequality.
Opoku et al. (2021)	36 African countries between the 2000-2015 periods	System GMM	Increase in women political energy enhances access to electricity, sustainable energy consumption and energy efficiency.

Source: Authors' construction

In the second strand of debate, environmental tax has been argued to have varying effects on various economic sectors. The environmental tax is very important in explaining the emission of greenhouse gases (Ekins et al., 2011; Shahzad, 2020; Mardones and Baeza, 2018; Lin and Li, 2011; Ghazouani et al., 2020; Wolde-Rufael and Mulat-Weldemeskel, 2022; Agostini et al., 1992; Doğan et al., 2022). The underlying studies argue that environmental tax curb environmental pollution as polluters turn to reducing their pollution habits to escape such a tax. Besides, the revenue from the said tax can be used to invest in environmental governance to further curb environmental degradation, which could take the form of investments in renewable energy sources. Lin and Li (2011) however argue about some of the inconveniences of environmental taxation. These include the fact that environmental tax will increase the cost of running the enterprise, reduces competition in energy-based industries, and as a consequence, harms economic growth in the short run. Also, enterprises may shift the increased cost of running the enterprise due to increase environmental tax to consumers leading to high levels of prices within the economy.

Talking of the effect of green taxation on economic growth, several studies have established this relationship (Bovenberg and De Mooij, 1997; Conefrey et al., 2013; Abdullah and Morley, 2014). In this line of debate, green taxation could have a detrimental effect on economic growth through a reduction of competitiveness in the energy industries (Lin and Li, 2011). It could on the other hand enhance economic growth through two principal mechanisms (Bovenberg and De Mooij, 1997). The first channel is through environmental production externality while the second channel is the net return on investment. Hassan et al. (2020) argue that environmental taxes enhances economic growth in rich economies, which is not always the case in other economies, while Ekins et al. (2011) argue that this does have little effect on economic productivity and that it rather enhances employment. Yip (2018) rather argues that environmental taxation leads to an increase in unemployment, especially for educated individuals.

Another macroeconomic indicator that is vital for renewable energy investment is innovation. In this regard, Doğan et al. (2022) recommend the use of environmental tax to invest in research in new technology that can be used for renewable energy production. These innovations which mostly take the form of technological innovation in the energy sector could result in the adoption of renewable energy technology that curbs environmental pollution (Alvarez-Herranz et al., 2017). However, these technologies require huge financing and this finance could result from financial integration (Fotio et al., 2022), from domestic financial system development (Shahbaz et al., 2021a; Shahbaz et al., 2022). Moreover, He et al. (2019) argue that green financing is essential for renewable energy consumption. This is through the fact that green financing inhibits investment in RE through the reduction of credits issued by banks. Recently, Shen et al. (2021) argue that the effect of environmental taxation on green innovation is dependent on market structure. Environmental taxes in the monopoly case encourage the manufacturer to invest more in green technologies while the buyer's market share determines whether environmental taxes motivate the manufacturer to invest more in green technology in the case of a monopoly. Wolde-Rufael and Mulat-Weldemeskel (2022) argue that environmental tax reduces CO2 emissions and enhances the adoption of renewable energy, and they conclude that environmental tax and renewable energy are essential in curbing environmental degradation. Bashir et al. (2022) find that environmental taxes are negatively associated with renewable energy consumption in a sample of 29 OECD countries. This finding contradicts that of Fang et al. (2022), who report that a 1% increase in environmental tax increases renewable energy consumption in 15 countries of the Belt Road Initiative by 1.201%.However, Wang and Yu (2021) find that the effect of environmental tax on green technology innovation is rather than simple. When distinguishing between air pollution and water pollution taxes, they find that the effect of the air pollution tax rate on green technology innovation is non-linear while that of water pollution is uncertain.

3. Empirical methodology

3.1. Data and preliminary statistics

The aim of this paper is to investigate the effect of environmental tax on renewable energy technologies adoption. The data is of secondary nature and is collected on a global sample of 49 countries[1] between the 1996-2017 periods. The choice of study period and sample countries are based principally on the availability of relevant data. The data is collected from the World Development indicators of the Wold Bank, the Worldwide Governance indicators of the World Bank and OECD database.

Dependent variable

The dependent variable is renewable energy consumption (% of total energy consumption). This variable has been largely used as a proxy to the adoption of renewable energy technologies (Fotio et al., 2022; Polcyn et al., 2022; Wolde-Rufael and Mulat-Weldemeskel, 2022). The data for this variable is collected from the World Development Indicators of the World Bank.

The independent variable of interest

[1] Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Cyprus, Czech Republic, Denmark, Ecuador, Finland, France, Germany, Greece, Guatemala, Hungary, Iceland, Israel, Italy, Jamaica, Japan, Latvia, Lithuania, Madagascar, Malaysia, Mexico, Netherlands, New Zealand, Norway, Peru, Philippines, Poland, Portugal, Romania, Slovenia, South Africa, Spain, Sweden, Switzerland, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay.

The independent variable of interest is environmental taxation, which is use as the total environmental taxation (%GDP) and the variable is collected from the OECD database. Wolde-Rufael and Mulat-Weldemeskel (2022) argue that environmental tax reduces CO2 emission and enhance the adoption of renewable energy, while Doğan et al. (2022) recommend the use of environmental tax to investment in research in new technology that can be used for the renewable energy production. The variable is therefore expected to present a positive sign. Figure 1 presents the perceived correlated relationship in the form of a fitted plot.

Figure 1. Fitted plot on the relationship between renewable energy technology and environmental tax

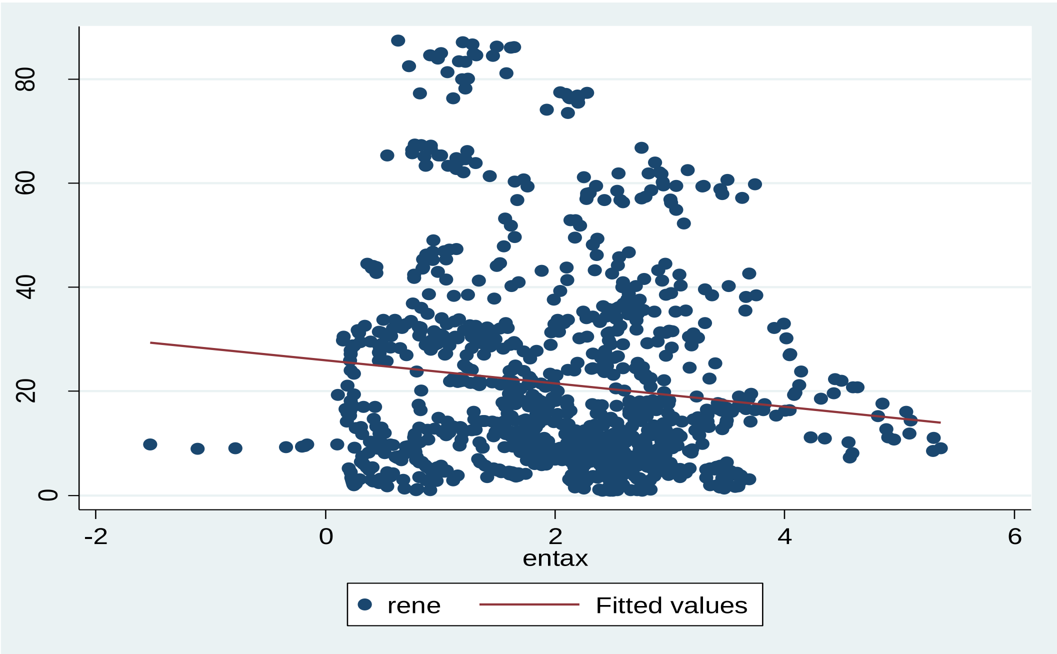

Figure 1 presents an apparent negative relationship between environmental taxation and renewable energy in this study. To actually access the real effect, a regression analysis is required.

Control variables

The first control variable used is trade openness measured as the sum of imports and exports all to GDP. Trade openness promotes the commercialization of green technologies on a global scale, which in turn boosts the adoption of the most efficient technologies. However, Chenet al. (2021) argue that trade openness enhances RE in high democracies while the positive effect is experienced in high democracies. This variable can therefore take a positive or negative sign depending on the type of democracy under consideration. The next control variable is financial development proxied by the domestic credit to private sector (%GDP) and is expected to show a positive sign in accordance to Asongu and Odhiambo (2021 a). Natural resources rents are the next control variable and is used as the total natural resources rents (%GDP). It is expected to present a negative sign in line with Papież et al. (2018). Also, economic growth, proxied by the per capita GDP is used and is expected to enhance RE in line with the study of Papież et al. (2018). The last but not the least variable is governance. The variable is used at first place through the average of the six governance indicators of Kaufmann (2010)[2]. A similar approached has been used in literature by Ngouhouo et al. (2021). The sub-indicators are further used successively and the results observed. The variables are expected to produce negative signs in line with the study of Asongu and Odhiambo (2021 b).

The data for the control variables are collected from the World Development indicator of the World Bank except for the governance variable that is from Worldwide Governance Indicators of the World Bank. Tables 1 and 2 present the summary statistics and the correlation matrix respectively.

Table 2: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Renewable energy consumption	1078	21.313	18.616	0.853	87.354
Environmental tax	1062	2.021	1.026	.0997028	5.36
Trade openness	1078	75.215	35.622	15.636	220.407
Financial development	1078	.512	.235	0.082	1
Total natural resources rents	1078	2.234	3.142	0	18.86
GDP per capita (log)	1077	9.564	1.108	6.054	11.363
Governance	1078	.708	.87	-.845	12.768
Control of corruption	1078	.822	2.275	-1.27	67.603
Government effectiveness	1078	.846	.857	-1.3	2.354
Political stability	1078	.372	.829	-2.374	1.878
Regulatory quality	1078	.828	.744	-1.296	2.098
Rule of law	1078	.724	.943	-1.251	2.13
Voice and accountability	1078	.659	.816	-1.987	1.801

Tables 2 and two show that the percentage of renewable energy in total energy consumption (Table 1) varies between 0.853 and 87.354 for our sample. Besides, the standard deviation value of 18.616 shows that the variables are very much dispersed from the mean. The environmental tax variable of its part varies between .0997028 and 5.36 for our sample, with very low standard deviation value (1.026). Equally, considering the correlation matrix in Table 2, the explaining variables are weakly correlated among themselves, enabling the possibility to easily use these variables in the same model. The highest correlation coefficient between the control variables is 0.759, which is lower than the value of 0.8 which serves as a rule thumb for multicollinearity among the variables[3]. This suggests that our model is free from multicollinearity. Also, the result points out a negative correlation between renewable energy technologies adoption and environmental tax. However, the correlation coefficient does say much about the magnitude of the impact of one variable on another. So it remains important to do econometric analyses to highlight such an impact.

[2]These six indicators are: Control of corruption, government effectiveness, regulatory quality, rule of law, voice and accountability, and political stability and absence of violence.
[3]The correlation coefficients between some of the institutional variables are greater than 0.8. To address this issue, only one institutional variable is included in the model at a time.

Table 3: Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) renewable energy	1.000												
(2) environmental tax	-0.122	1.000											
(3) trade openness	-0.179	0.247	1.000										
(4) financial development	-0.305	0.273	0.020	1.000									
(5)Total natural resources rents	0.153	-0.486	-0.039	-0.285	1.000								
(6) GDP per capita	-0.235	0.479	0.099	0.414	-0.370	1.000							
(7) governance	-0.085	0.489	0.190	0.360	-0.340	0.795	1.000						
(8) control of corruption	-0.034	0.237	0.083	0.355	-0.150	0.403	0.768	1.000					
(9) government effectiveness	-0.166	0.458	0.222	0.488	-0.347	0.886	0.879	0.457	1.000				
(10) political stability	-0.003	0.461	0.266	0.492	-0.300	0.661	0.786	0.383	0.737	1.000			
(11) regulatory quality	-0.140	0.471	0.212	0.434	-0.388	0.836	0.863	0.430	0.920	0.709	1.000		
(12) rule of law	-0.095	0.506	0.195	0.462	-0.373	0.877	0.899	0.455	0.960	0.792	0.935	1.000	
(13) voice and accountability	-0.037	0.498	0.058	0.344	-0.297	0.575	0.690	0.307	0.589	0.599	0.634	0.651	1.000

3.2. Model specification and regression technique

Based on extant literature, equation 1 specifies the empirical model.

$$RET_{it} = \beta_0 + \beta_1 ENTAX_{it} + \beta_j X_{it} + \upsilon_i + \gamma_t + \varepsilon_{it} \qquad (1)$$

Where, RET is renewable energy technology, ENTAX is environmental taxation, X is the vector of control variables at time, t and country, i. j is the subscript of number of coefficients associated to control variables, μis the country fixed effect, γ is the time fixed effect and ε is the stochastic error term.

In order to take care of the possible cross-sectional dependence that could exist between the panels due to economic integration of these countries (Kengdo et al., 2020), the fixed effect Driscoll and Kraay (1998) standard error correction is used at first place. This method equally corrects for first order serial correlation and the heteroscedasticity of the errors. Also, the Newey-West standard error is equally used which apart from correcting for autocorrelation, equally corrects for heteroscedasticity up to a given lag. Given the distribution of the variable is not always uniform, the mean group estimator is used to take care of averages of the panels for each group (Pesaran and Smith, 1995).

Furthermore, the correlation of the first period lagged dependent variable with the dependent variable produces a very high correlation coefficient (0.9971). This shows the importance of initial conditions in explaining renewable energy in our sample. Specifying equation (1) taking into account this lag produces (2) thus:

$$RET_{it} = \beta_0 + \beta_1 RET_{i(t-1)} + \beta_2 ENTAX_{it} + \beta_j X_{it} + \upsilon_i + \gamma_t + \varepsilon_{it} \qquad (2)$$

The inclusion of the lagged dependent variable as an explanatory variable in (2) is likely to correlate with country specific effects, generating the Nickell bias (Nickell, 1981). The system Generalized Method of Moments (system GMM) is therefore used firstly for its advantage in correcting this bias. Secondly, the method controls for unobserved heterogeneity that may arise due to different cross-sectional dimensions with each having unique specificities. It equally controls for bidirectional causality that may exist between two or more explanatory variables of the model. The GMM framework can therefore be specified both at level and first difference thus:

$$RET_{it} = \beta_0 + \beta_1 RET_{i(t-\tau)} + \beta_2 ENTAX_{it} + \sum_{h=1}^{k} \delta_h X_{h,i(t-\tau)} + \upsilon_i + \gamma_t + \varepsilon_{it} \qquad (3)$$

$$RET_{it} - RET_{i(t-\tau)} = \beta_1 \left(RET_{i(t-\tau)} - RET_{i(t-2\tau)}\right) + \beta_2 \left(ENTAX_{it} - ENTAX_{i(t-\tau)}\right) + \sum_{h=1}^{k} \delta_h (X_{h,i(t-\tau)} - X_{h,i(t-2\tau)}) + (\gamma_t - \gamma_{t-\tau}) + \varepsilon_{i(t-\tau)} \qquad (4)$$

There are several challenges that may be associated with the GMM methodology. These are the problem of (i) identification; (ii) simultaneity and (iii) exclusion restrictions. To resolve these problems, all our explanatory variables are suspected to be endogenous and treated as such (Tchamyou, 2020; Tchamyou, 2021; Nchofoung et al., 2022; Nchofoung and Asongu, 2022 a, b). Besides, period dummies are used as instruments in both the level and difference equations. Roodman (2009) as an extension of the Arellano and Bover (1995) adopted the forward orthogonal deviation to limit instruments' proliferation and maximize sample size. We adopt the said forward orthogonal deviation methodology in this study to limit instrument proliferations.

Another issue to account is the possibility that the effect of environmental tax can differ across the distribution tail of renewable energy technology adoption in the N individuals in the panel. One feature of panel data is that most series commonly exhibit outliers and are non-normally distributed (Lin and Xu, 2020). As a result, usual econometric techniques might provide non-robust estimators. As in Fotio et al. (2022) and Wolde-Rufael and Mulat-Weldemeskel (2022), we rely on the Method of Moments Quantile Regression (MMQR) with fixed effects.

The quantile version of Eq(1) is written as follows:

$$Q_{RET_{it}}(\tau_k/\alpha_i, x_{it}) = \beta_i + \beta_1 ENTAX_{it} + \beta_j X_{it} + \upsilon_i + \gamma_t + \varepsilon_{it} \quad (5)$$

Where all the variables are defined as above. Q is the i^{th} quantile level.

4. Results and Discussions

Table 4 reports the estimates of equation 1. The static version of the model is estimated through the FE Driscoll-Kraay, Newey West and Mean group estimators while the dynamic version (equation 2) is estimated through the system GMM. All these techniques allow controlling for the cross-sectional dependence and individual heterogeneity. Regarding our control variables, except the results obtained from the mean group estimator, the findings from the other estimators suggest a positive and statistical connection between environmental tax and renewable energy technology. A unit increase in environmental tax augments the adoption level of renewable energy technologies by 0.886 units (FE Driscroll-Kraay) and 1.846 units (Newey West).

Table 4: Baseline findings

	Dependent variable: renewable energy technology (RENE)			
Variables	FE-Driscoll Kraay	Newey West	Mean Group	System GMM
Environmental tax	0.886*	1.846***	-0.0152	0.0907
	(0.453)	(0.533)	(0.465)	(0.121)
Trade openness	0.119***	-0.101***	-0.00330	-0.00437
	(0.0142)	(0.0108)	(0.0126)	(0.00555)
Finacial development	-0.872	-0.82	1.112	0.459
	(2.813)	(3.895)	(2.335)	(2.373)
Resource rents	-0.390**	0.319*	0.0555	-0.159***
	(0.140)	(0.186)	(0.136)	(0.0379)
Per capita growth	0.000459***	0.000624***	-0.000337	2.83e-05
	(6.84e-05)	(4.91e-05)	(0.000207)	(2.89e-05)

Governance	-0.274	1.783	-0.725	-0.144
	(0.206)	(1.137)	(1.018)	(0.310)
RENE (-1)				0.992***
				(0.0162)
Constant	9.333***	20.18***	19.93***	1.810
	(1.975)	(2.364)	(3.764)	(1.200)
Observations	1,061	1,061	1,061	1,016
Number of groups	49		49	49
Fisher	36.95***	65.04***		11329***
chi2			3.631***	
Period FE				Yes
Prop>AR1				0.000127
Prop>AR2				0.102
Instruments				26
Prop>Hansen				0.639

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' computation

We further investigate the effect of environmental tax on renewable energy technologies adoption using the System GMM. This technique is useful since it accounts for the different sources of endogeneity, unobserved heterogeneity, simultaneity, and dynamic endogeneity (Wintoki et al., 2012). We perform four diagnostic tests to check for the validity of the estimates from the GMM. The first diagnostic test assumes the absence of second-order self-correlation i.e. Prob (AR (2)) <10%. The second assumption is that the Sargan and Hansen statistical tests should not be significant, suggesting that the instruments are valid and uncorrelated with the error term (Asongu et al., 2020). Finally, the number of instruments must be less than the number of individuals (Roodman, 2009). The findings in Table 4satisfy all the diagnostic tests.

The findings reveal a positive and statistically significant effect of the environmental tax on renewable energy technologies regardless of the estimated model. A 1unit increase in the environmental tax (as % of the total tax) increases the adoption of renewable energy technologies (as a share of final energy us) by about 0.0907 units. This corroborates the results of Wolde-Rufael and Mulat-Weldemeskel (2022) who argue that environmental tax leads to the reduction of greenhouse gas emission as a result of the adoption of renewable energy by enterprises and households. This result can be justified in two ways. First, through the *behaviour effect*, firms will engage in research and development activities that will lead to the adoption of clean production technologies as means to avoid the burden of the environmental tax. In this case, they will adopt renewable energy technologies or improve their energy efficiency. Secondly, the *income effect* can explain why environmental tax enhances the adoption of renewable technologies. Indeed, through environmental tax, governments could mobilize sufficient resources to invest in renewable energy technologies and environmental protection. This effect allows the state to internalize the negative external effect due to pollution. This result is consistent with the intuition that the tax does not only serves to mobilize incomes but also, can be used as an incentive to force individuals to change their behaviour by adopting greener production technologies (Pigou, 1920; Wolde-Rufael and Mulat-Weldemeskel, 2022). This finding is in line with that of Abban and Hassan (2021) who reported a positive effect of an environmental tax on renewable energy investment in 60 countries. Thus, renewable energy technology is a channel through which environmental tax can help to achieve the low carbon development goal.Guo et al. (2021) also argue that environmental tax policy can encourage enterprises to increase R&D investment in green technology innovation.

The results on the Mean Group estimator is rather negative though non-significant and corroborates the finding of Wang and Yu (2021), who argue that the actual effect of environmental taxation on renewable energy innovation is rather non-linear. Though this effect is non-significant, there is an indication that there is a negative relationship in the link at some point in time and this should occur after the optimal environmental taxation threshold is exceeded. Given that the Mean group estimates the averages between the estimation of the individual cross-sections, unlike other methods with fixed effect that annulled all the across groups action and holds constant the average effects for whatever explanatory variable of the model.

Concerning the control variables, trade openness is negatively associated with renewable energy adaption. Though surprising, this result suggests that a unit increase in the trade openness ratio reduces renewable energy consumption (as a share of final energy consumption). This finding is in line with that of Lin et al. (2011) who reported a negative and statistically significant effect of trade openness on renewable energy consumption in China. Financial development has a negative and statistically significant impact on renewable energy consumption. This result would reflect the fact that renewable energy, despite the various environmental gains it generates, remains expensive for private investors. This result partly reflects the uncertainty and risks inherent in investing in renewable energy. In addition, the payback period is generally long-term, which discourages financial institutions from financing such projects.

The exploitation of natural resources significantly reduces the consumption of renewable energy. This result confirms the literature on the curse of natural resources. Indeed, many studies have led to the paradox that there is a negative link between the exploitation of natural resources. Cockx and Francken (2014; 2016) for example highlight the negative effect of natural resource exploitation on health. Tadadjeu et al (2020) observe that dependence on natural resources decreases access to basic social services such as water and sanitation in Africa. Others conclude that natural resource exploitation has retarded economic growth (Majumder et al., 2020). The negative link between natural resource exploitation and development indicators can be justified by several obstacles such as rentier behaviour of the elite, corruption, and low diversification in resource-dependent countries. This result supports Shinwari et al. (2022) who observe that dependence on natural resource revenues is one of the biggest barriers to renewable investment in China.

GDP per capita growth has a positive effect, although not significant in all estimated models. This result supports the idea that economic growth allows countries to invest in the acquisition of clean generation technologies. This finding falls within the scope of studies that find a positive effect of economic growth on renewable energy consumption (Przychodzen and Przychodzen, 2020; Polcyn et al., 2022). The overall index of governance has an insignificant impact on renewable technologies adoption in this study. Alternative specifications of institutional quality are presented in Table 5 for a clearer picture of the effect. The only significant effect apparent is political stability which present a negative effect.

Table 5 shows the results across different development levels and income groups. The environmental tax increases the adoption of renewable energy technologies in developed countries and high and middle-income countries. In contrast, its effect is negative and statistically significant in developing and low-income countries. The differential effect can be justified by the quality of institutions, as developing countries are less democratic than developed ones. This can undermine the efficiency of the tax system. In line with this finding, Chen et al. (2021) show that democratic institutions shape the relationship between economic growth and renewable energy investments. They find that economic growth undermines renewable energy consumption in developing countries while the opposite relationship holds in democratic countries.

Table 5: Accounting for the development level of countries

	Dependent variable: renewable energy technology				
Variables	Developed countries	Developing countries	High-income countries	Middle-income countries	Low-income countries
Environmental tax	1.425*	-3.678***	1.613**	1.419***	-2.908
	(0.838)	(1.036)	(0.692)	(0.461)	(6.668)
Trade openness	-0.00366	-0.224***	-0.0445*	-0.117***	0.168
	(0.0240)	(0.0367)	(0.0266)	(0.0362)	(0.200)
Financial development	-56.08***	-11.98	-70.02***	13.72*	-92.08
	(6.451)	(11.37)	(6.708)	(7.789)	(302.3)
Resource rents	2.314***	-0.100	1.798***	-0.479***	0.280
	(0.359)	(0.347)	(0.242)	(0.166)	(1.867)
Per capita growth	0.000506***	-0.00170***	0.000614***	-0.00155***	0.000418
	(5.76e-05)	(0.000251)	(6.41e-05)	(0.000161)	(0.123)
Governance	5.121	14.50***	4.541	-6.809***	8.859
	(3.665)	(1.536)	(2.967)	(2.273)	(9.524)
Constant	30.40***	55.94***	41.02***	31.67***	89.37*
	(7.441)	(4.618)	(6.936)	(3.089)	(49.79)
Time fixed effect	Yes	Yes	yes	Yes	Yes
Observations	611	450	677	362	22

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

Given the heterogeneity in terms of dispersion of the variables from one country to another, it is important to integrate the quantile regression methodology to see if our results are robust across different quantiles. Table 6 presents these results. As in Fotio et al. (2022), countries are categorized regarding their adoption level of renewable energy technologies. So have countries with low adoption level of renewable energy technology (10th to 30th quantile level), countries with middle adoption level (40th to the 60th quantile level), and countries with high adoption level (70th to 90th level). While positive effects are apparent in low and medium adoption levels, countries with high adoption presents negative effects. In reality, the quantile regression results show that environmental tax will increase the use of renewable energy technologies and at a certain level of adoption of renewable energy (from the 70th percentile), further increase in environmental tax, leads to increase firms adjusting their energy efficiency than investment in energy to minimise production cost.

Table 6: Quantile regression results

	Dependent variable: Renewable energy technology (RENE)								
Variables	Low renewable level			Medium adoption level			High adoption level		
Quantile level	q10	q20	q30	q40	q50	q60	q70	q80	q90
Environmental tax	0.105	0.106	0.247	0.339	1.465	1.211	-2.373***	-2.917***	-8.286***
	(0.277)	(0.329)	(0.443)	(1.088)	(1.049)	(0.866)	(0.728)	(0.872)	(1.860)
Trade openness	-0.0305***	-0.0306***	-0.0230**	-0.0483**	-0.103***	-0.107***	-0.117***	-0.140***	-0.173***
	(0.00643)	(0.00593)	(0.0101)	(0.0220)	(0.0137)	(0.0111)	(0.0138)	(0.0181)	(0.0282)
Financial development	-14.01***	-19.71***	-25.18***	-33.42***	-59.10***	-64.52***	-69.81***	-80.57***	-100.0***
	(2.764)	(3.122)	(3.588)	(9.160)	(4.805)	(5.002)	(4.832)	(7.249)	(7.481)
Resource rents	0.322***	0.346***	0.233*	0.251	0.795**	0.772***	0.489**	0.245	-0.659
	(0.0757)	(0.0942)	(0.127)	(0.378)	(0.320)	(0.266)	(0.196)	(0.171)	(0.545)
GDP per capita	0.000116***	0.000190***	0.000243***	0.000277**	0.000535***	0.000544***	0.000663***	0.000754***	0.000985***
	(3.81e-05)	(4.03e-05)	(5.40e-05)	(0.000114)	(6.59e-05)	(6.26e-05)	(8.59e-05)	(6.22e-05)	(0.000157)
Governance	-0.0433	-0.176	-0.351	1.339	2.259	3.397***	2.981**	1.639	1.239
	(0.828)	(1.120)	(1.986)	(3.064)	(1.388)	(1.013)	(1.467)	(1.977)	(3.152)
Constant	11.76***	14.95***	18.04***	26.82***	45.10***	50.05***	58.41***	71.70***	104.1***
	(1.068)	(1.233)	(1.862)	(6.333)	(3.240)	(3.014)	(2.940)	(6.589)	(5.332)
Time Fixed effect	Yes	Yes	yes	Yes	yes	Yes	Yes	Yes	Yes
Observations	1,061	1,061	1,061	1,061	1,061	1,061	1,061	1,061	1,061
Replications	200	200	200	200	200	200	200	200	200

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

5. Conclusions and Policy implications

There is substantial literature on the determinants of renewable energy consumption. This growing interest is related to the fact that renewable energy is not only one of the main drivers of greenhouse gas mitigation but also its contribution to economic growth and the other sustainable development goals. In this paper, we investigate one of the determinants so far ignored by the literature, namely the environmental tax. The intuition is that the introduction of the environmental tax can change the attitude of individuals towards pollution sources by leading them to adopt clean energy. But also, the revenues from environmental taxes allow governments to increase investments in the energy transition. This study, therefore, examined the effect of environmental taxes on the adoption of renewable technologies. Due to data limitation, this study involved a sample of 49 developed and developing countries over the period 1996 - 2017. The estimation procedure allows for cross-sectional dependence bias, endogeneity, and country heterogeneity. The results through the FE Driscoll and Kraay (1998), the Newey-West, and the system GMM showed that the environmental tax can increase the consumption of renewable energy in the global panel. However, taking into account disparities in the level of development, the results suggested that the environmental tax increased renewable energy consumption in developed countries while it undermines renewable energy technologies adoption in developing countries. Finally, the Methods of Moments Quantile Regression (MMQR) with fixed effects results showed that the effect of the environmental tax is heterogeneously distributed across the various levels of adoption of renewable technologies. Indeed, while the environmental tax can undermine the adoption of technologies in countries from the 70th to the 90th quantile, that is, countries with the highest levels of adoption of renewable technologies, it can exert a favourable effect on the adoption of renewable energy in countries between the 30th and 60th quantile of adoption of renewable energy technologies, that is in countries with low and middle adoption levels of renewable energy technologies. These finding suggest that environmental tax is more effective in countries in countries with average adoption level than in countries with high adoption level.

Some policy recommendations emerge from this study. Firstly, policymakers within this sample should consider the optimization of environmental taxation as a policy toward environmental protection. This would cause energy consumers to opt for renewable energy sources of energy to escape these taxes. The results indicate, however, that the effect of the environmental tax differs between developed and developing countries. In developed countries, the environmental tax can effectively boost the demand of non-fossil fuels technologies. In developing countries, on the other hand, weak institutions may create distortions and undermine the effectiveness of an environmental policy. Because of the weakness of institutions, the environmental tax may be perceived by governments as rent to finance other projects than environmental preservation. Furthermore, for technological reasons, the development costs of renewable energy technologies are high for entrepreneurs. Therefore, the adoption of a high environmental tax may not lead to entrepreneurs resorting more to non-renewable energy whose costs remain relatively low. To be effective in these countries, the environmental tax should be greater than the cost-benefit obtain from using non-renewable energy. Importantly, the results suggest that improved institutions could increase the adoption of renewable energy in developing countries. Thus, developing countries to create an incentive framework for foreign investors but also encourage a system of bonuses such as premiums for adopting renewable energy technologies and the institution of public-private contracts for renewable energy development. The lever of the tax would be activated only gradually on the large polluters.

This study has some limitations. For instance, due to data limitation, it did was not possible to carry out a country-specific study. Future studies could consider this aspect when longer data will be available. Also, future studies could consider sectoral consumption of renewable energy and identify the potential channels through which the environmental tax affect renewable energy adoption.

Declarations:

Conflict of Interest: The authors declare no potential conflict of interest

Data availability: The data supporting the findings of this study are available upon a reasonable demand addressed to the corresponding author.

Ethical declaration: This article is not under consideration in another outlet.

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