Is your valley as green as it should be? Incorporating economic development into environmental performance indicators

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Abstract

Sustainability rankings are receiving increasing attention by the academic and the policy making communities because of their potential to influence environmental legislation and reshape competitive landscapes. Unfortunately, most of the indicators used to produce these rankings do not take into account economic development and tend to be biased in favor of richer countries. To circumvent this limitation we develop a novel, rigorous and simple metric that ranks countries by their potential environmental performance relative to their wealth; in other words, by the degree of sustainability that a country should achieve, given its level of affluence. We apply our approach to measure the sustainability level of 15 developed economies with respect to the share of renewable energy sources in their electricity generating portfolios. The resulting ranking produces changes in the perceived greenness of certain countries. If adopted, it would allow these countries to increase their bargaining power in international negotiations. It would also alter the pressure faced by their governments to implement or discontinue environmental policies such as feed-in tariffs. Although we applied it at the country level and in the context of renewable energy, the method has far-reaching implications and it can also be used to compare corporate sustainability levels.

Keywords: Sustainability indicators; renewable energy; environmental rankings; panel data

JEL Codes: C23, Q20, Q56

1. Introduction

Measuring a country's environmental performance relative to that of its peers is becoming an increasingly important exercise, with relevant policy-making and business implications. International negotiations on climate change, the adoption of regional emission standards and even debates over domestic waste management policies are often directly or indirectly influenced by how a country scores against other nations in a number of sustainability dimensions.

Motivated by the above requirements and by growing public concern over the quality of life, several rankings of countries' sustainability have been put forth by experts and practitioners alike. Prominent examples such as the Environmental Performance Index (EPI), the Human Development Index or the Ecological Footprint indicator play an important role in orienting the public debate on environmental and development policies. Through their strong influence on public perception, such rankings affect the position and actions of national delegations in international negotiations. They also shape domestic policies by creating social and institutional pressure on governments, which may result in the enforcement of stricter environmental legislation in certain jurisdictions. The business community too follows these developments with an interested eye because of their potential impact on the attractiveness and the competitiveness of certain markets. The automotive industry's resistance to the progressive tightening up of vehicle emission limits in certain jurisdictions is, for instance, a typical case in point.

The basic premise behind such indexes is that the "higher" a country's position in the ranking, the higher its level of greenness and the more environmentally proactive its population. In the case of climate change discussions, for instance, countries are typically compared using the percentage of electricity generated from renewable sources as the discriminating factor, with the implicit assumption that countries with a higher share of renewables are inherently greener and more virtuous.

However, if “greenness” were a “luxury” that richer nations could afford to buy and if environmental awareness were a relative wealth notion, such indices would not reflect the actual sustainability performance of the countries being ranked. An emerging body of research suggests that developed nations “maintain their privileged place in the world (and relatively pristine environments) partly by transferring many of the negative consequences of industrialization onto poorer regions” (Morse and Fraser 2005; p.636). If that is the case, are the existing rankings that do not take this “wealth bias” into account a fair means of comparison and a valid instrument to support the design of environmental policies?

Consider, for example, the case of Brazil and Rwanda. Despite the major land degradation problems affecting the Amazon rainforest[2], which have implications for climate change at the global level, Brazil enjoys a much better EPI ranking (46 in the 2016 ranking) than poorer countries such as Rwanda (147 in the 2016 ranking)[3], where environmental problems have only local consequences. Although the significant gap between these rankings might result from actual differences in environmental performance, the comparison suggests that a country’s wealth plays an important role in orienting its choices towards more sustainable paths.

If economic growth is an important driver of sustainability, how, then, can we compare different countries on a fair basis using simple, widely applicable and easy-to-implement methods? Unfortunately, as much as they are widely used, established multi-criteria indexes such as the EPI are not well suited to that purpose. By giving more importance to variables in which advanced economies score better than poorer nations, these indicators make rich nations look clean by design (The Ecologist, 2001).

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[2] Based on computer models, Laurance et al. (2001) make grim predictions about the condition of Brazilian Amazonian forests by 2020. Foley et al. (2007) review recent research to highlight the tremendous loss and degradation of Amazonian rainforests.

[3] Hsu et al. (2016).

In order to address this issue, we propose an innovative index of environmental proactiveness that explicitly takes into account the role of wealth and economic growth as sustainability drivers. Our approach is based on the idea that countries should be ranked not by their actual (or gross) environmental performance but rather by the difference between their actual environmental performance and their potential environmental performance—i.e., by the degree of sustainability that they should achieve, given their level of affluence. The central premise of our approach is that the consumption of environmental goods such as renewable energy resources is costly. Thus the demand for such goods arises only after a country has reached a certain level of wealth and it keeps increasing with economic growth. Indeed, if we inspect the EPI for 2016, it is easy to notice that countries with higher per capita income score far better in environmental performance than their less wealthy counterparts. This hypothesis is highly consistent with a strand of literature that focuses on the relationship between environmental degradation and income per capita – the so-called Environmental Kuznets Curve (EKC), predicting an inverted U-shaped relationship between environmental degradation and income per capita. At the early stages of growth, per capita pollution increases because investments are allocated to the cheapest and dirtiest technologies, and it decreases after income per capita crosses the GDP threshold, when investments get redirected to more efficient (but more expensive) technologies.

Drawing upon the above observation we develop a novel wealth-adjusted indicator of environmental performance and we illustrate it through an application to the case of renewable energy diffusion. After empirically estimating the relationship between per capita Gross Domestic Product (GDP) and renewable energy share for 15 OECD countries, we compute the difference between a country's average GDP per capita and its estimated RE turning point (i.e.

the level of affluence above which renewables start being massively adopted). We then use the so-obtained index to rank the 15 countries based on their pseudo willingness-to-pay for cleaner energy technologies. Finally, we compare the resulting ranking to a ranking based on a simpler, unadjusted measure of RE adoption. The results suggest that taking into account economic growth significantly alters a country's environmental ranking and confirm that the proposed method allows for the incorporation of fairness considerations in a simple, intuitive and yet robust manner. Thus, we suggest the approach can be widely applied to compute other wealth-adjusted measures of environmental performance, which focus on other environmental issues such as waste or air and water pollution.

The remainder of this paper is organized as follows. Section 2 briefly reviews the literature on environmental indicators. Section 3 summarizes the theoretical background underlying our proposed approach. Section 4 illustrates the proposed indicator, the method to compute it and the associated econometric issues. Section 5 presents an application to the case of renewable energy adoption in 15 OECD countries. Section 6 concludes and indicates avenues for further research.

2. Literature review

Although the concept of sustainability has come to the public attention in the past few decades, its concept and consequences have been observed for centuries. The city of London, for example, has been struggling with air pollution resulting from burning "sea coal" as early as 13th century. Policy intervention to modify behavior has an equally long history. In London, the situation became so bad in 1307 that King Edward 1 intervened prohibiting, by a decree, the use of sea coals in lime kilns because of the "intolerable smell" that resulted in "annoyance … and injury of their bodily health" for all in the vicinity (Clark 2015). Despite the long history of policy makers to intervene when sustainability issues are at stake, policy making for sustainability is not without its challenges (Common 1995).

One of the most important of such challenges for making sustainability policies is tracking progress in sustainable development.[4] (This is partly because the concept of sustainability spans various environmental, social and economic factors. There are numerous indices and assessment methodologies to track progress in multiple dimensions ranging from energy-based indices to social and quality- of-life-based indices (for a comprehensive review see Singh et al. 2009). On the other hand, *aggregate* sustainability indices attempt to rank or compare human events or development over an uncertain information landscape. In doing so, they also stir a debate on their significance and legitimacy in guiding decision makers to measure the impact of policy response through aggregated indicators. Anthropologist Ian Morris offers a convincing argument to dispel the doubts surrounding the use of composite indicators at all levels. As he writes: “reducing the ocean of facts to simple numerical scores has drawbacks but it also has the one great merit of forcing everyone to confront the same evidence—with surprising results” (Morris, 2011, p. 497).[5]

Over the past 20 years, there have been dramatic increases in the development and use of indicators as a basis for cost effective and efficient means of to inform decision making and management (Hsu et al., 2013). For example, Parris and Kates (2003) note over 500 sustainable indicator efforts in existence in 2003.[6] Böhringer and Jochem (2007) provide an overview of several sustainability indices that are widely used in the policy debate. These include the Living

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[4] See Fig. 1 in Moldan et al. (2012) for various indicators of monitoring progress of Goal 7 (environmental sustainability) of the Millennium Development Goals.

[5] Originally cited in Brynjolfsson and McAfee (2014).

[6] Created in 1934, the Gross Domestic Product (GDP) has become a ubiquitous measure of economic progress.

Planet Index (LPI, WWF 1998), Ecological Footprint (EF, Wackernagel and Rees 1997), City Development Index (CDI, UNCHS 2001), Human Development Index (HDI, UNDP 2005), Environmental Sustainability Index (ESI, Esty et al. 2005), Environmental Performance Index (EPI, Esty et al. 2006), Environmental Vulnerability Index (EVI, SOPAC 2005), Index of Sustainable Economic Welfare/Genuine Progress Index (ISEW/GPI, Cobb 1989), Well- Being Index (WI, Prescott and Allen 2001), Genuine Savings Index (GS, Hamilton et al. 1997), and Environmental Adjusted Domestic Product (EDP, Hanley 2000). In surveying these indices, Böhringer and Jochem (2007) note a number of weaknesses in methodological calculations, thus stressing the need for caution in interpreting the results or projections that appears from these indicators.

Among the various methodological challenges associated with constructing valid and reliable sustainability indicators, it is clear that one should take into account a country's level of wealth, but *how* to do so remains a particularly thorny problem.[7] In the attempt to approach this problem, GDP has been proposed as a measure of public well-being. The argument that GDP (and GDP per capita) are very crude indicators of human development is not new, and many researchers have attempted to develop alternatives and/or supplements to GDP without much success in the academic, social and political communities. Frugoli et al. (2015, p. 379) argue that non-GDP indices are not yet "capable of encompassing all of the significant aspects of economic, social and environmental well-being". In a detailed study, Giannetti et al. (2015) summarizes the main challenges that confront the construction of indices that intend to go beyond GDP. The most typical difficulties for the cross-country comparisons are the paucity of good data and deciding how to weigh environmentally oriented indicators. For instance, global

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[7] Liu et al. (2016) convert economic products and services (along with other socio-economic and thermodynamic basis) into one coherent energy equivalent in constructing their Emergy Sustainability Index.

warming may mean a lot to Scandinavians, but people in the poor world's filthy cities care much more about local air or water pollution. A more fundamental problem with approaches alternative to GDP rests in the distinction between GDP and economic value. It is not difficult to compute value for environmental assets, but it is almost impossible to put a number on them. And until we have a price for every environmental service, efforts to adjust GDP for pollution and depleted resources will remain highly challenging.[8]

In summary, despite the various approaches proposed, the question of how to effectively incorporate a country's level of economic development into the calculation of its environmental performance remains open. In this paper, we aim to contribute to this debate. We argue for the case that GDP per capita is a driver for attaining higher environmental quality and we propose a method for incorporating this effect in the design of sustainability rankings. In the section below, we provide a number of reasons in favor of this hypothesis suggesting that increases in income have both direct and indirect effects on the demand for environmental quality.

3. Theoretical background

The main theoretical argument used in our analysis to study the income-environmental quality relationship originates from the Environmental Kuznets Curve (EKC). According to the EKC hypothesis, during the early stages of a country's development process environmental degradation and pollution increase. It is only after economic development, and consequently per capita income, has reached a certain threshold that per capita pollution reduces. This implies that any environmental impact indicator is an inverted U-shaped function of income per capita. Grossman and Krueger (1991) first provided empirical evidence in favour of this hypothesis,

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[8] There is a similarity of this issue with information goods, where accounting for services such as Wikipedia or Google search in official GDP is devilishly difficult.

although it is Panayotou (1993) who first coined the term “EKC” after the original Kuznets curve (that refers to income inequality). Since then there has been a diffusion of empirical studies testing the validity of the EKC hypothesis with a variety of data and econometric methodologies – see Stern (2014), among others, for a survey of empirical studies on the EKC relationship.

In this paper, we argue that the same reasoning as applies to an environmental version of the Kuznets curve can also be used to describe the supposedly non-linear relationship between renewable energy development and income, especially among rich countries. In the same way economic growth has brought large scale availability of potable water and increased protection of human populations against both water- and air-borne disease in industrial countries (cf. Dasgupta 2010), a similar process is at work in the United States and the European Union that has resulted in acceleration in renewable energy diffusion as a viable alternative to traditional fossil fuels—particularly coal and oil. Because of the relatively high cost of renewable energy sources such as solar and wind, today it is mostly rich countries that are able to afford the widespread adoption of such technologies through generous support measures.

Wealth exerts an indirect effect on environmental quality, too. As average education increases with rising income, environmental awareness and the concern for reduced life expectancy grow accordingly. Put differently, growing economic affluence of a country induces the population to demand greater environmental quality because of its effects on quality of life and wellbeing (Bayer and Urpelainen 2013).[9] Such demand may create “institutional pressure” and induce policy makers to implement legislation that makes renewables more competitive vis-a-vis fossil fuel technologies, thereby creating new market opportunities. Lieb (2003) cites a

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[9] The argument that the demand for environmental quality rises with income is typically advanced under the “prosperity/affluence hypothesis” in environmental economics (e.g. Baumol and Oates 1979). A recent study by Saad and Taleb (2018) underscores economic growth as a core factor to improve renewable energy consumption in the short run among 12 EU countries. Further, renewable energy stimulates economic growth in the long run.

number of studies showing evidence (i) that advanced social, legal, and fiscal institutions may only be feasible in rich democratic countries, (ii) that higher GDP makes policy-decisions more environmentally friendly, (iii) that democratic countries have lower pollution levels, and (iv) that democracies are more likely to sign international environmental agreements.

Recently, Aflaki et al. (2014) provide empirical evidence for the existence of a renewable energy (RE) version of the environmental Kuznets curve. In the latest edition of the World Energy Outlook, the International Energy Agency also notes that “energy intensity falls and GDP per capita grows in all regions in the New Policies Scenario” (WEO 2017; p. 287).

4. Methods

4.1 Overall Analytical Approach

Applying the above insights from the EKC hypothesis, we develop a novel metric of environmental proactiveness that ranks countries by their environmental performance relative to their wealth. Whereas existing rankings such as the EPI are constructed based on the actual appropriation of environmental resources (e.g. forests, fisheries, air quality), we focus on a country’s affordability (measured by income per capita) as the main driver of environmental quality. This ranking is consistent with the fact that in a market economy, the consumption of environmental services is ultimately shaped by supply (i.e. the availability of financial resources for environmental protection) and demand (i.e. the citizens of affluent countries demanding higher environmental quality) factors.

Our approach follows a three-stage process. We first apply a macroeconomic model to estimate the relationship between a raw indicator of environmental performance – i.e. the amount of investment in renewable technologies for energy production – and economic wealth, measured by GDP per capita. Second, we use the coefficient estimates from the econometric model to calculate the “turning point” income per capita. This is the threshold wealth level at which a country starts redirecting investments from polluting technologies to more environmentally friendly options. Finally, we measure environmental proactiveness as the difference between a country's average income per capita and its turning point income per capita. We dub this term "pseudo willingness to pay" (pseudo-WTP), because of its direct analogy with the willingness to pay notion in economics. If the value is positive, the country is environmentally proactive, indicating that at least certain segments of its population are willing to buy environmental products and services before other needs are satisfied. Likewise, if the value is negative, a country is dubbed as environmentally passive, suggesting that investments in environmental technologies are a second-order priority for most of its population. In a nutshell, the approach provides a simple and intuitive method to assess how inclined a country is to trade off affluence for higher environmental quality.

The approach is implemented on data from 15 OECD countries over the period 1990–2012. The 15 countries include Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, the UK, and the United States. The main reasons for focusing on these countries owe to their higher renewable progress and their homogeneous policy framework. The start date was chosen to reflect the rapid deployment of RE sources after 1990 as a result of the energy policies adopted by the EU and the US; the endpoint was chosen based on data availability.

4.2 Model Specification and Econometric Issues

The typical EKC regression model used in our analysis, with modifications to match the available data is:

$$\ln RE_{it} = \alpha_i + \delta t + \beta_{1i} \ln Y_{it} + \beta_{2i} (\ln Y_{it})^2 + \varepsilon_{it}, \tag{1}$$

where $i=1,\ldots,15$ and $t=1990,\ldots,2012$ refer to country and year, respectively. *RE* is the share of renewable energy in total electricity generation (a raw indicator of "environmental quality") and *Y* is GDP per person, both expressed in natural logarithms. α is an intercept that varies across countries, *t* is a linear time trend that captures the common technological trend towards lower costs in the renewable energy industry and ε is a random error term. It is expected that $\beta_2 > 0$, such that after income crosses a certain threshold level (or "turning point"), the diffusion of RE accelerates. However, the sign of β_1 is indeterminate but is assumed to be negative in order to obtain a U-shaped renewables Kuznets curve. The turning point (τ_i) level of income for country *i* is obtained from:

$$\tau_i = \exp(-0.5\beta_{1i}/\beta_{2i}). \tag{2}$$

The pseudo-WTP for a greener environment is then defined as:

$$WTP_i = \bar{Y}_i - \tau_i, \tag{3}$$

that is, the difference between GDP per capita and the turning point income. Thus, a pseudo-WTP>0 implies "environmental proactiveness," whereas a pseudo-WTP<0 denotes "environmental passiveness". Countries are then ranked in descending order based on their pseudo-WTP for a greener environment. The above model is estimated using appropriate panel data estimator(s), with proper accounting of time-series properties and cross-sectional dependence in the data, as discussed in the next section (see Aflaki et al., (2014) for a detailed description).

By the nature of our panel data, we apply the Common Correlated Effects (CCE) mean group estimator of Pesaran (2006), which permits individual-specific regressors, while at the same time allowing them to be cross-sectionally dependent. Besides cross-section dependence

(CSD), there are other forms of interaction among variables that are either unobservable or difficult to measure. Pesaran (2006) solved this problem by augmenting Equation (1) with the cross-section averages of the independent and dependent variables:

$$\ln RE_{it} = \alpha_i + \varphi_i t + \beta_{1t} \ln Y_{it} + \beta_{2i}(\ln Y_{it})^2 + \ \delta_{1i}\overline{RE} + \delta_{2i}\bar{Y} + \delta_{3i}\bar{Y}^2 + u_{it} \tag{4}$$

where δ_i are the individual specific loading coefficients of the cross-sectional averages of all observable variables in the model. The $\widehat{\beta_\iota}$ coefficient estimates the effect of income on RE's contribution after controlling for common factors in the data. The dynamics and common unobserved factors are modeled in the error terms ε_{it}, which are assumed to have the following structure:

$$u_{it} = \lambda_i^{'} \boldsymbol{f}_t + \epsilon_{it}, \tag{5}$$

where $\boldsymbol{f}_t$ is an $m \times 1$ vector of unobserved common effects and ϵ_{it} represents the country-specific (idiosyncratic) errors that are assumed to be distributed independently of the regressors $\boldsymbol{x}_{it}$ and $\boldsymbol{f}_t$. However, ϵ_{it} is allowed to be weakly dependent across *i*. The CCE estimator is based on the assumption that $\boldsymbol{x}_{it}$ is generated as:

$$x_{it} = a_i + \lambda_i^{'} \boldsymbol{f}_t + v_{it}, \tag{6}$$

where a_i is a $k \times 1$ vector of individual effects, λ_i is a $m \times k$ factor of loading matrices with fixed components and v_{it} represents the specific components of $\boldsymbol{x}_{it}$ distributed independently of the common effects and across i. The CCE estimator is equivalent to ordinary least squares technique applied to an auxiliary regression such as Equation (2). The CCE mean group (CCEMG) estimator, which has been adopted in our application, is a simple average of the individual CCE estimators, β_i:

$$\hat{\beta}_{CCEMG} = \frac{1}{N}\sum_{i=1}^{N} \hat{\beta}_i. \tag{7}$$

As pointed out by Eberhardt and Teal (2013), the CEE estimator is robust even when the cross-section dimension *N* is small; when variables are nonstationary, subject to structural breaks;

and/or in the presence of "weak" unobserved common factors (spatial spillover) and global/local business cycles.

4.3. Data and descriptive statistics

The dependent variable of Equation (1), which accounts for the diffusion of RE sources, is the ratio of renewable to total electricity. This metric is commonly used to monitor the progress of RE development in OECD countries. RE share data were collected from the World Energy Balance dataset[10], published by the International Energy Agency (IEA). The RE sources include geothermal, solar photovoltaics, solar thermal, tidal energy, wind power, waste, biofuels, and charcoal. Following the tradition of previous empirical work, we have excluded hydropower from the definition of RE. Affluence, the independent variable in Equation (1), was measured as GDP per capita (in 2005 US dollars). Data for this indicator were obtained from the World Bank's World Development Indicator.

Figure 1 (upper panel) presents linear plots for panel data for the dependent and independent variables. The variables are shown in the way they are entered in the regression equations (i.e. log transformed). A general feature of the variables is that they all exhibit a smooth upward trend. The log of RE share depicts an interesting trend of convergence in RE sources across the EU countries. However, the logs of real per capita GDP—widely recognized as being unit root processes—show country variation in income among the EU nations.

The lower panel in Figure 1 plots the kernel density estimates (smoothed histogram) for GDP per capita and the contribution of RE in electricity output for the countries in our sample. The solid (dashed) line is the kernel density estimate for the same countries in 1990 (2012). For GDP per person, the 2012 density has a shorter mode and is shifted to the right of the 1990,

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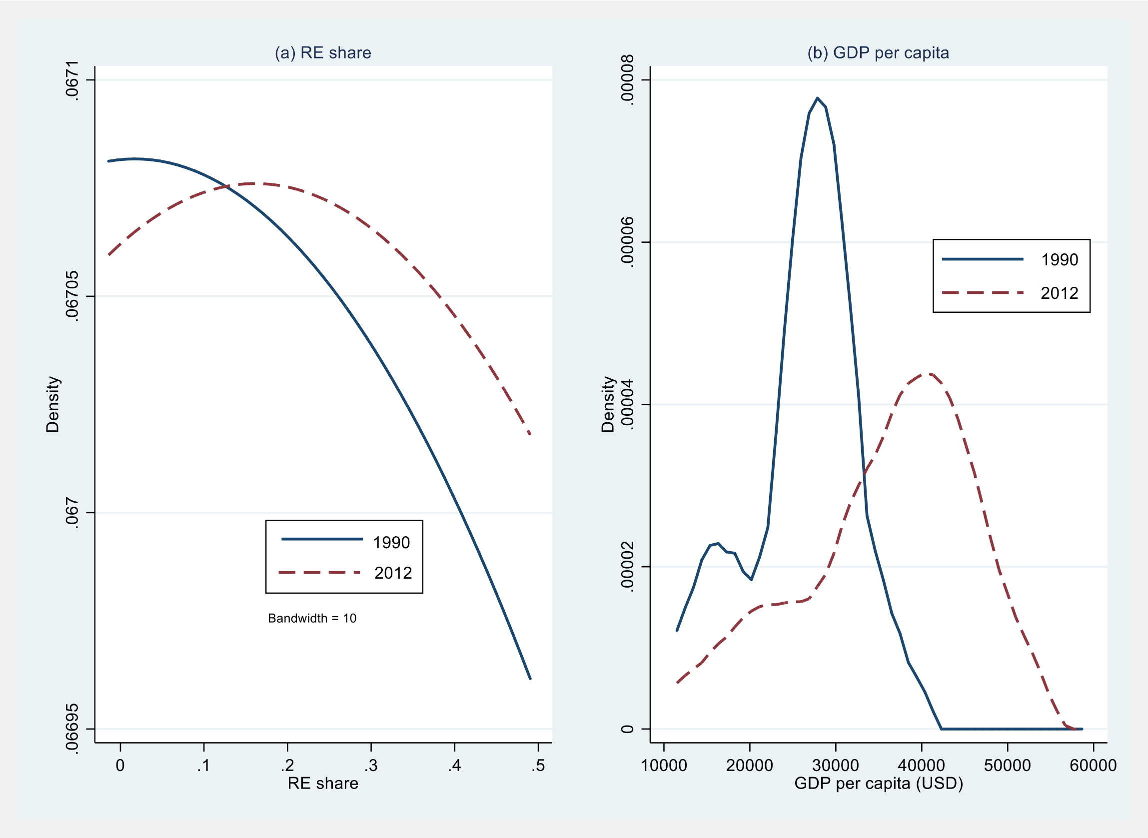
[10] https://www.iea.org/statistics/relateddatabases/worldenergystatisticsandbalances/

implying an increase per capita income as well an indication of rising income convergence between advanced countries today than in 1990. We also see that the 2012 density of RE share is shifted to the right of the 1990 density, indicating an increase in overall contribution of RE in electricity output. Note that each of the densities of RE share uses a particular smoothing parameter to make the figures easier to read.

Figure 1. Upper panel – Logarithm of RE share and GDP per person; Lower panel – kernel density of RE share and GDP per person



Further details about these variables emerge from Table 1, which presents mean and standard deviation for the dependent and independent variables. For the sake of greater comparability, these descriptive statistics have been obtained using the original data without transformation.

A few remarks are in order. Over the full sample, the average share of RE in most countries is low (5% or less), with the exception of Denmark, Finland, and Portugal. However, since 2000, the diffusion of RE has increased noticeably in countries such as Finland, Germany, and Spain, with a RE share of 10% or more. France remains an outlier, with a negligible contribution of RE to total energy (less than 2%). This is because nuclear energy accounts for over three-fourths of electricity production in France. Denmark, which has nearly zero hydroelectric resources, is really a forerunner in clean energy generation among EU countries.

RE sources in Denmark rely solely on wind energy and biomass, and have maintained an average share of 25% in the post-2000 period. Other countries in which the adoption of RE significantly increased in the new millennium are Austria, Ireland, Italy, the Netherlands and Sweden; with an average RE share of 7% or higher. Income per capita ranges from $16,940 (Portugal) to $43,757 (Denmark), with the majority of the countries showing a per capita income above the $30,000 threshold.

Table 1. Descriptive statistics

	GDP per person ($2005 constant prices)		Share of RE in electricity production (%)	
	μ	σ	μ	σ
Austria	$34,478	4131.85	0.05	0.03
Belgium	$33,313	3349.07	0.02	0.03
Denmark	$43,757	4133.07	0.17	0.13
Finland	$32,975	5382.05	0.12	0.02
France	$31,689	2561.53	0.01	0.01
Germany	$32,615	2885.88	0.05	0.06
Greece	$18,713	2864.42	0.02	0.02
Ireland	$36,709	11522.27	0.04	0.05
Italy	$28,710	1816.59	0.04	0.04
Netherlands	$36,385	4431.14	0.05	0.04
Portugal	$16,940	1764.31	0.09	0.08
Spain	$23,281	2931.49	0.06	0.07
Sweden	$36,684	5371.15	0.05	0.04
United Kingdom	$33,631	5047.23	0.03	0.03
United States	$39,940	4581.35	0.03	0.01

To make an individual country's RE position conditional on its income level, Figure 2 depicts a matrix that maps countries according to two dimensions. The first dimension is the country's position regarding renewable development relative to the rest of the group. Hence, a country has a lower (higher) RE share if its average level is lower (higher) than the median level of all 15 countries over the observation period. Similarly, the second dimension, which reflects a country's economic strength, identifies a country as having lower (higher) GDP per capita if its average income level is lower (higher) than the median income level of all countries over the sample period. This perspective serves as a proxy for the relative ability to deploy the necessary measures to foster renewable energy development. The information in Figure 2 speaks for itself. Italy, Portugal, and Spain are clearly ahead in fostering the growth of non-hydro RE sources. In contrast, Belgium and the UK trail other nations in their effort to hit the energy targets set for 2020[11]. Overall, these results demonstrate substantial heterogeneity by income groups for their pursuit of fostering renewable energy sources. They also support that the CCE is the choice of estimator for this data, given its satisfactory small sample properties under a substantial degree of heterogeneity and dynamics for panels with relatively small values of N and T (see Pesaran (2006) for further details).

Figure 2. The renewable energy-income matrix

	Lower GDP per capita	*Higher GDP per capita*
Lower RE share	France, Greece	Belgium, UK, US
Higher RE share	Germany, Italy, Portugal, Spain	Austria, Denmark, Finland, Ireland, the Netherlands, Sweden

Finally, Figure 3 shows the scatterplot of the two economic relationships considered in the analysis. The solid line represents a quadratic regression fit between the dependent (log RE share) and independent variables (log income and income squared) for the countries in our sample. Although this example is simplistic, we see evidence of a U-shape relation between RE share in electricity output and income per person, confirming our conjecture about the renewable version of the EKC theory.

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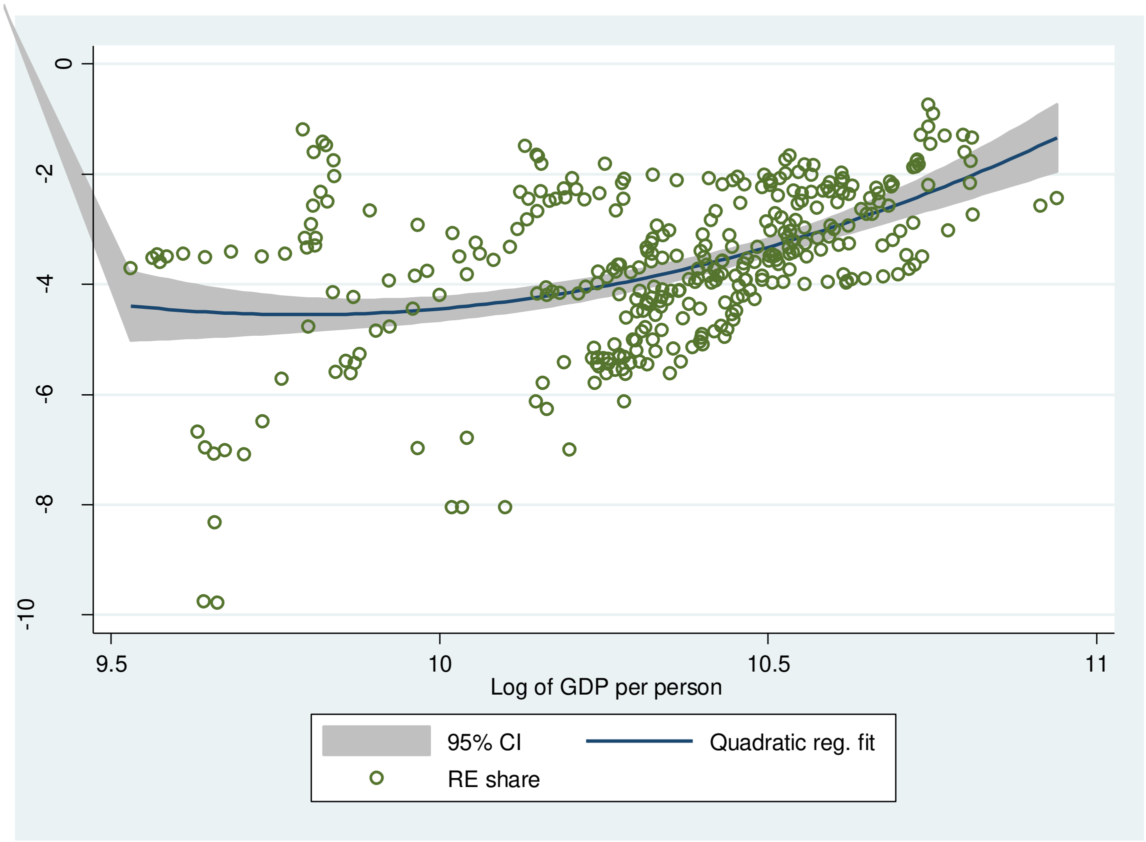
[11] According to the Renewable Energy Directive, the EU countries are required to fulfil at least 20% of their total energy needs through renewable energy sources by 2020. Source: https://ec.europa.eu/energy/en/topics/renewable-energy

Figure 3. Scatterplot of log GDP per person and log RE share



5. Results

During the pretesting of the data, we investigated the time series and cross-section properties of all variables using the panel unit root test of Pesaran (2007) and the cross-section dependence test by Pesaran (2004). The results suggest that the variables have unit roots, implying that shocks have permanent effects. In addition, there is strong cross-section dependence in our panel, for both variables in levels and first differences. Since the variables are integrated of order one, a convention in the existing literature for testing the validity of the EKC hypothesis is by testing for the existence of the cointegrating relationship between the dependent (RE share) and independent variables (income and income squared). The results suggest that the null hypothesis of no cointegration is rejected at the conventional level of significance, indicating a long-run equilibrium relationship between RE and income and income squared. These results are available in a Supplement.[12]

The estimation results for Equation (4) is as follows (standard errors in parenthesis)[13]:

$$\ln RE_{it} \;=\; \underset{(646.90)}{745.73} \;+\; \underset{(0.050)}{0.018t} \;-\; \underset{(121.27)}{237.67\,\ln Y_{it}^{**}} \;+\; \underset{(5.84)}{11.56\ln Y_{it}^{2**}} \qquad (7)$$

As can be seen, the estimated coefficients for income and income squared are, respectively, negative and positive and statistically significant at the 5% level (indicated with asterisk **), which is consistent with our main hypothesis that the relationship between RE and income follows a U-shaped curve. According to this result, up to a certain income threshold, the contribution of RE to a country's total electricity generation is negative (or nil). However, once the threshold income level is crossed, coupled with increased environmental awareness, the diffusion of RE sources increases. To verify that this result is not erroneously driven by an extreme point, we conduct a formal test for a U-shaped relationship using the likelihood ratio test proposed by Lind and Mehlum (2010). The result confirms that the Kuznets curve for the RE-income relationship is indeed U-shaped, as we can reject the composite null hypothesis of monotone or inverse U-shape against the alternative hypothesis of a U-shape relationship (*t*-value of 1.73, with a p-value of 0.041). More to the point, the *t*-value of the slope coefficient at the lower bound of the curve is -1.73 (p-value 0.941) versus a *t*-value at the upper bund equals to 2.22 (p-value 0.013). Hence, there is a significant U-shape relationship over the range of the

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[12] These results are in line with the recent findings by Aflaki et al. (2014) and Basher et al. (2015).

[13] The estimated coefficients on the cross-sectional average are not presented because they do not have any meaningful interpretations. They are used in the regression to account for the impact of unobservable common factors.

data. Recently, similar evidence of a U-shaped relationship between renewable energy and income has been documented by Aflaki et al. (2014).

The next step in our analysis is to compute the country-specific turning points. As mentioned earlier, the CCE estimator permits individual-specific regressors, which imply that it is possible to obtain estimates of income and income squared for each country in the panel that are used in the computation of the turning points – see Equation (2). The results are reported in Table 2. The estimates for Austria is clearly out of range, and therefore it is dropped from subsequent analysis.[14] For all other countries, the turning point estimates range from $15,793 (Portugal) to $56,073 (United States).

Table 2. Turning points

	τ
Austria	$623,130
Belgium	$33,111
Denmark	$41,370
Finland	$28,191
France	$31,969
Germany	$31,716
Greece	$19,852
Ireland	$32,451
Italy	$32,279
Netherlands	$30,327
Portugal	$15,793
Spain	$23,833
Sweden	$38,878
United Kingdom	$41,981
United States	$56,073

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[14] It is not unusual to find high turning points in the emission-income relationship. For example, in Holtz-Eakin and Selden (1995), the turning point occurs at a per capita income of US$ 8 million. To speculate on possible explanation for the higher turning point for Austria, there may be a need to use of a cubic function (rather than a quadratic form) on the possibility of a second turning point. Therefore, the assumed U-shaped relationship may be a statistical artifact in the sense that the 'true' relationship might be even more flexible that the one considered in the analysis (i.e. quadratic functional form that uses natural logarithm).

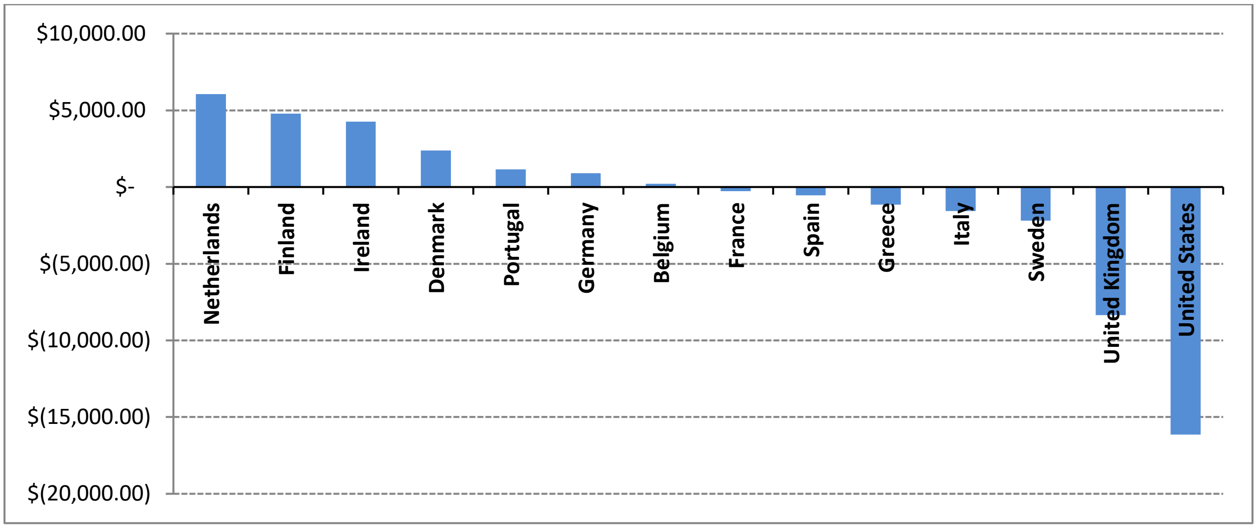
The final step in the analysis is to show the values of the wealth-adjusted index of environmental proactiveness for the countries in our sample using Equation (3). The results are displayed in Figure 4, in which the size of each bar represents a country's pseudo-WTP for RE technologies relative to its wealth. Remember that the pseudo-WTP for RE is the difference between a country's average income per capita and its turning point income per capita. That is, the difference between a country's average income per capita and the threshold wealth level at which a country starts redirecting investments from polluting technologies to more environmentally friendly options (based on the assumption that EKC hypothesis is applicable). Therefore, countries like Netherlands or Finland that display positive pseudo-WTP's can be considered environmentally proactive, because most segments of their population are willing to buy environmental products and services before other needs are satisfied. Conversely, countries with negative values of the pseudo-WTP index can be considered as environmentally passive, suggesting that investments in environmental technologies are a second-order priority for most of their population.

The results indicate that for 8 of the 14 countries in the sample (Portugal, Germany, Belgium, France, Spain, Greece, Italy and Sweden) the difference between the average per-capita GDP and their turning point income per capita is relatively small (it does not exceed $1,500). Conversely for 6 countries (Netherlands, Finland, Ireland Denmark, United Kingdom and United States) the difference is much more significant. It exceeds $ 6,000 (positive) for the most proactive countries (e.g. Netherlands) and can be as large as $16,000 (negative) for the most passive countries such as the United States. It is also worth noticing that the pseudo WTP is larger (in absolute terms) for passive countries than for proactive countries.

The new wealth-adjusted RE ranking (calculated by ranking countries in descending order based on their pseudo-WTP values) is displayed in Table 3. Table 3 also compares the ranking issued from our wealth-adjusted method to the simpler ranking based on the percentage of electricity generated from renewable sources, one of the indices typically used to assess a country's contribution to the reduction of greenhouse gas emissions. Based on the simpler index (and excluding hydropower) between 1990 and 2012, Denmark and Finland were the obvious RE leaders, with average RE shares exceeding 10% of their total generating capacity, whereas Belgium, Greece and France were lagging at the bottom of the ranking with hardly noticeable contributions (between 1% and 2%). The United States were ranked at number 9. Our wealth-adjusted index suggests a radically different picture, with the Netherlands and Ireland both climbing up seven places to finish first and third, and Denmark falling down to fourth place. France enjoys the biggest improvement, finishing eighth (+7 places), whereas the countries that lost most places are, surprisingly, Spain (-5 places) and Sweden (-4 places). The United States get also penalized (-3 places), ending up in 14th place. This result must be interpreted with care and not be taken as an indication of a future slow-down of RE development in the US. First, the result was driven by higher GDP levels in the US compared to EU countries in the period of our analysis. Second, it must be considered that most of the RE support policies implemented in the US (such as tender schemes, tax credits or net metering schemes) are market-based. In the early phases of the RE development cycles (i.e. when renewables were not yet cost competitive), such policies were less effective than the feed-in-tariffs schemes adopted by many EU countries. Conversely, this trend is likely to be reversed in the coming years. With the increased cost competitiveness of renewables, the market-based policies adopted in the US are providing a sharp acceleration to the development of renewables in the country. As an example, in 2017, the

US enjoyed the second largest new photovoltaic (PV) capacity PV growth in the World after China.

Figure 4. Pseudo average willingness to pay for renewable energy sources



Our results have important implications. First, they highlight an important feature of investments in environmentally friendly technologies: the amount of investment depends greatly on a country's wealth. Second, our approach is unique in that it ranks countries not based on what they actually achieved but on what they could have achieved, given the resources available to them. Although subtle, the difference is important. If applied, the ranking would produce a significant change in the perceived greenness of certain countries and hence a change in their bargaining power in international negotiations. This is particularly timely given the ongoing debate on the right to pollute between developed and developing countries. It would also increase (or decrease) internal pressure on certain governments to implement or discontinue environmental policies such as feed-in tariffs or product take-back legislation.

Table 3. Environmental performance rankings by method

		Ranking based on			
	Actual RE share (%) (2012)	Average RE share (1990–2012)	EPI 2012	Wealth-adjusted environmental proactiveness	Difference
Denmark	47.62	1	21	4	–3
Finland	16.03	2	19	2	=
Portugal	30.21	3	41	5	–2
Spain	22.49	4	32	9	–5
Germany	18.88	5	11	6	–1
Netherlands	11.95	7	16	1	+6
Sweden	10.82	8	9	12	–4
Ireland	16.16	9	36	3	+6
Italy	16.25	10	8	11	–1
United States	5.57	11	49	14	–3
United Kingdom	9.96	12	9	13	–1
Belgium	11.80	13	24	7	+6
Greece	8.14	14	33	10	+4
France	4.47	15	6	8	+7

6. Conclusions

Producing valid and reliable indicators to measure the sustainability performance of economic systems is no longer a mere academic exercise. Such indicators, especially when they are applied at the country level and are used to produce rankings, have relevant policy-making and business implications. A country’s perceived sustainability level has the potential to influence environmental legislation and ultimately to reshape competitive landscapes. In essence, “metrics and solid analytic underpinnings are critical not only for good environmental policymaking but also for sustainable development” (Esty et al., 2008).

Although distinguished, most of the available sustainability indicators have been criticized for indirectly favoring richer nations. By offering a new framework for estimating the sustainability level of an economic system, this paper aims at providing robust and yet simple metrics to facilitate a fairer discussion on the environmental performance of different countries or jurisdictions; one that takes into account their wealth and prosperity. The basic premise is that economic wealth significantly affects environmental performance. Therefore, instead of looking at how well each country performs in absolute terms, the proposed approach considers environmental performance relative to what countries should be doing based on their level of affluence. If economic prosperity would automatically lead to higher environmental performance, then the “greener” countries are those which start environmental investment at lower wealth levels, irrespective of their absolute level of performance.

To achieve this goal we propose a simple three-step approach. After noting that the relationship between per capita GDP and environmental technology adoption is not linear, we econometrically estimate the environmental turning point—i.e. the wealth level at which environmental technologies start to be significantly adopted. Second, we compute the difference between a country’s average GDP per capita and its estimated environmental turning point. We then use the so-obtained index to rank countries based on their pseudo willingness-to-pay for cleaner technologies. To illustrate the approach, we apply it to the case of renewable energy adoption in 15 OECD countries from 1990 to 2012. We show that such an approach has the potential to significantly alter the nations’ environmental performance rank and that has important policy implications as it decouples the effect of economic development from that of environmental awareness in assessing a country’s sustainability performance.

The main results can be summarized as follows. First, the relationship between RE and income follows a U-shaped curve. The estimated turning points range from \$15,793 (Portugal) to \$56,073 (United States). Second, the pseudo WTP for RE is larger (in absolute terms) for passive countries (e.g., the United States) than for proactive countries (e.g., Finland). Compared to a simpler but commonly used ranking based on the percentage of electricity generated from renewable sources, our wealth-adjusted index produces a radically different ranking with countries like Netherlands and France exhibiting significant improvement in environmental proactiveness, while Spain and Sweden have slipped down the ranking. Our results have important implications. First, they highlight an important feature of investments in environmentally friendly technologies: the amount of investment depends greatly on a country's wealth. Second, our approach is unique in that it ranks countries not based on what they actually achieved but on what they *could have* achieved, given the resources available to them. Although subtle, the difference is important. If applied, the ranking would produce a significant change in the perceived greenness of certain countries and hence a change in their bargaining power in international negotiations. It would also increase (or decrease) internal pressure on certain governments to implement or discontinue environmental policies such as feed-in tariffs or product take-back legislation.

Although simple and robust, our approach is not exempt from certain limitations which indicate avenues for future research. First, to validate the method, we focus on investment in renewable energy technologies. Although renewable technology adoption is an indicator of environmental performance, it does not include other important environmental aspects such as waste management or water or soil pollution. While the neglecting this aspect from the current analysis does not limit the validity of the framework, it paves the way for future studies that take into account a multitude of other sustainability dimensions. Furthermore, we have tested our framework on a relatively small sample of countries. Extending this sample would be useful to further validate the proposed framework.

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