Received July 30, 2018, accepted September 19, 2018, date of publication October 1, 2018, date of current version October 19, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2872786

Analysis of the Potential of Clean Energy Deployment in the European Union

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ABSTRACT This paper aims to assess the situation of the energy system throughout the European Union member states (EU28), with a focus set on renewable energy and energy efficiency programs. The first section briefly presents the situation in terms of the improvement in clean energy and highlights the main gains recorded during time in EU28. The second part introduces an index of transformation of the economy through clean energy (ITCE) which is based on two main factors which reveal the contribution (inputs) and success (outcomes) of the EU28 on the clean energy path. Each factor is based on four sub-factors which portray, on one hand, the contribution in terms of the development of renewable energy use in transport, electrical energy, and heat and cooling together with the development of regulatory legislation, and, on the other hand, the gains in terms of energy security, energy intensity, environmental emissions, and total energy efficiency. The ITCE is identified by panel data analysis involving EU28 and shows the best and worst performers in terms of clean energy deployment. The findings of this paper show that, despite a gain acquired during the last years in EU28, the real potential of clean energy is still to be unlocked. By applying the ITCE to EU28 the best practices are emphasized and these may be spread out in the European space. The ITCE constitutes a useful performance tracking tool and it may be used as a support for new, better-designed, more suitable measures, and policies needed by national policymakers and regulatory authorities in the area of clean energy.

INDEX TERMS Clean energy, energy efficiency, energy policy, European Union, panel analysis, renewable energy, sustainable energy.

I. INTRODUCTION

Energy sector is tremendously important for the economy of a nation and region, considering its cascading effects on competitiveness, industrial production, economic growth, but also on environment, security and human health. Therefore, a worldwide special attention was devoted to clean energy especially through energy efficiency plans and renewable energy (RE) development, involving low carbon products and services [1], [2].

Recent declarations and documents in the area of energy sector have at the core of their documentation the assertion "*energy efficiency is the most universally available source of energy*" [3]. Apart from being the most available source of energy, energy efficiency constitutes the cleanest form of energy, as it does not need to be produced. The European Union's (EU) energy efficiency target was reviewed in 2016 and a new binding target of 30% was set to be met by 2030, improved from 27%, showing a very ambitious tackling of the energy efficiency by the European Commission [4]. Energy efficiency implies energy efficiency programs in public and private buildings, energy efficiency for high intensive industries (like steel, automotive industries, but also defense), and the development of energy efficiency standards (like eco-design, energy labeling). Regardless of the strong advancement of RE in the last decades, the world still relies on fossil fuels, therefore the use of these natural non-renewable sources with increased efficiency should be more seriously taken into consideration [5].

RE plays an important role in the transition to clean energy and its deployment proved a continuous improvement during the last decades. The consumption of RE in the energy mix of the European Union member states (EU28) showed a doubling in the period 2005-2015 [6], increasing from 9% in 2005, to about 18% in 2015 [7]. This large increase still leaves room for improvement, as the EU has the potential to double this figure by 2030, in a cost-effective way [8].

TABLE 1. Energy dependence by product in EU28 in 2005-2015 (% of imports in total energy consumption).

EU28	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Growth rate, %
Oil	82.2	83.5	82.3	84.6	83.8	84.5	85.4	86.7	87.5	87.5	88.8	8
Coal	39.4	41.5	41.3	44.8	40.9	39.4	41.9	42.3	44.3	45.8	42.4	8
Gas	57.1	60.3	59.5	61.7	63.6	62.5	67.2	65.9	65.4	67.4	69.0	21
All energy products	52.1	53.6	52.8	54.5	53.6	52.7	54.0	53.4	53.1	53.4	53.9	3

Unfortunately, all over the world the policymakers still rely on old clean energy regulations and are not keen to update the requirements in-line with the technological improvements or to develop new well-designed policies aimed to boost this sector [9]. Many sustainability indicators were monitored in the EU28 [10], but they did not include the success of the application of a specific measure in the energy domain, to the best knowledge of the author. During the last two decades, inappropriate indicators and inadequate levels of ambition were employed [11] which hindered the contribution and success of countries in applying specific measures to boost the transition towards clean energy in a cost-effective way. Like for instance, domestic energy intensity which was regarded as a result of the application of energy efficiency measures, but this is true only taken together with energy efficiency modifications. Otherwise, the energy intensity may be influenced by either the structure of the economy, weather conditions or a certain standard of living [9]. Multi objective goal programming (MOGP) and multi-criteria decision analysis (MCDA) have been employed for energy planning, optimal RE technology selection, and sustainable energy package choice presenting complicated or overstuffed methodologies based on more than 30 indicators [12], [13]. Moreover, some of the indicators have also employed the economic component, favoring the countries with large gross domestic product (GDP). In addition, scenarios on the change of energy sources have been developed by relevant bodies like International Energy Agency (IEA) and World Energy Council (WEC), but they have been conservatory and mainly based on incremental modifications [14], [15]. However, none of the methods has considered a straightforward application, where the actual success of the contribution of the countries on the clean energy path to be seriously taken into consideration. Therefore, a new consistent path for the transition towards clean energy is necessary which includes the contribution of each country, but also the success of that contribution. To this end, this paper introduces a methodology which develops a straightforward new tool that accesses the potential of a nation to transformation its economy through clean energy, by an index of transformation of the economy through clean energy (ITCE). The applied panel data analysis [16] implies two multi-dimensional data sets, grouped together under factor 1 and factor 2, that are based on the scrutiny of multiple phenomena based on 8 sub-factors over a long period of time. Factor 1 reveals the contribution (inputs) and factor 2 discloses the success (outcomes) of the EU28 on the clean energy path. The deployment of RE in EU28 is strong, with a special input from wind, solar and biomass [17]. Therefore, RE inputs in transports and electrical energy are introduced within the scaffold of the model of clean energy, along with the RE employed in heating and cooling (H&C). The actual effectiveness of these inputs is revealed by the outputs listed under factor 2 as gains in energy security, energy intensity of the economy, environmental emissions and total energy efficiency. ITCE captures the real picture in terms of clean energy developments in the EU28 and constitutes also a performance tracking tool since the best practices may be spread around in countries with similar structures of the economies. The data for each factor of the ITCE considered for the panel data analysis are selected based on their relevancy, quality and availability. The main contribution of this paper is the development of the ITCE which allows the classification of EU28 in 3 main groups, allowing the identification of best practices and gaps to be filled out for each country.

The rest of the paper is organized as follows: first chapter sets the context by analyzing the clean energy deployment in EU28, the second chapter presents in detail the methodology of research, the third chapter introduces the results, the fourth chapter contains the discussion and reveals the main contributions, while the conclusion part identifies the next steps in the complex research of clean energy.

II. CONCISE ANALYSIS OF THE CLEAN ENERGY DRIVERS IN EU(28)

The EU28 is a region with very low self-sufficient energy. The region is depended on imported fossil fuels resources, and has an overall mean value of energy dependence above 50% (see table 1) [18].

In 2005, about 82% of the consumed oil came from import, while in 2015 this figure increased to about 89%. In the case of coal the situation worsened, from 39% in 2005 to about 42% in 2016. The situation of gas is even worse, as the imports accounted for 57% of the consumed gas in 2005, while in 2015 this figure rose to about 70%, having the largest growth rate from all fossil fuels during the monitored interval. This dependence makes EU28 very vulnerable to fossil fuels' price variations and undesired political pressures from exporting countries.

Therefore, EU28 qualifies as the best region to focus on clean energy development through available means as enhancement of energy efficiency, investments, enforcements of new targets in RE field and pricing the carbon. The investments in energy efficiency may determine important

TABLE 2. Factors, sub-factors and descriptors of clean energy framework.

Factor	Sub-factor	Descriptor (unit)
Inputs	RET: RE consumption in transport	Share of renewable energy in fuel consumption of transport (%)
	REE: RE generated by electrical energy	Share of electricity generated from renewable sources (%)
	REH: RE consumption in H&C	Share of renewable energy in H&C (%)
	TET: Environmental taxes	Total environmental taxes (% of GDP)
Outputs	EDF: Energy security	Energy dependence for all fuels (%)
	EIE: Energy intensity of the economy	Gross inland consumption of energy divided by GDP (kg of oil equivalent / 1000 EUR)
	EEC: Environmental emissions	GHG emissions per capita (tons of CO_2 equivalent / capita)
	EEG: Energy efficiency	Total energy efficiency gains (%)

benefits such as reduced consumption which leads to lower emissions, reduced energy spending, increase in the labor demand and a better security of supply. However, important challenges are to be surmounted, as the policies addressed to energy efficiency must capture multiple, but usually conflicting interests from producers and distributors of energy, industrial corporations, and consumer representatives.

There are 3 main energy consumers in national economies from EU28, namely transport, households and industry, which accounted for more than 80% of the final energy consumption in 2015 [19]. Transports accounted for 33%, while residential sector recorded 25% and the industry accounted for another 25% of the final energy consumption in 2015 [20]. The energy efficiency improved in households by an average of 2%/year, namely 22% over the period 2005-2015. The energy efficiency in industry improved as well, by an average rate of 1.4%/year, namely about 15% over the period 2005-2015. At the same time, energy efficiency in transport rose by only 0.7%/year, recording an overall increase during 2005-2015 of about 8%, mainly due to improvements in aviation [21]. The total energy efficiency gains increased noticeably in the EU28, from an average of 6% in 2005 to 18% in 2015, scoring almost a tripling in the last years, but are still far from the target set by 2020 of 27% [22]. 11 countries already surpassed this target (Bulgaria, Ireland, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia and United Kingdom), but other six are way behind (Austria, Croatia, Denmark, Finland, Luxembourg, and Malta), while the rest of 11 countries are above 80% compliance with the efficiency target (resulted from calculations on [22]).

The shares of RE in gross final energy consumption in EU28 increased over the time, from 9% in 2005 to about 17% in 2015, many countries being near their national targets set by 2020 [7]. 11 member states already surpassed their domestic targets (Bulgaria, Czech Republic, Croatia, Denmark, Estonia, Finland, Hungary, Lithuania, Italy, Romania and Sweden), but other six are way behind (Belgium, Ireland, Luxembourg, Malta, Netherlands and United Kingdom) while the rest of 11 member states are above 70% compliance with the domestic target (resulted from calculation on [7]). In this respect, there are also many barriers to be surmounted, structural and financial in nature. As regards the main structural aspects, the distribution of electrical energy is the key issue, as it is mostly based on one-direction flow from centralized units to consumers, whereas a bi-directional flow is needed for RE [23]. Moreover, the main challenge for electrical energy from RE remains the development of a secure, efficient and economic electric smart grid. The financial part is also important as RE are more expensive than fossil fuels since no carbon-tax is considered, therefore RE proves a slower penetration in areas with well defined infrastructure based on fossil fuels.

III. METHODOLOGY OF RESEARCH

Clean energy deployment is of strategic importance for any nation, as it may provide the means for energy independence and security, green economic growth, low environmental impact and a sustainable use of resources. However, the path to a clean, but secure and affordable energy goes mainly through a framework that rests on 3 main pillars:

- enhancement of energy efficiency;
- development of RE;
- appropriate pricing of environmental damage.

When looking separately at the pillars, the progress varies largely for each pillar across EU28. Therefore, the paper introduces an index of the transformation of the economy through clean energy (ITCE) which assesses the potential of the transformation of the economies through clean energy in EU28 for all 3 pillars working in synergy. For this purpose, a framework is designed which is based on 2 factors (see table 2), built on the available data for 2005 and 2015:

- *factor 1* (inputs): refers to specific contribution of the EU28 on the clean energy, based on 4 sub-factors involving:
  - RE consumption in transport: shows the development of RE in transport [24] (code: RET).
  - RE consumption in electrical energy: depicts the development of RE in generating electricity [25] (code: REE).
  - RE consumption in H&C: shows the development of RE in H&C [26] (code: REH).
  - Total environmental taxes: describes the pricing of environmental damage as revenue used by

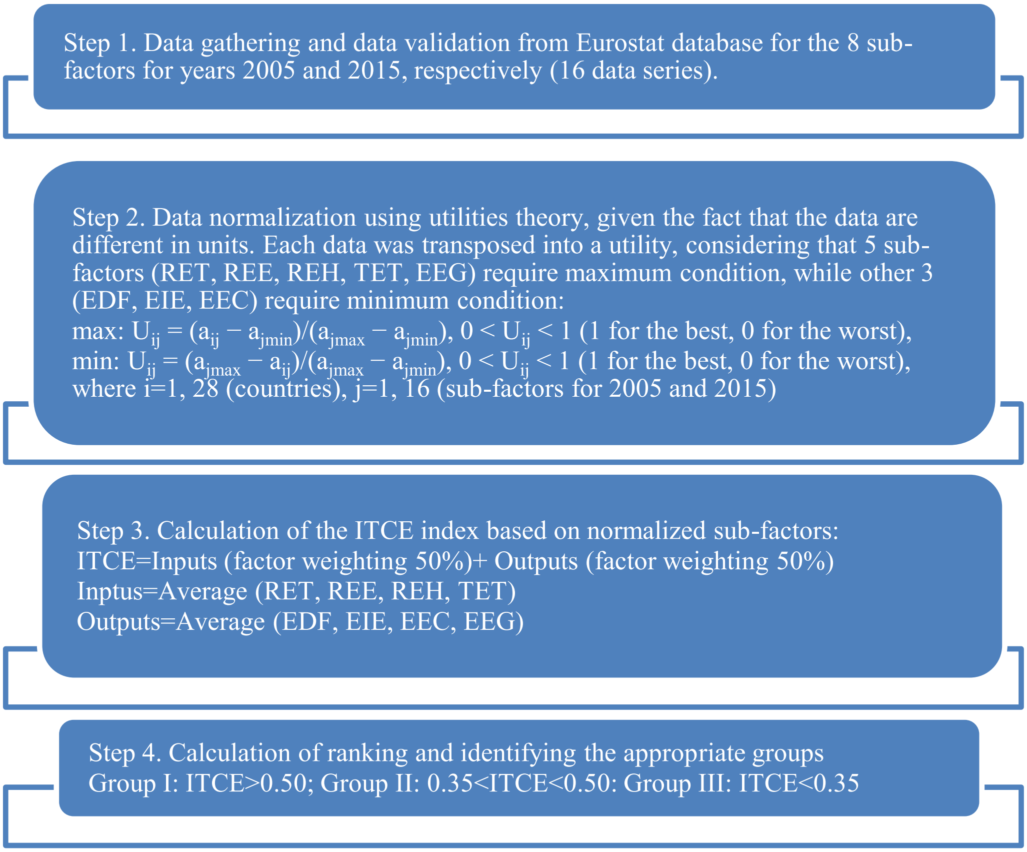

FIGURE 1. **Methodology of ITCE identification.**

Governments to foster the development of clean energy (include resource taxes, transport taxes, energy taxes, and pollution taxes) [27] (code: TET).

- *factor 2* (outputs): refers to the success of implementation of the specific contribution of the EU28, based on 4 sub-factors involving:
    - Energy security: portrays the energy dependence for all fuels [28] (code: EDF).
    - Energy intensity of the economy: expresses the consumption of energy divided by GDP [29] (code: EIE).
    - Environmental emissions: shows the green house gases emissions (GHG) per capita [30] (code: EEC).
    - Energy efficiency: presents total energy efficiency gains for main sectors of the economy (households, industry, transports and services) [22] (code: EEG).

The steps of the methodology are presented in Fig. 1. The ITCE is based on an equal importance established for the input and output factors, each having a 50% contribution. Each factor represents the average of the considered 4 sub-factors.

IV. RESULTS

Factor 1 contains 4 sub-factors which refer to the countries' contributions, and are selected based on their importance for the clean energy deployment, but also on their availability from reliable data bases (see table 3).

A. RE IN FUEL CONSUMPTION OF TRANSPORT

This sub-factor is taken into consideration because this sector accounts for about 33% of the energy demand in EU. It is mainly driven by road transport which accounts for 80% of the EU28 energy demand in transport [17]. Despite its potential, mainly driven by electrical cars, the contribution of this domain to RE development was only 7% in 2015 (mean value for EU28 for RE share in transports), and referred to the quota of bio-fuel required by the European Commission [31]. In 2005, the best performer was Sweden and the worst, with no inputs, were Cyprus and Malta. The situation changed in 2015, when Sweden had still the leading role, but Estonia was the worst performer.

B. RE GENERATED BY ELECTRICAL ENERGY

This sub-factor is selected because the advancement in this field reflects the willingness of Governments to support RE development. This sub-factor showed the strongest increase during 2005-2015. In 2005 the best performer was Sweden and the worst, with no inputs, were also Cyprus and Malta. The situation remained the same in 2015, when Sweden had still the leading role, and Malta was the worst performer.

TABLE 3. Sub-factors of factor 1 of the clean energy model.

Sub-factors	RET		REE		REH		TET	
Country\time	2005	2015	2005	2015	2005	2015	2005	2015
Belgium	0.6	3.8	2.4	15.4	3.4	7.8	2.5	2.1
Bulgaria	0.8	6.5	9.3	19.1	14.3	28.6	2.9	2.9
Czech Republic	0.9	6.5	3.7	14.1	10.9	19.6	2.5	2.1
Denmark	0.4	6.7	24.6	51.3	22.8	40.1	4.9	4.0
Germany	4.0	6.8	10.5	30.7	6.8	12.9	2.4	1.9
Estonia	0.2	0.4	1.1	15.1	32.2	49.6	2.3	2.8
Ireland	0.1	6.5	7.2	25.2	3.5	6.6	2.5	1.9
Greece	0.1	1.4	8.2	22.1	12.8	25.6	2.1	3.7
Spain	1.3	1.7	19.1	36.9	9.4	16.8	1.9	1.9
France	2.1	8.5	13.7	18.8	12.2	19.7	2.0	2.2
Croatia	1.0	3.5	35.6	45.4	30.0	38.5	3.9	4.1
Italy	1.0	6.4	16.3	33.5	8.2	19.3	2.9	3.4
Cyprus	0.0	2.5	0.0	8.4	10.0	22.5	3.3	3.0
Latvia	2.4	3.9	43.0	52.2	42.7	51.8	2.5	2.7
Lithuania	0.6	4.6	3.8	15.5	29.3	46.1	2.3	1.8
Luxembourg	0.1	6.5	3.2	6.2	3.6	7.1	3.0	1.9
Hungary	0.9	6.2	4.4	7.3	6.0	21.2	2.7	2.7
Malta	0.0	4.7	0.0	4.2	2.2	14.1	3.1	2.9
Netherlands	0.5	5.3	6.3	11.1	2.4	5.5	3.6	3.4
Austria	4.8	11.4	62.0	70.3	22.3	32.4	2.6	2.4
Poland	1.6	6.4	2.7	13.4	10.2	14.5	2.7	2.7
Portugal	0.5	7.4	27.7	52.6	32.1	33.4	2.9	2.4
Romania	1.6	5.5	26.9	43.2	18.0	25.9	2.0	2.4
Slovenia	0.8	2.2	28.7	32.7	18.9	33.9	3.2	3.9
Slovakia	1.6	8.5	15.7	22.7	5.0	10.8	2.3	1.8
Finland	0.9	22.0	26.9	32.5	39.1	52.5	3.0	2.9
Sweden	6.2	24.0	50.9	65.8	51.9	68.6	2.7	2.2
United Kingdom	0.5	4.4	4.1	22.4	0.8	6.3	2.3	2.5

C. RE CONSUMPTION IN H&C

This sub-factor is considered as this sector accounts for about 50% of the energy demand in EU28 [32]. Unfortunately, its potential was not fully grasped and this is the sector with the slowest pace in the deployment of RE in EU28. In 2005, the best performer was Sweden and the worst was United Kingdom. The situation somehow changed in 2015, when Sweden had still the leading role, and Netherlands was the worst performer.

D. ENVIRONMENTAL TAXES

This sub-factor is used to portray the development of regulatory legislation in the area of environment through the enforcement of taxes on resource, transport, energy, and pollution (expressed as % of GDP revenues and not by actual values to not create a false input from the countries with large GDPs). In 2005, the best performer was Denmark and the worst was Spain. The situation changed in 2015, when Croatia was the best performer, and Slovakia was the worst.

Factor 2 consists of 4 sub-factors which refer to the success of the implementation of the contributions, selected based on their significance for the clean energy deployment, but also on their availability from reliable data bases (see table 4).

E. ENERGY SECURITY

This sub-factor is expressed by the energy dependence of a given country. In 2005, the best performer was Denmark, which was actually a net exporter of energy, and the worst

TABLE 4. Sub-factors of factor 2 of the clean energy model.

Sub-factors	EDF		EIE		EEC		EEG	
Country\time	2005	2015	2005	2015	2005	2015	2005	2015
Belgium	80.1	84.3	173.3	141.3	14.2	10.8	14.9	25.6
Bulgaria	46.7	35.4	614.0	448.5	8.4	8.6	19.2	33.8
Czech Republic	27.8	31.9	327.0	249.2	14.6	12.2	11.6	24.8
Denmark	-49.8	13.1	81.3	65.1	12.7	9.0	6.4	18.3
Germany	60.5	61.9	140.9	112.2	12.3	11.4	9.5	19.8
Estonia	26.1	7.4	373.9	355.1	14.2	13.8	14.8	26.0
Ireland	89.6	88.7	94.3	59.4	17.6	13.5	10.9	29.1
Greece	68.6	71.7	136.7	132.5	12.7	9.1	13.3	33.3
Spain	81.4	73.3	140.7	113.4	10.4	7.5	4.8	19.9
France	51.6	46.0	143.7	120.5	9.1	7.1	6.3	17.1
Croatia	52.5	48.3	222.5	192.9	6.9	5.7	9.2	18.9
Italy	83.4	77.1	116.6	100.2	10.2	7.3	4.8	14.1
Cyprus	100.0	97.7	148.9	128.0	13.9	10.9	10.2	26.9
Latvia	63.9	51.2	251.9	207.5	5.1	5.9	16.9	32.0
Lithuania	56.8	78.4	329.5	205.4	6.9	7.0	11.1	28.7
Luxembourg	97.4	95.9	134.8	90.2	31.0	20.8	7.4	21.6
Hungary	63.1	53.4	276.4	231.8	7.6	6.3	10.9	29.5
Malta	100.0	97.3	162.8	90.8	8.2	6.0	14.2	18.1
Netherlands	37.8	52.1	141.9	117.9	13.8	12.2	10.8	25.1
Austria	71.8	60.8	123.1	106.4	11.5	9.4	10.0	18.3
Poland	17.2	29.3	321.7	227.3	10.5	10.2	16.9	30.0
Portugal	88.6	77.4	157.4	133.6	8.4	7.0	11.0	28.0
Romania	27.6	17.1	357.2	226.7	6.9	5.9	21.3	36.4
Slovenia	52.5	48.7	220.2	177.9	10.3	8.2	15.2	23.8
Slovakia	65.3	58.7	355.1	214.7	9.6	7.6	24.8	59.3
Finland	54.1	46.8	192.1	177.7	13.5	10.5	4.0	10.1
Sweden	36.8	30.1	149.5	110.9	7.6	5.7	12.8	25.9
United Kingdom	13.4	37.4	129.3	93.5	12.0	8.3	9.6	27.0

were Cyprus and Malta. The situation somehow changed in 2015, when Estonia was the best, and Cyprus was the worst performer.

F. ENERGY INTENSITY OF THE ECONOMY

This sub-factor is expressed as gross inland consumption of energy divided by GDP. In 2005, the best performer was Denmark and the worst was Bulgaria. The situation somehow changed in 2015, when Ireland was the best, but Bulgaria was still the worst performer in EU28.

G. ENVIRONMENTAL EMISSIONS

This sub-factor is rendered as GHG emissions per capita, expressed in CO_2 equivalent. In 2005, the best performer was Latvia and the worst was Luxembourg. The situation somehow changed in 2015, when Croatia was the best, but Luxembourg was still the worst performer in EU28.

H. ENERGY EFFICIENCY

This sub-factor is expressed as total energy efficiency gains for industry, households and services. In 2005, the best performer was Slovakia and the worst was Finland. The situation remained the same in 2015, when Slovakia was the best, and Finland was still the worst performer in EU28.

The 8 sub-factors are normalized as presented by step 2 of the methodology and the results are shown in tables 5 and 6.

The data from tables 5 and 6 allowed the identification of ITCE for EU28 in 2005 and 2015, as mentioned in step 3 of

TABLE 5. The utilities of the factor 1 of the clean energy model.

Utilities for factor 1	Utilities for RET		Utilities for REE		Utilities for REH		Utilities for TET	
Country\time	2005	2015	2005	2015	2005	2015	2005	2015
Belgium	0.097	0.144	0.047	0.182	0.051	0.036	0.182	0.145
Bulgaria	0.129	0.258	0.183	0.242	0.264	0.366	0.338	0.483
Czech Republic	0.145	0.258	0.073	0.161	0.198	0.223	0.192	0.137
Denmark	0.065	0.267	0.483	0.765	0.431	0.548	1.000	0.949
Germany	0.645	0.271	0.206	0.430	0.117	0.117	0.172	0.064
Estonia	0.032	0.000	0.022	0.177	0.614	0.699	0.123	0.419
Ireland	0.016	0.258	0.141	0.341	0.053	0.017	0.192	0.064
Greece	0.016	0.042	0.161	0.291	0.235	0.319	0.060	0.838
Spain	0.210	0.055	0.375	0.531	0.168	0.179	0.000	0.051
France	0.339	0.343	0.269	0.237	0.223	0.225	0.033	0.175
Croatia	0.161	0.131	0.699	0.669	0.571	0.523	0.646	1.000
Italy	0.161	0.254	0.320	0.476	0.145	0.219	0.331	0.692
Cyprus	0.000	0.089	0.000	0.068	0.180	0.269	0.470	0.517
Latvia	0.387	0.148	0.845	0.779	0.820	0.734	0.205	0.397
Lithuania	0.097	0.178	0.075	0.183	0.558	0.643	0.129	0.017
Luxembourg	0.016	0.258	0.063	0.032	0.055	0.025	0.364	0.034
Hungary	0.145	0.246	0.086	0.050	0.102	0.249	0.278	0.376
Malta	0.000	0.182	0.000	0.000	0.027	0.136	0.391	0.483
Netherlands	0.081	0.208	0.124	0.112	0.031	0.000	0.550	0.692
Austria	0.774	0.466	1.218	1.073	0.421	0.426	0.228	0.274
Poland	0.258	0.254	0.053	0.149	0.184	0.143	0.255	0.376
Portugal	0.081	0.297	0.544	0.786	0.613	0.442	0.328	0.282
Romania	0.258	0.216	0.528	0.633	0.337	0.323	0.026	0.282
Slovenia	0.129	0.076	0.564	0.463	0.354	0.450	0.414	0.919
Slovakia	0.258	0.343	0.308	0.300	0.082	0.084	0.146	0.000
Finland	0.145	0.915	0.528	0.459	0.750	0.745	0.354	0.491
Sweden	1.000	1.000	1.000	1.000	1.000	1.000	0.272	0.192
United Kingdom	0.081	0.169	0.081	0.295	0.000	0.013	0.129	0.299

the methodology. Table 7 shows the actual values of ITCE for EU28, ranked from best to worst, for 2005 and 2015, respectively.

V. DISCUSSION

The panel data analysis applied for EU28 countries implies two multi-dimensional data sets, grouped together under factor 1 and factor 2. The factors are based on the scrutiny of multiple phenomena based on 8 sub-factors over a long period of time. The individual results for each sub-factor portray a mixed very complex picture in EU28 progress towards clean energy. While the best and worst performers are easily grasped for each sub-factor from the tables 3-6, the computation of the ITCE allows the proper ranking of countries and identification of the overall best/worst performer in terms of clean energy deployment, the countries' performances being judged against each other.

The identification of ITCE allows the splitting of the countries in 3 groups, depending on the countries' overall performance recorded for all sub-factors. The groups portray the countries which are leading in implementing clean energy programs identified as *active builders of transformation of their economies* into cleaner ones (group I), countries with necessary but insufficient measures, identified as *in progress builders of transformation of their economies* (group II) and the last countries in terms of clean energy performance identified as *slow builders of transformation of their economies* (group III) (see table 7).

TABLE 6. The utilities of the factor 2 of the clean energy model.

Utilities for factor 2	Utilities for EDF		Utilities for EIE		Utilities for EEC		Utilities for EEG	
Country\time	2005	2015	2005	2015	2005	2015	2005	2015
Belgium	0.133	0.148	0.827	0.790	0.648	0.658	0.524	0.315
Bulgaria	0.356	0.690	0.000	0.000	0.874	0.804	0.731	0.482
Czech Republic	0.482	0.729	0.539	0.512	0.635	0.565	0.365	0.299
Denmark	1.000	0.937	1.000	0.985	0.705	0.777	0.115	0.167
Germany	0.264	0.396	0.888	0.864	0.722	0.619	0.264	0.197
Estonia	0.493	1.000	0.451	0.240	0.649	0.462	0.519	0.323
Ireland	0.069	0.100	0.976	1.000	0.516	0.481	0.332	0.386
Greece	0.210	0.288	0.896	0.812	0.708	0.773	0.447	0.472
Spain	0.124	0.270	0.888	0.861	0.795	0.875	0.038	0.199
France	0.323	0.573	0.883	0.843	0.847	0.901	0.111	0.142
Croatia	0.317	0.547	0.735	0.657	0.932	1.000	0.250	0.179
Italy	0.111	0.228	0.934	0.895	0.805	0.892	0.038	0.081
Cyprus	0.000	0.000	0.873	0.824	0.662	0.656	0.298	0.341
Latvia	0.241	0.515	0.680	0.619	1.000	0.985	0.620	0.445
Lithuania	0.288	0.214	0.534	0.625	0.930	0.913	0.341	0.378
Luxembourg	0.017	0.020	0.900	0.921	0.000	0.000	0.163	0.234
Hungary	0.246	0.491	0.634	0.557	0.904	0.960	0.332	0.394
Malta	0.000	0.004	0.847	0.919	0.882	0.976	0.490	0.163
Netherlands	0.415	0.505	0.886	0.850	0.664	0.564	0.327	0.305
Austria	0.188	0.409	0.922	0.879	0.752	0.749	0.288	0.167
Poland	0.553	0.757	0.549	0.568	0.793	0.699	0.620	0.404
Portugal	0.076	0.225	0.857	0.809	0.871	0.914	0.337	0.364
Romania	0.483	0.893	0.482	0.570	0.932	0.981	0.832	0.535
Slovenia	0.317	0.543	0.739	0.695	0.800	0.831	0.538	0.278
Slovakia	0.232	0.432	0.486	0.601	0.827	0.868	1.000	1.000
Finland	0.306	0.564	0.792	0.696	0.674	0.677	0.000	0.000
Sweden	0.422	0.749	0.872	0.868	0.902	0.995	0.423	0.321
United Kingdom	0.578	0.668	0.910	0.912	0.732	0.826	0.269	0.343

The top 5 countries leading in their efforts to develop clean energy and succeeding in doing that are Sweden, Denmark, Latvia, Austria and Croatia for 2005. The situation is about the same in 2015, but Austria was outranked by Finland. The first observation is that the Nordic countries are leading in their overall effort to build a cleaner economy, with Sweden and Denmark leaders for both 2005 and 2015. The best mix of inputs and outputs proved to be that of Sweden which best developed RE in all sectors (transport, electricity generation and H&C) and gained in energy intensity of the economy and GHG emissions, proving that the measures taken were working in synergy to improve the situation. The situation of Denmark is somehow different and is correlated with the structure of the economy, as the country contributed with the best environmental taxation and gained in energy intensity of the economy, but also in energy dependence.

The situation was better in 2015 in respect with 2005, as the number of countries belonging to group I evolved from 5 to 9, from 18% of the EU28 in 2005, to 32% of the EU28 in 2015. At the same time, the situation was better for the countries belonging to group III, as the number of countries decreased from 10 in 2005 to only 4 in 2015, moving from 36% of the EU28 in 2005, to only 14% of the EU28 in 2015. Nevertheless, Cyprus, Ireland, Belgium and Luxembourg were still the

TABLE 7. Country rankings in EU28.

Rank 2005/2015	Country\time	2005	Country\time	2015	Country group
1/1	Sweden	0.736	Sweden	0.766	*ITCE>0.50 Active builders of transformation Group I*
2/2	Denmark	0.600	Denmark	0.674	
3/4	Latvia	0.600	Croatia	0.588	
4/6	Austria	0.599	Latvia	0.578	
5/3	Croatia	0.539	Finland	0.568	
6/7	Romania	0.485	Austria	0.555	
7/8	Slovenia	0.482	Romania	0.554	
8/9	Portugal	0.463	Slovenia	0.532	
9/5	Finland	0.444	Portugal	0.515	
10/12	Slovakia	0.417	Greece	0.479	*0.35<ITCE<0.50 In progress builders of transformation Group II*
11/22	Germany	0.410	Italy	0.467	
12/15	Poland	0.408	Slovakia	0.453	
13/19	Netherlands	0.385	United Kingdom	0.441	
14/14	France	0.378	France	0.430	
15/20	Lithuania	0.369	Poland	0.419	
16/18	Estonia	0.363	Bulgaria	0.416	
17/16	Bulgaria	0.359	Hungary	0.415	
18/11	Italy	0.356	Estonia	0.415	
19/13	United Kingdom	0.348	Netherlands	0.404	*ITCE<0.35 Slow builders of transformation Group III*
20/10	Greece	0.342	Lithuania	0.394	
21/17	Hungary	0.341	Spain	0.378	
22/24	Malta	0.330	Germany	0.370	
23/23	Czech Republic	0.329	Czech Republic	0.361	
24/21	Spain	0.325	Malta	0.358	
25/27	Belgium	0.314	Cyprus	0.346	
26/25	Cyprus	0.310	Ireland	0.331	
27/26	Ireland	0.287	Belgium	0.302	
28/28	Luxembourg	0.197	Luxembourg	0.191	

last 4 countries in both years, but not in the same order. The last 2 countries, Belgium and Luxembourg had small values for all the 8 utilities of sub-factors; Luxembourg recorded the worst value for environmental emissions, while Belgium was not the worst for any of the sub-factors, but recorded very low values for all utilities of the 8 sub-factors.

Overall, the situation improved, with a major increase for Greece, which gained 10 positions in ranking (from position 20 in 2005 to 10 in 2015), but also with a major loss for Germany which lost 11 positions in ranking (from position 11 in 2005 to 22 in 2015). Nevertheless, Greece was very slow in incorporating clean energy in its agenda and only after 2011 started to make a noticeable progress on RE development [33] and on taxation [34]. During the analyzed interval only one country regressed as absolute values and ranking, namely Germany and this situation was mainly due a poor GHG emissions record coming from its large consumption based on fossil fuels, especially in transport and H&C (see table 5 for the utilities of the sub-factors RET and REH, and table 6 for the utilities of EEC and EEG). However, it is to be mentioned that Germany conserved its belonging to the group II. This situation comes as a proof of sound application of ITCE, as Germany, regardless of its technical efficiency, is presently confronted with criticism about its low compliance with the clean energy targets of EU [35].

The main limitation of ITCE is that the selection of the sub-factors depends on data availability for all countries and all considered years. Maybe better sub-factors might be imagined, as for instance the Governmental interventions in energy market for inputs, and economy competitiveness in terms of clean energy for the outputs, but they have no or very limited availability [36]. Furthermore, more factors and sub-factors might be incorporated within the model's framework, but this will create an overstuffed result, difficult to manage and apply. The difficulty in finding/retrieving relevant data for research from national/international databases reveals the need of institutional change in the energy field within EU28, mainly based on data transparency about Governments' interventions. Nevertheless, the employed sub-factors of each factor suitably cover the intended outcomes and provide important insights into finding the best and worst performers in the clean energy deployment and also help in identifying specific remedial measures. This study acknowledges that ITCE best application depends on the actual possibilities of the countries of the EU28 to adopt the clean energy requirements, therefore, at first, the best practices are to be applied and the worst practices are to be avoided by countries with comparable economies. Moreover, even if the countries can learn from each other and exchange good practices, they can only gradually adjust their inputs leading to a potential increase of clean energy deployment on longer term.

The main findings of this paper are:

- in EU28 clean energy area there are 3 groups of countries ranked on their involvement in the building of the transformation of their economies into cleaner ones: active (group I), in progress (group II) and slow builders of the transformation (group III). In 2005, only 18% of the EU28 countries were in group I, whereas in 2015 the percentage increased to 32% of EU28 countries.
- during 2005-2015 more than 80% of EU28 countries improved and greened their energy systems. Only 5 countries out of EU28 recorded lower absolute values of ITCE in 2015 in respect with 2005, namely Latvia, Austria, Germany, Belgium and Luxembourg. However, Latvia and Austria are still in the group I, showing a slower progress in the recent years.
- the countries with best performances belonging to group I were actively transforming their economies into cleaner ones by the establishment of favorable conditions for the use of RE and also by involving the environmental concern within their legislation. However, only the countries with synergic improvements that spilled over the entire energy system were the best performers.
- the best and the worst performers in specific clean energy areas are identified through sub-factors; ITCE offers the combined effect of the measures taken by each country of EU28 in its path towards a clean energy, showing the country-specific improvement levers that can be replicated by countries with similar conditions.
- despite the common perception that the selection of the best energy package depends mainly on country endowment and geographical conditions for RE, the clean energy progress is mainly constrained by national policy in the field of energy and environment.
- the need of institutional change of the energy system mainly through transparent and responsible Governments' interventions.

There are still many changes needed in the area of clean energy, both at national, but also at EU level, as the present challenges and identified problems cannot be addressed only by national Governments. The present perception is that the EU slowed down the active support of RE in the recent years, mainly due politicians' laxity or interests who decided to back nuclear/fossil fuels over RE [37], therefore a more responsible, knowledgeable and up-to-date policy-making is needed. Moreover, despite ambitious targets and optimist declarations, many countries of the EU adopted a short-sighted planning in terms of clean energy [38]. In addition, given the large spreading of the internet of things (IoT) [39] and the possibilities to build and connect smart vehicles, smart buildings, and smart homes, the energy efficiency might need a very different approach in the near future in order to cope with the present technological advancement.

VI. CONCLUSIONS

This paper investigates the clean energy deployment in EU28 and provides a methodology for the identification of an index of transformation of the economy through clean energy for each country of the EU28. The value of the ITCE for each country judged against its own energy endowment and geographic potential may lead to the identification of the best practices to be followed and the worst practices to be avoided by other countries. In such a way, by spurring the lessons learned in EU28, the management of the energy sector can be improved. ITCE might be regarded as a useful tracking tool of the performance in the clean energy field and it may be used as a support for new, better-designed, more suitable measures and policies required by national policymakers and regulatory authorities in the area of clean energy.

Despite a substantial gain obtained during the last years in EU28, the real potential of clean energy is still to be unlocked and further efforts are needed. This research makes clear that, despite the common perception that the selection of the best energy package depends mainly on country endowment and geographical conditions for RE, the clean energy progress is mainly constrained by national policy in the field of energy and environment. The competition of low prices of fossil fuels combined with business models with disregard for CO_2 emissions [40], policy uncertainty and unfavorable regulatory environment are the main problems to be tackled by countries that are still struggling to progress on the clean energy path. Furthermore, the phasing out of fossil fuels subsidies, the design of an effective carbon pricing through carbon taxes or efficient emissions trading system may accelerate the clean energy deployment by creating a competitive advantage in comparison with high-emitting technologies. Initiatives that are designed to catalyze the transition towards clean energy are to be followed and lessons should be learned both from success stories, but also from the failures, as the countries may learn from each other.

However, if all the appropriate measures evoked by this paper are to be applied and better political initiatives are to be implemented, there will be still important work to be done. The whole society must change through behavioral changes, as this will be an important enabler of clean energy deployment. This line of investigation will continue with a further development of the end consumers, mainly households, due to their immediate effect on the responsible energy consumption and energy efficiency. Nevertheless, the ability to quantify the behavioral changes, but also the so-called rebound effect (increase in energy use due to energy efficiency measures) remain challenging.

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