Current state of renewable energies performances in the European Union: A new reference framework

Idiano D'Adamo [1,*] and Paolo Rosa [2]

1 Department of Industrial and Information Engineering and Economics, University of L'Aquila, Via G. Gronchi 18, 67100 L'Aquila, Italy

2 Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Piazza L. Da Vinci 32, 20133 Milano, Italy

idiano.dadamo@univaq.it; paolo1.rosa@polimi.it

* Corresponding author

Abstract

Initially pushed by the European Union (EU) through the Europe 2020 strategy, the development of renewable energies is a strategic action aiming to limit climate changes and cut greenhouse gas emissions. National subsidies favoured the diffusion of this new kind of energy sources, even if there are interesting economic opportunities also in non-subsidized markets. Renewable energy (RE) is a sustainable choice, but its management requires a proper analysis, both from political and operational levels. The aim of this paper is the assessment of European renewable energy source (RES) trajectory towards 2020, starting from historical values and through common scientific methods. In addition, a new reference framework is proposed, in order to evaluate RESs performances in Europe. The framework is based on three indicators: (i) share of energy from RESs in gross final energy consumption, (ii) REs primary production per capita and (iii) gross final consumption of REs per capita. Results could have practical implications for the decision makers involved in the management of energy sources throughout Europe and could be used for the comparison on a global scale.

Keywords: Energy Management, European Union, Renewable energy, Sustainability

1. Introduction

The Renewables Directive, officially coded as 2009/28/EC, defines an overall policy for the energy production from RESs within Europe. This guideline forces European nations to gather at least the 20% of their total energy needs by renewables within 2020, with specific targets for each Member State (MS). Furthermore, European countries agreed recently on a new 2030 Framework on climate and energy, imposing at least a 27% in share of RE consumption [1]. This transformation of the European energy system aims to reach the following goals: (i) guarantee the energy supply, (ii) reduce greenhouse-gas (GHG) emissions, (iii) lower energy costs and (iv) lead industrial development, growth and occupation [2, 3].

Initially, the development of RESs was considered as an alternative to the depletion of fossil fuels in industrialized and developing areas. However, now it represents an opportunity to improve the sustainability of energy systems [4-6]. In fact, policy-supporting mechanisms favoured the development of RESs and the improvement of technical efficiency, viability and competitiveness of RES through a costs reduction strategy [7]. However, when these financial incentives end, a shock effect ensues [8].

The ongoing transition from centralized to distributed energy generation systems was pushed by RESs [9, 10]. Their management was analysed in a dynamic context, by evaluating the bi-directional interaction with external energy networks and coupling it with conventional fossil fuel-based energy systems [11]. Smart grids aimed to integrate RESs with already existing distribution and transmission systems, in order to solve power unbalances issues and other technical problems in real time [12]. The harmonization between consumption and production of energy, even if representing a key-element in decision-making processes, is not always possible [13]. Consequently, the balance can be obtained into two ways: Demand Side Management (DSM) and Energy Storage Systems (ESSs). DSM is the customers' ability to take more informed decisions about its energy consumption, by

adjusting both timing and quantity of electricity use [14]. ESSs are equipments able to solve the intermittency of solar and wind energy, by providing stability to applications when applied [15].

From one side, this topic is widely analysed in literature. Someone defines EU 20-20-20 targets as not ambitious enough, but others judge them as excessive [16]. These targets can be achieved only through strong investments in the European energy sector, especially in research and innovation [17]. However, the interaction between internal energy markets and climate change packages can be improved and different national energy policies represent a weakness point [18]. From another side, the European Commission continuously checks the trend towards 2020 targets. In 2014, the share of energy from RESs in gross final consumption of energy terms reached a 16.0% in the EU, doubling the 2005 data (9%). Only nine MSs already achieved their 2020 targets [19].

This paper aims to reach two goals: (i) the definition of a 2015-2020 RES trajectory based on average values obtained in the 2008-2014 period and (ii) the comparison of twenty-eight European countries. For these reasons, REs primary production per capita and gross final consumption of REs per capita will be proposed as reference indexes. This methodology does not criticizes the current one (represented by an indicative trajectory and the share of energy from RESs in gross final energy consumption), but tries to offer additional information in order to support governmental actors during the definition of corrective measures.

2. Materials and methods

The Renewable Energy Directive (2009/28/EC) defines the levels of REs use within Europe. Given the initial level of REs (taken 2005 as reference period (S_{2005})), an indicative trajectory is proposed, in order to reach the final level of REs (taken 2020 as reference period (S_{2020})). A growing steps structure is taken into account: $S_{2005} + 0.20*(S_{2020} – S_{2005})$ is the average for 2011-2012 period, $S_{2005} + 0.30*(S_{2020} – S_{2005})$ is the one for 2013-2014 period, $S_{2005} + 0.45*(S_{2020} – S_{2005})$ is the one for 2015-2016 period and $S_{2005} + 0.65*(S_{2020} – S_{2005})$ is the one for 2017-2018 period [2]. For example, by setting S_{2005} equal to 2.2% and S_{2020} to 13% for Belgium, indicative/trajectory values are equal to

4.36% in 2011-2012, 5.44% in 2013-2014, 7.06% in 2015-2016 and 9.22% in 2017-2018. Half of European nations must increase at least of 10% their share of energy from REs in gross final energy consumption terms – Table 1.

Table 1. Share of energy from RESs in gross final energy consumption terms in 2005-2020 (%) [2]

GEO/TIME	2005	2020	Δ2020-2005	GEO/TIME	2005	2020	Δ2020-2005
United Kingdom	1.3	15	*13.7*	Malta	0	10	*10*
Denmark	17	30	*13.0*	Finland	28.5	38	*9.5*
Ireland	3.1	16	*12.9*	Sweden	39.8	49	*9.2*
France	10.3	23	*12.7*	Slovenia	16	25	*9*
Germany	5.8	18	*12.2*	Hungary	4.3	13	*8.7*
Italy	5.2	17	*11.8*	Lithuania	15	23	*8*
Netherlands	2.4	14	*11.6*	Poland	7.2	15	*7.8*
Spain	8.7	20	*11.3*	Latvia	32.6	40	*7.4*
Greece	6.9	18	*11.1*	Slovakia	6.7	14	*7.3*
Belgium	2.2	13	*10.8*	Estonia	18	25	*7*
Austria	23.3	34	*10.7*	Czech Republic	6.1	13	*6.9*
Portugal	20.5	31	*10.5*	Bulgaria	9.4	16	*6.6*
Luxembourg	0.9	11	*10.1*	Romania	17.8	24	*6.2*
Cyprus	2.9	13	*10.1*	Croatia	23.8	20	*-3.8*

2.1 Share of energy from renewables in gross final energy consumption terms

Eurostat is a General Directorate of the European Commission with the main responsibility to give statistical information to European institutions, by favouring the harmonisation of statistical methods across member states. Latest available data (released the 10th of February, 2016) highlight that the share of RESs in gross final energy consumption terms grew significantly in many MSs [19]. Among the twenty-eight European countries, one third of them already reached their 2020 target (Sweden, Finland, Croatia, Estonia, Romania, Lithuania, Bulgaria, Italy and Czech Republic). However, it does not means that these countries have a greater value in share of RESs terms (see Latvia, Austria and Denmark) – Table 2.

Table 2. Share of energy from renewables in gross final energy consumption terms (%) [19]

GEO/TIME	2008	2009	2010	2011	2012	2013	2014	Target 2020
EU 28	11.0	12.4	12.8	13.1	14.3	15.0	16.0	*20*

Belgium	3.8	5.1	5.5	6.2	7.2	7.5	8.0	*13*
Bulgaria	10.5	12.1	14.1	14.3	16.0	19.0	18.0	*16*
Czech Republic	7.6	8.5	9.5	9.5	11.4	12.4	13.4	*13*
Denmark	18.6	20.0	22.1	23.5	25.6	27.3	29.2	*30*
Germany	8.6	9.9	10.5	11.4	12.1	12.4	13.8	*18*
Estonia	18.9	23.0	24.6	25.5	25.8	25.6	26.5	*25*
Ireland	4.1	5.1	5.6	6.6	7.1	7.7	8.6	*16*
Greece	8.0	8.5	9.8	10.9	13.4	15.0	15.3	*18*
Spain	10.8	13.0	13.8	13.2	14.3	15.3	16.2	*20*
France	11.1	12.1	12.6	11.1	13.4	14.0	14.3	*23*
Croatia	22.0	23.6	25.1	25.4	26.8	28.1	27.9	*20*
Italy	11.5	12.8	13.0	12.9	15.4	16.7	17.1	*17*
Cyprus	5.1	5.6	6.0	6.0	6.8	8.1	9.0	*13*
Latvia	29.8	34.3	30.4	33.5	35.7	37.1	38.7	*40*
Lithuania	18.0	20.0	19.8	20.2	21.7	23.0	23.9	*23*
Luxembourg	2.8	2.9	2.9	2.9	3.1	3.6	4.5	*11*
Hungary	6.5	8.0	8.6	9.1	9.6	9.5	9.5	*13*
Malta	0.2	0.2	1.1	1.9	2.9	3.7	4.7	*10*
Netherlands	3.6	4.3	3.9	4.5	4.7	4.8	5.5	*14*
Austria	28.2	30.2	30.6	30.8	31.6	32.3	33.1	*34*
Poland	7.7	8.7	9.2	10.3	10.9	11.3	11.4	*15*
Portugal	23.0	24.4	24.2	24.7	25.0	25.7	27.0	*31*
Romania	20.5	22.7	23.4	21.4	22.8	23.9	24.9	*24*
Slovenia	15.0	20.0	20.5	20.2	20.9	22.5	21.9	*25*
Slovakia	7.7	9.4	9.1	10.3	10.4	10.1	11.6	*14*
Finland	31.4	31.4	32.4	32.8	34.4	36.7	38.7	*38*
Sweden	45.3	48.2	47.2	49.0	51.1	52.0	52.6	*49*
United Kingdom	2.7	3.3	3.7	4.2	4.6	5.6	7.0	*15*

> National target 2020

A description of models used to assess European decarbonisation pathways was proposed by [20, 21]. These authors classified several types of models:

- Partial equilibrium energy system models (e.g. PRIMES and TIMES-PanEu),
- Energy models dedicated to specific sectors (e.g. GAINS and Green-X),
- General equilibrium models (e.g. GEM-E3 and WorldScan),
- Macro-econometric models (e.g. NEMESIS).

Advantages coming from the adoption of a strong climate migration action were proposed by [22]. They use the GEME3-RD model basing on learning curves for clean energy technologies. Furthermore, the energy transition towards renewables is a key-element for a successful continuation of the European peace project and integration [23].

Several EU-funded projects (GREEN-X, OPTRES, FORRES 2020, GREENNET and FUTURES-E) were dedicated to evaluate the future of RESs development in Europe [24]. The GREEN-X model was initially focused on the electricity sector, but its development allowed to obtain nation-specific dynamic cost-resource curves for all key RES technologies on a yearly basis [25]. Its use is widespread in literature, where the GREEN-X model indicates consequences of RES policy choices in a real energy policy context [26, 27]. Policy options for reducing costs related to the achievement of the European renewables target are analysed within this model [27], often considered by European Commission for the evaluation of intermediate targets towards 2020 [28]. The comparison among values proposed in Table 2 and intermediate 2013-2014 targets (reported in [2]) highlights that only Netherlands fails to reach its target.

The authors opted for a common mathematical model (average value), representing the key-element to define future trends. From one side, this choice is justified by two considerations: (i) the topic is not well analysed in literature and (ii) this approach is compatible to the one used by the European Commission, in which the same equation for the calculation of the indicative trajectory related to each MSs is proposed. This way, the simplicity of the average value method and values obtained from a consolidated database represent two strengthens. From the other side, technological, environmental, economic and political factors affecting the development of each RESs are not analysed in this model. This point represents a weakness in a dynamic context.

The achievement of national 2020 targets represents the final goal of this model and three scenarios are hypothesized in this direction:

- A Moderate scenario, where the annual growth rate is constant and equal to the average value obtained in the 2008-2014 period.
- An Intermediate scenario, where this rate is equal to an intermediate value between the average and maximum values obtained in the 2008-2014 period.
- An Accelerate scenario, where this rate is equal to the maximum value obtained in the 2008-2014 period.

Given that the 2014-2020 interval is composed by six periods, consolidated data referred to the 2008-2014 period are evaluated (see Table 2). For example, the average increase in share of energy from RESs terms is equal to 0.7% for Belgium, while the maximum increase is equal to 1.3% (2009 on 2008). Consequently, by considering the Moderate scenario, the annual growth rate is equal to 0.7%, while it reaches 1% and 1.3% in the Intermediate and Accelerate scenarios, respectively.

2.2 Renewables energy primary production per capita

By considering the second aim of this paper, each MSs is evaluated according to the share of REs in gross final energy consumption terms. Typically, the energy sector is characterized by percentage values, for example the energetic mix in a national portfolio [29], or the weight of RESs in a specific sector [30]. Instead, environmental impacts are proposed, generally, in terms of kilograms of recycled material per capita (e.g. see indexes proposed by Eurostat for waste from electrical and electronic equipments, or for municipal solid wastes). Under this perspective, REs primary production per capita is proposed within this paper and the comparison among European countries represents the aim of this index. The proposed index is calculated by exploiting the following Eurostat items: REs Primary production as numerator and Population as denominator [19] – Table 3.

Table 3. Statistical data in Europe - [19]

	2008	2009	2010	2011	2012	2013	2014	Rate
REs primary production (Mtoe)	145.4	152.3	167.9	164.3	180.6	192.8	195.8	*5.2%*
Gross final consumption of REs (Mtoe)	134.2	142.1	154.1	149.8	164.0	172.0	175.3	*4.6%*
Gross final consumption of energy (Mtoe)	1216	1150	1202	1142	1144	1145	1098	*-1.6%*
Population (million inhabitants)	500.3	502.1	503.2	504.5	504.1	505.1	506.9	*0.2%*

This index has no 2020 targets and, consequently, the authors set them according to values proposed by the European Directive (the share of energy from REs in gross final energy consumption terms is equal to 20%). By considering the possible change of scenarios, the authors observed that REs primary production, gross final consumption of REs, gross final consumption of energy and

population will be equal to 265.5 Mtoe, 230 Mtoe, 996 Mtoe and 513 million of inhabitants in 2020, respectively. These values are obtained by applying the annual growth rate obtained in the 2008-2014 period, also for the 2014-2020 period. This way, the share of energy from REs in gross final energy consumption is equal to 23.1% (obtained by the ratio between 230 Mtoe and 996 Mtoe - Accelerate 2020 Target). Instead, when the annual growth rate of gross final consumption of REs is equal to 2.2%, it is equal to 199.8 Mtoe in 2020. In this last scenario, the share of energy from REs in gross final energy consumption is equal to 20% (obtained by the ratio between 199.8 Mtoe and 996 Mtoe - Moderate 2020 Target). Again, by considering that the value of REs primary production is 15.4% (obtained by the ratio between to 265.5 Mtoe and 230 Mtoe) greater than the gross final consumption of REs in Accelerate 2020 Target, the authors proposed the same ratio also in Moderate 2020 Target. This way, REs primary production will be equal to 230.6 Mtoe in 2020 (obtained multiplying 199.8 Mtoe and 1.154). Given these inputs, it is possible to define targets also for this index:

- Moderate 2020 target is equal to 450 kg per capita (obtained by the ratio between 230.6 Mtoe and 513 million of habitants).
- Accelerate 2020 target is equal to 518 kg per capita (obtained by the ratio between 265.5 Mtoe and 513 million of habitants).

Among the twenty-eight European MSs, nine countries (Finland, Sweden, Latvia, Austria, Estonia, Slovenia, Portugal, Denmark and Croatia) already reached their required level in the Accelerate 2020 target and Lithuania in the Moderate 2020 target – Table 4 (input values taken from Eurostat).

Table 4. Renewables energy primary production per capita (kg per capita) [19]

GEO/TIME	2008	2009	2010	2011	2012	2013	2014
EU 28	291	303	334	326	358	382	386
Belgium	153	174	206	245	255	261	255
Bulgaria	145	154	203	195	224	251	254
Czech Republic	234	249	277	289	309	346	348
Denmark	513	507	562	551	533	551	560
Germany	281	296	339	360	399	418	446
Estonia	564	647	741	734	797	850	901
Ireland	122	140	136	158	159	165	185

Greece	149	163	178	179	204	226	213
Spain	226	268	315	299	313	376	387
France	287	289	319	270	311	345	319
Croatia	396	444	504	440	455	543	540
Italy	320	327	328	307	355	394	389
Cyprus	97	97	100	114	124	126	129
Latvia	813	966	926	998	1140	1056	1185
Lithuania	328	368	377	381	399	434	461
Luxembourg	183	168	174	158	173	188	219
Hungary	160	185	192	186	198	207	207
Malta	2	2	11	16	21	22	30
Netherlands	156	176	185	193	234	261	271
Austria	991	1000	1052	988	1112	1115	1102
Poland	142	158	180	195	222	224	212
Portugal	411	453	534	509	433	537	561
Romania	259	258	281	249	261	278	305
Slovenia	416	482	536	489	499	546	572
Slovakia	192	227	260	257	265	271	266
Finland	1738	1499	1763	1708	1846	1830	1847
Sweden	1701	1709	1820	1757	1953	1755	1731
United Kingdom	82	88	92	104	119	138	151

> Moderate target 2020
> Accelerate target 2020

2.3 Gross final consumption of renewables per capita

Gross final consumption of REs per capita is an intermediate index between the above-cited ones. In fact, it has the same numerator of share of energy from RESs in gross final energy consumption index and the same denominator of REs primary production per capita index. Again, this index has no 2020 targets. Given the inputs proposed in section 2.2, scenario values are the following:

- Moderate 2020 target equal to 389 kg per capita (obtained by the ratio between 199.8 Mtoe and 513 million of habitants).
- Accelerate 2020 target equal to 448 kg per capita (obtained by the ratio between 230 Mtoe and 513 million of habitants).

Seven countries (Sweden, Finland, Austria, Denmark, Estonia, Latvia and Slovenia) confirmed to reach the Accelerate 2020 target, as proposed in section 2.2, while Portugal, Croatia and Lithuania have a less relevant goal (Moderate 2020 target) – Table 5 (input values are taken from Eurostat).

Table 5. Gross final consumption of renewables per capita (kg per capita) [19]

GEO/TIME	2008	2009	2010	2011	2012	2013	2014
EU 28	268	283	306	297	325	340	346
Belgium	136	170	199	203	231	249	246
Bulgaria	154	158	188	201	225	253	249
Czech Republic	199	211	238	231	273	298	309
Denmark	563	577	671	672	704	738	754
Germany	236	256	290	302	330	345	368
Estonia	470	517	585	597	621	619	631
Ireland	123	137	150	161	169	184	205
Greece	159	162	174	192	216	219	229
Spain	230	255	275	254	263	275	286
France	281	294	313	256	318	339	323
Croatia	390	407	436	427	432	449	425
Italy	272	283	293	278	330	347	333
Cyprus	118	124	127	122	124	136	152
Latvia	592	672	622	656	737	742	786
Lithuania	304	310	317	328	367	382	408
Luxembourg	248	235	240	236	245	272	320
Hungary	114	136	149	153	149	152	155
Malta	2	2	11	20	31	41	53
Netherlands	120	136	133	142	147	149	157
Austria	955	972	1048	1017	1039	1093	1067
Poland	132	146	168	182	192	196	193
Portugal	411	432	425	415	396	400	420
Romania	261	265	276	256	278	279	290
Slovenia	408	495	527	515	521	547	511
Slovakia	169	189	200	212	206	202	220
Finland	1581	1464	1659	1591	1676	1743	1815
Sweden	1704	1748	1835	1810	1885	1857	1826
United Kingdom	65	74	85	88	98	121	140

> Moderate target 2020
> Accelerate target 2020

3. Results

RESs are an instrument towards the development of a sustainable energy system. Globally, the correct management of these energy resources and technologies is a crucial issue requiring the analysis from both politicians and practitioners. European advances and recent developments were assessed starting from 2014 Eurostat data on REs.

3.1 RES trajectory within the 2015-2020 period

The first aim of this paper is the evaluation of MS's trends within the 2015-2020 period, by assessing them in several scenarios. Starting from the annual growth rate characterizing each scenario (Section 2) and inputs defined in Table 2, the share of energy from renewables in gross final energy consumption is proposed in Table 6. For example, given both the annual growth rate in Austria (equal to 0.8%, 1.4% and 2% in a Moderate, Intermediate and Accelerate scenarios, respectively) and a starting value equal to 33.1% in 2014, this country will present the share of energy from RESs equal to 38%, 41.6% and 45.1% in 2020, respectively. Its 2020 national target is equal to 34% and, consequently, only in a Moderate scenario during 2015 this aim will not be reached (33.9%).

Table 6. Results - Share of energy from renewables in gross final energy consumption (%) in 2020

GEO/SCENARIOS	Moderate scenario	Intermediate scenario	Accelerate scenario	Target 2020
EU 28	21.0	22.7	24.4	20
Belgium	12.2	14.0	15.8	13
Bulgaria	25.5	30.8	36	16
Czech Republic	19.2	22.0	24.8	13
Denmark	39.8	40.8	41.8	30
Germany	19.0	20.6	22.2	18
Estonia	34.1	42.6	51.1	25
Ireland	13.1	13.9	14.6	16
Greece	22.6	26.5	30.3	18
Spain	21.6	25.5	29.4	20
France	17.5	22.8	28.1	23
Croatia	33.8	35.7	37.5	20
Italy	22.7	27.4	32.1	17
Cyprus	12.9	14.9	16.8	13
Latvia	47.6	56.7	65.7	40
Lithuania	29.8	32.9	35.9	23
Luxembourg	6.2	8.1	9.9	11
Hungary	12.5	15.5	18.5	13
Malta	9.2	10.0	10.7	10
Netherlands	7.4	8.6	9.7	14
Austria	38.0	41.6	45.1	34
Poland	15.1	16.6	18	15
Portugal	31.0	33.2	35.4	31
Romania	29.3	33.7	38.1	24
Slovenia	28.8	40.4	51.9	25
Slovakia	15.5	18.7	21.8	14
Finland	46.0	49.3	52.5	38
Sweden	59.9	65.0	70	49
United Kingdom	11.3	13.4	15.4	15

< National target 2020

Results proposed in Table 6 highlight that Europe could reach its goals in all scenarios taken into account. However, the European energy policy does not aim to obtain an equitable distribution of RESs (e.g. see maximum and minimum values of 2020 national targets equal to 49% for Sweden and 10% for Malta). Legislators preferred to propose potentially feasible values. However, this policy did not led to the empowerment of each MSs towards the development of the RE sector. In fact, nine countries will not meet their 2020 national targets in a Moderate scenario, by sharing a position in the lowest part of the 2020 national targets ranking: Ireland (17°), United Kingdom (19°), Netherlands (21°), Belgium, Cyprus and Hungary (23°), Luxembourg (27°) and Malta (28°). France (10°) represents the only exception. Cyprus does not reach its target only for 0.1%. Furthermore, France and United Kingdom (two of the most populated MSs) do not reach their goals also in an Intermediate scenario, in which five countries present lower values than their 2020 national targets. Three countries do not meet their 2020 national targets in all the selected scenarios and, consequently, require urgent actions. Luxembourg, Ireland and Netherlands do not reach their targets for 1.1%, 1.4% and 4.3% in an Accelerate scenario. In addition, it is opportune to highlight that the negative performance of Luxembourg and Ireland was not cited by previous analyses of intermediate targets. These results demonstrate as several MSs will attempt to use cooperation mechanisms with other MSs for achieving 2020 targets, and negotiations are ongoing.

3.2 A comparison among twenty-eight European countries in the renewables sector

The second aim of this paper is to propose a current ranking of European countries in terms of development in REs. The EU's Renewable Energy Directive proposed the share of REs in gross final energy consumption as reference index and fourteen MSs have a higher value than 16% (average value of Europe). Taken 2014 as reference period, maximum and minimum values are obtained by Sweden (52.6%) and Luxembourg (4.5%). Initially, the authors calculate REs primary production per

capita and Gross final consumption of REs per capita for each MSs and then it is possible to propose a comparison among these indexes - Table 7.

Table 7. Ranking of European nations in function of renewable energy indexes in 2014

Share of RE in gross final energy consumption (%)			REs primary production per capita (kg per capita)			Gross final consumption of REs per capita (kg per capita)		
Rkg	Countries	Value	Rkg	Countries	Value	Rkg	Countries	Value
1°	Sweden	52.6	1°	Finland	1847	1°	Sweden	1826
2°	Finland	38.7	2°	Sweden	1731	2°	Finland	1815
2°	Latvia	38.7	3°	Latvia	1185	3°	Austria	1067
4°	Austria	33.1	4°	Austria	1102	4°	Latvia	786
5°	Denmark	29.2	5°	Estonia	901	5°	Denmark	754
6°	Croatia	27.9	6°	Slovenia	572	6°	Estonia	631
7°	Portugal	27.0	7°	Portugal	561	7°	Slovenia	511
8°	Estonia	26.5	8°	Denmark	560	8°	Croatia	425
9°	Romania	24.9	9°	Croatia	540	9°	Portugal	420
10°	Lithuania	23.9	10°	Lithuania	461	10°	Lithuania	408
11°	Slovenia	21.9	11°	Germany	446	11°	Germany	368
12°	Bulgaria	18.0	12°	Italy	389		EU 28	346
13°	Italy	17.1	13°	Spain	387	12°	Italy	333
14°	Spain	16.2		EU 28	386	13°	France	323
	EU 28	16.0	14°	Czech Republic	348	14°	Luxembourg	320
15°	Greece	15.3	15°	France	319	15°	Czech Republic	309
16°	France	14.3	16°	Romania	305	16°	Romania	290
17°	Germany	13.8	17°	Netherlands	271	17°	Spain	286
18°	Czech Republic	13.4	18°	Slovakia	266	18°	Bulgaria	249
19°	Slovakia	11.6	19°	Belgium	255	19°	Belgium	246
20°	Poland	11.4	20°	Bulgaria	254	20°	Greece	229
21°	Hungary	9.5	21°	Luxembourg	219	21°	Slovakia	220
22°	Cyprus	9.0	22°	Greece	213	22°	Ireland	205
23°	Ireland	8.6	23°	Poland	212	23°	Poland	193
24°	Belgium	8.0	24°	Hungary	207	24°	Netherlands	157
25°	United Kingdom	7.0	25°	Ireland	185	25°	Hungary	155
26°	Netherlands	5.5	26°	United Kingdom	151	26°	Cyprus	152
27°	Malta	4.7	27°	Cyprus	129	27°	United Kingdom	140
28°	Luxembourg	4.5	28°	Malta	30	28°	Malta	53

By considering REs primary production index, 13 MSs have a higher value than 386 kg per capita (average value of EU 28). Maximum and minimum values are obtained by Finland (1847 kg per capita) and Malta (30 kg per capita) in 2014, respectively. The comparison between the share of REs in gross final energy consumption and REs primary production defines as only three countries have

the same position in 2014 and this difference is confirmed in other periods: there are seven coincidences in 2011 and only two in 2013.

By considering gross final consumption of REs per capita index, eleven MSs have a higher value than 346 kg per capita (average value of EU 28. Maximum and minimum values are obtained by Sweden (1826 kg per capita) and Malta (53 kg per capita) in 2014, respectively. By considering the difference of this index with the share of RE in gross final energy consumption, it is possible to highlight that only three countries have the same position within the ranking of MSs, while by comparison with REs primary production per capita there are seven coincidences.

These results define that the evaluation of development of REs for each country is different in function of the considered index. Consequently, the usefulness of the proposed framework compared to those already used by the international community are additional data, based on historical values, supporting decision makers.

Primary production and consumption of energy can present significant differences (e.g. see gross inland energy consumption, energy transformation, or the energy sector consumption). Several aspects can explain the reduction of energy consumption: (i) economic crisis, (ii) energy efficiency measures and (iii) decrease of the population. Consequently, a relationship between these two indexes is clear and Table 8 proposes an emblematic case study: the renewable performance of Netherlands is greater than the Bulgarian one according to REs primary production per capita, but is lower than the Bulgarian one according to both share of REs in gross final energy consumption terms and gross final consumption of REs per capita. Netherlands presents a greater growth of REs primary production due to the increase in both transport and heating and cooling sectors. Bulgaria presents not only a reduction of gross final consumption of energy from RES, but also an increase of gross final consumption of energy, particularly in the transport sector (opposite situation than Netherlands). The number of inhabitants is characterized by not significant changes.

Table 8. Renewable energy indexes in Netherlands and Bulgaria [19]

	Netherlands			Bulgaria		
	2013	2014	Δ%	2013	2014	Δ%
REs electricity (Ktoe)	1029	1014	-1.5	599	608	1.5
Electricity generation from all sources (Ktoe)	10,316	10,159	-1.5	3172	3222	1.6
REs in transport (Ktoe)	502	586	16.8	111	120	7.9
Fuel used in transport (Ktoe)	10,829	10,198	-5.8	1973	2245	13.8
REs in heating and cooling (Ktoe)	1179	1288	9.2	1143	1087	-4.8
All fuel consumed for heating and cooling (Ktoe)	28,474	24,968	-12.3	3912	3839	-1.9
Gross final consumption of REs (Ktoe)*	2498	2639	5.6	1846	1806	-2.1
Gross final consumption of energy (Ktoe)*	52,364	47,597	-9.1	9732	10,025	3.0
Share of RE in gross final energy consumption (%)	*4.8*	*5.5*		*19.0*	*18.0*	
Ranking (°)	*26*	*26*		*12*	*12*	
Primary production of REs (Ktoe)	4373	4555	4.2	1826	1842	0.9
Population (inhabitant*1000)	16,780	16,829	0.3	7285	7246	-0.5
REs primary production per capita (kg/capita)	*261*	*271*		*251*	*254*	
Ranking (°)	*18*	*17*		*20*	*20*	
Gross final consumption of REs (Ktoe)*	2498	2639	5.6	1846	1806	-2.1
Population (inhabitant*1000)	16,780	16,829	0.3	7285	7246	-0.5
Gross final consumption of REs per capita (kg/capita)	*149*	*157*		*253*	*249*	
Ranking (°)	*25*	*24*		*18*	*18*	

* adjustment are considered

The comparison among indexes is proposed in Figure 1 and Figure 2 and four groups can be identified:

- "Top four", in which four countries have a dominant position than the other ones. These differences are relevant. Sweden reached its national 2020 target in 2011, while Finland obtained this result in 2014. As opposite, it is opportune to highlight that other two MSs did not reached their target, even if they are very near to their goal. In fact, by considering a Moderate scenario in 2015, Latvia will reach its target while Austria will fail it of about 0.1% (consequently, under this scenario this event is postponed to 2016).
- Higher than national 2020 Target – Nine countries have already reached their target. Sweden and Finland are included within the previous group, while Estonia, Croatia and Lithuania, have a positive performance in perspective of the development of RESs. Other countries do not present a homogeneous behavior. In fact, Italy presents a better performance than the European average into two out of three indexes (gross final consumption of REs per capita is the exception), while Romania and Bulgaria exceeds EU 28 only by considering the share of RE in gross final energy consumption and this is never verified for Czech Republic.

- Lower than national 2020 Target – In this group there are MSs that have not reached their target. However, among them, three countries have relevant performances, greater than the European average, but also Italy (already present in the previous group) and in a Moderate scenario Denmark, Slovenia (characterized by fluctuating trend) and Portugal reaching their targets in 2015, 2017 and 2020, respectively. In addition, this group is not homogeneous. Spain and Germany present values greater than European average one in two of the three scenarios (the exceptions are gross final consumption of REs per capita and the share of RE in gross final energy consumption, respectively). These countries could reach their targets in a Moderate scenario in 2019. The remaining countries have values lower than the European average one. From one side, Greece, Slovakia and Poland could reach their target in 2017, 2018 and 2020, under the hypothesis of a Moderate scenario. From another side, other MSs could fail this goal in this scenario for 0.2% (Belgium and Cyprus) and 0.5% (Hungary and Malta).
- Flop five – This group consists of MSs that must be monitored because, even if in an Intermediate scenario, the national 2020 target would not be reached. In addition, this group is not homogeneous. In fact, France presents values near to the European average. France and United Kingdom could fail their targets of a 0.3% and 1.4% under the hypothesis of an Intermediate scenario. As cited above, three countries would not reach their targets also under an Accelerate scenario of a 1.1%, 1.4% and 4.3%, respectively in Luxembourg, Ireland and Netherlands. This last country presents the most critical situation. In fact, Netherlands failed to reach its intermediate target.

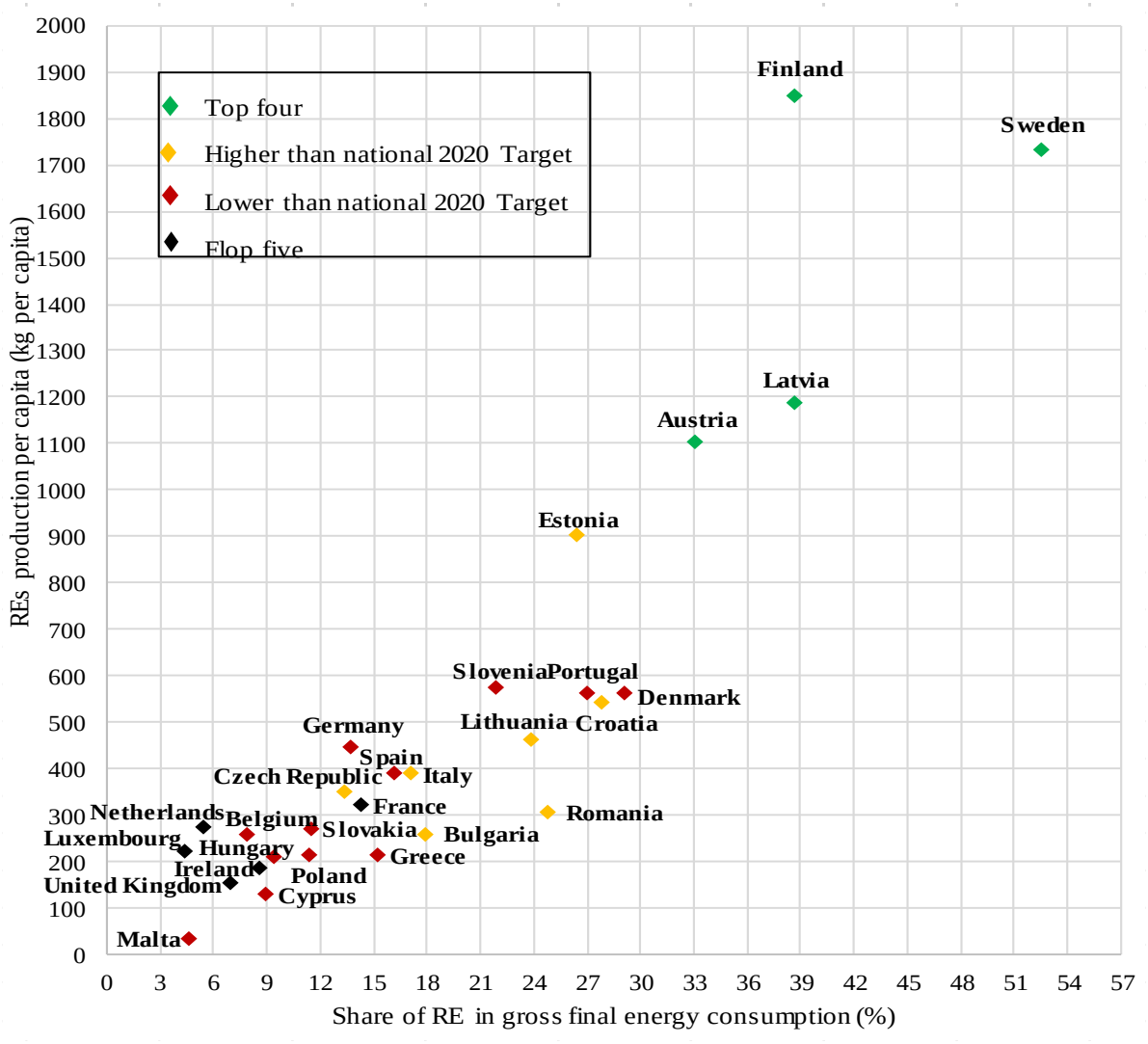

Figure 1. Share of RE in gross final energy consumption and REs production per capita in 2014

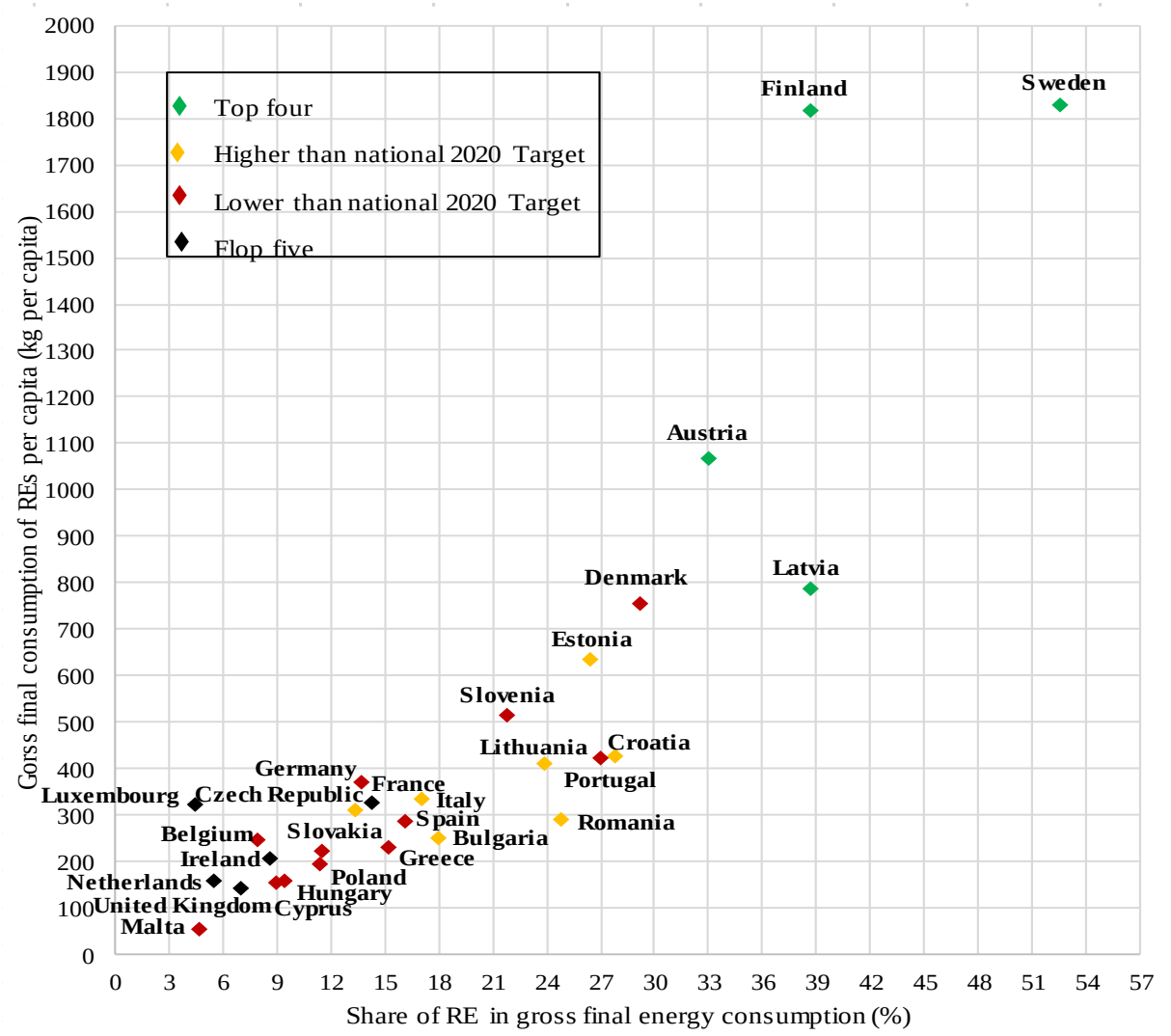

Figure 2. Share of RE in gross final energy consumption and gross final consumption of REs per capita in 2014

Actually, European countries are evaluated in function of the share of RE in gross final energy consumption, according to Directive 2009/28/EC, but an alternative useful tool for decision-makers is proposed in this paper. In fact, Sweden, Finland, Croatia, Estonia and Lithuania are five of nine MSs that have already reached their 2020 national target and have a greater value than the European average one for each index analysed. Furthermore, there are other five countries with values greater than the European average one and some are very near to their goals (e.g. Denmark (0.8%), Austria (0.9%) and Latvia (1.3%)), while other nations have values very far from their targets (e.g. Slovenia (3.1%) and Portugal (4%)) – Table 9.

Table 9. Main findings from the renewable indexes

National 2020 targets
• Sweden, Finland, Croatia, Estonia, Romania, Lithuania, Bulgaria, Italy and Czech Republic have reached their targets fixed by European Union in terms of the share of energy from REs in gross final energy consumption. • Other two indexes are proposed in this paper (REs primary production per capita and gross final consumption of REs per capita). In both, Finland, Sweden, Latvia, Austria, Estonia, Slovenia, Portugal, Denmark, Croatia and Lithuania have reached their targets.
RES trajectory within the 2015-2020 period
• European Union will reach its goal in all scenarios. The share of energy from REs in gross final energy consumption will be equal to 21-24.4% in 2020. • Malta, Belgium, Cyprus and Hungary do not meet their 2020 national targets in Moderate scenario • United Kingdom and France do not meet their 2020 national targets in Intermediate scenario. • Netherlands, Luxembourg and Ireland do not meet their 2020 national targets in Accelerate scenario.
Ranking of European nations in function of renewable energy indexes
• Sweden, Finland, Latvia and Austria are defined as “Top four”. • United Kingdom, France, Netherlands, Luxembourg and Ireland are defined as “Flop Five” • Sweden, Finland, Latvia, Austria, Denmark, Estonia, Croatia, Lithuania, Slovenia and Portugal have a value greater than EU 28 one for each index analysed.

4. Conclusions

Renewables have a key role in creating a sustainable energy system. The Renewable Energy Directive pushed each European country to adopt a national renewable energy action plan showing what actions they should implement to meet their renewable targets. RESs mitigated climate change, by avoiding CO_2eq emissions, leading a reduction in the EU’s demand for fossil fuels and, consequently, lowering the risk of European energy stability due to geopolitical issues.

Twenty-seven countries reached their 2013/2014 intermediate renewable energy targets and this paper proposed several RES trajectory towards 2020. Several scenarios were developed according to historical values of the share of energy from RESs in gross final energy consumption obtained within the 2008-2014 period through common methods (average and maximum values of annual growth

rate). Nine, five and three MSs do not reach their national 2020 target in Moderate, Intermediate and Accelerate scenarios, respectively. France and United Kingdom need an Intermediate scenario in order to reach their goals. Instead, Luxembourg, Ireland and Netherlands will not reach their targets even under the hypothesis of an Accelerate scenario.

From one side, these methods do not consider dynamic aspects. However, they propose new information. In fact, intermediate renewable targets provided an annual growth rate that increases every two years and it is not adapt to current scenarios. Furthermore, national renewables targets (ranging from 10% in Malta to 49% in Sweden) do not favour a balanced distribution of RESs. These two considerations help to frame the crucial role of cooperation mechanisms.

Trying to answer to some of these issues, this paper proposes a comparison among European MSs through a new reference framework. New information give a different picture of the situation. In fact, the Renewable Energy Directive considers only the share of energy from RESs in gross final energy consumption, while this new method is based on three indicators (the above-cited one, REs primary production per capita and gross final consumption of RESs per capita).

Ten MSs (Sweden, Finland, Austria, Latvia, Denmark, Estonia, Slovenia, Croatia, Portugal and Lithuania) have a national value greater than average one of Europe for each indicator. This way, it is possible to define that these countries are significantly developed from a RESs point of view. However, it is opportune to highlight that only five of these ten MSs already reached their national 2020 target. In addition, there are four countries (Sweden, Finland, Austria and Latvia) with relevant values having a dominant position in comparison to the other twenty-four MSs.

Europe, through a set of specific directives, is trying to develop new circular economy models. However, not all of them are ready to receipt these guidelines and reach these targets. Results could be useful for all decision makers involved in energy management, constituting the starting point for the definition of new targets and for an accurate evaluation of performances of each country in the renewable sector.

References

[1] European commission. A policy framework for climate and energy in the period from 2020 to 2030. Brussels: COM(2014) 15 final; 2014.

[2] European Commission. Renewable energy progress report. Brussels: COM (2015) 293 final; 2015.

[3] Scarlat N, Dallemand J-F, Monforti-Ferrario F, Banja M, Motola V. Renewable energy policy framework and bioenergy contribution in the European Union–An overview from National Renewable Energy Action Plans and Progress Reports. Renewable and Sustainable Energy Reviews. 2015;51:969-85.

[4] Cucchiella F, D'Adamo I. Issue on supply chain of renewable energy. Energy Conversion and Management. 2013;76:774-80.

[5] Bogdanov D, Breyer C. North-East Asian Super Grid for 100% renewable energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options. Energy Conversion and Management. 2016;112:176-90.

[6] Cucchiella F, D'Adamo I. Technical and economic analysis of biomethane: A focus on the role of subsidies. Energy Conversion and Management. 2016;10.1016/j.enconman.2016.04.058.

[7] Casisi M, De Nardi A, Pinamonti P, Reini M. Effect of different economic support policies on the optimal synthesis and operation of a distributed energy supply system with renewable energy sources for an industrial area. Energy Conversion and Management. 2015;95:131-9.

[8] Cucchiella F, D'Adamo I, Gastaldi M. Financial analysis for investment and policy decisions in the renewable energy sector. Clean Technologies and Environmental Policy 2015;17:887-904

[9] Khan MRB, Jidin R, Pasupuleti J. Multi-agent based distributed control architecture for microgrid energy management and optimization. Energy Conversion and Management. 2016;112:288-307.

[10] Cucchiella F, D'Adamo I, Gastaldi M. Optimizing plant size in the planning of renewable energy portfolios. Lett Spat Resour Sci. 2015;http://dx.doi.org/10.1007/s12076-015-0150-6:1-19.

[11] Angrisani G, Canelli M, Roselli C, Sasso M. Microcogeneration in buildings with low energy demand in load sharing application. Energy Conversion and Management. 2015;100:78-89.

[12] Cui B, Wang S, Yan C, Xue X. Evaluation of a fast power demand response strategy using active and passive building cold storages for smart grid applications. Energy Conversion and Management. 2015;102:227-38.

[13] Chiaroni D, Chiesa V, Colasanti L, Cucchiella F, D'Adamo I, Frattini F. Evaluating solar energy profitability: A focus on the role of self-consumption. Energy Conversion and Management. 2014;88:317-31.

[14] Wolisz H, Punkenburg C, Streblow R, Müller D. Feasibility and potential of thermal demand side management in residential buildings considering different developments in the German energy market. Energy Conversion and Management. 2016;107:86-95.

[15] Wen H, Su B. Operating modes and practical power flow analysis of bidirectional isolated power interface for distributed power systems. Energy Conversion and Management. 2016;111:229-38.

[16] Baumann F. A Common Market and sustainable energy for Europe. Sustainable Development and Governance in Europe: The Evolution of the Discourse on Sustainability2013. p. 77-90.

[17] da Graça Carvalho M. EU energy and climate change strategy. Energy. 2012;40:19-22.

[18] Helm D. The European framework for energy and climate policies. Energy Policy. 2014;64:29-35.

[19] Eurostat. Share of renewables in energy consumption in the EU rose further to 16% in 2014. 2016.

[20] Capros P, Paroussos L, Fragkos P, Tsani S, Boitier B, Wagner F, et al. Description of models and scenarios used to assess European decarbonisation pathways. Energy Strategy Reviews. 2014;2:220-30.

[21] Capros P, Paroussos L, Fragkos P, Tsani S, Boitier B, Wagner F, et al. European decarbonisation pathways under alternative technological and policy choices: A multi-model analysis. Energy Strategy Reviews. 2014;2:231-45.

[22] Karkatsoulis P, Capros P, Fragkos P, Paroussos L, Tsani S. First-mover advantages of the European Union's climate change mitigation strategy. International Journal of Energy Research. 2016;40:814-30.

[23] Creutzig F, Goldschmidt JC, Lehmann P, Schmid E, von Blücher F, Breyer C, et al. Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition. Renewable and Sustainable Energy Reviews. 2014;38:1015-28.

[24] del Río P. Analysing future trends of renewable electricity in the EU in a low-carbon context. Renewable and Sustainable Energy Reviews. 2011;15:2520-33.

[25] Hamelinck C, Koper M, Luis Janeiro, Klessmann C, Kuwahata R, Nabe C, et al. Renewable energy progress and biofuels sustainability. Ecofys, Project number: BIENL13010 (EC contract ENER/C1/428-2012-SI2653362 LOT 1),2014.

[26] Resch G, Gephart M, Steinhilber S, Klessmann C, del Rio P, Ragwitz M. Coordination or Harmonisation? Feasible Pathways for a European Res Strategy Beyond 2020. Energy & Environment. 2013;24:147-70.

[27] Klessmann C, Rathmann M, de Jager D, Gazzo A, Resch G, Busch S, et al. Policy options for reducing the costs of reaching the European renewables target. Renewable Energy. 2013;57:390-403.

[28] Resch G, Liebmann L, Ortner A, Busch S, Panzer C, del Rio P, et al. Cost-benefit analysis of policy pathways for a harmonisation of RES(-E) support in Europe. Intelligent Energy – Europe (IEE), ALTENER (Grant Agreement no IEE/10/437/SI2589880),2014.

[29] Park SY, Yun B-Y, Yun CY, Lee DH, Choi DG. An analysis of the optimum renewable energy portfolio using the bottom–up model: Focusing on the electricity generation sector in South Korea. Renewable and Sustainable Energy Reviews. 2016;53:319-29.

[30] Flórez-Orrego D, Silva JAM, Oliveira Jr Sd. Renewable and non-renewable exergy cost and specific CO2 emission of electricity generation: The Brazilian case. Energy Conversion and Management. 2014;85:619-29.