energies

Article

Achievements of the European Union Countries in Seeking a Sustainable Electricity Sector

Indre Siksnelyte [1,2,*] and Edmundas Kazimieras Zavadskas [1]

1 Institute of Sustainable Construction, Vilnius Gediminas Technical University, Sauletekio al. 11, LT-10223 Vilnius, Lithuania; edmundas.zavadskas@vgtu.lt
2 Institute of Social Sciences and Applied Informatics, Kaunas Faculty, Vilnius University, Muitines 8, LT-50229 Kaunas, Lithuania
* Correspondence: indre.siksnelyte@knf.vu.lt; Tel.: +370-37-422523

Received: 8 May 2019; Accepted: 7 June 2019; Published: 12 June 2019

Abstract: The electricity production sector has a significant share of final energy consumption and has a huge potential to use more renewable energy sources. Over the last two decades, the European Union (EU) reform of electricity markets has had positive results, and market liberalization acts as a stimulus for energy efficiency, lower prices, and technological progress. Today's EU policy for the development of electricity and the entire energy sector seeks to provide system modernization, stability, reinforcement of the single market, and implementation of climate change policy with an emphasis on the decarbonization of energy sources and the increase of energy efficiency. After all of the EU efforts to form an electricity sector in member states, it is necessary to assess the efficiency of the policy implemented and to identify the results achieved in shaping a sustainable electricity sector. The purpose of this article is to carry out a sustainability assessment of the electricity sector in the EU countries. A set of eight indicators designed to assess the sustainability of the electricity sector of different EU countries in 2017 has been drawn up. The assessment is made using the multi-criteria decision-making method (MCDM) Technique for Order Preference (TOPSIS). The assessment shows that the electricity market of Slovenia is the most sustainable, with Luxembourg in the second position in the EU.

Keywords: renewable energy; electricity sector; renewable electricity; multi-criteria decision-making; MCDM; TOPSIS; European Union; sustainable energy; sustainability assessment

1. Introduction

Many countries are setting ambitious targets for their energy sector with the emphasis on developing a safe, sustainable, environmental, resource-efficient, and low-carbon energy sector [1]. In 2005, there were only 43 countries with national renewable electricity, renewable heating/cooling, or renewable transport targets. During the decade until 2015, the number of countries with national renewable energy targets increased to 164. One hundred and fifty of them had renewable electricity targets, 59 had renewable transport targets, and 47 countries had renewable heating/cooling targets [2]. This re-orientation is encouraged by both public demands and political motives, such as the United Nations' Sustainable Development Goals, the 2015 Paris Agreement, etc. The costs of energy production has a significant and substantial impact on the development of energy generated from renewable energy sources (RES). The costs of solar photovoltaic (PV) modules declined by approximately 80% from 2010 until 2017, while levelised costs of electricity generated from solar PV declined from 0.36 to 0.1 USD/kWh in 2016, which is more than a 72% reduction [2]. As far as wind energy is concerned, global onshore wind total installed costs declined from 1843 to 1477 USD/kWh in 2016, which is about a 20% decrease. The costs of onshore wind energy are getting similar to the costs of hydropower.

Levelised costs of electricity for onshore wind declined by around 25% from 2010 to 2017 and cost about 0.06 USD/kWh [1,2].

Cost reduction and country promotion policies, as well as market activation measures, have a positive impact on the use of RES for energy generation: from 2010 to 2018, global solar PV installed capacity grew more than 12 times from 39.603 MW to 480.357 MW, global onshore wind installed capacity increased more than 3 times from 177.798 MW to 540.370 MW, while global solid biomass installed capacity almost doubled from 48.540 MW to 83.063 MW. However, despite this relatively fast growth, 85% of electricity should be generated from RES by 2050 in order to meet the targets of the Paris Agreement. Thus, solar and wind power capacity should grow from 1.000 GW in 2018 to 13.000 GW in 2050 [3]. This means that it is necessary to increase the annual wind energy growth by three times and the growth of solar energy by two times if compared with the rates in 2018. Szabo et al. [4] has modelled the chances of South-East European countries reaching 85% of electricity generated from RES by 2050. In the performed modelling, the South-East European region, which consists of nine European countries (three of them are the European Union (EU) members) may reach and even exceed 85%. However, the input of individual countries varies significantly and in order to reach such a high level of electricity generated from RES in the region, the countries with high RES potential (e.g., Albania and Montenegro) should become electricity exporters, while other countries, such as Bulgaria or Serbia, would be dependent on energy import. Regional policy and market instruments play an important role in this case.

The importance of energy sector planning and energy demand modelling has significantly increased over the past decades, and scientists are trying to predict and model the most efficient methods to move towards sustainable energy system. In order to find out whether policy instruments and investment in certain projects are efficient, it is very important to measure and evaluate achievements in the fight against climate change [5]. The research done by Chaton and Guillerminet [6] reveals that a feed-in tariff policy increases investment in the development of wind power plants and solar PV stations in France. However, this increase in competition may distort the market and increase CO_2 emissions in electricity generation sector, although the share of RES in the end-use energy consumption would be higher. In addition, a feed-in tariff policy is the most expensive in terms of social welfare because consumers have to pay for more expensive energy due to increased electricity prices. Therefore, such a policy becomes useful to new market players and for the implementation of official RES goals but is less efficient for CO_2 reduction and is unfavourable to end users. The results of the study carried out by Lehmann et al. [7] confirm the conclusions of the study discussed above, though the subsidization of RES was considered to be ambiguous: on the one hand, it can help to remove or reduce the use of gas and oil for electricity generation, and on the other hand, it increases the use of coal for electricity generation.

The electricity generation sector has the greatest potential in the European Union (EU) to reduce greenhouse gas (GHG) emissions [8]. Corsateaa and Giaccaria [9] made a simulation of 13 EU countries whose CO_2 emissions account for 40% of total EU emissions and found out that an increase of technological efficiency might help to reach a decline of 5.6% in CO_2 emissions. If such an effect was achieved, the target to reduce CO_2 emissions in the electricity production sector by 90% by 2050 (if compared with 1990) would be met. The survey made by Knopf et al. [10] that focused on the analysis of economic costs and investment in RES in the electricity sector revealed that in order to reach the target set by the European Commission to generate 27% of energy from RES by 2030, the share of RES in the electricity sector should be 49%. It has also been noted that the cost-effective share of RES in the electricity sector varies from 43 to 56%, depending on the country's infrastructure, economic situation, available energy capacities, etc.

The EU has set ambitious goals in the fight against climate change; therefore, the energy policy of the region is developed consistently in all energy sectors. Strategies are developed, targets are set for the member states, infrastructure projects are initiated and funded, and market competitiveness measures are developed and implemented in order to achieve energy policy goals. Electricity consumption in the three largest end-use sectors (industry, buildings, and transport) is projected to double by 40% in 2050 (in 2015, it accounted for around 20%) [2]. Therefore, technological progress, new business, and market models that create new opportunities and promote RES development in end-use sectors are very important. After all of the EU actions to form the electricity sector in member states, it is necessary to assess the efficiency of the policy implemented and to identify the results achieved in shaping a sustainable electricity sector. The purpose of this article is to carry out a sustainability assessment of the electricity sector in the EU countries. The assessment is made using the latest available statistical data of 2017 and a multi-criteria decision-making method (MCDM) technique for order preference (TOPSIS).

The EU policy for the electricity sector and the main indicators of the sector are presented in the second part of the paper. The third part of the paper focuses on the assessment methodology where the assessment indicators are selected and justification of a MCDM method is given. Results and conclusions of the assessment are given in the fourth part of the paper.

2. EU Policy in the Electricity Sector

The development of a common EU electricity market is 27 years in the making and it is still in process. In the policy of the electricity sector of the member states, actions and regulations are mainly based on the EU agreements and targets [11]. EU legislation and directives issued since 1990 have gradually harmonized the structure of the electricity sector in the member states and a common electricity policy is currently being implemented for the whole region. The most significant changes in the sector include the liberalization of retail and wholesale markets, as well as the separation of production and transmission of activities and the establishment of independent national regulatory instruments.

When the world realized the consequences of climate change and clearly identified the significance of the energy sector in it, the EU, while implementing energy policy in the region, has started to focus on the implementation of targets through various directives and regulations. Today, the EU seeks the main four targets in climate change and energy policy.

The first target is to reduce GHG emissions by 20% by 2020 from the 1990 levels (5407 $MtCO_2e$), which is a 14% reduction from the 2005 levels (4915 $MtCO_2e$) [12]. Furthermore, the target for 2030 is even more ambitious: to reduce GHG emissions by 40% compared to 1990. All large industrial producers, including power plants, are obliged not to exceed a certain level of CO_2 emissions, i.e., the *EU Emissions Trading System* (*EU ETS) has set the target to reduce* CO_2 emissions by 21% by 2020 compared to 2005 [13]. According to the study carried out by Thema et al. [14], a reduction of CO_2 emissions up to 30% compared to 2005 can be reached if appropriate measures are chosen.

A total of 20% of final energy consumption is aimed to be generated from RES (i.e., in the transport sector, heating and cooling sector, and electricity sector) by 2020, and by 27% by 2030 [15] is a second target.. Since the use of RES for transport sector, and for the heating and cooling sector, is significantly more complex, the electricity sector will have to reach a significantly higher share than 20% by 2020 in order to reach the target.

The third target is to increase energy efficiency by 20% by 2020 and more than 20% (try to reach 30% higher efficiency) by 2030. Figure 1 provides the EU-28 primary and final energy consumption distance to the 2020 and 2030 targets. Primary energy consumption measures the total energy demand of a country and covers the consumption of the energy sector itself, losses during the transformation and distribution of energy, and the final consumption by end users. The final energy consumption is the energy that reaches the final consumer's and excludes that which is used by the energy sector itself. It is natural that 2030 targets are significantly less achieved than 2020 targets. Figure 1 reveals that none of the targets in 2017 were achieved. Final energy consumption target was the only one that was achieved and was exceeded 1.88% in 2014; however, this rate again increased in 2015 and has been growing for the last three years. This is related to a higher demand for energy in almost all EU countries, so both final energy consumption, and primary consumption targets can be achieved by a significant increase in the efficiency of technologies and mechanisms promoting energy saving. Household equipment is one of the sectors in which efficiency can be increased. As far as households are concerned, they consume the highest share of energy for information technologies and entertainment. According to surveys, if you choose more efficient technologies and combine them with sustainable consumption, and try not to waste energy, it is possible then to save up to 48% of energy that is used in households for information technologies and entertainment [16]. As far as the industry sector is concerned, the results can be even more significant.

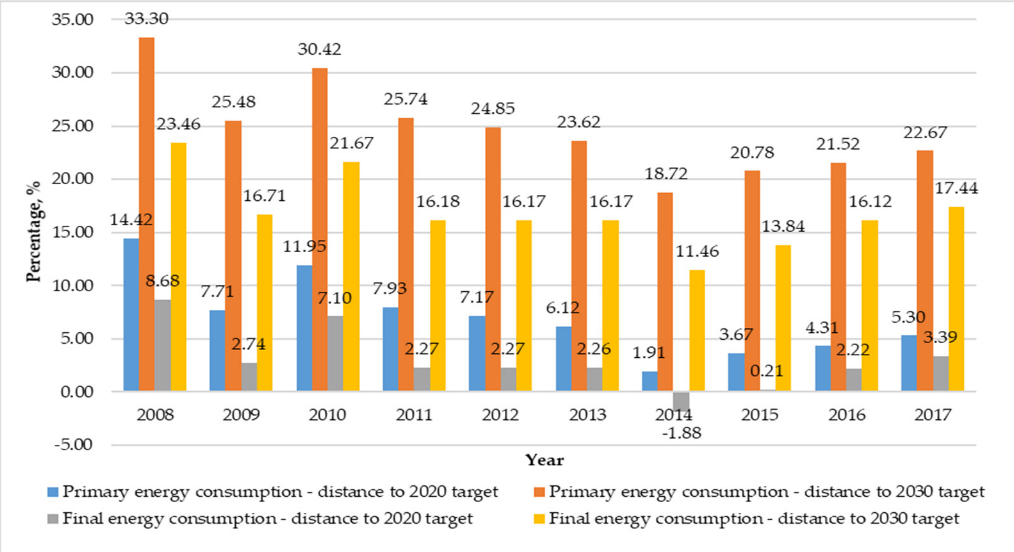

Figure 1. Distance to EU energy efficiency targets implementation, 2008–2017 (%). * 0 (zero) means that the target is reached. Source: data from [12].

The fourth target is to expand electricity interconnection by at least 10% by 2020 and at least by 15% by 2030 compared to the 2014 electricity interconnection level.

The policy of the electricity sector implemented by the EU can be grouped in the following two stages: policy in order to liberalize electricity sector, and policy for smarter and more sustainable electricity sector [17]. The main steps toward the liberalization and development of a sustainable electricity market are given in Tables 1 and 2.

2.1. Policy That Seeks to Liberalize Electricity Sector

For the whole century since 1878 when electricity was commercialized, only one company was in charge of electricity generation, transmission, and distribution to end users, as well as the management of the whole electricity system. This vertical integration of all functions was a typical model of electricity industry management all over the world and was accompanied by monopoly legalization, i.e., only one company was provided with the legal possibility to supply electricity to users. This model of electricity industry management has become akin to a rule and there were no discussions, neither at scientific nor at political level, regarding changing this state of affairs. However, it was understood in the long run that this market management model is not efficient, and the market has been gradually liberalized in different parts of the world, including the EU.

The reasons for electricity market liberalization can be divided into the following four groups:

(1) Efficiency, costs, and prices (i.e., improved productivity of electricity industry, increased economic efficiency, lower electricity prices; improved work productivity, creation of competition, user choice, privatization);
(2) Development and reliability of renewable energy (i.e., to promote demand management, reduce the impact on the environment, improve reliability of electricity supply, eliminate price anomalies);

(3) Increasing investment and changes of capital structure (i.e., to increase trust of investors, reduce government debt, reduce state ownership, promote foreign investment, develop capital markets);
(4) Social welfare (i.e., to raise accessibility, accelerate electrification).

Table 1. Policy instruments for the EU electricity market liberalization. Source: data from [18–20].

Years	Policy Instrument	Main Aspects
1996	The First Energy Package, Directive 96/92/EC [18]	• Unbundling generation from transmission and distribution • Competition for electricity generation • Open market for large consumers • Non-discriminatory access to networks • Distribution system operator responsibility is to provide a secure, reliable, and efficient service
2003	The Second Energy Package, Directive 2003/54/EC [19]	• Retail market competition for households • Network activities unbundling • National Regulatory Authorities were established • Distribution system operator became responsible for providing information for efficient access to the networks
2009	The Third Energy Package, Directive 2009/72/EC [20]	• Procedures to switch retail supplier • Procedures to unbundle ownership for transmission system operators • Underlined importance of modernizing electricity distribution networks • Underlined importance of smart grids and energy efficiency

Table 2. Policy instruments for the smarter and more sustainable EU electricity. Source: data from [15,21–23].

Years	Policy Instrument	Main Aspects
2010	Energy 2020 [21]	• Set 2020 targets for energy efficiency • Set target that all EU countries are not isolated from the internal energy market by 2015 • Deployment of low carbon technologies • Integration of neighbouring countries into EU internal energy market
2011	Energy Roadmap 2050 [15]	• Set 2050 targets for low carbon economy • A framework for power sector decarbonization • The scenario analysis exploring possibilities toward energy decarbonisation
2015	Energy Union Package [22]	• Implementation of previous energy goals are further supported by the Energy Union framework • Five interrelated and mutually strengthening dimensions (energy security; the internal EU energy market; energy efficiency; decarbonisation; research, innovation, and competitiveness)
2016	Clean Energy for All Europeans [23]	• The revised Renewable Energy Directive • Framework for renewable electricity • Empowering and informing consumers • Attention to the EU binding targets

Liberalization of electricity markets in the EU is based on the directives. The main political instruments and their contribution in the process of liberalization of EU electricity markets are given in Table 1.

Liberalization of electricity markets gave the following results: a decrease in wholesale prices of electricity, more choices to consumers as suppliers compete and are forced to reduce prices and provide better services, and competition has been strengthened in the sector on legal bases. However, the dependence on import, old infrastructure, a lack of investment, not a fully functioning retail market, the need to fight against climate change, and a move towards the economy of low-carbon technologies are still the challenges facing the EU energy sector today.

2.2. Policy That Seeks Smarter and More Sustainable Electricity

The amount of GHG emissions declined by 22% in the EU from 1990 until 2017, whereas the economy rose by 58% within the same period. A systematic policy of the EU and the member states, as well as the introduction of low-carbon technologies, have contributed to the results achieved. Innovations, including progress related to the development of RES and the efficiency of energy consumption, have become the main stimulus to reducing emissions. As far as the electricity sector is concerned, the development of a smarter and more sustainable electricity sector is based on the EU strategies and documents. The main policy instruments are presented in Table 2.

Today's policy for the development of electricity and the entire energy sector seeks for system modernization, stability, and reinforcement of the single market, and implementation of climate change policy with the emphasis on decarbonization of energy sources and increasing of energy efficiency [21–23]. Public and private investments in the energy sector are expected to amount to approximately EUR 177 billion annually (from 2021), which may increase the GDP by 1% within the next decade.

It should also be noted that the EU is currently updating its energy policy system in order to easily move toward clean energy and adapt it to the latest technologies of the 21st century and further develop them. Negotiations on the supplements of all new energy legislation have been completed and new documents will be officially published and approved in 2019. The latest amendments are expected to be an important step toward the establishment of the Energy Union and fulfilment of the commitments of the EU Paris Agreement. Recent changes will encourage European consumers to become active players in the energy sector. It will also set the following two new EU targets for 2030: to fulfil at least 32% of its total energy needs with renewables, and to increase energy efficiency by at least 32.5%. New targets promote competitiveness, economic growth, job creation, reduce energy prices, and contribute to the fulfilment of climate change goals. Table 3 provides the main indicators for monitoring the progress of the electricity sector toward Energy Union objectives.

Table 3. Indicators for monitoring the progress of the electricity sector toward Energy Union objectives.

Unit / Country	Electricity Interconnection	Market Concentration Index	Wholesale Electricity Prices	Annual Switching Rates–Electricity Retail Markets	Share of RES in Gross Final Electricity Consumption
	% of Installed Capacity, 2017	0–10,000, 2015	Euro/MWh, 2017	% of Total Consumers, 2015	% of Gross Final Consumption, 2017
EU28	NA	3725.78	43.79	6.23156	30.75
Austria	15.31	1600.63	35.37	2.3	72.17
Belgium	18.95	3208.8	44.85	NA	17.24
Bulgaria	7.08	3210.43	39.3	NA	19.12
Croatia	51.99	7304.97	NA	2.32	46.42
Cyprus	NA	9551.25	NA	0	8.9
Czech Republic	19.3	4072.01	37	3.6	13.65
Denmark	50.57	932.98	30.97	NA	60.36
Estonia	23.67	7134.23	33.22	2	17.03
Finland	28.78	1087.98	33.21	12.5	35.22
France	9.44	5928.58	45.3	4.3	19.91
Germany	8.95	377.87	34.7	8.7	34.41
Greece	10.6	3480.26	54.7	0.33	24.47
Hungary	58.25	2123.74	50.36	NA	7.49
Ireland	7.41	2318.55	46.91	14	30.09
Italy	8.18	814.86	53.94	8	34.1
Latvia	23.67	9080.26	34.7	0	54.36
Lithuania	23.67	5055.44	35.15	0	18.25
Luxembourg	109.22	5405.14	NA	0.07	8.05
Malta	24.24	9297.4	NA	NA	6.58
Netherlands	18.11	949.55	39.41	15.1	13.8
Poland	4.05	1541.77	37.52	0.86	13.09
Portugal	8.73	3155.75	53.42	26.56	54.17
Romania	6.92	1367.48	48.38	0.066	41.63
Slovakia	43.29	5694.96	40.98	2.74	21.34
Slovenia	83.56	5872.69	49.52	6.65	32.43
Spain	5.79	968.57	53.84	10.73	36.34
Sweden	25.61	2079.41	31.38	10.3	65.89
United Kingdom	≈5.00	706.19	51.76	12.2	28.11

NA: Not available. Source: data from [12,24].

Electricity interconnection shows how much the country's electricity networks are connected with other countries. The three Baltic States (Estonia, Latvia, and Lithuania) are not synchronized with the European network, but the projects by which these countries will be connected to the European network are already being implemented. Electricity connections between the member states are a prerequisite for the full functioning in the EU electricity markets and for cross-border energy sharing. At present, European electricity transmission systems, in particular cross-border interconnection lines, are insufficient to enable the internal market to function properly and to help address the energy isolation of some European regions. Luxembourg (109.22%) and Slovenia (83.56%) have the biggest electricity interconnection in 2017, and even 10 countries have electricity interconnection that is less than 10% of installed capacity. The latest report on the state of the Energy Union [25] states that 11 member states have not yet reached the 10% electricity interconnection target (Bulgaria, Cyprus, Germany, Spain, France, Ireland, Italy, Poland, Portugal, Romania, and the United Kingdom). The European Commission also forecasts that four countries, specifically Cyprus, Spain, Poland, and the United Kingdom, will not, however, reach the target by 2020.

A single European energy network is essential for Europe's energy security, for bigger competition in the internal market that would lead to more competitive prices, and in order to achieve the EU objectives of reducing fossil fuel dependency and climate policy objectives more smoothly. A single network will help achieve the overriding objective of the Energy Union, i.e., to ensure safe and sustainable supply of affordable energy, as well as growth and creating jobs across the EU [26]. In 2002, the European Council set itself the objective of increasing EU electricity interconnection by 10% of installed electricity production, followed by an extension by 2020. In 2014, the European Commission proposed that this target should be increased to 15% by 2030. In the same year, the European Council endorsed the target of 15%, underlining that electricity interconnection projects must be implemented in an integrated manner together with other energy infrastructure projects [25]. According to a study prepared by the European Commission [26], a properly interconnected European energy network could save EUR 12–40 billion annually to European consumers by 2030.

The market concentration index is based on the Herfindahl–Hirschman Index (HHI) and is calculated as the sum of the square market shares of the three largest power generation companies, expressed as a percentage of the total installed capacity where 10,000 means a single supplier (monopoly). The calculations show that the HHI of six countries is less than 1000, which means that the electricity markets of those countries are not very concentrated (Denmark, Germany, Italy, Netherlands, Spain, the United Kingdom). However, there are countries where the electricity market is highly concentrated; for example, there is an HHI of more than 9000 in Latvia and Cyprus, and the index is also very high (more than 7000) in Estonia and Croatia.

Annual switching rates (electricity retail markets) show the percentage of end users having switched to other electricity suppliers. The liberalization of electricity markets has enabled consumers to freely choose their electricity supplier. According to the data of 2015, only about 6% of end users in the EU switched to a new electricity supplier. Most of the switches occurred in Portugal (26.56%) and in the Netherlands (15.1%). Low switching to new supplies may be due to liberalization procedures that were not completed back in 2015 or due to the lack of consumer information. Customer switching also depends on the lack of financial incentives, which may result from the regulated electricity prices, complex procedures, or simply due to the absence of an automated and user-friendly process [27].

However, even a few years after market liberalization, consumers in some member states are sluggishly switching to new electricity supplier. In terms of the annual switching rates of non-household consumers, it also fluctuates very strongly. The countries with a switching rate of more than 25% are Poland (60%), Italy (38.4%), Lithuania (28.4%), Romania (28.4%), and Portugal (27.7%). However, there are countries where this indicator is less than 10%; for example, in Luxembourg this indicator is only 1.3%, in Finland 6%, and in Greece 6.6%.

The EU has set different targets for the member states for the use of RES in energy production. Those targets vary widely (depending on the country's potential to implement them) from 10% for Malta to 49% for Sweden. As can be seen from the characteristics of the countries presented in Table 2, some countries use a lot of RES for electricity generation, such as Austria (72.17%), Sweden (65.89%), Denmark (60.36%), Latvia (54.36%), Portugal (54.17%), and Croatia (46.42%), while others use very little RES, such as Malta (6.58%), Hungary (7.49%), Luxembourg (8.05%), and Cyprus (8.9%). The sustainability of the electricity sector in the country can be analysed using a set of indicators. In some respects, the indicators can be very positive and even exemplary, but negative in others.

Identifying which countries have the most sustainable electricity sector would be very difficult without MCDM methods. The next section provides a justification of the selection of sustainability assessment indicators for the EU electricity sector and describes the MCDM method used.

3. Assessment Methodology

3.1. Selection of Assessment Indicators

Indicators that are properly analyzed and interpreted can be a useful tool in making the decisions related to the issues of energy expansion and sustainable development, both for policy makers and for the public. Indicators provide an opportunity to systematize and explain statistical data that affect the state of the environment, economic development, and social welfare. Properly selected indicators can also be used to monitor progress, and assess policy decisions and their relevance with respect to sustainable development objectives. In this study, the procedure for selecting a set of evaluation indicators consisted of four stages:

I. review and analysis of indicators;
II. dividing indicators into groups;
III. prioritization of indicators;

IV. testing of indicators and creation of the final set of indicators (verification of reliability of indicators, checking whether the indicators duplicate each other or not, etc.).

In the first stage, a set of indicators, which include economic, social, environmental, and other characteristics of the electricity sector, is created. Initially, a higher number of indicators of certain categories may be defined, for example, descriptive, normalized, comparative, structural, stress, decomposition, causal, consequence, and physical indicators [28]. In the second stage, indicators are divided into groups. When selecting indicators, great attention is paid to their simplicity, realism, comparability, technical-scientific compliance, compliance with international standards, and quality of the statistics. In the third stage, taking into account the time horizon and the impact of the indicators on the human and the environment, the priority of the indicators is determined, i.e., their importance in the overall set of indicators. The fourth stage provides an opportunity to supplement and adjust the set of indicators, and a final set of indicators is formed.

A set of indicators for assessing the sustainability of the electricity sector has been developed on the basis of a methodology developed by the International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat, and European Environment Agency [29], and is also based on the analysis of scientific literature (analysis of methods for sustainable energy system planning [30–32] and impact analysis [33], analysis of methods for renewable energy development [34–37], analysis of alternative methodologies for analysing off-grid electricity supply [38], and analysis of empirical studies that are based on MCDM methods (the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) [39–41], Fuzzy Sets [42]; the Weighted Sum Model (WSM) [43], Monte Carlo Simulation [44]).

After summarizing the results and taking into account the possibility of obtaining reliable and accurate statistical data, a set of eight indicators designed to assess the sustainability of the electricity sector of different EU countries in 2017 was drawn up. The grouping of indicators reflecting sustainability can be varied. In order to achieve the objective of this article, the indicators were grouped into three groups of indicators: economic, environmental, and energy security.

Wholesale and retail electricity prices (measurement - kWh/Eur, PPS, including taxes and levies) are the main economic indicators for assessing the sustainability of the EU electricity sector. The aim is to keep the prices as low as possible, which is one of the main reasons for the implementation of liberalization of the electricity markets.

The environmental dimension of assessment of the sustainability of the electricity sector is particularly important for the implementation of international commitments and for the implementation of strategic long-term environmental, climate change plans. The main environmental indicators for assessing the sustainability of the EU electricity sector are as follows: distribution losses in electricity (measurement - %/GWh from final electricity consumption) and transformation losses in electricity (measurement - tonne of oil equivalent (TOE)/GWh from gross electricity production), and share of renewable energy in gross final energy consumption (measurement - % in gross final electricity consumption). According to statistical data, about 80% of the energy reaches the end users. A large part of energy is lost in production, supply, and distribution activities. For this reason, distribution and transformation losses represent a very important indicator in measuring the sustainability of the electricity sector from the point of view of environmental protection because it shows the effectiveness of activities, and the aim is to keep the indicator as low as possible. Share of renewable energy shows the level of the implementation of EU 2020 and 2030 objectives and strategies, as well as a variety of manufacturers' structure, and the aim is to maximize the indicator.

The main indicators of energy security for assessing the sustainability of the EU electricity sector were as follows: electricity interconnection (measurement—% of installed capacity), electricity demand fulfilment with inland production (measurement—% of gross electricity production of inland demand), and imported electricity from non-EU countries (measurement—% of imported electricity from non-EU countries of final consumption). The more electricity connections the country has, the more energy-secure it is, and its market is more competitive, which leads to more competitive energy prices. Demand fulfilment with inland production is also aimed at being as high as possible. The more the country can satisfy its internal energy demand, the more energy-independent it is. The EU's energy strategies foresee the development of a single EU energy market with the objective of being independent of energy imports from non-EU countries. The aim is to minimize the value of the indicator of imported electricity from non-EU countries.

All indicators in this study have the same weight, except for distribution and transformation losses. The relative weight of these indicators is less than half that of the others as they are usually measured together. However, the presentation of statistical data made it difficult to combine their values into one single indicator. Table 4 presents indicators of sustainability assessment for the electricity sector in all 28 EU countries, measurement units, and target values:

Table 4. Indicators for the assessment of sustainability of electricity sector, 2017.

	Economic		Environmental			Energy Security		
Indicator	**Wholesale Electricity Prices**	**Household Electricity Prices**	**Distribution Losses**	**Transformation Losses**	**Share of Renewable Energy**	**Electricity Interconnection**	**Demand Fulfilment**	**Import Dependency from Non-EU Countries**
Measurement	kWh/Eur	kWh/Eur	%, GWh	TOE/GWh	%	%	%	%
Target value	min	min	min	min	max	max	max	min
Weight	1/7	1/7	1/14	1/14	1/7	1/7	1/7	1/7
Belgium	0.2265	0.4726	4.44	0.1059	17.24	18.95	99.00	0.00
Bulgaria	0.2715	0.2093	11.07	0.1315	19.12	7.08	130.62	0.36
Czech Republic	0.3005	0.4082	7.41	0.0670	13.65	19.3	133.30	0.00
Denmark	0.2257	0.2768	5.20	0.0002	60.36	50.57	91.51	16.85
Germany	0.2648	0.4464	5.09	0.0735	34.41	8.95	117.08	0.00
Estonia	0.1745	0.1870	10.09	0.1243	17.03	23.67	151.80	0.00
Ireland	0.1961	0.3786	8.38	0.0653	30.09	7.41	106.41	0.00
Greece	0.2426	0.2522	1.98	0.0656	24.47	10.6	97.44	8.98
Spain	0.3437	0.6325	11.19	0.0920	36.34	5.79	101.97	0.00
France	0.1596	0.2747	8.70	0.1344	19.91	9.44	114.56	1.45
Croatia	0.2234	0.3066	10.75	0.0172	46.42	51.99	65.88	22.77
Italy	0.2732	0.3151	6.18	0.0520	34.1	8.18	92.29	7.15
Cyprus	0.2400	0.2725	5.02	0.1250	8.9	0.00	104.73	0.00
Latvia	0.3282	0.2756	7.31	0.0200	54.36	23.67	108.22	14.72
Lithuania	0.2236	0.1842	8.34	0.0300	18.25	23.67	35.27	40.49
Luxembourg	0.1179	0.2237	2.44	0.0119	8.05	109.22	34.13	0.00
Hungary	0.2252	0.2182	8.72	0.0825	7.49	58.25	75.47	12.28
Malta	0.2506	0.4464	5.72	0.0951	6.58	24.24	66.93	0.00
Netherlands	0.1777	0.3245	4.86	0.0482	13.8	18.11	100.25	4.47
Austria	0.1744	0.3430	5.11	0.0182	72.17	15.31	103.93	0.71
Poland	0.3310	0.3331	6.83	0.0029	13.09	4.05	108.98	0.61
Portugal	0.3088	0.4872	10.70	0.0611	54.17	8.73	112.64	0.00
Romania	0.2284	0.2609	14.31	0.0736	41.63	6.92	114.82	2.54
Slovenia	0.1978	0.3119	6.56	0.0582	32.43	83.56	112.47	0.00
Slovakia	0.3447	0.3461	4.68	0.0274	21.34	43.29	98.09	0.03
Finland	0.0883	0.2774	3.36	0.0587	35.22	28.78	79.40	7.39
Sweden	0.1322	0.2914	6.50	0.0652	65.89	25.61	118.22	6.97
United Kingdom	0.1667	0.2530	8.49	0.0775	28.11	5.00	101.23	0.00

Sources: data from [12,24].

3.2. MCDM Tool

The use of the MCDM methods in recent years has become particularly popular in dealing with different issues in the energy sector. The MCDM methods are actively used to solve energy sustainability problems, where the most popular in this field are AHP, ANP, Fuzzy Set theory, TOPSIS, the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Elimination and Choice Transcribing Reality (ELECTRE) methods [31,45,46]. To determine which EU country's electricity sector is the most sustainable, the multi-criteria evaluation TOPSIS method was used for calculations.

The TOPSIS method was proposed in 1980 by scientists Hwang and Yoon [47]. They developed a methodology for prioritizing variants based on the concept that the optimal alternative has the least distance from the optimal solution and the maximum distance from the worst. Each variant criterion has a tendency for monotonically increasing or decreasing utility. Therefore, it is easy to determine the ideal and opposite to ideal solutions. The essence of the TOPSIS method is that the selected alternative must have the shortest distance from the ideal solution and the maximum distance from the worst solution. The best solution or, in the case of this study, the ranking of countries under this method, was achieved in accordance with the following seven steps:

Step 1. Creating the decision matrix, which has *m* alternatives and *n* criteria:

$$D = \left[x_{ij}\right] = \begin{matrix} \\ a_1 \\ a_2 \\ \dots \\ a_m \end{matrix} \begin{bmatrix} X_1 & X_2 & \dots & X_n \\ x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2. Obtaining the normalized matrix using Equation (2):

$$\overline{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}};\ i = \overline{1, m},;\ j = \overline{1, n}, \tag{2}$$

Step 3. Calculate the weighted normalized matrix:

$$V = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \dots & \dots & \dots & \dots \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix};\ \sum_{j=1}^{n} w_j = 1 \tag{3}$$

Step 4. The positive A^+ and negative A^- ideal solutions could be found using:

$$A^+ = \left\{\max_j v_{ij} \middle| i \in \mathrm{I}),\ (\min_j v_{ij} \middle| i \in \mathrm{I}'), j = \overline{1, n,}\right\} = \left\{v^+{}_1, v^+{}_2 \dots v^+{}_n\right\}; \tag{4}$$

$$A^- = \left\{\min_j v_{ij} \middle| i \in \mathrm{I}),\ (\max_j v_{ij} \middle| i \in \mathrm{I}'), j = \overline{1, n,}\right\} = \{v^-{}_1, v^-{}_2 \dots v^-{}_n\} \tag{5}$$

Step 5. Calculation of the relative distance of each solution from the positive and negative ideal solution:

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2}, j = \overline{1, m}, \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, i = \overline{1, m}, \tag{7}$$

Step 6. Calculation of the relative closeness of each alternative to the ideal solution:

$$C_i = \frac{S_i^+}{S_i^+ + S_i^-} \tag{8}$$

Step 7. Choosing the best variant, i.e., the variant that is the closest to one. The closer the C_i value is close to one, the closer the *i* variant is to A^+, i.e., the best variant will be the one with the highest C_i value. Based on the values of C_i, a series of priorities of variants was created.

4. The Results of the Assessment of Sustainability of EU Countries' Electricity Sector

The results of the assessment of sustainability of EU countries' electricity sector following the assessment using the TOPSIS method are given in Table 5. Comparing with other countries, the electricity market of Slovenia was the most sustainable (0.7515), and Luxembourg was in second position (0.7091). These two countries were noticeably far away from other comparable countries. As far as Slovenia was concerned, although electricity prices for the household consumers in the country were not the lowest, the country was characterized by a high interconnection of electricity networks, the full satisfaction of demand for electricity with domestically produced energy, and it was completely independent of electricity imports from non-EU countries. Luxembourg had low electricity prices, low distribution and transformation losses, and a high level of interconnection of electricity networks. The country was also independent of electricity produced outside the EU. Austria was in third position (0.6224), Slovakia was in fourth position (0.6149), and Sweden was in fifth position (0.6139).

Table 5. The results of the assessment of sustainability of EU countries' electricity sector, 2017.

Alternatives	S_i^+ *	S_i^- **	C_i ***	Rank
Slovenia	0.043	0.131	0.752	1
Luxembourg	0.059	0.143	0.709	2
Austria	0.075	0.123	0.622	3
Slovakia	0.073	0.116	0.615	4
Sweden	0.069	0.110	0.614	5
Estonia	0.083	0.118	0.587	6
Denmark	0.067	0.095	0.585	7
Finland	0.074	0.103	0.582	8
Portugal	0.088	0.114	0.565	9
United Kingdom	0.090	0.114	0.559	10
Germany	0.088	0.112	0.559	11
Ireland	0.089	0.112	0.558	12
Czech Republic	0.089	0.112	0.557	13
Romania	0.088	0.109	0.555	14
Belgium	0.089	0.110	0.553	15
Hungary	0.078	0.094	0.548	16
France	0.092	0.110	0.546	17
Malta	0.092	0.109	0.544	18
Netherlands	0.087	0.103	0.543	19
Bulgaria	0.095	0.113	0.543	20
Poland	0.098	0.111	0.531	21
Spain	0.099	0.109	0.523	22
Cyprus	0.102	0.112	0.523	23
Italy	0.090	0.096	0.517	24
Latvia	0.083	0.089	0.517	25
Greece	0.091	0.094	0.509	26
Croatia	0.083	0.078	0.485	27
Lithuania	0.135	0.048	0.264	28

* relative distance from the positive ideal solution; ** relative distance from the negative ideal solution; *** the relative closeness to the ideal solution.

Lithuania (0.2644) took the last position in the ranking and this country's evaluation was very far from the penultimate position, i.e., Croatia (0.4845) was in 27th position. The evaluation results of all 21 other countries, i.e., from the sixth position to the 26th, did not differ so drastically and fell within the range (0.5874–0.5086). The main reason for Lithuania's low rating was its dependence on electricity imports (40.5%) from non-EU countries, namely Russia and Belarus. Electricity supplied from these countries respectively accounted for 14.8% and 25.7% of the country's total electricity consumption. Croatia ranked 27th for the same main reason; 22.8% of energy consumed in the country was supplied from Bosnia and Herzegovina (17.7%) and Serbia (5.1%).

Electricity is an essential part of the energy system, but today it is not a major part of the energy sector in many EU countries. Meeting the heating needs consumes the largest share of energy in 25 of the 28 EU countries, and meeting the heat demand also consumes more energy than cooling in all EU countries. In this context, it can be argued that decisions regarding heating and cooling can have a major impact on the further development of the electricity sector. For example, electrification of heating and ventilation systems can double the demand for electricity [48]. Also, switching to electric cars in the future will require more electricity [49]. This accordingly presupposes that the development of RES in the electricity sector can have a major impact on the overall sustainability of the energy sector in the future. Therefore, it is very important to assess the sustainability of the electricity sector and to perform the assessment of the used market instruments in different countries and across the EU. The current focus on the electricity sector in the EU common and in the national energy policies of the member states is not properly addressed. The current energy policy is rather related to centralized energy planning, and in many countries, with the implementation of EU documents. Electricity prices vary widely across the EU. This is mainly influenced by market competition. Unfortunately, in many countries the price is too low. This is revealed by the HHI (Table 3) and the share of RES for electricity generation. With regard to market activation measures in installing RES for electricity generation, some kind of stagnation in communication with the end users can be noticed as there is still a lack of initiatives to encourage end users to adopt sustainable technologies; in some countries, there is also a lack of information on promotion opportunities, the use of the State funding, possible benefits, etc. The new documents planned in 2019 are expected to provide effective measures that encourage RES development for energy production in the final sectors. Countries also need to be cautious about granting subsidies for electricity production from RES, which are set by the ETS. Electricity generation from RES is criticized in scientific literature and in various empirical studies for its high costs and lack of benefits [6,7,50,51]. In some countries, subsidizing electricity production from RES can lead to high electricity prices.

The study conducted by Manolopoulosa et al. [52] revealed that bureaucracy (lengthy administrative procedures, disagreements over responsibilities between national authorities), changing government (processes slow down before and after the elections, procedures change), and public objections to new projects that slow down their implementation or lead to their postponement are the main barriers that are encountered in Greece when it comes to increasing RES in electricity generation. It can be assumed that other countries where the level of bureaucracy is high encounter similar barriers to the development of RES in the electricity sector.

It follows from the EU electricity sector sustainability assessment that Slovenia and Luxembourg have the most sustainable electricity sectors, while Lithuania and Croatia are the least sustainable sectors compared to other EU countries. Looking at individual indicators of the countries that describe the electricity sectors, it can be said that, although significant results have been achieved over the last decade, today's results are insufficient to combat climate change. The policy of promoting the reduction of GHG emission for energy generation from RES is necessary to increase the sustainability of the electricity sector. Looking at the set EU targets, it should be much more aggressive in order to achieve the targets set by the deadlines established. Properly selected policy measures can promote implementing more efficient technologies and attract investment to the electricity sector. When implemented at the same time, the climate change mitigation policy and the RES promoting policy help to ensure each other's implementation [53,54], i.e., they have a synergistic effect, and this leads to lower and more stable costs for both policies.

5. Conclusions

Over the last two decades, the EU reform of electricity markets has had positive results, and market liberalization acts as a stimulus for efficiency, lower electricity prices, and technological progress. In the policy of the electricity sector in the EU member states, actions and regulations are mainly based on the EU agreements and targets, which are seeking to solve climate change and energy security problems.

In this study, a set of eight indicators for assessing the sustainability of the electricity sector was developed where the indicators were grouped into three groups: economic, environmental, and energy security. The set of indicators can be used to assess electricity sector sustainability of different regions or countries. In future research, the set of indicators could be extended according to the specific of assessment.

The electricity sector of Slovenia was the most sustainable in the EU in 2017, and Luxembourg was in second position. Although electricity prices for the household consumers in Slovenia were not the lowest, the country was characterized by a very high interconnection of electricity networks, the fulfilment of demand for electricity with domestically produced energy, and it was completely independent of electricity imports from non-EU countries. Luxembourg had low electricity prices and low distribution and transformation losses, and the highest level of interconnection of electricity networks in the EU. The country was also independent of electricity produced outside the EU.

The last position was taken by Lithuania in the ranking and this country's evaluation was very far from the penultimate position (Croatia). The main reason for Lithuania's lowest rating was its dependence on electricity imports (40.5%) from non-EU countries, namely Russia and Belarus. Electricity supplied from these countries respectively accounts for 14.8% and 25.7% of the country's total electricity consumption. Austria was in third position, Slovakia in fourth, and Sweden in fifth position. The evaluation results of all 21 other countries, i.e., from the sixth position to the 26th, did not differ so drastically.

After analysis, it could be concluded that in most EU countries, retail electricity markets suffer from low levels of competition and passive consumer participation in the market. The share of renewable energy in gross final electricity consumption was too low in many EU countries. Nowadays, it is very important to actively use policy instruments that seek smarter and more sustainable electricity production, distribution, and use. Unfortunately, despite technical innovations, such as smart grids, smart homes, and the availability of independent power generation technologies, consumers were not sufficiently informed and encouraged to participate actively in the electricity markets. As a result, consumers lost the ability to control and manage their energy consumption, which would include cost savings and the search for more efficient consumption.

Author Contributions: The contribution of all authors is equal.

Funding: This project has received funding from European Social Fund (project No 09.3.3-LMT-K-712-02-0015) under grant agreement with the Research Council of Lithuania (LMTLT).

Acknowledgments: Authors are grateful for reviewers' comments and valuable suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IRENA. *Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables*; International Renewable Energy Agency: Abu Dhabi, UAE, 2019; p. 163. ISBN 978-92-9260-111-9.
2. IRENA. Data and Statistics. 2019. Available online: http://resourceirena.irena.org/gateway/dashboard/ (accessed on 18 April 2019).
3. IRENA. *Global Energy Transformation: A Roadmap to 2050*; International Renewable Energy Agency: Abu Dhabi, UAE, 2019; p. 52. ISBN 978-92-9260-121-8.
4. Szabo, L.; Kelemen, A.; Mezosi, A.; Pato, Z.; Kacsor, E.; Resch, G.; Liebmann, L. South East Europe electricity roadmap–modelling energy transition in the electricity sectors. *Clim. Policy* **2019**, *19*, 495–510. [CrossRef]
5. Mardani, A.; Streimikiene, D.; Cavallaro, F.; Loganathan, N.; Khoshnoudi, M. Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Sci. Total Environ.* **2019**, *649*, 31–49. [CrossRef] [PubMed]
6. Chaton, C.; Guillerminet, M.L. Competition and environmental policies in an electricity sector. *Energy Econ.* **2013**, *36*, 215–228. [CrossRef]
7. Lehmann, P.; Sijm, J.; Gawel, E.; Strunz, S.; Chewpreecha, U.; Mercure, J.F.; Pollitt, H. Addressing multiple externalities from electricity generation: A case for EU renewable energy policy beyond 2020? *Environ. Econ. Policy Stud.* **2019**, *21*, 255–283. [CrossRef]
8. Eskeland, G.S.; Rive, N.A.; Mideksa, T.K. Europe's climate goals and the electricity sector. *Energy Policy* **2012**, *41*, 200–211. [CrossRef]
9. Corsateaa, T.D.; Giaccaria, S. Market regulation and environmental productivity changes in theelectricity and gas sector of 13 observed EU countries. *Energy* **2018**, *164*, 1286–1297. [CrossRef]

10. Knopf, B.; Nahmmacher, P.; Schmid, E. The European renewable energy target for 2030—An impact assessment of the electricity sector. *Energy Policy* **2015**, *85*, 50–60. [CrossRef]
11. Lockwood, M.; Froggatt, A.; Wright, G.; Duttona, J. The implications of Brexit for the electricity sector in Great Britain: Trade offs between market integration and policy influence. *Energy Policy* **2017**, *110*, 137–143. [CrossRef]
12. Eurostat. Main Tables: Sustainable Development Indicators–Affordable and Clean Energy. 2019. Available online: https://ec.europa.eu/eurostat/web/sdi/main-tables (accessed on 20 April 2019).
13. Van den Bergh, K.; Delarue, E.; D'haeseleer, W. Impact of renewables deployment on the CO2 price and the CO2 emissions in the European electricity sector. *Energy Policy* **2013**, *63*, 1021–1031. [CrossRef]
14. Thema, J.; Suerkemper, F.; Grave, K.; Amelung, A. The impact of electricity demand reduction policies on the EU-ETS: Modelling electricity and carbon prices and the effect on industrial competitiveness. *Energy Policy* **2013**, *60*, 656–666. [CrossRef]
15. European Commission. *Energy Roadmap 2050*; European Commission: Brussels, Belgium, 2011.
16. De Almeida, A.; Fonseca, P.; Schlomann, B.; Feilberg, N. Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations. *Energy Build.* **2011**, *43*, 1884–1894. [CrossRef]
17. Pereira, G.I.; da Silva, P.P.; Soule, D. Policy-adaptation for a smarter and more sustainable EU electricity distribution industry: A foresight analysis. *Environ. Dev. Sustain.* **2018**, *20* (Suppl. 1), 231–267. [CrossRef]
18. European Union. Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. *Off. J. Eur. Communities* **1996**, *L 27*, 20–29.
19. European Union. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC. *Off. J. Eur. Union* **2003**, *L 176*, 37–55.
20. European Union. Directive of 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. *Off. J. Eur. Union* **2009**, *211*, 55–93.
21. European Commission. *Energy 2020. A Strategy for Competitive, Sustainable and Secure Energy*; European Commission: Brussels, Belgium, 2010.
22. European Commission. *Energy Union Package. A Framework Strategy for a Resilient Energy Union with a Forward Looking Climate Change Policy*; European Commission: Brussels, Belgium, 2015.
23. European Commission. *Clean Energy for All Europeans. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank*; European Commission: Brussels, Belgium, 2016.
24. European Commission. Energy-Database-Indicators for Monitoring Progress Towards Energy Union Objectives. 2019. Available online: https://ec.europa.eu/energy/en/atico_countrysheets/scoreboard (accessed on 26 April 2019).
25. European Commission. *Towards a Sustainable and Integrated Europe*; Report of the Commission Expert Group on Electricity Interconnection Targets; European Commission: Brussels, Belgium, 2017.
26. Booz & Co. *Benefits of an Integrated European Energy Market*; Report for Directorate-General Energy European Commission; European Commission: Brussels, Belgium, 2013.
27. Council of European Energy Regulators (CEER). *Monitoring Report on the Performance of European Retail Markets in 2017*; CEER: Bruxelles, Belgium, 2018.
28. Patlitzianas, K.D.; Doukas, H.; Kagiannas, A.G.; Psarras, J. Sustainable energy policy indicators: Review and recommendations. *Renew. Energy* **2008**, *33*, 966–973. [CrossRef]
29. IAEA. *Energy Indicators for Sustainable Development: Guidelines and Methodologies*; International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat and European Environment Agency: Viena, Austria, 2005; p. 161. ISBN 92-0-116204-9.
30. Ioannou, A.; Angus, A.; Brennan, F. Risk-based methods for sustainable energy system planning: A review. *Renew. Sustain. Energy Rev.* **2017**, *74*, 602–615. [CrossRef]
31. Mardani, A.; Zavadskas, E.K.; Khalifah, Z.; Zakuan, N.; Jusoh, A.; Nor, K.M.; Khoshnoudi, M. A review of multi-criteria decision-making applications to solve energy management problems: Two decades from 1995 to 2015. *Renew. Sustain. Energy Rev.* **2017**, *71*, 216–256. [CrossRef]
32. Greening, L.A.; Bernow, S. Design of coordinated energy and environmental policies: Use of multi-criteria decision-making. *Energy Policy* **2004**, *32*, 721–735. [CrossRef]

33. Shortall, R.; Davidsdottir, B. How to measure national energy sustainability performance: An Icelandic case-study. *Energy Sustain. Dev.* **2017**, *39*, 29–47. [CrossRef]
34. Bhowmik, C.; Bhowmik, S.; Ray, A.; Pandey, K.M. Optimal green energy planning for sustainable development: A review. *Renew. Sustain. Energy Rev.* **2017**, *71*, 796–813. [CrossRef]
35. Kumar, A.; Sah, B.; Singh, A.R.; Deng, Y.; He, X.; Kumar, P.; Bansal, R.C. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew. Sustain. Energy Rev.* **2017**, *69*, 596–609. [CrossRef]
36. Kurka, T.; Blackwood, D. Selection of MCA methods to support decision making for renewable energy developments. *Renew. Sustain. Energy Rev.* **2013**, *27*, 225–233. [CrossRef]
37. Cavallaro, F. Multi-criteria decision aid to assess concentrated solar thermal technologies. *Renew. Energy* **2009**, *34*, 1678–1685. [CrossRef]
38. Bhattacharyya, S.C. Review of alternative methodologies for analysing off-grid electricity supply. *Renew. Sustain. Energy Rev.* **2012**, *16*, 677–694. [CrossRef]
39. Cucchiella, F.; D'Adamo, I.; Gastaldi, M.; Koh, S.C.; Lenny, R.P. A comparison of environmental and energetic performance of European countries: A sustainability index. *Renew. Sustain. Energy Rev.* **2017**, *78*, 401–413. [CrossRef]
40. Ligus, M. Evaluation of Economic, Social and Environmental Effects of Low-Emission Energy Technologies Development in Poland: A Multi-Criteria Analysis with Application of a Fuzzy Analytic Hierarchy Process (FAHP). *Energies* **2017**, *10*, 1550. [CrossRef]
41. Claudia, R.M.; Martinez, M.; Pena, R. Scenarios for a hierarchical assessment of the global sustainability of electric power plants in Mexico. *Renew. Sustain. Energy Rev.* **2014**, *33*, 154–160. [CrossRef]
42. Ren, J.; Lutzen, M. Selection of sustainable alternative energy source for shipping: Multi criteria decision making under incomplete information. *Renew. Sustain. Energy Rev.* **2017**, *74*, 1003–1019. [CrossRef]
43. Klein, S.J.W.; Whalley, S. Comparing the sustainability of US electricity options through multi-criteria decision analysis. *Energy Policy* **2015**, *79*, 127–149. [CrossRef]
44. Noori, M.; Kucukvar, M.; Tatari, O. A macro-level decision analysis of wind power as a solution for sustainable energy in the USA. *Int. J. Sustain. Energy* **2015**, *34*, 629–644. [CrossRef]
45. Wang, L.; Xu, L.; Song, H. Environmental performance evaluation of Beijing's energy use planning. *Energy Policy* **2011**, *39*, 3483–3495. [CrossRef]
46. Siksnelyte, I.; Zavadskas, E.K.; Streimikiene, D.; Sharma, D. An Overview of Multi-Criteria Decision-Making Methods in Dealing with Sustainable Energy Development Issues. *Energies* **2018**, *11*, 2754. [CrossRef]
47. Hwang, C.L.; Yoon, K. *Multiple Attributes Decision Making Methods and Applications*; Springer: Berlin/Hedelberg, Germany, 1981; pp. 22–51.
48. Connolly, D. Heat Roadmap Europe: Quantitative comparison between the electricity, heating, and cooling sectors for different European countries. *Energy* **2017**, *139*, 580–593. [CrossRef]
49. Strielkowski, W.; Volkova, E.; Pushkareva, L.; Streimikiene, D. Innovative Policies for Energy Efficiency and the Use of Renewables in Households. *Energies* **2019**, *12*, 1392. [CrossRef]
50. Flues, F.; Löschel, A.; Lutz, B.J.; Schenker, O. Designing an EU energy and climate policy portfolio for 2030: Implications of overlapping regulation under different levels of electricity demand. *Energy Policy* **2014**, *75*, 91–99. [CrossRef]
51. Del Río, P.; Resch, G.; Ortner, A.; Liebmann, L.; Busch, S.; Panzer, C. A techno-economic analysis of EU renewable electricity policy pathways in 2030. *Energy Policy* **2017**, *104*, 484–493. [CrossRef]
52. Manolopoulosa, D.; Kitsopoulosb, K.; Kaldellisc, J.K.; Bitzenis, A. The evolution of renewable energy sources in theelectricity sector of Greece. *Int. J. Hydrogen Energy* **2016**, *41*, 12659–12671. [CrossRef]
53. Fagiani, R.; Richstein, J.C.; Hakvoort, R.; De Vries, L. The dynamic impact of carbon reduction and renewable support policies on the electricity sector. *Util. Policy* **2014**, *28*, 28–41. [CrossRef]
54. Linares, P.; Javier Santos, F.; Ventosa, M. Coordination of carbon reduction and renewable energy support policies. *Clim. Policy* **2008**, *8*, 377–394. [CrossRef]