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Utilization of Renewable Energy Sources in Road Transport in EU Countries—TOPSIS Results

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Abstract: The primary aim of this study was to assess and compare EU countries in terms of the use of renewable energy sources in road transport. The following research tasks were undertaken to realize this aim: (1) a review of the literature concerning the negative externalities in road transport, the concept of sustainable development, and legal regulations referring to the utilization of renewable energy sources; (2) presentation of changes in energy consumption (both traditional and renewable) in road transport in EU countries in the years 2008–2019; and (3) identification of leaders among the EU countries in terms of consumption of renewable energy sources in road transport. The aim and tasks were realized using the literature review and TOPSIS method as well as descriptive, tabular, and graphic methods. The analysis was conducted for 28 EU countries according to the status for 2019. The period of 2008–2019 was investigated. Sources of materials included literature on the subject and Eurostat data. Although renewable energy sources accounted for as little as 6% of total energy consumption in road transport in EU countries in 2019, this is a significant topical issue. It results from the direction in which changes need to be implemented in terms of energy generation in this area of human activity. It turned out that blended biodiesel and blended biogasoline were the most commonly used fuels originating from renewable sources. The application of the TOPSIS method resulted in the identification of five groups of EU member countries, which differed in terms of the degree of utilization of renewable energy sources in road transport. Luxemburg, Sweden, and Austria were leaders in this respect. In turn, Malta, Estonia, and Croatia were characterized by very low consumption of renewable energy. The greatest progress in the utilization of renewable energy sources in road transport was recorded in Sweden, Finland, and Bulgaria (changes in the relative closeness to the ideal solution from 0.15 to 0.27), while the greatest reduction in relation to other countries was observed in Austria, Germany, and Lithuania (changes from −0.35 to −0.22).

Keywords: road transport; renewable energy sources; energy consumption; TOPSIS

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1. Introduction

The road transport sector is one of the most dynamically developing sectors of the economy not only in Europe but worldwide [1]. With an increase in the number of vehicles, we are faced with a growing problem of contaminant emissions to the atmosphere (generating negative externalities). Thus, legislative bodies are attempting to implement various regulations and standards to curb, e.g., carbon dioxide (CO_2) emissions, which are jointly termed decarbonization. One of the solutions proposed in this respect is to increase the consumption of renewable energy sources such as blended biodiesel and blended biogasoline.

The utilization of renewable energy sources in road transport has been analyzed by many researchers. Nevertheless, it needs to be remembered that these analyses were conducted for individual countries. The consumption of renewable energy sources in road transport in Germany, Scandinavian countries, or Poland was discussed, e.g., by Meisel et al. (2020) [2], Hansen et al. (2019) [3], Lindfeldt et al. (2010) [4], Åkerman and Höjer (2006) [5], Bebkiewicz et al. (2020) [6], and Wołek et al. (2021) [7]. Thus, very few publications on the subject concern similar comparisons at the international level. In particular, due to the numerous regulations adopted in recent years to increase the use of renewable energy sources in EU countries, it is necessary to see which countries have made the most progress in this regard.

For this reason, it was decided to assess and compare EU countries in terms of the use of renewable energy sources in road transport. The following research tasks were undertaken to realize this objective: (1) a review of the literature concerning the negative externalities in road transport, the concept of sustainable development, and legal regulations referring to the utilization of renewable energy sources; (2) presentation of changes in energy consumption (both traditional and renewable) in road transport in the EU countries in the years 2008–2019; and (3) identification of leaders among the EU countries in terms of consumption of renewable energy sources in road transport.

Our study makes several contributions. Firstly, our study organizes the knowledge of the negative externalities in road transport, the concept of sustainability, and the legal regulations supporting it. Secondly, this study makes a comparison between EU countries in the consumption of renewable energy sources in road transport (there is a lack of international benchmarking). Thirdly, it helps to identify leaders among the EU countries in terms of the consumption of renewable energy sources in road transport. Therefore, we hope that this study will be received with interest not only by researchers carrying out projects in this field but also by practitioners, especially regulators and representatives of the transport sector.

This article is composed of five parts. The first part, the Introduction, presents a justification for the selection of this topic, the main aim, and research tasks. The next provides a review of literature on negative externalities in road transport and methods of their internationalization within the concept of sustainable development. The third part gives information concerning the materials and applied research methods. Part 4 presents the results of conducted analyses and a discussion with findings reported by other authors. The final part of this paper gives conclusions together with the presentation of limitations for the obtained results. That part also contains a proposal for future research directions.

2. Literature Review

Road transport is the most commonly used form of land transport of goods and passengers [8]. However, its functioning may be a source of multiple problems [9]. In economic literature, they are termed external costs or negative externalities [10]. They constitute "all costs associated with the realisation of the transport service, which are incurred neither by the service provider nor the buyer, but by the third party, i.e., the general population" [9] (p. 34).

The problem of externalities of road transport has been frequently discussed in the literature on the subject, e.g., [11–17]. Researchers typically included accidents [18], noise (Margorínová et al., 2018), volatile and particulate air pollutants [13], climate change [19], changes in the natural environment and landscape [20], fragmentation of urban spaces [21], additional costs related to the manufacturing of vehicles and maintenance of the transport system [22], as well as traffic congestion [23]. Since there are many externalities of road transport, they are divided into four categories [24]: (1) environmental costs, (2) costs of accidents, (3) costs of infrastructure, and (4) costs of traffic congestion.

As it was indicated by Raczyński [25], environmental costs account for the greatest share in the total externalities of road transport (Table 1). They account for 58%. Costs of accidents comprising"costs related to rescuing and rehabilitation of accident victims (. . .) and costs of emergency services, as well as material losses, that is losses in production not covered by insurance and losses resulting from incurred outlays, e.g., to education" [24],

p. 100, are as high as 29%. The share of infrastructure costs is 12%, while that of traffic congestion is only 1%.

Table 1. Categories of externalities of road transport.

Categories of Costs	Components of Costs	Share in Total Externalities (%)
Environmental costs	• Air pollution (including costs of lost harvests and losses in forests); • Climate change (costs of losses caused by CO_2 emissions); • Noise (costs of measures aiming at noise mitigation); • Changes in the natural environment and landscape (additional costs related to mitigation of environmental losses).	58
Costs of accidents	• Collisions (costs of health care, potential social costs).	29
Costs of infrastructure	• Shortage of urban areas (costs of allocation of space for bicycle traffic); • Additional costs of the manufacturing process (costs for the production and maintenance of vehicles, construction, and maintenance of the transport system).	12
Costs of traffic congestion	• Congestion (costs of time wasted due to traffic congestion and inefficiency of the transport system).	1

Source: the authors' study is based on [25].

In the international discussion on that subject, the focus is primarily on the need to reduce environmental costs of road transport [26], particularly to limit CO_2 emissions in the atmosphere. Thus, increasingly often, researchers propose to undertake actions leading to decarbonization [27]. Egorova et al. [28] assumed that decarbonization is a direction of development, in which the primary objective is to implement the transition to the "green" economy model. It comprises both the rationalization of consumption of oil, natural gas, and other carbon fuels (e.g., lignite, hard coal, or peat), as well as utilization of renewable energy sources [29,30]. In particular, the potential use of the latter sources is increasingly often investigated by researchers, e.g., [31,32].

Fu et al. [33] proposed the following solutions for the decarburization of economies: limiting the consumption of primary energy thanks to the replacement of fossil fuels with clean energy (particularly the substitution of commonly used natural gas with solar energy to power buses); changes in the current lifestyle patterns aiming at the use of means of public transport to cover short distances, participation of local governments in the construction of bicycle rental systems, and eventually, the establishment of ecopolis-type housing districts; elimination of dirty industries; and undertaking of actions aiming at the acquisition of capital for investments in advanced technologies, or encouraging public participation in oversight and supervision processes over environmental protection actions.

The potential use of renewable energy sources in road transport was presented, e.g., by Manzini [34], Hillman and Sandén [35], Flizikowski et al. [36], and Aldenius [37]. They pointed to the utilization of alternative fuels, i.e., electricity, hydrogen, biofuels, synthetic and paraffin fuels, natural gas (including biomethane in the form of condensed and liquefied natural gas), with liquefied gas being a substitute for energy sources originating from crude oil. It is essential that the utilization of these energy sources is also in line with the concept of sustainable development, strongly supported by EU legislation.

The idea of sustainable development (SD) was created in the early 1970s. In view of the multiple and diverse ecological threats (environmental pollution and degradation as well as high demand for raw material resources) [38], it may be stated that it is a concept defined in a variety of ways and found in numerous areas of both everyday life and science; it is interdisciplinary in character, which may result in the need to combine various research disciplines in terms of both pure and applied science [39]. In turn, Stanny and Czarnecki [40] indicated that SD is a certain compromise between social, environmental, and economic goals, which determine the welfare of future generations.

Present-day development is inseparably connected with the consumption of energy. Thus, ensuring energy security is an obvious priority task. It is dependent on the actual access of each country to energy sources, and as such, it is considered to be a strategic goal [41]. Energy security is connected with SD policy, economic factors, development of energy markets, as well as changes in transport and information technologies [42,43]. EU countries particularly focus on the SD of the energy sector, which is advantageous for the natural environment and may never compromise the welfare of future generations [44,45]. Joint actions of the EU countries in the field of energy policy and environmental protection were specified in the treaties establishing the European Coal and Steel Community (ECSC) and the European Atomic Energy Community (Euratom), in the Single European Act (SEA) of 1987, in the Maastricht Treaty of 1992 [46] as well as legal acts including three energy packages (comprising Directives 96/92/EC, 98/30/EC, 2003/54/EC, 2003/55/EC, 2009/72/EC; Regulations 1228/2003, 715/2009, 714/2009) and the energy and climate package (including Directives 2009/29/EC, 2009/406/EC, 2009/31/EC, 2009/28/EC, and 2009/30/EC, and Regulation no. 443/2009) [47–49]. A particularly important role in terms of sustainable energy development (SED) is played by the internal aspect (balancing demand and supply considering the environment, consumers, and economic and political ramifications) and the external aspect (ensuring a safety gap between domestic demand and domestic production) of energy security [50]. The European Union is a leader in environmental protection [51]. In 2010, the European Commission adopted the strategy to ensure a competitive, sustainable and safe energy sector, indicating the EU priorities in energy policy by 2020. Assumptions of the Europe 2020 strategy provided for an increase in energy efficiency by 20%, an increase to 20% in the share of energy generated from renewable sources in the total energy consumption, and a reduction in greenhouse emissions by 20% in relation to 1990 [52]. In the Energy Strategy 2030, EU countries declared to protect the natural environment by increasing outlays to reduce pollutant emissions. The obligation of EU countries by 2030 concerned a minimum 40% reduction in greenhouse gas emissions in relation to the level of 1990, an increase in the share of renewable energy to 32% in the total energy consumed in the EU, an increase in energy efficiency by 30% and the potential to transfer to other EU countries 15% of electricity generated within the EU's interconnected grid systems [45,52]. In the Energy Roadmap 2050, EU countries declared to reduce greenhouse emissions by 80–90% compared to 1990 [53]. The European Union, in the document "Clean Energy for all Europeans", proposes as an ambitious goal to increase the use of renewable energy sources and increase energy efficiency to 32% [54]. In 2019, at the climate summit in Spain, the EU adopted the assumptions of the climate strategy, the European Green Deal, according to which EU countries are to become net-zero emitters, i.e., climate-neutral [54,55]. Decarbonization of the economies in the EU countries has become a priority. This is a process consisting of the limitation and eventually elimination of CO_2 emissions to the atmosphere due to their harmful environmental impact. The EU strives to reduce emissions of harmful greenhouse gases by 40% in 2030, while in 2050, the target is to reduce them by 80–90% in relation to the levels of 1990. The process of decarbonization involves the entire economic system within the next 30 years. It is an extremely difficult undertaking and refers to many sectors of the economy, such as, e.g., the energy sector, the manufacturing industry, flights within the EU, transport, the construction industry, agriculture and navigation, and water transport [56,57]. One of the areas connected with climate changes is the transport sector, which, in contrast to trends in other sectors within the last few years, increased its greenhouse gas emissions [51]. In the years 1990–2018, emissions in the entire EU decreased by 21.6%, in the energy sector dropped by 30%, while at the same time, transport emissions increased by 21% [58]. This was caused by increased vehicle traffic in the EU. The transport sector generates 25% of total greenhouse gas emissions in 28 EU member countries, of which 90% of emissions are generated by road transport [59]. Reduction in greenhouse gas emissions in road transport may be implemented by the limitation of demand for transport, optimization of prices and rationalization of transport operations, improved parameters of vehicle performance (improved technologies of combustion engines and electrification), as well as the use of alternative energy sources, including biofuels and renewable energy [60].

Regulations concerning carbon dioxide emissions in road transport are contained in many EU documents, e.g., [60]:

- Directive 2014/94/EU on the deployment of the alternative fuels infrastructure;
- Directive 2009/28/EC RED and RED II concerning the use of energy from renewable sources, which imposes an obligation for the share of renewable energy in 2030 in the transport sector to be 10% (RED), while RED II introduces an obligation on all the member countries to have the share of energy from renewable energy sources in 2030 within the range of 2.6% to 10.5%;
- Directive 2009/30/EC on quality of fuels, which requires fuel suppliers to reduce the mean emissions of greenhouse gases from their fuels by 6% in 2020;
- Decision no. 406/2009/EC on the efforts of the member states to reduce their emissions in sectors not covered by the emissions-trading scheme.

Definite trends within the EU to reduce CO_2 emissions and use alternative energy sources require in the nearest future an accelerated and increased use of renewable energy sources in transport. Particularly, numerous benefits are associated with the use of biofuels, such as, e.g., investments and modernization efforts in the agricultural and industrial sector, stimulation of economic development and increased employment in agricultural regions, increased energy security and diversification of energy sources, while in the case of exceeding the limits specified in the legal regulations, it may generate additional domestic revenue from the sale of emission permits to other countries [60].

3. Materials and Methods

In order to assess and compare the level of utilization of renewable energy sources in road transport in the EU countries, EUROSTAT data were used [61]. When presenting the results, the acronyms for individual countries were used according to the ISO 3166-1 standard: Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), the Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxemburg (LU), Malta (MT), the Netherlands (NL), Poland (PO), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), and Great Britain (GB).

This article compares data from the years 2008–2019 (2008 being the first, while 2019 the last year, for which information is available for all the EU countries). Thus, it was possible to monitor the progress of the EU countries in meeting their renewable energy targets. Assumptions of the Europe 2020 strategy provided for an increase in energy efficiency by 20%, an increase to 20% in the share of energy generated from renewable sources in the total energy consumption, and a reduction in greenhouse emissions by 20% in relation to 1990 [52].

The basic variable, which characterizes the investigated phenomenon, is connected with the share of renewable energy sources in road transport. The share of renewable energy sources used in road transport makes it easy to compare countries, despite the different number of transport modes. However, in the opinion of the authors, this is not sufficient because it does not take into consideration the standard of development of individual countries and their population sizes. For this reason, the consumption of renewable energy sources in road transport per capita and per GDP were adopted as additional variables. Thus, the set of diagnostic variables is as follows:

- X_1: the share of renewable energy sources in road transport (%) (considered renewable energy sources include blended biodiesels, blended biogasoline, pure biodiesels, biogases, electricity, pure biogasoline, and other liquid biofuels);
- X_2: renewable energy sources in road transport per capita (kg of oil equivalent per capita);
- X_3: renewable energy sources in road transport per unit GDP (kg of oil equivalent per 1 thousand Euro).

Table A1 presents selected statistical parameters of diagnostic variables for the years 2008–2019 for the EU countries.

A comparison of the level of complex phenomena such as the utilization of renewable energy sources in road transport in the EU countries is facilitated, among other things, by the application of such methods as TOPSIS (Technique for Order Preference using Similar to Ideal Solution). This method was proposed by Hwang and Yoon [62], and it is representative of the Multiple Attribute Decision Making (MADM) methods. TOPSIS may also be applied in the linear ordering of objects, and in this sense, it is considered a Multidimensional Comparative Analysis method. The spectrum of its potential application is extensive. Behzadian, Otaghsara, Yazdani, and Ignatius [63] presented a review of the literature concerning the application of this method to solve specific problems in many areas of economic activity.

We assume that a complex phenomenon characterizes the studied objects—variants (in MADM, they are called decision alternatives). This phenomenon comprises many attributes or properties, referred to as diagnostic variables (in MADM, they are called criteria). These variables are aggregated in order to obtain the so-called synthetic variable. A synthetic variable facilitates a comparison of objects in terms of the analyzed complex phenomenon. A synthetic variable is constructed in several steps, which may be conducted in various ways. A review of the methods may be found, e.g., in studies by Kukuła [64], Gatnar and Walesiak [65], Młodak [66], and Panek [67].

The first stage consisting of the identification and selection of variables leads to the determination of matrix $X = \left[x_{ij}\right]_{n\times k}$, where $x_{ij} \in R$. Index i denotes the number of the object, while j denotes the number of the diagnostic variable. Diagnostic variables may differ in their dimensional units, orders of magnitude, and directions of effects on the assessed complex phenomenon; for this reason, in the second stage, they are normalized. In the case of certain variables, their high values are considered desirable (LTB—larger-the-better [68]), which in MADM are referred to as profit attributes, while in the case of others, it is the opposite, as their low values are desirable (STB—smaller-the-better), and these are called cost attributes. Considering the type of variable requires different normalization formulas or prior transformation of STB variables into LTB variables. Since all the diagnostic variables determining the utilization of renewable energy sources in road transport were LTB, this aspect will not be followed further.

In the third step, weights are established for normalized diagnostic variables. It may be assumed that weights are identical; they are selected based on expert opinions or involve applied methods based on statistical properties of variables. The following may be given here as examples: Correlation Coefficient and Standard Deviation method (CCSD) [69], the method proposed by Betti and Verma [70], the Shannon entropy method [71], or Criteria Importance Through Intercriteria Correlation method (CRITIC) [72].

In this study, the CCSD approach was used to determine weights for diagnostic variables characterizing the utilization of renewable energy sources in road transport. In this method, the vector of weights $\boldsymbol{w} = (w_1, \ldots, w_k)$ is the solution of the following optimization problem:

$$\begin{gathered} \min_{w} \sum_{j=1}^{k} \left(w_j - \frac{s_j\sqrt{1-R_j}}{\sum_{i=1}^{n} s_i\sqrt{1-R_i}} \right) \\ \sum_{j=1}^{k} w_j = 1, w_j \geq 0 \end{gathered} \quad (1)$$

where s_j is the standard deviation of normalized j-th variable, while R_j shows the effect of the elimination of individual attributes on the synthetic variable. It is the coefficient of correlation between the normalized j-th variable (z_j) and the synthetic variable (d_j) established from the other normalized attributes:

$$R_j = \frac{\sum_{i=1}^{n}\left(z_{ij} - \bar{z}_j\right)\cdot\left(d_{ij} - \bar{d}_j\right)}{\sqrt{\sum_{i=1}^{n}\left(z_{ij} - \bar{z}_j\right)^2}\cdot\sqrt{\sum_{i=1}^{n}\left(d_{ij} - \bar{d}_j\right)^2}} \tag{2}$$

where $\bar{z}_j = \frac{1}{n}\sum_{i=1}^{n} z_{ij}$, $\bar{d}_j = \frac{1}{n}\sum_{i=1}^{n} d_{ij}$, $d_{ij} = \sum_{l=1, l\neq j}^{k} w_l z_{il}$.

After weights have been established, weighted normalized diagnostic variables may be determined:

$$v_{ij} = w_j z_{ij} \tag{3}$$

In stage 4, the ideal and anti-ideal solutions may be established:

$$\boldsymbol{A}^{+} = \left(v_1^{+}, \ldots, v_k^{+}\right),\ \boldsymbol{A}^{-} = \left(v_1^{-}, \ldots, v_k^{-}\right) \tag{4}$$

where $v_j^{+} = \max_i v_{ij}$, $v_j^{-} = \min_i v_{ij}$.

Next, we calculate distances (e.g., Euclidean distances) for all objects (variants) from the ideal and anti-ideal solutions (stage 5):

$$d_i^{+} = \sqrt{\sum_{j=1}^{k}\left(v_{ij} - v_j^{+}\right)^2},\ d_i^{-} = \sqrt{\sum_{j=1}^{k}\left(v_{ij} - v_j^{-}\right)^2} \tag{5}$$

In the last—sixth—step, for each object (variant), the relative closeness to the ideal solution indexes is established:

$$Q_i = \frac{d_i^{-}}{d_i^{-} + d_i^{+}} \tag{6}$$

The highest position is taken by the object with the greatest value of Q_i.

Values of the index Q_i may be the basis for the construction of groups (classes) of objects with a similar level of the investigated complex phenomenon. This division may be based on the mean and standard deviation of the index. However, such a solution in the case of asymmetric distributions may lead to a considerable diversification of the population size for the distinguished classes. In this case, it is better to apply positional measures, i.e., quantiles. Depending on the population size of the analyzed set of objects, they may be terciles, quartiles, quintiles, deciles, or percentiles.

The population for the EU countries in terms of the utilization of renewable energy sources in road transport was divided into five classes (using quintiles).

4. Findings and Discussion

4.1. Changes in Energy Consumption in Road Transport

In the years 2008–2019, an increase was observed in the use of fuels originating from renewable energy sources in road transport in EU countries. This is connected with the adopted transport policy assuming a reduction of greenhouse gas emissions and promotion of clean transport. In 2019, the mean consumption of energy from renewable sources in all EU countries was 8.9%. Compared to 2008, in 2019, the use of renewable energy in road transport increased almost two-fold, reaching the level of 17.7 million tons of oil equivalent (Figure 1). We also need to stress an almost constant level of energy consumption from non-renewable sources in the analyzed period. In 2019, it decreased by as little as 2% compared to 2008, while the mean consumption amounted to 284.3 million tons of oil equivalent annually. This situation was connected with the specific character of vehicles used in road transport and their long service life. A given means of transport has to be adapted to the use of fuel produced from renewable sources. We observe an increase in the number of new electric cars and buses, and consequently, the demand for electricity and charging stations is also growing [73,74].

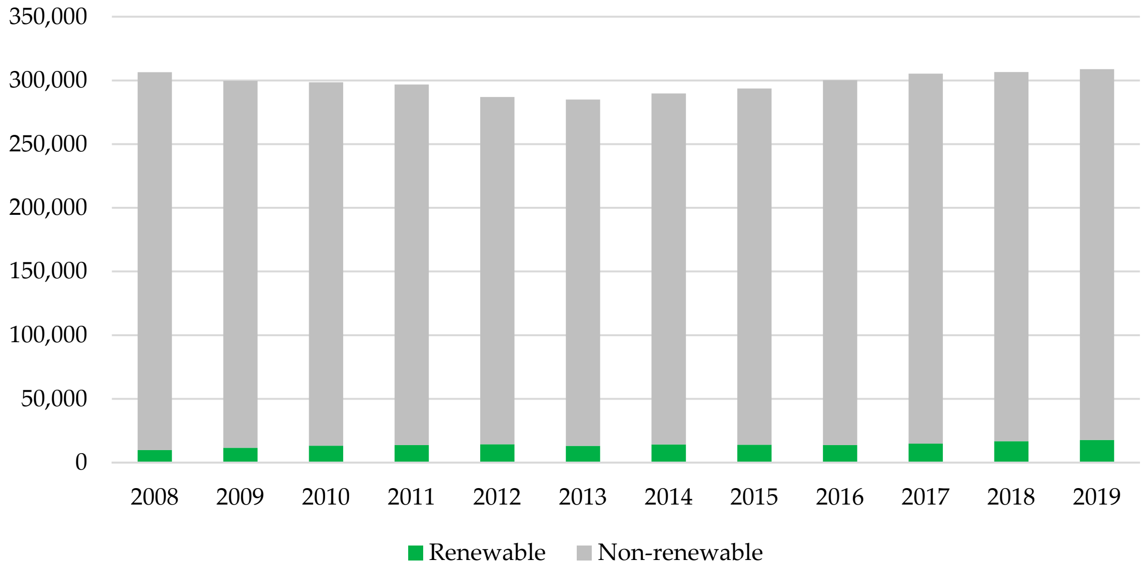


Figure 1. Final energy consumption in road transport by type of fuel in 2008–2019 (thousand tons of oil equivalent).

When considering only renewable sources, the most commonly used fuels in road transport in the EU countries are blended biodiesels and blended biogasoline (Figure 2). We should also stress the increasing amounts of consumed electricity. In the analyzed period, this type of fuel was characterized by the greatest increase. However, when comparing individual years and EU countries, it is still not a highly popular fuel (Figure 3). A considerable limitation in this power source for means of road transport is connected with the condition of the power network, limited distances covered between charging, and a small number of charging stations [75].

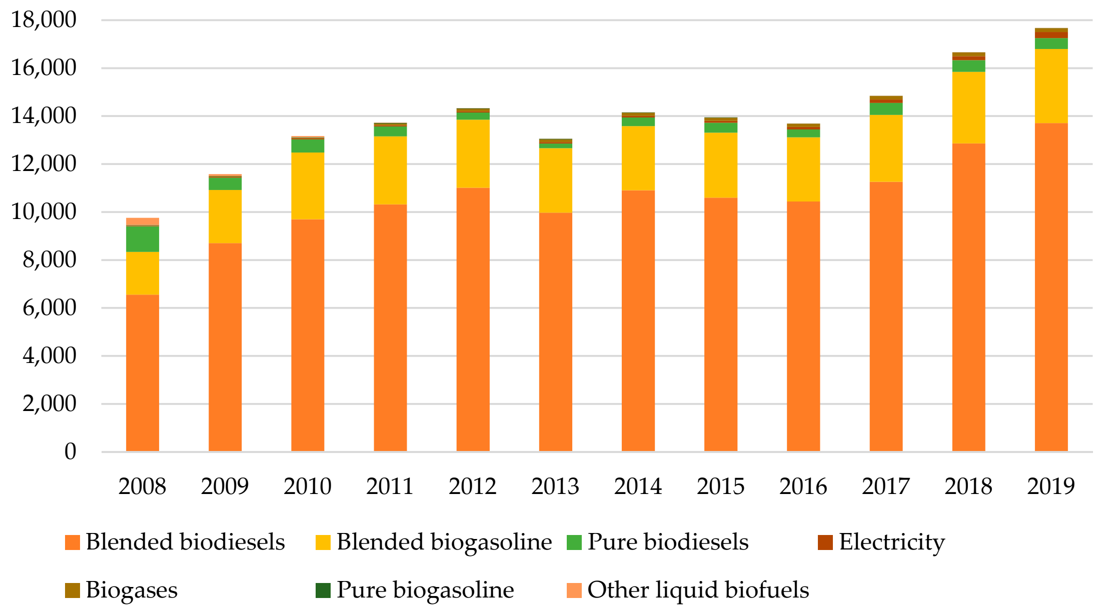
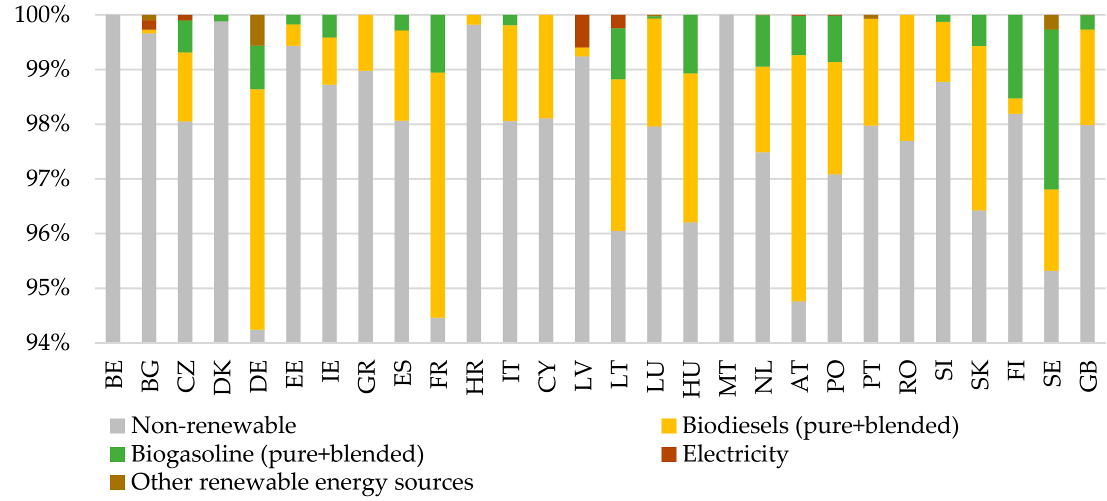
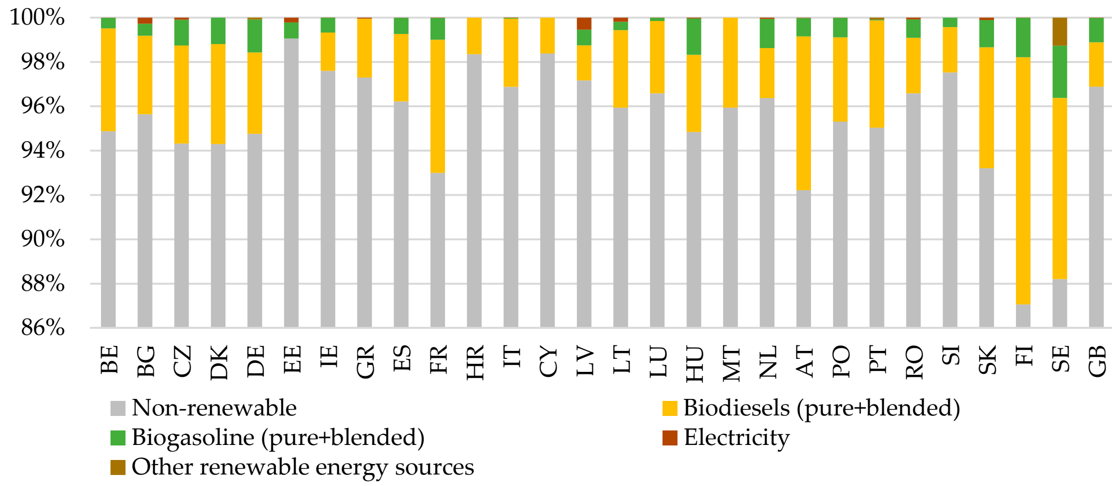


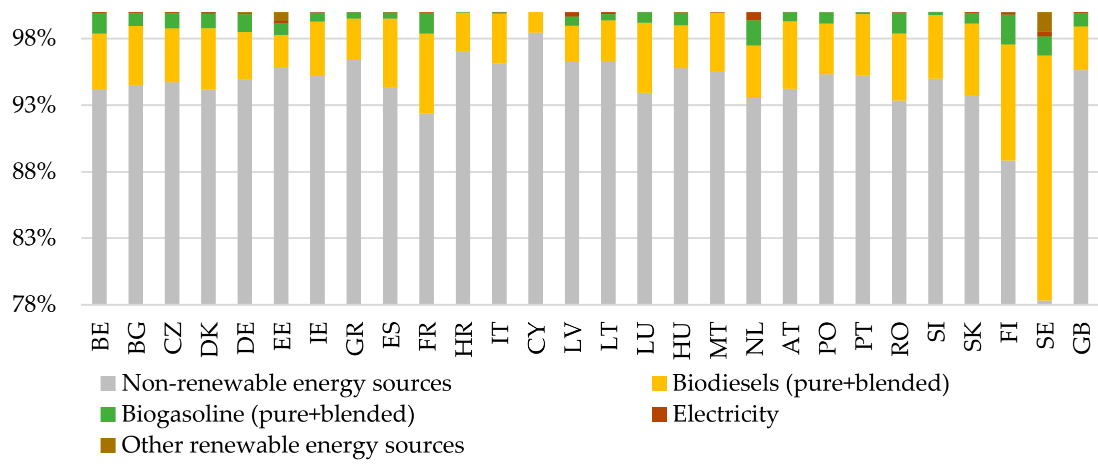
Figure 2. Total renewable energy consumption in road transport by type of fuel in 2008–2019 (thousand tons of oil equivalent).



(**a**)



(**b**)



(**c**)

Figure 3. Final energy consumption in road transport by type of fuel by UE country in 2008 (**a**), 2014 (**b**), and 2019 (**c**).

In the analyzed years, all the EU countries increased their shares of fuels from renewable sources used in road transport. Sweden and Finland are definite leaders in this respect. Those countries have already reached the required 10% share of renewable fuels in the total energy consumption. A relatively high share of fuels coming from renewable sources is also observed in France, Romania, and the Netherlands. In turn, the lowest share of renewable energy sources used in road transport is recorded in Croatia and Cyprus, where it is below 3%.

4.2. Ranking of EU Countries in Terms of the Use of Renewable Energy Sources in Road Transport—TOPSIS Results

The TOPSIS approach was applied in order to compare the utilization of renewable energy sources in road transport in EU countries. In this method, values of the relative closeness to the ideal solution index (a synthetic variable) were used to characterize the use of renewable energy sources in road transport for the years 2008–2019 in the EU countries (detailed data are presented in Table A2 in Appendix A). It needs to be observed that values of the synthetic variable for individual countries vary in time. For this reason, the joint evaluation of the investigated phenomenon in the EU countries for the period of 12 years was conducted based on the mean value of the relative closeness to the ideal solution index for the entire period.

Definite leaders in the utilization of renewable energy sources in road transport are Luxemburg, Sweden, and Austria (for which the values of the synthetic variable are 0.72, 0.62, and 0.51, respectively) (Table 2). A high level is also observed in Finland (0.40), France (0.38), and Germany (0.31). A level above the mean (between 0.25 and 0.29) is also recorded for the following countries: the Czech Republic, Poland, Slovakia, Lithuania, Sweden, Portugal, and Hungary. The mean level and that below that value is found for Belgium, Bulgaria, Romania, Slovenia, and Denmark (from 0.20 to 0.24). Low utilization of renewable energy sources is recorded in Italy, the Netherlands, Latvia, Ireland, Great Britain, Cyprus, and Greece (from 0.11 to 0.18), while it is very low in Malta, Estonia, and Croatia (below 0.10).

Table 2. Mean values of the relative closeness to the ideal solution index for 12 years and its changes from 2008 to 2019.

Country	Mean Value of the Index for 12 Years	Changes in Value of the Index	Country	Mean Value of the Index for 12 Years	Changes in Value of the Index
LU	0.72	−0.10	BG	0.24	0.20
SE	0.62	0.27	DK	0.20	0.15
AT	0.51	−0.35	RO	0.20	0.00
FI	0.40	0.21	SI	0.20	0.04
FR	0.38	−0.25	IT	0.18	−0.10
DE	0.31	−0.35	NL	0.17	−0.06
CZ	0.29	−0.03	LV	0.15	0.02
LT	0.28	−0.27	IE	0.14	−0.01
PO	0.28	−0.10	GB	0.14	−0.09
SK	0.28	−0.11	CY	0.13	−0.24
PT	0.27	−0.07	GR	0.11	−0.02
ES	0.27	−0.03	MT	0.08	0.09
HU	0.25	−0.22	EE	0.05	0.05
BE	0.24	0.17	HR	0.04	0.06

High utilization of renewable energy sources is thus observed in Scandinavia, most developed countries of western Europe, and former Comecon countries of central Europe, while it is low in most countries of southern and eastern Europe. These results are consistent with the analysis conducted by Kacperska et al. [45] using cluster analysis. According to those authors, the highest mean consumption of renewable energy in transport, heating, and cooling operations in 2019 was recorded in Sweden and Finland. Similar conclusions were reached by Tutak et al. [76], who investigated SED in terms of the economic and demographic potential of individual EU countries. In their opinion, the highest level characterizes Sweden, Finland, and Austria. In contrast, the lowest level of SED was attained by countries such as Cyprus and Estonia.

Changes in the relative closeness to the ideal solution index in the period from 2008 to 2019 make it possible to evaluate to what extent individual countries improve (or lower) their position in the ranking compared to the others (Table 2). The greatest progress in the utilization of renewable energy sources in road transport was made in Sweden, Finland, Bulgaria, Belgium, and Denmark (changes from 0.15 to 0.27). The greatest decrease in the index value was recorded in Austria, Germany, Lithuania, France, Cyprus, and Hungary (changes from −0.35 to −0.22). In the other countries, the changes were much smaller. Among the countries with a high and very high level of the investigated phenomenon in the period of 12 years, only in two (Sweden and Finland) the index increased, while in three, a very big decrease was found (Austria, Germany, and France). In 9 of the other countries, the utilization of renewable energy sources in road transport improved, while in 14, it deteriorated. This may indicate barriers in the development of the analyzed aspect in EU countries.

Figures 4–6 present classes of countries distinguished in terms of the relative closeness to the ideal solution indexes characterizing the utilization of renewable energy sources in road transport in the EU countries in 2008, 2014, and 2019.

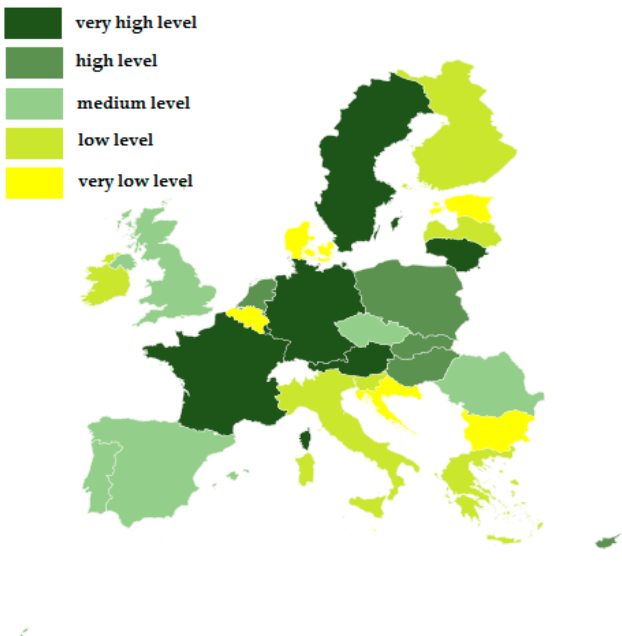


Figure 4. Relative closeness to the ideal solution index, characterizing utilization of renewable energy sources in road transport in 2008 in EU countries. Remark: values of the index for the distinguished classes are as follows: very high level (0.40–0.78), high level (0.23–0.34), medium level (0.18–0.20), low level (0.08–0.18), and very low level (0.00–0.06).

Among the six countries with a very high level of this index in 2008, four were classified in this class in 2014 and 2019 (Luxemburg, Austria, France, and Sweden). However, it needs to be mentioned here that the bottom value of this index in 2019, in this class, was almost two-fold lower than in 2008. This means that even for these countries, the distance from the leaders is increasing. In 2019, definite leaders in the utilization of renewable energy sources in road transport were Sweden and Luxemburg (with relative closeness to the ideal solution indexes of 0.71 and 0.68—Table A1 in the Appendix A). Another country (Finland) reached 0.38, while for the next in the ranking (Bulgaria), it was only 0.24. In 2008, the disproportions were much smaller. Luxemburg and Austria were leaders (with index values of 0.78 and 0.57, respectively). In the next countries in the ranking (France, Germany, and Sweden), the index values were 0.47, 0.44, and 0.40. The increase in the distance from the best in the classes with a high and average level of the phenomenon is not that marked, and it is not observed in the classes with a low and very low level of this phenomenon.

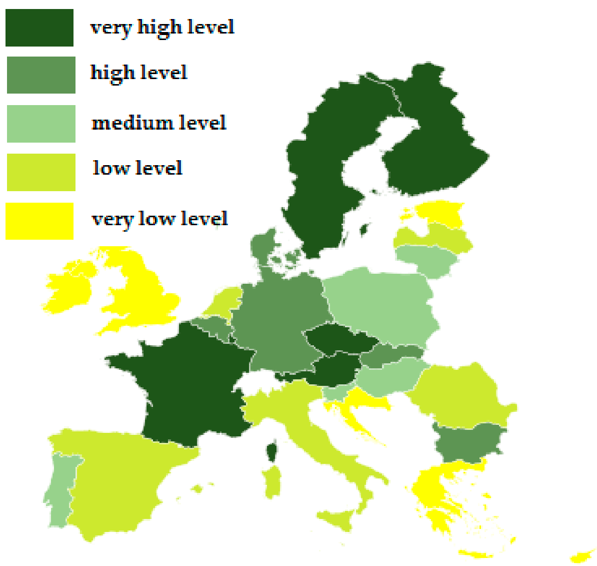


Figure 5. Relative closeness to the ideal solution index, characterizing utilization of renewable energy sources in road transport in 2014 in EU countries. Remark: values of the index for the distinguished classes are as follows: very high level (0.32–0.74), high level (0.26–0.32), medium level (0.17–0.25), low level (0.12–0.16), and very low level (0.00–0.11).

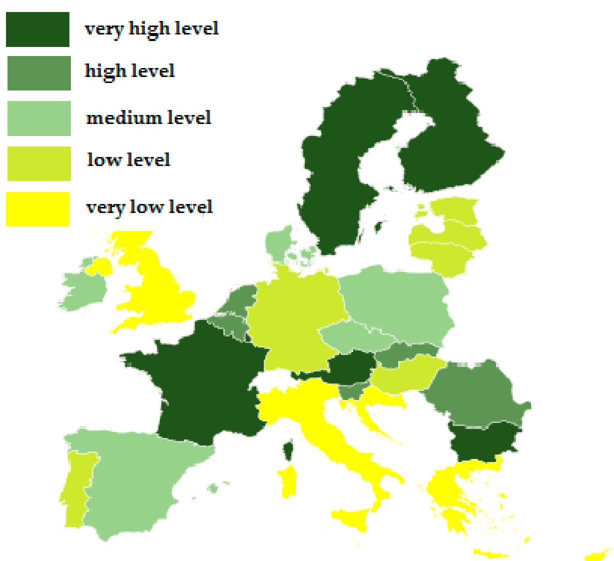


Figure 6. Relative closeness to the ideal solution index, characterizing utilization of renewable energy sources in road transport in 2019 in EU countries Remark: values of the index for the distinguished classes are as follows: very high level (0.22–0.71), high level (0.17–0.22), medium level (0.14–0.17), low level (0.10–0.13), and very low level (0.00–0.09).

5. Conclusions

The utilization of renewable energy sources is one of the main environmental objectives realized by individual EU countries. This is particularly important in the context of transport, especially road transport, in which the volume of freight and traffic increases from year to year.

In this paper, EU countries are classified in terms of the use of renewable energy sources in road transport. For this purpose, tools of multidimensional analyses were applied, such as the TOPSIS algorithm. In order to realize the research aim, a set of three indexes was used (X1: the share of renewable energy sources in road transport (%); X2: renewable energy sources in road transport per capita (kg of oil equivalent per capita); and X3: renewable energy sources in road transport per unit GDP (kg of oil equivalent per 1 thousand Euro)). The analysis was conducted for a period of 12 years, applying the mean value of the relative closeness to the ideal solution coefficient for the entire period.

Based on the conducted investigations, it may be observed that: (1) five groups of EU member countries were distinguished, which differ in terms of their consumption of renewable energy in road transport (Luxemburg, Sweden, and Austria are definite leaders in the utilization of renewable energy sources in road transport; (2) the analysis of the TOPSIS results show the greatest progress in the utilization of renewable energy sources in road transport in Sweden, followed by Finland, Bulgaria, Belgium, and Denmark; (3) the greatest decrease in this index was recorded in Austria, Germany, Lithuania, France, Cyprus, and Hungary.

The findings obtained in this study make an important contribution to theory and practice. Firstly, the knowledge of negative externalities and the concept of SD has been organized. Furthermore, we identified the most important legal regulations that support the use of renewable energy sources in EU countries. Secondly, we have shown the possibility of using TOPSIS analysis in ranking countries in the consumption of renewable energy sources in road transport. Thirdly, the obtained results can support national regulators. They show how a country compares against other EU countries (a benchmarking tool).

Although the aim of this study was realized, it nevertheless needs to be observed that our study also has certain limitations. Analysis using the TOPSIS method was conducted based on only three indexes, which were selected on the basis of the availability of data (convenience sampling). Moreover, the division into five groups was applied, as a result of which the range between the relative closeness to the ideal solution indexes was not identical. Despite certain limitations, our study constitutes an interesting starting point for future research. The methodology used in this article may be recreated using other indexes and assess this phenomenon in a few years. Another suggestion we would like to propose is to use the same indexes but apply different multidimensional methods (e.g., analytical hierarchy methods) in order to compare obtained results.

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Appendix A

Table A1. Selected characteristics of adopted diagnostic variables for the EU countries in the years 2008–2019.

Country	Variable	Mean	Median	Minimum	Maximum	Standard Deviation	Coefficient of Variation	Kurtosis	Skewedness
AT	X_1	6.6	6.6	5.2	8.3	0.8	0.1	0.4	0.5
	X_2	59.8	59.2	47.4	76.0	7.4	0.1	1.4	0.8
	X_3	1.5	1.5	1.2	1.9	0.2	0.1	−1.1	0.0
BE	X_1	4.1	4.3	0.0	5.8	1.8	0.4	1.6	−1.4
	X_2	30.8	32.9	0.0	43.1	13.1	0.4	1.8	−1.4
	X_3	0.8	1.0	0.0	1.1	0.3	0.4	2.9	−1.8
BG	X_1	3.5	4.4	0.3	5.5	2.2	0.6	−1.7	−0.6
	X_2	14.2	15.6	1.2	26.1	9.8	0.7	−1.7	−0.3
	X_3	2.1	2.7	0.2	3.5	1.3	0.6	−1.6	−0.6
HR	X_1	1.0	0.8	0.0	2.9	1.0	1.0	−0.6	0.7
	X_2	4.6	3.8	0.1	15.4	4.7	1.0	0.9	1.0
	X_3	0.4	0.3	0.0	1.2	0.4	1.0	−0.9	0.6
CY	X_1	1.8	1.8	1.3	2.4	0.4	0.2	−1.3	0.2
	X_2	14.7	14.8	10.0	18.9	3.9	0.3	−2.3	0.0
	X_3	0.6	0.7	0.4	0.8	0.2	0.3	−2.1	−0.1
CZ	X_1	4.7	5.0	1.9	5.7	1.0	0.2	3.9	−2.0
	X_2	26.2	28.5	11.2	32.1	5.9	0.2	3.2	−1.8
	X_3	1.6	1.7	0.7	2.0	0.3	0.2	3.9	−1.6
DK	X_1	4.1	5.5	0.1	5.8	2.4	0.6	−0.7	−1.1
	X_2	27.9	37.3	0.9	39.8	15.9	0.6	−0.7	−1.1
	X_3	0.6	0.7	0.0	0.8	0.3	0.6	−0.5	−1.2
EE	X_1	1.2	0.8	0.4	4.2	1.1	0.9	5.8	2.4
	X_2	6.6	4.1	2.6	25.7	6.8	1.0	6.0	2.4
	X_3	0.4	0.3	0.2	1.2	0.3	0.8	3.6	1.9
FI	X_1	7.1	5.3	1.8	12.9	3.9	0.6	−1.5	0.4
	X_2	50.5	38.5	13.4	90.7	27.3	0.5	−1.5	0.4
	X_3	1.3	1.0	0.4	2.4	0.7	0.5	−0.9	0.5
FR	X_1	6.6	6.7	5.5	7.6	0.7	0.1	−1.5	−0.1
	X_2	42.3	43.0	35.9	47.7	4.3	0.1	−1.6	−0.2
	X_3	1.3	1.3	1.2	1.4	0.1	0.1	−0.6	−0.7
DE	X_1	5.3	5.2	4.8	5.8	0.4	0.1	−1.1	0.3
	X_2	33.3	33.0	31.2	36.5	1.7	0.1	−1.1	0.4
	X_3	0.9	0.9	0.8	1.1	0.1	0.1	−1.8	0.1
GR	X_1	2.4	2.6	1.0	3.6	0.8	0.4	−0.8	−0.4
	X_2	11.7	11.7	6.1	17.3	3.4	0.3	−0.6	−0.1
	X_3	0.7	0.7	0.3	1.0	0.2	0.4	−0.9	−0.4
HU	X_1	4.3	4.3	3.8	5.2	0.4	0.1	1.5	0.7
	X_2	17.5	17.2	14.0	21.0	2.0	0.1	−0.5	0.1
	X_3	1.6	1.6	1.3	1.8	0.2	0.1	−1.0	0.2
IE	X_1	2.6	2.4	1.3	4.8	1.1	0.4	−0.1	0.9
	X_2	21.4	18.8	12.5	38.8	8.9	0.4	−0.3	1.0
	X_3	0.4	0.4	0.3	0.6	0.1	0.2	−1.4	0.1
IT	X_1	3.5	3.7	1.9	4.1	0.6	0.2	3.3	−1.6
	X_2	19.8	20.1	12.4	24.1	3.3	0.2	0.9	−0.8
	X_3	0.7	0.7	0.4	0.9	0.1	0.2	0.8	−0.7
LV	X_1	2.4	2.8	0.8	3.8	1.1	0.5	−1.5	−0.4
	X_2	11.4	11.7	3.8	20.5	5.6	0.5	−0.9	0.2
	X_3	1.0	1.0	0.3	1.8	0.5	0.5	−0.6	0.1
LT	X_1	3.9	4.0	3.3	4.4	0.3	0.1	−0.7	−0.6
	X_2	21.3	20.4	15.3	28.2	4.2	0.2	−0.8	0.3
	X_3	1.7	1.7	1.5	2.1	0.2	0.1	−0.3	0.4
LU	X_1	3.6	3.0	2.0	6.1	1.7	0.5	−1.6	0.5
	X_2	132.5	115.7	84.3	211.5	48.5	0.4	−1.3	0.6
	X_3	1.5	1.3	1.1	2.0	0.4	0.3	−1.4	0.6

Table A1. *Cont.*

Country	Variable	Mean	Median	Minimum	Maximum	Standard Deviation	Coefficient of Variation	Kurtosis	Skewedness
MT	X_1	2.5	3.2	0.0	4.7	1.8	0.7	−1.7	−0.3
	X_2	10.8	13.2	0.0	22.2	8.2	0.8	−1.5	−0.1
	X_3	0.5	0.6	0.0	0.8	0.3	0.7	−1.5	−0.5
NL	X_1	3.4	3.0	2.1	6.5	1.2	0.4	2.9	1.7
	X_2	21.4	19.0	13.8	39.1	7.1	0.3	3.1	1.8
	X_3	0.5	0.5	0.4	0.8	0.1	0.3	1.7	1.4
PO	X_1	4.3	4.5	2.6	5.5	1.0	0.2	−0.8	−0.7
	X_2	19.3	19.1	11.5	27.1	4.8	0.3	−0.8	−0.1
	X_3	1.8	1.9	1.1	2.4	0.4	0.2	−0.9	−0.2
PT	X_1	4.6	4.9	2.0	6.1	1.0	0.2	3.5	−1.6
	X_2	24.6	25.4	11.9	31.2	4.9	0.2	3.7	−1.6
	X_3	1.4	1.5	0.7	1.8	0.3	0.2	1.5	−1.0
RO	X_1	4.1	4.1	2.3	6.7	1,2	0.3	0.7	0.4
	X_2	11.1	10.1	5.2	21.4	4.6	0.4	1.0	1.0
	X_3	1.4	1.4	0.7	1.9	0.3	0.2	0.6	−0.7
SK	X_1	5.5	5.5	3.6	7.3	1.2	0.2	−1.2	0.0
	X_2	22.1	21.9	13.8	29.2	5.7	0.3	−1.9	−0.1
	X_3	1.5	1.6	1.1	1.8	0.3	0.2	−1.6	−0.2
SI	X_1	2.4	2.2	1.0	5.0	1.2	0.5	0.6	0.9
	X_2	21.7	19.6	8.9	45.8	10.9	0.5	0.7	1.1
	X_3	1.1	1.1	0.5	2.0	0.5	0.4	−1.0	0.3
ES	X_1	4.7	4.3	1.9	8.2	1.6	0.3	1.1	0.7
	X_2	27.9	25.9	13.7	44.6	9.0	0.3	−0.6	0.3
	X_3	1.2	1.1	0.6	2.0	0.4	0.3	0.8	0.8
SE	X_1	12.1	10.5	4.7	22.6	6.8	0.6	−1.4	0.5
	X_2	82.1	71.7	35.5	146.5	42.4	0.5	−1.5	0.4
	X_3	1.8	1.6	0.9	3.1	0.8	0.5	−1.4	0.5
GB	X_1	2.8	2.7	2.0	4.4	0.6	0.2	3.3	1.5
	X_2	16.7	16.0	13.0	25.3	3.3	0.2	3.2	1.6
	X_3	0.5	0.5	0.4	0.7	0.1	0.2	−1.0	0.3

Table A2. Relative closeness to the ideal solution index for the EU countries from 2008 to 2019.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AT	0.57	0.75	0.71	0.66	0.63	0.57	0.54	0.52	0.41	0.30	0.25	0.22
BE	0.00	0.16	0.42	0.37	0.33	0.29	0.28	0.15	0.27	0.25	0.19	0.17
BG	0.05	0.06	0.09	0.09	0.30	0.35	0.32	0.37	0.41	0.35	0.25	0.24
HR	0.02	0.04	0.00	0.01	0.11	0.09	0.06	0.05	0.00	0.00	0.01	0.00
CY	0.24	0.26	0.24	0.23	0.18	0.16	0.06	0.07	0.09	0.07	0.02	0.00
CZ	0.19	0.33	0.37	0.43	0.36	0.34	0.32	0.28	0.28	0.24	0.16	0.16
DK	0.01	0.02	0.05	0.26	0.38	0.35	0.28	0.25	0.26	0.22	0.16	0.16
EE	0.06	0.06	0.14	0.07	0.00	0.00	0.00	0.00	0.02	0.02	0.05	0.11
FI	0.17	0.32	0.32	0.41	0.37	0.39	0.74	0.66	0.22	0.42	0.34	0.38
FR	0.47	0.51	0.49	0.45	0.46	0.41	0.36	0.34	0.33	0.30	0.24	0.22
DE	0.47	0.44	0.46	0.41	0.40	0.32	0.26	0.22	0.22	0.19	0.15	0.12
GR	0.09	0.10	0.16	0.12	0.08	0.11	0.10	0.12	0.15	0.14	0.07	0.08
HU	0.34	0.37	0.37	0.32	0.27	0.22	0.25	0.22	0.25	0.18	0.14	0.12
IE	0.15	0.21	0.24	0.13	0.09	0.12	0.11	0.10	0.14	0.18	0.12	0.14
IT	0.18	0.28	0.32	0.29	0.25	0.20	0.12	0.14	0.14	0.13	0.09	0.07

Table A2. *Cont.*

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
LV	0.08	0.12	0.35	0.27	0.17	0.15	0.13	0.12	0.07	0.06	0.12	0.10
LT	0.40	0.39	0.34	0.30	0.32	0.28	0.24	0.26	0.23	0.23	0.17	0.13
LU	0.78	0.76	0.73	0.75	0.75	0.74	0.71	0.71	0.68	0.68	0.65	0.68
MT	0.00	0.00	0.01	0.04	0.04	0.12	0.14	0.13	0.14	0.13	0.11	0.09
NL	0.23	0.30	0.17	0.22	0.17	0.15	0.14	0.12	0.11	0.13	0.14	0.17
PO	0.27	0.39	0.46	0.44	0.36	0.31	0.24	0.21	0.16	0.17	0.17	0.17
PT	0.20	0.32	0.45	0.40	0.35	0.30	0.24	0.30	0.25	0.20	0.14	0.12
RO	0.18	0.27	0.19	0.28	0.23	0.22	0.14	0.17	0.23	0.22	0.14	0.18
SK	0.29	0.33	0.34	0.31	0.25	0.26	0.29	0.30	0.31	0.26	0.19	0.18
SI	0.17	0.23	0.33	0.24	0.30	0.33	0.17	0.10	0.08	0.09	0.18	0.22
ES	0.19	0.34	0.43	0.48	0.55	0.19	0.17	0.17	0.20	0.20	0.19	0.16
SE	0.44	0.47	0.47	0.53	0.59	0.60	0.64	0.66	0.75	0.78	0.78	0.71
GB	0.18	0.22	0.24	0.20	0.12	0.13	0.12	0.09	0.11	0.09	0.07	0.09

References

1. Gis, M. Emisja dwutlenku węgla z transportu drogowego–Cz. 2 Samochody klasy HDV (Carbon dioxide emissions from road transport–part 2 HDV class vehicles). *Transp. Samoch.* **2018**, *1*, 49–54.
2. Meisel, K.; Milliniger, M.; Naumann, K.; Müller-Langer, F.; Majer, S.; Thrän, D. Future Renewable Fuel Mixes in Transport in Germany under RED II and Climate Protection Targets. *Energies* **2020**, *13*, 1712. [CrossRef]
3. Hansen, K.; Mathiesen, B.V.; Skov, I.R. Full energy system transition towards 100% renewable energy in Germany in 2050. *Renew. Sustain. Energy Rev.* **2019**, *102*, 1–13. [CrossRef]
4. Lindfeldt, E.G.; Saxe, M.; Magnusson, M.; Mohseni, F. Strategies for a road transport system based on renewable resources–The case of an import-independent Sweden in 2025. *Appl. Energy* **2010**, *87*, 1836–1845. [CrossRef]
5. Åkerman, J.; Höjer, M. How much transport can the climate stand?—Sweden on a sustainable path in 2050. *Energy Policy* **2006**, *34*, 1944–1957. [CrossRef]
6. Bebkiewicz, K.; Chłopek, Z.; Lasocki, J.; Szczepański, K.; Zimakowska-Laskowska, M. Analysis of Emission of Greenhouse Gases from Road Transport in Poland between 1990 and 2017. *Atmosphere* **2020**, *11*, 387. [CrossRef]
7. Wołek, M.; Wolański, M.; Bartłomiejczyk, M.; Wyszomirski, O.; Grzelec, K.; Hebela, K. Ensuring sustainable development of urban public transport: A case study of the trolleybus system in Gdynia and Sopot (Poland). *J. Clean. Prod.* **2021**, *279*, 123807. [CrossRef]
8. Roman, M. Rola transportu samochodowego w Polsce ze szczególnym uwzględnieniem generowanych kosztów. *Zesz. Nauk. Uniw. Szczecińskiego. Probl. Transp. I Logistyki* **2014**, *26*, 127–139.
9. Poliński, J. Identyfikacja, estymacja i internalizacja kosztów zewnętrznych transportu. *Problemy kolejnictwa* **2012**, *156*, 33–67.
10. Huderek-Glapska, S. Efekty zewnętrzne transportu. Aspekty teoretyczne. *Zesz. Nauk. Uniw. Szczecińskiego. Probl. Transp. I Logistyki* **2014**, *25*, 83–97.
11. Cravioto, J.; Yamasue, E.; Okumura, H.; Ishihara, K.N. Road transport externalities in Mexico: Estimates and international comparisons. *Transp. Policy* **2013**, *30*, 63–76. [CrossRef]
12. Rizzi, L.I.; De La Maza, C. The external costs of private versus public road transport in the Metropolitan Area of Santiago, Chile. *Transp. Res. Part A Policy Pract.* **2017**, *98*, 123–140. [CrossRef]
13. Mostert, M.; Caris, A.; Limbourg, S. Road and intermodal transport performance: The impact of operational costs and air pollution external costs. *Res. Transp. Bus. Manag.* **2017**, *23*, 75–85. [CrossRef]
14. Jacyna, M.; Wasiak, M.; Lewczuk, K.; Karoń, G. Noise and environmental pollution from transport: Decisive problems in developing ecologically efficient transport systems. *J. Vibrorngineering* **2017**, *19*, 5639–5655. [CrossRef]
15. Margorínová, M.; Trojanová, M.; Decký, M.; Remisova, E. Noise Costs from Road Transport. *Civ. Environ. Eng.* **2018**, *14*, 12–20. [CrossRef]
16. Cai, M.; Li, J.; Wang, Z.; Wang, H. Evaluation of external costs in road transport under the openness of a gated community. *Front. Earth Sci.* **2020**, *14*, 140–151. [CrossRef]
17. Euchi, J.; Kallel, A. Internalization of external congestion and CO_2 emission costs related to road transport: The case of Tunisia. *Renew. Sustain. Energy Rev.* **2021**, *142*, 110858. [CrossRef]
18. Persson, U.; Ödegaard, K. External Cost Estimates of Road Traffic Accidents: An International Comparison. *J. Transp. Econ. Policy* **1995**, *29*, 291–304.

19. Hagedorn, T.; Sieg, G. Emissions and External Environmental Costs from the Perspective of Differing Travel Purposes. *Sustainability* **2019**, *11*, 7233. [CrossRef]
20. Pawłowska, B. Koszty zewnętrzne transportu w Polsce. *Przegląd Naukowy–Inżynieria i Kształtowanie Środowiska* **2018**, *27*, 28–41. [CrossRef]
21. Tennøy, A.; Tønnesen, A.; Gundersen, F. Effects of urban road capacity expansion–Experiences from two Norwegian cases. *Transp. Res. Part D Transp. Environ.* **2019**, *69*, 90–106. [CrossRef]
22. Odeck, J. Cost overruns in road construction: What are their sizes and determinants? *Transp. Policy* **2004**, *11*, 43–53. [CrossRef]
23. Aftabuzzaman, M.; Currie, G.; Sarvi, M. Evaluating the Congestion Relief Impacts of Public Transport in Monetary Terms. *J. Public Transp.* **2010**, *13*, 1–24. [CrossRef]
24. Kotowska, I. Problemy internalizacji kosztów zewnętrznych transportu drogowego. *Zesz. Nauk. Uniw. Szczecińskiego. Probl. Transp. I Logistyki* **2014**, *25*, 99–113.
25. Raczyński, J. Koszty zewnętrzne w polityce rozwoju transportu. *Tech. Transp. Szyn. Forum Prod. Konstr. I Użytkowników* **2003**, *10*, 12–17.
26. Santos, G. Road transport and CO_2 emissions: What are the challenges? *Transp. Policy* **2017**, *59*, 71–74. [CrossRef]
27. Załoga, E.; Szaruga, E. Dekarbonizacja transportu jako wyzwanie dla współczesnych gospodarek. *Zesz. Nauk. Wydziału Ekon. Uniw. Gdańskiego. Ekon. Transp. i Logistyka* **2016**, *59*, 261–269.
28. Egorova, M.; Pluzhnic, M.; Glik, P. Global Trends of «Green» Economy Development as a Factor for Improvement of Economical and Social Prosperity. *Procedia-Soc. Behav. Sci.* **2015**, *166*, 194–198.
29. Ferguson, P. The green economy agenda: Business asusual or transformational discourse? *Environ. Politics* **2014**, *24*, 17–37. [CrossRef]
30. Death, C. Four discourses of the green economy in the global South. *Third World Q.* **2015**, *36*, 2207–2224. [CrossRef]
31. Brodny, J.; Tutak, M.; Saki, S.A. Forecasting the Structure of Energy Production from Renewable Energy Sources and Biofuels in Poland. *Energies* **2020**, *13*, 2539. [CrossRef]
32. Marks-Bielska, R.; Bielski, S.; Pik, K.; Kurowska, K. The Importance of Renewable Energy Sources in Poland's Energy Mix. *Energies* **2020**, *13*, 4624. [CrossRef]
33. Fu, B.; Wu, M.; Che, Y.; Wang, M.; Huang, Y.; Bai, Y. The strategy of low-carbon economy based on the STIRPAT and SD models. *Acta Ecol. Sin.* **2015**, *35*, 76–82. [CrossRef]
34. Manzini, F. Inserting renewable fuels and technologies for transport in Mexico City Metropolitan Area. *Int. J. Hydrogen Energy* **2006**, *31*, 327–335. [CrossRef]
35. Hillman, K.M.; Sandén, B.A. Exploring technology paths: The development of alternative transport fuels in Sweden 2007–2020. *Technol. Forecast. Soc. Chang.* **2008**, *75*, 1279–1302. [CrossRef]
36. Flizikowski, J.; Tomporowski, A.; Antczak, M. Energia odnawialna i emisje w transporcie. *Inżynieria I Apar. Chem.* **2014**, *53*, 69–71.
37. Aldenius, M. Influence of public bus transport organisation on the introduction of renewable fuel. *Res. Transp. Econ.* **2018**, *69*, 106–115. [CrossRef]
38. Adamczyk, J. Dyfuzja koncepcji zrównoważonego rozwoju i społecznej odpowiedzialności przedsiębiorstw. *Mark Rynek* **2017**, *11*, 5–15.
39. Matuszczak, A. *Zróżnicowanie Rozwoju Rolnictwa w Regionach Unii Europejskiej w Aspekcie jej Zrównoważenia*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2013.
40. Stanny, M.; Czarnecki, A. *Zrównoważony Rozwój Obszarów Wiejskich Zielonych Płuc Polski*; Próba Analizy Empirycznej; IRWIR PAN: Warsaw, Poland, 2011.
41. Kwiatkiewicz, P. (Ed.) *Bezpieczeństwo Energetyczne–Rynki Surowców i Energii*; Wyższa Szkoła Bezpieczeństwa: Poznań, Poland, 2011.
42. Shukla, A.; Sharma, A. *Energy Security and Sustainbility*; CRC Press: Boca Raton, FL, USA, 2016.
43. Hippel, D.; Suzuki, T.; Williams, J.H.; Savage, T.; Hayew, P. Energy security and sustainability in Northeast Asia. *Energy Policy* **2011**, *39*, 6719–6730. [CrossRef]
44. Patterson, W. *Keeping the Lights On: Towards Sustainable Electricity*; Royal Institute for International Affairs/Chatham House and Earthscan: London, UK, 2009; p. 14.
45. Kacperska, E.; Łukasiewicz, K.; Pietrzak, P. Use of Renewable Energy Sources in the European Union and the Visegrad Group Countries—Results of Cluster Analysis. *Energies* **2021**, *14*, 5680. [CrossRef]
46. Treaty of Paris Setting Up the European Coal and Steel Community (ECSC). Available online: https://eur-lex.europa.eu/legalcontent/EN/TXT/HTML/?uri=LEGISSUM:xy0022&from=PL (accessed on 2 September 2021).
47. The Single European Act. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:xy0027&from=PL (accessed on 2 September 2021).
48. Treaty of Maastricht on European Union. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:xy0026&from=PL (accessed on 2 September 2021).
49. Małuszyńska, E.; Gruchman, B. *Kompedium Wiedzy o Unii Europejskiej*; PWN: Warsaw, Poland, 2018.
50. Bednorz, J. Decarbonisation of the European Union sa a threat to its Energy security and sustainable development. *Polityka Energetyczna* **2012**, *15*, 181–195.

51. Haas, T.; Sander, H. Decarbonizing Transport in the European Union: Emission Performance Standards and the Perspectives for a European Green Deal. *Sustainability* **2020**, *12*, 8381. [CrossRef]
52. Kryk, B. Ensuring Sustainable Energy as a Sign of Environmental Responsibility and Social Justice in European Union Members. *Ekon. Sr. Econ. Environ.* **2019**, *71*, 25.
53. European Commission. *Energy Roadmap 2050*; Publications Office of the European Union: Luxembourg, 2012.
54. A European Green Deal. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 23 September 2021).
55. European Council. 10–11 December 2020. Available online: https://www.consilium.europa.eu/pl/meetings/european-council/2020/12/10-11/# (accessed on 25 September 2021).
56. Pelc, W. Dekarbonizacja gospodarek Unii Europejskiej-jak to działa. *Energetyka* **2015**, 6–8. Available online: https://codozasady.pl/p/dekarbonizacja-gospodarek-unii-europejskiej-jak-to-dziala (accessed on 1 October 2021).
57. Simon, F. Unijna polityka klimatyczna: Dekarbonizacja przemysłu czy industrializacja Europy? In *Unijna Reforma Handlu Uprawnieniami do Emisji. Koszty Zmian Poniosą Najbiedniejsi?* Energia i Środowisko. Raport 2021; Available online: www.euractiv.pl (accessed on 1 October 2021).
58. Crippa, M.; Oreggioni, G.; Guizzardi, D.; Muntean, M.; Schaaf, E.; Lo Vullo, E.; Solazzo, E.; Monforti-Ferrario, F.; Olivier, J.G.J.; Vignati, E. *Fossil CO_2 and GHG Emissions of All World Countries-2019 Report*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-76-11100-9.
59. Greenhouse Gas Emissions from Transport in Europe. Available online: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-10 (accessed on 2 September 2021).
60. Hamelinck, C.; Spöttle, M.; Mark, L.; Staat, M. *Możliwości Dekarbonizacji Transportu do 2030 Roku*; Ecofys: Utrecht, The Netherlands, 2019.
61. EUROSTAT 2021. Available online: https://ec.europa.eu/eurostat/web/main/data/database (accessed on 12 September 2021).
62. Hwang, C.L.; Yoon, K. *Multiple Attribute Decision Making: Methods and Applications*; Springer: Berlin, Germany, 1981; pp. 128–132.
63. Behzadian, M.; Otaghsara, S.K.; Yazdani, M.; Ignatius, J. A state-of the art survey of TOPSIS applications. *Expert Syst. Appl.* **2012**, *39*, 13051–13069. [CrossRef]
64. Kukuła, K. *Metoda Unitaryzacji Zerowanej*; PWN: Warszawa, Poland, 2000.
65. Gatnar, E.; Walesiak, M. (Eds.) *Metody Statystycznej Analizy Wielowymiarowej w Badaniach Marketingowych*; Wydawnictwo Akademii Ekonomicznej we Wrocławiu: Wrocław, Poland, 2004.
66. Młodak, A. *Analiza Taksonomiczna w Statystyce Regionalnej*; Difin: Warszawa, Poland, 2006.
67. Panek, T. *Statystyczne Metody Wielowymiarowej Analizy Porównawczej*; SGH, Oficyna Wydawnicza: Warszawa, Poland, 2009.
68. Kogut-Jaworska, M.; Ociepa-Kicińska, E. Smart Specialisation as a Strategy for Implementing the Regional Innovation Development Policy—Poland Case Study. *Sustainability* **2020**, *12*, 7986. [CrossRef]
69. Wang, Y.M.; Luo, Y. Integration of correlations with standard deviations for determining attribute weights in multiple attribute decision making. *Math. Comput. Model.* **2010**, *51*, 1–12. [CrossRef]
70. Betti, G.; Verma, V. Fuzzy measures of the incidence of relative poverty and deprivation: A multi-dimensional perspective. *Stat. Methods Appl.* **2008**, *17*, 225–250. [CrossRef]
71. Lotfi, F.H.; Fallahnejad, R. Imprecise Shannon's Entropy and Multi Attribute Decision Making. *Entropy* **2010**, *12*, 53–62. [CrossRef]
72. Diakoulaki, D.; Mavrotas, G.; Papayannakis, L. Determining objective weights in multiple criteria problems: The critic method. *Comput. Oper. Res.* **1995**, *22*, 763–770. [CrossRef]
73. Wilberforce, T.; El-Hassan, Z.; Khatib, F.N.; Al Makky, A.; Baroutaji, A.; Carton, J.G.; Olabi, A.G. Developments of electric cars and fuel cell hydrogen electric cars. *Int. J. Hydrogen Energy* **2017**, *42*, 25695–25734. [CrossRef]
74. Malling, N.; Heilig, M.; Weiss, C.; Chlond, B.; Vortisch, P. Modelling the weekly electricity demand caused by electric cars. *Future Gener. Comput. Syst.* **2016**, *64*, 140–150. [CrossRef]
75. Marmaras, C.; Xydas, E.; Cipcigan, L. Simulation of electric vehicle driver behaviour in road transport and electric power networks. *Transp. Res. Part C Emerg. Technol.* **2017**, *80*, 239–256. [CrossRef]
76. Tutak, M.; Brodny, J.; Siwiec, D.; Ulewicz, R.; Bindzar, P. Studying the Level of Sustainable Energy Development of the European Union Countries and Their Similarity Based on the Economic and Demographic Potential. *Energies* **2020**, *13*, 6643. [CrossRef]