doi:10.36689/uhk/hed/2022-01-014

Performance Assessment in the Bioenergy Field: Evidence from European Countries

Claudiu CICEA, Corina MARINESCU* and Nicolae PINTILIE

Bucharest University of Economic, Bucharest, Romania; claudiu.cicea@man.ase.ro; corina.marinescu@man.ase.ro; pintilienicolae15@stud.ase.ro

* Corresponding author: corina.marinescu@man.ase.ro

Abstract: The main goal of the article is to determine the performance in the bioenergy field for European countries, using a well-known approach – Data Envelopment Analysis (DEA). The variables chosen for the analysis try to substantiate: the innovation level in the bioenergy field, human resource, the degree of bioenergy use and the economic impact generated by the development of the bioenergy field, in order to achieve the relative level of performance. Nineteen European Countries (here decisional units) are in the spotlight of receiving the title of either performers or non-performers in this field, occupying a certain position in the country performance ranking. DEA also enables projections for each country that can be used in order to reach the efficiency threshold. Finally, a summary of peers is presented, for best practice models.

Keywords: bioenergy; economic impact; efficiency; innovation; performance

JEL Classification: D61; O13; Q42

1. Introduction

There is no doubt that the issue of energy consumption (particularly renewable energy) is a very important one, especially since recently, amid the SarsCov-2 pandemic and not only, both in Europe and worldwide, the price of energy has risen. Over time, the topic of renewable energy has been analyzed by many authors, from multiple perspectives: the efficiency of using renewable energy (Aldea & Ciobanu, 2011; Dracea et al., 2020), its role in transforming society (Carstea et al., 2019) and in human development (Zahid et al., 2021), the implications of renewable energy consumption in economic growth and economic development (Bildirici & Ozaksoy, 2018; Șoavă et al., 2018; Kouton, 2021), the influence of renewable energy on different economic activities (Lu et al., 2019; Baran, 2015; Waheed et al., 2018; Liu et al., 2018) etc.

In order to improve national energy security and to reduce the potential for global warming, renewable energy should play an important role in achieving sustainability. This is the reason why European countries developed their strategies in order to use bioenergy, trying to replace the fossil fuels with "eco-friendly" technologies or solutions. In this context, the performance assessment in the bioenergy field plays a leading role in economic and social development, as well as in terms of environmental issues.

Currently, the bioenergy sector has gained momentum in the global energy economy, primarily due to the fact that it is considered a clean and renewable energy source that can bring about a tremendous improvement in dealing with environmental issues (Marinescu & Cicea, 2018; Cicea et al., 2019; Marinescu et al., 2019). In this way, Winquist et al. (2019) showed that the promotion of the renewable energy sources is a direct consequence of the observations made on the climate change. Related to this statement, Cicea et al. (2019) highlighted the options which are used in response to increasing environmental concerns: biogas and biomass (solid biofuels or liquid biofuels). Also, as shown in various researches, bioenergy can have an important role in achieving economic growth, taking into account that it can be considered energy from renewable sources (Pirlogea & Cicea, 2011).

The novelty of this article is to provide a comprehensive method to measure the performance of the European countries in the bioenergy field, taking into account different dimensions. Meanwhile, this article can provide useful information to stakeholders in order to identify the opportunities to improve bioenergy production or the effectiveness of the actual bioenergy production process. In this article, recent methods used to assess the performance in the bioenergy field are highlighted. Depending on the objective of the research, there are approaches used at the microeconomic level and approaches used at the macroeconomic level, each with its own limitations, but useful in determining the potential.

2. Literature Review

One can talk about the performance assessment in the bioenergy field at the microeconomic level, Buonocore et. al (2012) highlights the performance and sustainability of bioenergy in Sweden (Enköping town), proposing a methodology that treats performance from several perspectives. An extended LCA approach was used in this study to investigate the Enköping integrated bioenergy production system. In the adopted framework, named "Sustainability Multimethod Multiscale Assessment" (SUMMA) (Ulgiati et al., 2012), several evaluation methods were jointly applied to provide a comprehensive set of extensive and intensive indicators at multiple scales and dimensions. In order to ensure the maximum consistency of input data, an inventory of all the input and output flows was carried out, to form the common basis for further processing: impact assessment, energy and material efficiency, performance indicators. Then, each of these input and output information was subsequently processed by applying the SUMMA framework.

In order to analyze the impact of bioenergy for each component, various methods have been outlined in the literature. Analyzing inputs such as abiotic raw materials, biotic raw materials, water and air, the Material Flow Accounting method (Hinterberger & Stiller, 1998; Bargigli et al., 2005) evaluates in which the environment is affected by the deviation of material flows from the normal cycle, producing products or services instead. Through this method all phases of the production are going to be investigated: production, use, recycling or disposal, showing us the extent to which we are able to protect the environment. The Emergy Accounting method (Odum, 1988; Brown & Ulgiati, 2004) is another method used in order to evaluate the environmental performance of the system taking into account both the environmental inputs (rain, wind, solar radiation, etc) and indirect environmental inputs such as human labor and services.

In the literature, life cycle thinking is an approach that is in the attention of specialists, being used in order to analyze the sustainability aspects of bioenergy product systems (Thabrew et al., 2009; Hosseinzadeh-Bandbafha et al., 2021), for which four specific methods have been outlined: social life cycle assessment (S-LCA); life cycle costing (LCC); life cycle assessment (LCA); life cycle sustainability assessment (LSCA) (Petit-Boix et al., 2017).

If we are interested in analyzing the performance in the bioenergy field at a macro level, there are several methods of significant interest such as, regression analysis, principal component analysis (Fucec & Marinescu, 2014), Data Envelopment Analysis (DEA) or Performance Index analysis in the bioenergy field. DEA method is known as the data wrap method and has been widely used in various fields for more than forty years since its conception by Charnes, Cooper and Rhodes (Olariu, 2017). It serves to analyze the performance of certain activities or areas of the economy, performance seen in the form of efficiency.

Table 1. DEA method in the literature

Nr.	Authors	Level	Field	Goal achieved
1	Aletras, Kontodimopoulos, Zagouldoudis, & Niakas, (2007)	Micro	Health	Effectiveness of health care reform on the Greek healthcare system.
2	Roman & Suciu (2012)	Macro	Research & Development	Efficiency of research and development activities for European countries, using as variables investments in the field, number of patents, R&D expenses, and staff employed.
3	Halkos & Tzeremes, (2012)	Micro	Renewable energy	Financial performance of companies operating in the field of renewable energy.
4	Paço & Pérez (2013)	Micro	Hotel services	Hotel performance due to the use of IT&C applications.
5	Dincă, Dincă, & Andronic (2016)	Micro	Public administration	Efficiency of public spending in the provision of goods and services (health, education, services).
6	Zhou, Poh, & Ang (2016)	Macro	Environment	Environmental performance of OECD countries.
7	Marinescu, Cicea, & Ciocoiu (2018)	Macro	Waste recycling of electrical and electronic equipment (WEEE)	WEEE management performance in European Union countries
8	Ulucan, Atici, & Ozkan, (2018)	Micro	Education	Assessment of academic quality for undergraduate programs in Turkish universities.

Roman and Suciu (2012) mention in their paper about the two types of efficiency, technical and allocative, which contribute to determining the total economic efficiency. Technical efficiency means obtaining a maximum output from the action of selected input elements. Allocative efficiency means the use of input elements in an optimal form to achieve a certain output. In the literature there are a multitude of scientific papers that use DEA to study efficiency and respectively, performance. Table 1 summarizes some of them, identifying the field for which the method was applied, the level at which has been developed, but also the objective achieved by the researchers appealing to it.

Also, similar studies have been conducted in the field. A recent study (Cicea, Marinescu, & Pintilie, 2021) highlights the Performance Index in the bioenergy field, an analytical tool built on a methodology consisting of 7 phases: Structure, Data Collection, Data processing, Normalization, Weighting, Aggregation, and Robustness. Based on this analytical tool, some European countries were analyzed taking into account a series of specific indicators for 3 dimensions: innovation, efficiency and sustainability.

3. Methodology

3.1. Sources

This research will use and process statistical data to determine bioenergy performance for European Union countries based on DEA method. It will be able to provide the performers and non-performers in this field, by building the efficiency frontier of decision-making units.

The performance obtained by the DEA method is not an "absolute" one, because this method calculates the value of the performance score in relation to the performances of the decisional units in the analyzed group, not to a certain well-defined theoretical threshold.

The advantage of applying this method is that it does not require inputs and outputs, which have the same measurement units. Decision units are given by European Union countries for which the following indicators have been selected (listed in Table 2):

1. Bioenergy turnover, expressed in millions of euros (values at the level of 2015) which represents the output variable.
2. Number of registered patents (values at the level of 2013), the first input variable.
3. Number of jobs in the field of bioenergy (values at the level of 2015), the second input variable.
4. Installed capacity in MW (values at the level of 2015), the third input variable.

The main reason for selecting these indicators as input and output variables is related to their notoriety (they are internationally recognized indicators) and their ability to provide information on:

- The degree of innovation in the field supported by the number of patents in the field (patents protect valuable information for the implementation of new technologies that are to be launched on the market);
- Human resources through the number of available jobs (most of them created with the development of the bioenergy field);
- The degree of bioenergy use (in the form of heat, fuel or electricity) given by the installed capacity each year.
- The economic impact generated by the development of the bioenergy field (measured by the obtained turnover).

However, there is a drawback in using these indicators. It refers to the fact that at the moment of conducting this research only data for 2015 were available for almost all countries in one EurObserv'ER database. The last reported year in EurObserv'ER for instance, was 2017 but it covered less countries.

If discussing drawbacks, it is necessary to substantiate the fact that the DEA method is very broad and general. Along time many authors tried to highlight strengths and weaknesses of DEA method (Stolp, 1990), advantages and disadvantages (Fenyves & Tarnóczi, 2020; Jordá, Cascajo, & Monzón, 2012), demonstrating pitfalls after applying it (Sueyoshi & Goto, 2013; Wojcik, Dyckhoff, & Clermont, 2019).

Table 2. Input and output variables for DEA analysis (IRENA, 2019; EurObserv'ER, 2019)

No.	Country	Bioenergy turnover	Number of registered patents	Number of jobs	Installed capacity (in MW)
1	Austria	2,270	4	12,400	1,396
2	Belgium	780	0	3,200	945
3	Bulgaria	340	0	11,500	54
4	Croatia	460	4	16,900	53
5	Cyprus	30	0	300	10
6	Denmark	1,130	17	6,600	1,240
7	Estonia	490	0	8,700	281
8	Finland	4,230	47	25,800	1,987
9	France	6,780	80	63,400	1,304
10	Germany	11,580	111	99,900	8,429
11	Greece	260	0	6,900	51
12	Ireland	140	0	1,200	70
13	Italy	3,680	21	42,900	3,367
14	Latvia	780	3	22,400	126
15	Lithuania	470	0	11,800	71
16	Luxembourg	30	0	300	24
17	Malta	30	0	300	3
18	Great Britain	2,920	53	23,760	4,829
19	Poland	2,650	43	65,500	961
20	Portugal	780	3	9,500	577
21	Czech Republic	1,310	7	22,200	771
22	Romania	980	8	32,300	118
23	Slovakia	720	5	14,100	242
24	Slovenia	130	1	2,300	63
25	Spain	2,040	43	36,800	1,018
26	Sweden	4,690	21	27,300	4,716
27	Netherlands	670	11	5,000	863
28	Hungary	1,020	4	26,100	519

The number of direct jobs includes equipment production, plant construction, engineering and management, operation and maintenance, supply and exploitation of biomass. The number of indirect jobs refers to secondary activities, such as transport and other services (EurObserv'ER, 2019). Human resource, in the form of intellectual capital, is considered a fundamental source for innovation and knowledge (Salehi & Zimon, 2021), and along with working capital (which is considered one of the most important factor driving energy commercialization) (Zimon, 2019; Zimon, 2021), contributes to obtaining competitive advantage within companies. The situations listed in the table above are among the most interesting. For example, by far Germany has a top turnover, but also a very large number of jobs in the field. France and Poland have created each more than 60,000 jobs, but the reported gain is about 2.5 times higher in France as compared to Poland. Finland and Sweden are very similar in terms of turnover but also in terms of jobs number. Denmark manages to gather a lot with little labor force, unlike Latvia, where there is four times as much labor force but a much lower turnover as compared to Denmark.

Given that the indicator on the number of registered patents is zero for certain countries at the level of the reported year, they (Belgium, Bulgaria, Cyprus, Greece, Ireland, Lithuania, Luxembourg, and Malta) will not be part of the analysis.

3.2. Applying DEA Method

In the application of the DEA method, the measurement of efficiency can be performed by reporting to inputs or to outputs (Marinescu, Cicea, & Ciocoiu). Thus, an efficiency measurement of inputs oriented analysis, involves minimizing inputs while maintaining the output level. On the other hand, an output-oriented measure of efficiency involves maximizing output and maintaining the current level of inputs.

As the name implies, the data envelopment method involves the existence of two enveloping surfaces, which refer to either constant return to scales (marked with CRS) or to variable (marked with VRS) return to scale. Both types will be used in the present analysis, as they are necessary to calculate the scale or allocative efficiency (as a ratio between the technical efficiencies reported by the two of them). Also, the DEA analysis will be performed with the help of DEAP 2.1. Figure 1 suggestively shows the input and output variables, but also the characteristics of the applied method. One of the features is the use of the one-stage method. Choosing "one stage DEA" from the five available in the program (1-stage, 2-stage, multi-stage, cost-dea, malmquist) (see appendix 1) will create a mathematical programming problem, which will find those values for outputs and inputs capable of maximizing efficiency for a country.

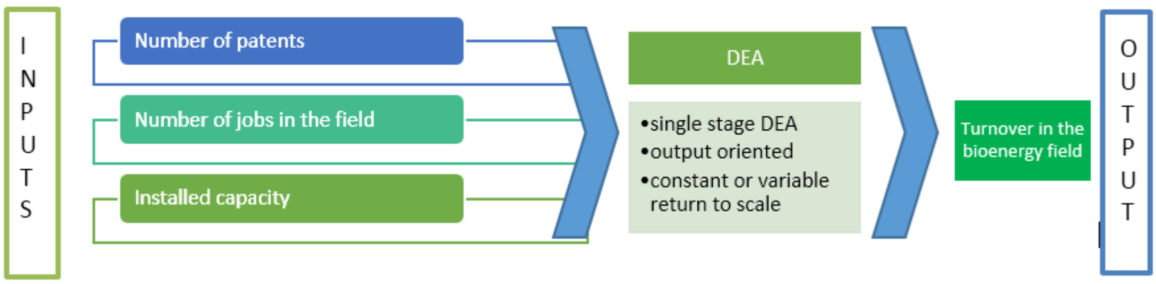

Figure 1. DEA with inputs, outputs and method

4. Results

Following the DEA analysis, values were obtained for the scale efficiency of each decision-making unit or the value of the performance pursued in the field of bioenergy.

Countries that have achieved a reported level of scale efficiency of 1 are efficient or performing countries in the field. Countries that have obtained values lower than 1, belong to the category of non-performers. Thus, they either do not use the inputs correctly to create the result or do not act as needed to influence the output.

For each inefficient decision-making unit, in addition to the value of scale efficiency, the type of scale returns, increasing or decreasing, is also reported (see Table 3). Increasing returns indicate that if a country experiences a slight change in its inputs, it will be felt in a major way in the value of output (here the turnover in the field). Decreasing returns indicate that if a country experiences a slight change in its inputs, the output will not change significantly.

Table 3. Efficiency of each analyzed unit

No.	Country	Technical efficiency through CRS DEA	Technical efficiency through VRS DEA	Scale efficiency	Scale returns
1	Austria	1	1	1	-
2	Croatia	1	1	1	-
3	Denmark	0.935	1	0.935	Increasing
4	Finland	1	1	1	-
5	France	1	1	1	-
6	Germany	0.706	1	0.706	Decreasing
7	Italy	0.586	0.893	0.656	Decreasing
8	Latvia	1	1	1	-
9	Great Britain	0.671	0.710	0.946	Decreasing
10	Poland	0.570	0.639	0.892	Decreasing
11	Portugal	0.713	0.728	0.979	Increasing
12	Czech Republic	0.726	0.749	0.970	Decreasing
13	Romania	1	1	1	-
14	Slovakia	0.849	0.871	0.975	Increasing
15	Slovenia	0.732	1	0.732	Increasing
16	Spain	0.496	0.497	0.997	Increasing
17	Sweden	0.938	1	0.938	Decreasing
18	Netherlands	0.732	0.884	0.828	Increasing
19	Hungary	0.733	0.795	0.922	Decreasing
20	Average	0.81	0.882	0.92	

Given that inefficient decision-making units have also been reported, the projections made in the DEA analysis can be further tracked in order for a unit to reach the efficiency threshold. As I explained in a previous paper (Marinescu, Cicea, & Ciocoiu, 2018) the purpose of DEA analysis is not only to determine the efficiency of revised units, but also to find target values for the inputs and outputs of an inefficient unit. Inefficient allocation is the failure to use the optimal combination of inputs. For example, in Table 4, Italy reports a value of 440.132 for radial dynamics of the output (turnover in the field) and a value of -17,010.190 for the second input's slack (number of jobs within the field).

Radial dynamic shows the improvements that can occur in the value of the output, while the slack values show the elements in excess, which should be diminished. Therefore, in order to converge towards performance, France may need to reduce the number of jobs (with the slack value of -17,010.19) and remain at the initially reported value of turnover or, given the current input conditions, it could achieve a turnover of 440.132 million euros.

The analysis does not indicate any slack on inputs 1 and 3, respectively the number of registered patents and the installed capacity. Therefore, the current level of these two input variables is able to support the reported level of turnover in the bioenergy field.

Table 4. Output projection for each unit to be efficient – Part 1

No.	Country	Variable	Initial Value	Radial dynamics	Slack	Projected Value
1	Austria	Output	2,270	0	0	2,270
		Input 1	4	0	0	4
		Input 2	12,400	0	0	12,400
		Input 3	1,396	0	0	1,396
2	Croatia	Output	460	0	0	460
		Input 1	4	0	0	4
		Input 2	16,900	0	0	16,900
		Input 3	53	0	0	53
3	Denmark	Output	1,130	0	0	1,130
		Input 1	17	0	0	17
		Input 2	6,600	0	0	6,600
		Input 3	1,240	0	0	1,240
4	Finland	Output	4,230	0	0	4,230
		Input 1	47	0	0	47
		Input 2	25,800	0	0	25,800
		Input 3	1,987	0	0	1,987
5	France	Output	6,780	0	0	6,780
		Input 1	80	0	0	80
		Input 2	63,400	0	0	63,400
		Input 3	1,304	0	0	1,304
6	Germany	Output	11,580	0	0	11,580
		Input 1	111	0	0	111
		Input 2	99,900	0	0	99,900
		Input 3	8,429	0	0	8,429
7	Italy	Output	3,680	440.132	0	4,120.132
		Input 1	21	0	0	21
		Input 2	42,900	0	-17,010.19	25,889.810
		Input 3	3,367	0	0	3,367
8	Latvia	Output	780	0	0	780
		Input 1	3	0	0	3
		Input 2	22,400	0	0	22,400
		Input 3	126	0	0	126
9	Great Britain	Output	2,920	1,195.047	0	4,115.047
		Input 1	53	0	-36.039	16.961
		Input 2	23,760	0	0	23,760
		Input 3	4,829	0	-901.779	3,927.221
10	Poland	Output	2,650	1,497.912	0	4,147.912
		Input 1	43	0	0	43
		Input 2	65,500	0	-23,673.6	41,826.314
		Input 3	961	0	0	961
11	Portugal	Output	780	291.511	0	1,071.511
		Input 1	3	0	0	3
		Input 2	9,500	0	0	9,500
		Input 3	577	0	0	577

Table 4. Output projection for each unit to be efficient – Part 2

No.	Country	Variable	Initial Value	Radial dynamics	Slack	Projected Value
12	Czech Republic	Output	1,310	438.720	0	1,748.720
		Input 1	7	0	0	7
		Input 2	22,200	0	-2,570.82	19,629.174
		Input 3	771	0	0	771
13	Romania	Output	980	0	0	980
		Input 1	8	0	0	8
		Input 2	32,300	0	0	32,300
		Input 3	118	0	0	118
14	Slovakia	Output	720	106.950	0	826.950
		Input 1	5	0	0	5
		Input 2	14,100	0	0	14,100
		Input 3	242	0	0	242
15	Slovenia	Output	130	0	0	130
		Input 1	1	0	0	1
		Input 2	2,300	0	0	2,300
		Input 3	63	0	0	63
16	Spain	Output	2,040	2,064.252	0	4,104.252
		Input 1	43	0	0	43
		Input 2	36,800	0	0	36,800
		Input 3	1,018	0	0	1,018
17	Sweden	Output	4,690	0	0	4,690
		Input 1	21	0	0	21
		Input 2	27,300	0	0	27,300
		Input 3	4,716	0	0	4,716
18	Netherlands	Output	670	87.626	0	757.626
		Input 1	11	0	0	11
		Input 2	5,000	0	0	5,000
		Input 3	863	0	-62.879	800.121
19	Hungary	Output	1,020	262.998	0	1,282.998
		Input 1	4	0	0	4
		Input 2	26,100	0	-6338.1	19,761.891
		Input 3	519	0	0	519

Following the DEA analysis, the next ranking (provided in Table 5) was obtained, depending on the performance score. There are six high-performing countries with a score of 1 and 13 less efficient countries in the field of bioenergy, with scores below 1. They have the opportunity to track performance in the field to improve their output (in this case turnover).

Also from Table 5, it can be seen that Germany, the country with the highest turnover in the field of bioenergy, is among the non-performers of the analysis, with a score of 0.706. It could do better than that, but not by using the example of other countries, but through its own mechanisms. This is shown in Table 6, where for Germany, in the "peer" column, no other country is suggested, but itself. The same for Slovenia, which, although a non-performer compared to the top countries, does not have a concrete example to follow as best practice models.

Table 5. Ranking based on performance score

No.	Country	Bioenergy Performance Score
1	Austria	1
	Croatia	
	Finland	
	France	
	Latvia	
	Romania	
2	Spain	0.997
3	Portugal	0.979
4	Slovakia	0.975
5	Czech Republic	0.97
6	Great Britain	0.946
7	Sweden	0.938
8	Denmark	0.935
9	Hungary	0.922
10	Poland	0.892
11	Netherlands	0.828
12	Slovenia	0.732
13	Germany	0.706
14	Italy	0.656

If we compare the values from Table 2 and Table 5, we can easily observe that countries with highest Installed capacity (in MW) have a small Bioenergy Performance Score. Germany, Sweden and Italy seems to be non-performers countries, even if they are in top 8 for all the analyzed indicators (Bioenergy turnover, Number of registered, Number of jobs, Installed capacity in MW). In this particular case, we emphasize the importance of appealing to the EROI concept (Energy Return of Investment), a tool used in order to predict which energy mix is the best. Weißbach et al. (2013) tried to highlight Energy Returned on Investment for various ways of producing energy, saying that the break-even number for fueling our modern society is about 7 for European Union. Other studies give similar results (Carbajales-Dale et al., 2014). Due to the fact that in these papers the score for biofuels is lower than 7, the authors highlighted that a lower EROI cannot sustain our society at our level of complexity as it is in the present.

Due to the fact that there are papers in the literature that reach the same conclusion as our work, that the level of performance in bioenergy varies from country to country and is influenced by many factors, we emphasize the importance of diversifying energy sources in European Union countries. A mix of renewable energy, fossil fuels and nuclear energy could be the most appropriate economic option in Europe, with renewable energy having the highest share. Each country must decide which mix is the healthiest, taking into account national and European legislation and objectives, which can generate high possibilities for economic expansion and diversification. In the case of Germany, Sweden or Italy, they are fully responsible of finding the best energy mix, Bioenergy Performance Score being an indicator that should be taken into account for the future direction.

Table 6. Summary of performers and followers

No.	Country	Peer / Peer weight	Peer / Peer weight	Peer / Peer weight
1	Austria	Austria / 1.0		
2	Croatia	Croatia / 1.0		
3	Denmark	Denmark / 1.0		
4	Finland	Finland / 1.0		
5	France	France / 1.0		
6	Germany	Germany / 1.0		
7	Italy	France / 0.09	Sweden / 0.596	Austria / 0.313
8	Latvia	Latvia / 1.0		
9	Great Britain	Sweden / 0.762	Austria / 0.238	
10	Poland	Austria / 0.178	France / 0.517	Latvia / 0.305
11	Portugal	Latvia / 0.149	Austria / 0.372	France / 0.007
12	Czech Republic	France / 0.046	Austria / 0.465	Latvia / 0.489
13	Romania	Romania / 1.0		
14	Slovakia	Austria / 0.080	France / 0.037	Latvia / 0.436
15	Slovenia	Slovenia / 1.0		
16	Spain	Austria / 0.229	France / 0.523	Latvia / 0.013
17	Sweden	Sweden / 1.0		
18	Netherlands	Austria / 0.001	Denmark / 0.625	Slovenia / 0.374
19	Hungary	France / 0.009	Austria / 0.301	Latvia / 0.690

Italy ranks last and has three good examples to follow, France, Austria and Latvia. Inefficient allocation is the failure to use the optimal combination of inputs. If we analyze the data in the above table, we can see that Austria is reported 9 times as a good example to follow by other decision-making units. It is followed by France, which appears as a "peer" 8 times, and Latvia, which appears 6 times. Although they are among the performers, Finland, Croatia and Romania are not mentioned as examples for other countries.

5. Conclusions

Based on the performed analysis, the DEA method offered the possibility to achieve a relative performance in the field of bioenergy in several countries of the European Union. In line with the obtained performance score, some countries have entered the category of non-performers in the field, but with the possibility to reach certain projected values of turnover, only if they consider various changes in the level of inputs. The human resource is the one that, through the number of jobs, has received most suggestions for change, in the sense of reducing them, in order to increase performance. By highlighting the best performance in the field of bioenergy, information and in-depth knowledge can be used to understand and disclose best practices that have contributed to the reported performance, but also to serve as examples for lower performing countries. We did not expect the countries with the highest Installed capacity in MW to have a low Bioenergy Performance Score. However, given that sustainability is the concept that ensures long-term development, it may be appropriate for these countries to direct their capital to other types of energy, including renewable energy, ensuring a mix that leads to a high Energy Return of Investment (EROI).

This research is not exempt from limitations emerging from data availability (which is directly connected to the possibility of using needed indicators for the necessary period of time) and data timeliness (which triggers the risk of presenting outdated results). Another limitation refers to indicators selection. For instance, the present analysis does not take into account capital expenditures necessary to install capital for bioenergy generation (cheap technology with comparatively higher use of labor can then still be competitive) or local climate conditions, which restricts the use of certain modes of bioenergy production.

As future research directions, there are two such examples that may constitute the aim of further research design and that refer to the methodological approach. Regression analysis or principal component analysis are two other methods that may be used for obtaining a relative measure for performance in the bioenergy field.

Acknowledgments: This paper is a result of the research conducted through the 2020–2023 Doctoral advanced research program at The Bucharest University of Economic Studies.

Conflict of interest: none

References

Aldea, A., & Ciobanu, A. (2011). Analysis of renewable energy development using bootstrap efficiency estimates. *Economic Computation and Economic Cybernetics Studies and Research*, *45*(1), 77–90.

Aletras, V., Kontodimopoulos, N., Zagouldoudis, A., & Niakas, D. (2007). The short-term effect on technical and scale efficiency of establishing regional health systems and general management in Greek NHS hospitals. *Health Policy*, *83*(2-3), 236–245. https://doi.org/10.1016/j.healthpol.2007.01.008

Baran, B. (2015). Support for renewable energy in Germany as an example of Effective Public Policy. *Oeconomia Copernicana*, *6*(2), 143–158. https://doi.org/10.12775/OeC.2015.017

Bargigli, S., Raugei. M., & Ulgiati, S. (2005). Mass flow analysis and mass-based indicators. In E. Sven Jorgensen, R. Constanza, F-L. Xu (Ed.), *Handbook of Ecological Indicators for Assessment of Ecosystem Health* (pp. 353–378). CRC Press.

Bildirici, M., & Ozaksoy, F. (2018). An analysis of biomass consumption and economic growth in transition countries. *Economic Research – Ekonomska Istrazivanja*, *31*(1), 386–405. https://doi.org/10.1080/1331677X.2018.1427610

Brown, M. T., & Ulgiati, S. (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy*, *2*(1), 329–354. https://doi.org/10.1016/B0-12-176480-X/00242-4

Carbajales-Dale, M., Barnhart, C. J., & Benson, S. M. (2014). Can we afford storage? A dynamic net energy analysis of renewable electricity generation supported by energy storage. *Energy & Environmental Science*, *7*(*5*), 1–9. https://doi.org/10.1039/c3ee42125b

Cicea, C., Marinescu, C., & Pintilie, N. (2019). Smart cities using smart choices for energy: integrating modern bioenergy in consumption. *Theoretical and Empirical Researches in Urban Management*, *14*(4), 22–34.

Cicea, C., Marinescu, C., & Pintilie, N. (2019). Biogas-innovation map: revealing links and dynamics in the field. In *Proceedings of the 13th International Management Conference: Management strategies for high performance* (pp. 483–492). Bucharest, Romania.

Cicea, C., Marinescu, C., & Pintilie, N. (2021). New Methodological Approach for Performance Assessment in the Bioenergy Field. *Energies*, *14*(4), 901. https://doi.org/10.3390/en14040901

Cirstea, S. D., Cirstea, A., Popa, I. E., & Radu, G. (2019). The role of bioenergy in transition to a sustainable bioeconomy – Study on EU countries. *Amfiteatru Economic*, *21*(50), 75–89. https://doi.org/10.24818/EA/2019/50/75

Dincă, M. S., Dincă, G., & Andronic, M. L. (2016). Efficiency and sustainability of local public goods and services. Case study for Romania. *Sustainability*, *8*(8), 760. https://doi.org/10.3390/su8080760

Dracea, R. M., Ignat, R., Trica, C. L., Teodor, C., Ciobanu, L., & Nedelcu, A. C. (2020). Energy efficiency of EU member states: A panel data analysis. *Economic Computation and Economic Cybernetics Studies and Research*, *54*(4), 153–171. https://doi.org/10.24818/18423264/54.4.20.10

EurObserv'ER. (2019c). *Employment and turnover.* https://www.eurobserv-er.org/online-database/#

Fenyves, V., & Tarnóczi, T. (2020). Data envelopment analysis for measuring performance in a competitive market. *Problems and Perspectives in Management*, *18*(1), 315–325. https://doi.org/10.21511/ppm.18(1).2020.27

Fucec, A. A., & Marinescu (Pirlogea), C. (2014). Knowledge Economies in the European Union: Romania's Position. *Procedia Economics and Finance*, *15*, 481–489. https://doi.org/10.1016/S2212-5671(14)00489-4

Halkos, G. E., & Tzeremes, N. G. (2012). Analyzing the Greek renewable energy sector: A Data Envelopment Analysis approach. *Renewable and Sustainable Energy Reviews*, *16*(5), 2884–2893. https://doi.org/10.1016/j.rser.2012.02.003

Hinterberger, F., & Stiller, H. (1998). Energy and material flows. In S. Ulgiati, M. T. Brown, M. Giampietro, R. A. Herendeen, & K. Mayumi (Eds.), *Advances in Energy Studies. Energy Flows in Ecology and Economy* (pp. 275–286). Musis Publisher.

Hosseinzadeh-Bandbafha, H., Aghbashlo, M., & Tabatabaei, M. (2021). Life cycle assessment of bioenergy product systems: A critical review. *E-Prime – Advances in Electrical Engineering, Electronics and Energy*, 1–10. https://doi.org/10.1016/j.prime.2021.100015

IRENA. (2019b). *Data and Statistics*, https://www.irena.org/Statistics

Jordá, P., Cascajo, R., & Monzón, A. (2012). Analysis of the technical efficiency of urban bus services in Spain based on SBM models. *International Scholarly Research Notices*, *2012*. https://doi.org/10.5402/2012/984758

Kouton, J. (2021). The impact of renewable energy consumption on inclusive growth: panel data analysis in African countries. *Economic Change and Restructuring, 54*(1), 145–170. https://doi.org/10.1007/s10644-020-09270-z

Liu, X. Y., Zhang, S., & Bae, J. (2018). Renewable energy, trade, and economic growth in the Asia-Pacific region. *Energy Sources Part B – Economics Planning and Policy*, *13*(2), 96–102. https://doi.org/10.1080/15567249.2017.1327994

Lu., Z., Gozgor, G., Lau, C. K. M., & Paramati, S. R. (2019). The dynamic impacts of renewable energy and tourism investments: Evidence from the G20 countries. *Journal of Business Economics and Management,* 20(6), 1102–1120. https://doi.org/10.3846/jbem.2019.10181

Marinescu, C., Cicea, C., & Ciocoiu, C. N. (2018). The development of a performance assessment method for e-waste management in the European Union. In *The Best Romanian Management Studies* (pp. 113–128). Trivent Publishing.

Marinescu, C., & Cicea, C. (2018). What Do We Know about Biofuels Today that Diesel and Ford Did Not? *Management and Economics Review*, *3*(2), 213–224. https://doi.org/10.24818/mer/2018.12-07

Marinescu, C., Cicea, C., & Colesca, S. E. (2019). Tracking biofuels-innovation relationship through scientific and technological advances. *Management Research and Practice*, *11*(2), 31–44.

Odum, H. T. (1988). Self organization, transformity and information. *Science*, *242*(1), 1132–1139. https://doi.org/10.1126/science.242.4882.1132

Olariu, G. V. (2017). *The improvement of university management by the use of efficiency methods – a case study in DEA*. http://stiintasiinginerie.ro

Paço, C. L., & Pérez, J. M. C. (2013). The use of DEA (Data Envelopment Analysis) methodology to evaluate the impact of ICT on productivity in the hotel sector. *International Interdisciplinary Review of Tourism,* (3). https://doi.org/10.4000/viatourism.1005

Petit-Boix, A., Llorach-Massana, P., Sanjuan-Delmas, D., Sierra-Perez, J., Vinyes, E., Gabarrell, X., et al. (2017). Application of life cycle thinking towards sustainable cities: A review. *Journal of Cleaner Production*, *166*, 939–951. https://doi.org/10.1016/j.jclepro.2017.08.030

Pirlogea, C., & Cicea, C. (2011). Obtaining economic growth from energy consumption in urban areas. *Theoretical and Empirical Researches in Urban Management*, *6*(3), 73–84.

Roman, M., & Suciu, C. (2012). *Analiza eficienței activității de cercetare dezvoltare inovare prin metoda DEA* [The Efficency Analysis of R&D Activities by Using DEA], MPRA Paper 44000, University Library of Munich, Germany. https://mpra.ub.uni-muenchen.de/44000/1/MPRA_paper_44000.pdf

Salehi, M., & Zimon, G. (2021). The effect of intellectual capital and board characteristics on value creation and growth. *Sustainability*, *13*(13), 7436. https://doi.org/10.3390/su13137436

Stolp, C. (1990). Strengths and weaknesses of data envelopment analysis: An urban and regional perspective. *Computers, Environment and Urban Systems*, *14*(2), 103–116. https://doi.org/10.1016/0198-9715(90)90016-M

Sueyoshi, T., & Goto, M. (2013). Pitfalls and remedies in DEA applications: how to handle an occurrence of zero in multipliers by strong complementary slackness conditions. *Engineering,* 4(5a), 29–34. https://doi.org/10.4236/eng.2013.55A005

Șoavă, G., Mehedintu, A., Sterpu, M., & Răduțeanu, M. (2018). Impact of renewable energy consumption on economic growth: Evidence from European Union countries. *Technological and Economic Development of Economy*, *24*(3), 914–932. https://doi.org/10.3846/tede.2018.1426

Thabrew, L., Wiek, A., & Ries, R. (2009). Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation. *Journal of Cleaner Production*, *17*(1), 67–76. https://doi.org/10.1016/j.jclepro.2008.03.008

Ulgiati, S., Anscione, M., Bargigli, S., Cherubini, F., Franzese, P. P., Viglia, S., et al. (2011). Material, energy and environmental performance of technological and social systems under a life cycle assessment perspective. *Ecological Modelling*, *222*(1), 176–189. https://doi.org/10.1016/j.ecolmodel.2010.09.005

Ulucan, A., Atici, K. B., & Ozkan, A. (2018). Benchmarking in Higher Education Using Data Envelopment Analysis and the Bologna Process Data. *Croatian Operational Research Review*, *9*(2), 301. https://doi.org/10.17535/crorr.2018.0024

Waheed, R., Chang, D. F., Sarwar, S., & Chen, W. (2018). Forest, agriculture, renewable energy and CO2 emission. *Journal of Cleaner Production*, *172*, 4231–4238. https://doi.org/10.1016/j.jclepro.2017.10.287

Weißbach, D., Ruprecht, G., Huke, A., Czerski, K., Gottlieb, S., & Hussein, A. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. *Energy*, *52*(1), 210–221. https://doi.org/10.1016/j.energy.2013.01.029

Winquist, E., Rikkonen, P., Pyysiainen, F., & Varho, V. (2019). Is biogas an energy or a sustainable product? Business opportunities in the Finnish biogas branch. *Journal of Cleaner Production*, 1344–1354. https://doi.org/10.1016/j.jclepro.2019.06.181

Wojcik, V., Dyckhoff, H., & Clermont, M. (2019). Is data envelopment analysis a suitable tool for performance measurement and benchmarking in non-production contexts? *Business Research*, *12*(2), 559–595. https://doi.org/10.1007/s40685-018-0077-z

Zahid, T., Arshed, N., Munir, M., & Hameed, K. (2021). Role of energy consumption preferences on human development: a study of SAARC region. *Economic Change and Restructuring, 54*(1), 121–144. https://doi.org/10.1007/s10644-020-09279-4

Zhou, P., Poh, K. L., & Ang, B. W. (2016). Data Envelopment Analysis for Measuring Environmental Performance. In S. N. Hwang, H. S. Lee, & J. Zhu (Eds.), *Handbook of Operations Analytics Using Data Envelopment Analysis. International Series in Operations Research & Management Science* (Vol. 239). Springer, Boston, MA.

Zimon, G. (2019). An Assessment of the Strategy of Working Capital Management in Polish Energy Companies. *International Journal of Energy Economics and Policy*, *9*. https://doi.org/10.32479/ijeep.8406

Zimon, G. (2021). Working Capital. *Encyclopedia*, *1*(3), 764–772. https://doi.org/10.3390/encyclopedia1030058