SUSTAINABILITY, INNOVATION AND EFFICIENCY AS DETERMINANTS OF PERFORMANCE IN THE ENERGY FIELD

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Abstract. *By protecting the environment through renewables, society makes an important step towards protecting future generations. Bioenergy, as a particular type of renewable energy, is being hailed as an alternative to fossil fuels, due to its main characteristics: renewable, sustainable, and environmentally friendly. The need to support this shift to green energy arises from studying performance in the bioenergy field in particular (and in the renewable energy field in general). This paper focuses on presenting three determinants of performance in the bioenergy field and discussing their influence from a macroeconomic perspective. An econometric model with panel data is used in this regard for countries in European Union. The analysis enables comparisons among countries and shows which determinant influences performance (given the highest number of positive relationships established between each independent variable and the level of performance). Negative relationships that appear may reveal influences that need to be further studied to understand what leads to them. Limitations of this research are explained in the last part of the conclusions.*

Keywords: *bioenergy; efficiency; innovation; performance; sustainability.*

Introduction

Since the industrial revolution in the early 19th century, countries across the globe have paid more attention to economic growth and development. From the advent of the steam engine to the development of internal combustion engines, all global economic activities have developed and diversified (Wu et al., 2022, p. 1). In this way, international demand for goods has undergone major changes, with a direct impact on production and the industrial environment as a whole. The pressure to develop international trade under conditions of economic performance has culminated in the neglect of environmental objectives, leading to the use of non-renewable energy sources. Over time, the effects have been observed: increased greenhouse gas emissions and environmental degradation (Shayanmehr et al., 2020, p. 1; Bölük & Mert, 2014, p. 439). The question that arises is: what is the value of the costs that we have to bear today due to environmental degradation? Do the benefits obtained over time through polluting activities outweigh the costs incurred by present and future generations?

Worldwide there have been various initiatives to reduce the environmental impact of industrial activities (Kyoto and Paris climate agreements), with notable targets such as reducing greenhouse gas emissions by up to 40% by 2030 compared to the 1990 baseline year (Wu et al., 2022, p. 1). The energy sector is considered to play an essential role in referring to global challenges related to sustainability (Zaharia, Popescu & Vreja, 2016). While at the European level the European Commission directives are already transposed into national legislation and are being respected, the key factors for economic growth in BRICS economies (Brazil, Russia, India, China & South Africa) are fossil fuels (Wang & Zhang, 2020, p. 2; Zhao et al., 2022, p. 316). In this way, governments are betting on increasing income at the expense of reducing emissions, which means that progress is conditional on an increase in energy consumption, ultimately leading to an increase in CO_2 emissions (Wu et al., 2022). Undoubtedly, there is a strong connection between innovation and economic development (Cicea et al., 2021). For this reason, it is imperative that innovation in renewable energy sources be a strategic activity worldwide, as they guarantee the rebalance between economic growth and environmental quality (Karimi et al., 2021, p. 1; Usman et al., 2021, p. 2). In other words, performance in renewable energy today is the guarantee of a future that is favorable for efficient and sustainable operations. Not to mention that renewables are also related to a relatively new concept and are considered to have a salient role in the transition to bioeconomy (Cîrstea et al., 2019). Bioenergy, as a specific type of renewable energy, represents this research paper's principal focus. The present study aims to present three determinants of performance in the bioenergy field and discuss their influence from a macroeconomic perspective. As related to it, the concept of performance in the field is highlighted and studied in accordance with three factors of influence: innovation, efficiency, and sustainability for countries members of the European Union. The present work is structured as follows: the *introduction* outlines the context related to bioenergy, as a specific type of renewable energy; the *Literature review* has been designed to analyze other publications that have covered the same topics; the analytical *Methodology* applied presents all needed assumptions characteristic to Least Squares method application, three research hypotheses are formulated - the relationships among mentioned factors and performance are described using a multiple regression analysis; the *Results and Discussion* section presents the results in the context of the current framework and comprises the core of the present study – in this section of the paper, the assumptions are either validated for some countries either rejected for another one, while influences of each independent variable (proxies for the determinants of performance) are revealed; the *Conclusions* section provides final observations related to bioenergy performance.

The multi-objective methodology is based on an econometric model with panel data, used in this regard for countries in European Union. The first step was the collection of data related to bioenergy characteristics; the second step was the choice of dependent and independent variables; the third step was defining the econometric model; the fourth step involved testing the seventh assumption about the model, independent variables, and errors.

Literature review

The countries ranking in the international market depends on their economic performance. Economic performance means how efficiently a country's economy performs (Zhang, 2022, p. 1). There are many advantages for countries with high economic performance, such as increased income, and higher volumes of goods and services. This way, the performance stabilizes economic growth by reducing inflationary tendencies, current account deficits, and environmental problems. Thus, in performing economies, the emergence of opportunities makes these countries desirable to their citizens (Bassetti et al., 2021, p. 21).

Economic performance is significantly influenced by energy production and consumption. In high-performing economies with opportunities and a focus on innovation, improved human capital, healthy living, and resource management, renewable energy is the path to sustainable development (Nishitani & Kokubu, 2020, p. 156). Renewable energy leaves no waste or pollution behind, and its use helps to maintain the quality of the environment, and provide inputs for economic activities, while human development relies on it (Pîrlogea, 2012, p. 497). According to Rehman et al. (2019, p. 21760), economic performance plays an important role in sustainable economic development. Of course, the issue of energy performance must be analyzed in any area, no matter the source of energy: wind energy (Zavadskas et al., 2022), solar energy (Suehrcke &McCormick, 1992), ocean energy (Sequeira & Man, 2019) or thermal energy (Gadalla & Ahmed, 2013).

Over time, a considerable number of methods have been used in order to examine efficiency and efficiency change in industries or organizations. As a result, parametric, non-parametric, and other productivity indices have been developed and used to measure efficiency and productivity (Abdulwakil et al., 2020, p. 2; Coelli et al., 1998, p. 69).

Several studies have applied the non-parametric data envelopment analysis (DEA) on diverse datasets to investigate the efficiencies of various firms and industries. With the DEA method, specialists can calculate a firm's income, expenses, and efficiency based on input and output data (Abdulwakil et al., 2020, p. 2; Han et al., 2019, p. 350). Moreover, a notable advantage of the method is the ability to quantify information using different units of measurement (Demirbag et al., 2007, p. 419; Reddy, 2013, p. 403). Based on the DEA method, there have been a number of papers that have examined renewable energy development (Aldea & Ciobanu, 2011), bioenergy performance (Alsaleh et al., 2017, p. 1335), respectively that have attempted to examine efficiency and performance determinants (Alsaleh et al., 2017, p. 1336; Wahab & Rahman, 2013, p. 34; Cicea et al., 2022, p. 1; Mardani et al., 2017, p. 1299; Gong et al., 2017, p. 466).

The multivariate statistical regression method is one of the widely used data-driven methods for analyzing the efficiency of a particular objective. According to Zhu et al. (2021, p. 2), this is used in many cases to assess energy efficiency, providing a perspective demonstrated by many researchers. The method’s main advantage is that it can be used to analyze the correlation between multiple variables involved in different processes. Among the most commonly used methods for building econometric models are the principal component regression (PCR) and the partial least squares (PLS), which are successfully used on a large scale (Geladi & Kowalski, 1986, p. 2; Abdi & Williams, 2010, p. 444; Zhu & Chen, 2019, p. 815; Zhang et al., 2017, p. 462).

Findings revealed that capital, labour, GDP, Inflation, and interest rate significantly affected the technical efficiency of bioenergy. Moreover, in developing countries, the efficiency of resource allocation is higher than in developed countries. However, technical efficiency in developed countries is higher than labor in developing countries, with influences on financial resources and innovation capacity (Alsaleh et al., 2017, p. 1336; Cicea et al., 2022, p. 8).

Recently, a multidimensional analysis of bioenergy performance has been conducted, reflecting three dimensions: innovation, efficiency, and sustainability, and developing, in the end, a new performance index in the bioenergy field (Cicea, Marinescu & Pintilie, 2021, p. 2). The analysis reveals countries outperforming in the bioenergy field, but also non-performers. At the same time, the authors explain that the index's three dimensions are dominant components for a country, meaning that each country can have a higher score for a specific dimension. Innovation, efficiency, and sustainability have been described before as having a major role in bioenergy field development (Cicea et al., 2019, p. 2405; Marinescu, Cicea & Colesca, 2019, p. 33). For this reason, within the present paper, these three dimensions are seen as determinants of performance in the bioenergy field, being included in a specific analysis that reveals their influence on performance.

Methodology

In order to build the econometric model with panel data, it is necessary to make a preliminary choice of the variables that will shape it. Thus, those variables were chosen to capture aspects related to performance, innovation, efficiency, and sustainability, characteristics of bioenergy. Related to these, the most difficult task was data collection; the lack of data (either for certain countries or for certain years) meant that the analysis had to consider the time period 2006-2016 for 14 EU member countries. Collecting the data and obtaining the indicators used (three of the four were obtained from their own calculations) was very time-consuming, as the IRENA database does not provide them free of charge, as it is one of the sources used for each of the four variables. In the end, we selected the following variables, whose recorded values in the 2010-2016 period (for the countries considered in the analysis) led to the graphical representations in figures 1-4.

The chosen dependent variable is Avoided emissions (tonnes CO2 equivalent) per GWh generated (IRENA, 2019) - a proxy for bioenergy performance (coded in the econometric model as PERFORM).

The chosen independent variables are: (1) Number of patents (IRENA, 2019) – innovation component (coded in the econometric model as INOV); (2) Bioenergy supplied per capita (IRENA, 2019) (MWh/capita) – sustainability component (coded in the econometric model as SUST); (3) Bioenergy productivity (IRENA, 2019) (dollar per capita / GWh)- efficiency component (coded in the econometric model as EF).

Emissions avoided through bioenergy are obtained as a value through a tool available on the IRENA website (avoided emissions calculator). It shows for each country that can be selected from the list, a fuel mix characteristic of that country (see Table 1), which can generate a certain amount of CO2 emissions through consumption. If the country produces and uses bioenergy, it avoids pollutants with each GWh produced and used.

Apart from the number of patents, all other variables are derived from calculations based on data collected from the mentioned sources.

Table 1. Fossil fuels mix (Source: IRENA, 2019)

No.	Country	Coal	Natural gas	Oil
1	Austria	45,3%	49,5%	5,2%
2	Denmark	79,2%	18,8%	2,0%
3	Finland	67,2%	31,7%	1,1%
4	France	55,8%	38,6%	5,6%
5	Germany	79,4%	18,6%	1,9%
6	Italy	28,1%	63,0%	9,0%
7	Great Britain	57,4%	41,6%	0,9%
8	Poland	95,2%	3,6%	1,2%
9	Czech Republic	96,1%	3,8%	0,1%
10	Romania	63,3%	34,5%	2,1%
11	Spain	37,5%	50,4%	12,1%
12	Sweden	51,9%	32,3%	15,9%
13	Netherlands	32,8%	65,7%	1,5%
14	Hungary	53,3%	46,2%	0,5%

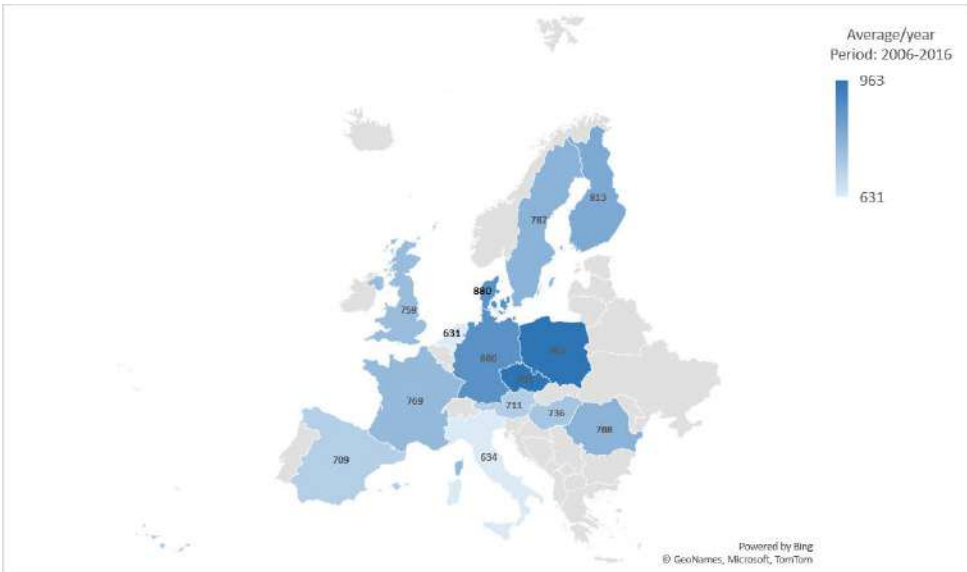

Figure 1. Annual average for avoided emissions (tonnes CO2 equivalent) per GWh generated (authors after IRENA, 2019)

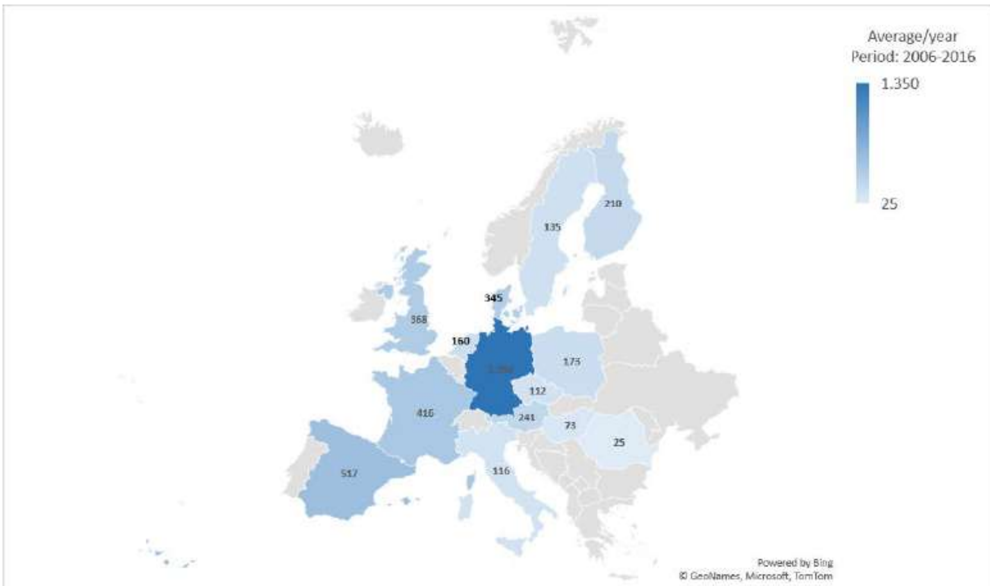

Figure 2. Annual average for number of patents in the field (proxy for innovation) (authors after IRENA, 2019)

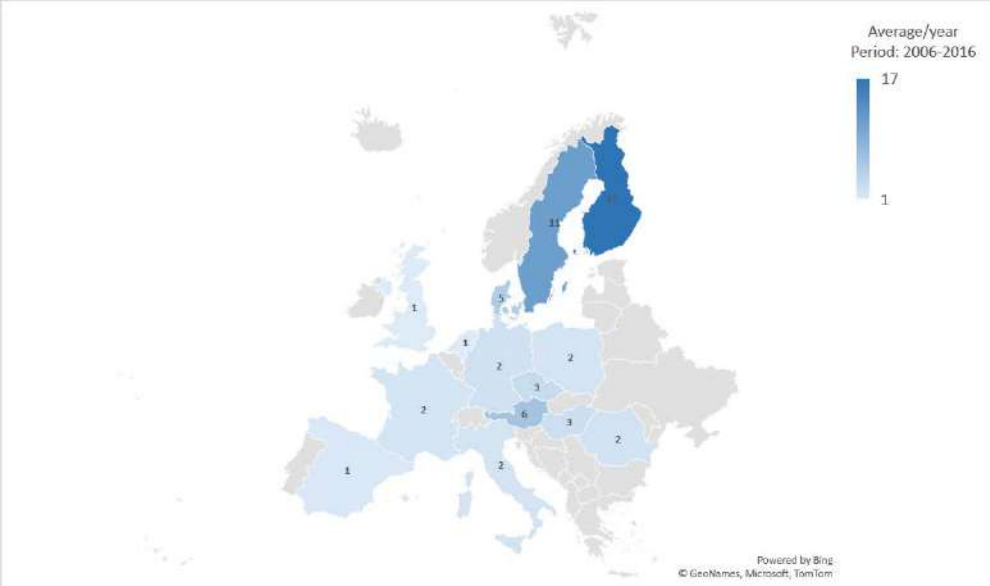

Figure 4. Annual average for bioenergy supplied per capita (proxy for sustainability) (authors after IRENA, 2019)

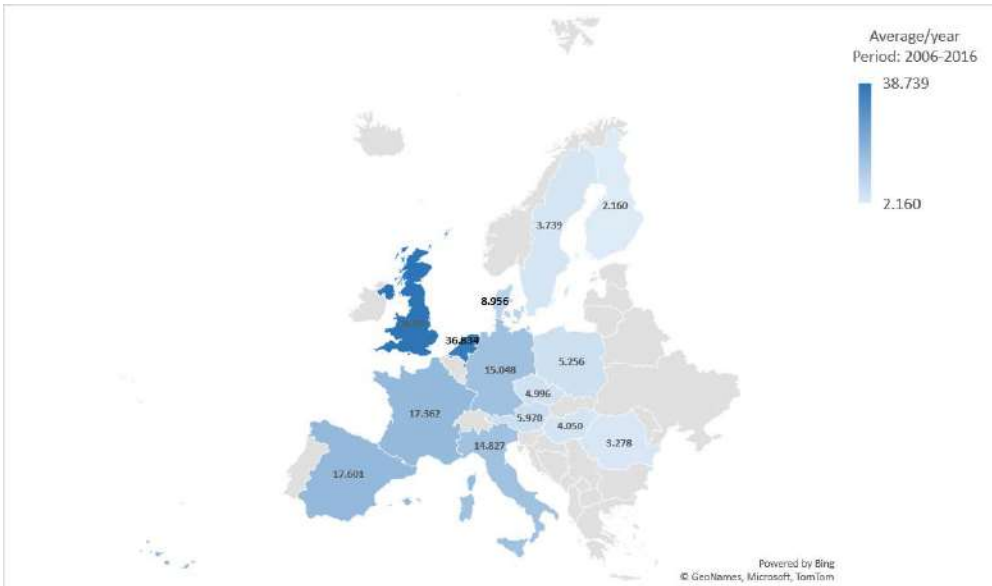

Figure 5. Annual average for bioenergy productivity (proxy for efficiency in the field) (authors after IRENA, 2019)

The econometric model to be proposed in this research has the following characteristics: (1) It is a linear multiple regression model (comprising one dependent variable and three independent variables); (2) It uses panel data (with two dimensions, temporal and geographical); (3) The time period for which the data was collected is 11 years, from 2006 to 2016.

The European Union Member States included in the analysis are (abbreviations used in the model are in brackets): Austria (AUT), Czech Republic (CEH), Denmark (DNK),

Finland (FIN), France (FRA), Germany (GER), Italy (ITA), Hungary (UNG), Poland (POL), Romania (ROM), Netherlands (TJOS), Spain (SUE), Sweden (SUE), Netherlands (TJOS), Romania (ROM), Spain (SPA), United Kingdom (UK);
Last, but not least, it is a fixed effects model, so for each country, a constant will be estimated. This is intended to add a small part of those elements that influence bioenergy performance that were not included in the model, bringing in country-specific characteristics.

The econometric model will be of the following form, given by the equation:

$$Y_{it} = \alpha_i + \beta_{i1} * X_{1it} + \beta_{i2} * X_{2it} + ... + \beta_{ik} * X_{kit} + E_{it}$$

The notations used in the model mean:

- ☐ Yit Y_{it} – the dependent variable of the model;
- ☐ αi – constant (varies per cross-sectional unit);
- ☐ 1…k – range of variation for the independent variable;
- ☐ βik β_{ik} - coefficient to be estimated for the independent variable k;
- ☐ Xkit X_{kit} - the independent variable k, with time-varying values at each cross-sectional unit;
- ☐ εit ε_{it} – error term;
- ☐ i – cross-sectional unit;
- ☐ t – time unit,

In this particular case, the econometric model will be written in the form given by the equation:

$$PERFORM_{it} = a_i + b_i * Inov_{it} + c_i * Ef_{it} + d_i * Sust_{it} + E_{it}$$

To estimate the coefficients of this econometric model, the Least Squares Method (LSM) will be used. This intrinsically involves testing the following seven assumptions about the model, independent variables, and errors, shown in Table 2. Within the same table, the validation of each hypothesis is also presented, given that the model involves the use of panel data and that for the ease of estimation of the coefficients, the software EViews 8,0 will be used. The program's LSM for panel data is called Pooled EGLS, an acronym for Pooled Estimated Generalized Least Squares.

Table 2. Intrinsic assumptions to the application of LSM (Source: authors)

No,	Gauss-Markov hypothesis	Hypothesis validation	Validation procedure
1	The model created is a linear one	✓	Presentation of the model shape (see equation 2)
2	Independent variables have non-zero dispersion	✓	Checking histograms of independent variables for dispersion or variance values other than 0

No,	Gauss-Markov hypothesis	Hypothesis validation	Validation procedure
3	The number of observations is higher than the number of parameters	✓	The number of observations is 616 (4 variables for 11 years and 14 countries)
4	No multicollinearity between model variables	✓	The correlation matrix of the independent variables is studied for each country, observing the degree of collinearity between the variables. If there is collinearity, to avoid looking for other variables, wait for the estimation of the model coefficients and check the values of the standard errors associated with the estimated coefficients. If the errors have small values, then multicollinearity is also reduced
5	Model errors have zero mean and normal distribution	✓	The plots of the residuals are studied to see that they are concentrated around zero. In order to influence the errors and validate the hypothesis, different constants per country are used in the model
6	No serial correlation between errors	✕	The residuals correlation matrix is studied. Since the correlation is present, the White Cross Section option will be used (from EViews when all conditions for applying the Least Squares are set). Thus, the correlation is allowed between cross-sections, and by estimating on the model with panel data, it is much reduced
7	Homo-scedasticity assumption (evolution of independent variables does not influence errors)	✕	The covariance matrix of the residuals is studied, which gives values of the variance and covariance. The observations do not have the same variance of errors, so the hypothesis is not validated. It is thus necessary to assign equal weight to each cross-sectional unit in the regression (Cross Section Weights option in EViews)

Regarding the hypotheses to be validated or rejected by the multiple regression model with panel data, they will follow whether:

H1: there is a direct positive link between the degree of innovation and the level of bioenergy performance;

H2: there is a direct positive link between the level of efficiency and the level of bioenergy performance;

H3: there is a direct positive link between sustainability and bioenergy performance levels,

To estimate the coefficients of the multiple regression model with panel data, the time series were imported into an EViews worksheet. The coding for countries, as specified above, was used, as well as the coding for the four variables also mentioned above.

Results and discussion

After applying the LSM to the panel data we had in hand (with all the options explained above, cross-sectional fixed effects, White cross-section to allow for correlation between sections and the Cross Section Weights option to also allow for heteroscedasticity) the following regression equations were obtained (1-13):

PERFORM_AUT = -100,56 + 811,66 - 0,000127 * INOV_AUT + 0,0000325 * EF_AUT + 0,0063 * SUST_AUT (1)
PERFORM_CEH = +65,66 + 811,66 - 0,0021 * INOV_CEH + 0,000239 * EF_CEH + 0,487 * SUST_CEH (2)
PERFORM_DNK = +0,87 + 811,66 + 0,000228 * INOV_DNK + 0,000004 * EF_DNK - 0,0161 * SUST_DNK (3)
PERFORM_FIN = -41,93 + 811,66 + 0,000158 * INOV_FIN - 0,000307 * EF_FIN - 0,029 * SUST_FIN (4)
PERFORM_FRA = +70,20 + 811,66 - 0,00021 * INOV_FRA - 0,000053 * EF_FRA - 0,459 * SUST_FRA (5)
PERFORM_GER = -177,32 + 811,66 + 0,00007 * INOV_GER + 0,0000064 * EF_GER - 0,097 * SUST_GER (6)
PERFORM_ITA = -53,31 + 811,66 - 0,000517 * INOV_ITA + 0,000027 * EF_ITA + 0,285 * SUST_ITA (7)
PERFORM_POL = +149,98 + 811,66 - 0,000422 * INOV_POL + 0,000012 * EF_POL + 0,162 * SUST_POL (8)
PERFORM_ROM = +150,67 + 811,66 + 0,0019 * INOV_ROM - 0,000054 * EF_ROM + 0,192 * SUST_ROM (9)
PERFORM_SPA = +272,9 + 811,66 + 0,064 * INOV_SPA - 0,00535 * EF_SPA - 178,7 * SUST_SPA (10)
PERFORM_SUE = -59,63 + 811,66 - 0,2834 * INOV_SUE + 0,0231 * EF_SUE - 8,1116 * SUST_SUE (11)
PERFORM_TJOS = -25,55 + 811,66 - 0,00031 * INOV_TJOS + 0,0000064 * EF_TJOS + 0,246 * SUST_TJOS (12)
PERFORM_UK = -180,81 + 811,66 - 0,000026 * INOV_UK + 3,1841 * EF_UK + 0,158 * SUST_UK (13)
PERFORM_UNG = -71,41 + 811,66 + 0,0151 * INOV_UNG - 0,000428 * EF_UNG - 1,328 * SUST_UNG (14)

In the regression equations obtained the following can be observed:

Table 3. Regression equations observations (Source: authors)

No.	Regression equations observations
1	The value of 811,66 appears each time, representing the average of the constant values for the 14 countries.
2	The first value (negative or positive) in each equation represents the deviation from the mean value for the 14 countries.
3	In this case, the constant of a regression equation is calculated as the sum of the average for all constant values and the deviation from that value. For example, in the case of Romania, the equation's constant is 962,33.
4	Regardless of the regression equation, the constant is positive, indicating that there are certainly other factors not included in the analysis that can greatly

No.	Regression equations observations
	influence bioenergy performance. The highest value of the constant term is for Spain, 1084,56, indicating that for Spain there are a number of variables that need to be found and validated as influencing performance. At the opposite pole is the UK with a constant in the regression equation of 630,85
5	The sub-unitary values (either positive or negative) of the coefficients associated with the representative variables for efficiency and innovation indicate a low influence of these on bioenergy performance.
6	Values close to unity or superiority are obtained for the coefficients associated with the sustainability variable, showing a high influence of the independent variable on performance. For example, the highest positive influence on performance is found in the Czech Republic, where a one-unit increase in the level of sustainability given by bioenergy production per capita means an increase of about 0,5 in the level of performance. The smallest positive influence is found in the case of Austria, only 0,0063.
7	Regarding the relationship between sustainability level and bioenergy performance in the case of Spain, the estimated coefficient for the sustainability variable is statistically significant at a 95% confidence level (resulting from the probability analysis displayed by EViews after estimation). Thus, to the extent that the level of sustainability increases by one unit, the level of performance decreases by 178,7 units. The situation needs attention, since the hypothesis assumes that a high level of sustainability positively influences performance.

We looked for explanations, among the component aspects of the two proxy variables for sustainability and performance. Thus, we observed that the main consumers of bioenergy in Spain are domestic consumers, followed by industry and transport, and the main use is for heating. The results can be correlated with other well-known studies which present similar situations: the bioeconomy actions are quite significant in Spain; biomass represents over 90% of renewable heat production and biomass applications in the residential sector are growing quite rapidly in this country as they offer great potential to achieve the goals of the European strategy for climate and energy (Paredes-Sanchez et al., 2019, p. 561; Las-Heras-Casas et al., 2018, p. 591). Bioenergy is considered CO2 neutral. Indeed, the amount of carbon dioxide released during biomass combustion is less than or equal to the amount of carbon dioxide sequestered from the atmosphere during biomass growth.

Given this, the issue is likely to be related to the efficiency of energy conversion, the way heating is achieved, and the performance of the appliances used; all of which play a role in achieving energy savings in residential, commercial, and industrial areas. Therefore, failure to do so can affect the sustainability of the activities carried out and thus the performance in the field.

Table 4 is particularly useful in observing the influences of each of the three variables on the level of bioenergy performance, According to Table 4, for none of the 14 countries can all three assumptions made at the beginning of the analysis be validated.

Table 4. Influences on performance levels (Source: authors, with EViews)

No.	Country	Level of innovation	Level of efficiency	Level of sustainability
1	Austria (AUT)	-	+	+
2	Denmark (DNK)	+	+	-
3	Finland (FIN)	+	-	-
4	France (FRA)	-	-	-
5	Germany (GER)	+	+	-
6	Italy (ITA)	-	+	+
7	Great Britain (UK)	-	+	+
8	Poland (POL)	-	+	+
9	Czech Republic (CEH)	-	+	+
10	Romania (ROM)	+	-	+
11	Spain (SPA)	+	-	-
12	Sweden (SUE)	-	+	-
13	Netherlands (TJOS)	-	+	+
14	Hungary (UNG)	+	-	-

In the case of France, all three hypotheses are rejected, as the results show only negative influences of the three variables on performance. However, the level of efficiency (through the proxy variable) helps to confirm hypothesis 2 in 9 out of 14 cases, while the level of innovation (represented by the number of patents) and the level of sustainability (represented by Emissions avoided (tonnes CO2 e) per GWh generated) help to confirm hypotheses 1 and 2 respectively, six and seven times respectively.

Conclusions

Based on the performed analysis, the econometric model with panel data (with Least Squares Method estimation) offered the possibility to observe the relative performance in the field of bioenergy in several countries of the European Union. Observing each regression model and constant term, one can conclude that at the basis of bioenergy, performance stays a combination of factors, in addition to those chosen by us in the model (innovation, efficiency, and sustainability). Even if the subunitary values (either positive or negative) of the coefficients associated with the representative variables for efficiency and innovation indicate a low influence of these on bioenergy performance, we have to take into account that the basis of development is knowledge, and innovation is the activity through which knowledge is combined producing synergy. Through innovation, great solutions to important problems are achieved, and even if the results do not lead directly to performance in the econometric model, this does not mean that efforts to increase bioenergy performance should not occur. Moreover, the use of bioenergy as a renewable energy source comes as a result of innovation activities. The fact that we are still at the beginning with this type of energy may be a reason for this research results. Bioenergy performance is closely linked to the concept of sustainability, but we highlighted that in order to achieve sustainability we need to focus not only on how bioenergy is produced but also on how it is used in different activities: the use of low-energy devices helps to increase overall performance, with a direct impact on sustainable development.

Of course, the evolution of mankind over the last 100 years has led to environmental degradation, but we cannot ignore the results regarding living standards. The fact that we have succeeded in finding and perfecting methods of using renewable energy sources is a major step towards correcting past mistakes. In other words, it is possible that without the last century's work, mankind would not have focused on renewables in the absence of need. Mistakes have been made in terms of environmental protection, but perhaps the most appropriate economic option for Europe at the moment is a mix of renewable energy, fossil fuels, and nuclear power, with a very big interest in developing the bioenergy sector.

Based on the results obtained, it is confirmed that in some European countries, there is a direct link between the degree of innovation, the degree of efficiency, the level of sustainability, and the level of performance in the field of bioenergy, with further research focusing on the use of updated data sets, taking into account other possible factors such as the level of education, the human development index, the level of investment in renewable energy targets. Using updated databases and considering other countries outside the European Union (Switzerland, Norway) can help us shape a broader framework in which bioenergy plays an essential role in the lives of communities.

Major limitations: Due to the fact that the paper is based on data between 2006-2016, we also considered Great Britain as a European Union member country. As far as we know, starting on 31.01.2020, the Brexit process has been completed and Great Britain has decided to leave the European Union.

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

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