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Assessment of the Impact of Bioenergy on Sustainable Economic Development

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Abstract: The Solow-Swan macroeconomic model reveals the fact that the marginal capital rate of the bioenergy sector, as well as the bioenergy productivity and productivity of the resources variation, having positive values of their estimated coefficients, have the capacity of stimulating the sustainable economic development of an emerging country, such as Romania. The economic model substantiated by the correlations between the macroeconomic indicators evaluates the convergence in relation with the European Union (EU) average. The main objective of this paper is to analyze the impact of bioenergy on sustainable economic development. The econometric analysis revealed the fact that the bioenergy productivity, the productivity of the resources and the capital productivity of the bioenergy sector have a positive and statistically significant impact on the sustainable economic development. Data was collected from The European Statistical Office and analyzed with SPSS 22 statistical software package. Quantitative methods highlight the disparities between developed and developing countries of EU in terms of bioenergy use and efficiency.

Keywords: bioenergy; sustainable development goal; biofuels; productivity; resources; economic growth; regression analysis

1. Introduction

The European Union (EU) is one of the main contributors to the achievements of the sustainable goals of the United Nations. Accordingly, the energy efficiency objective pursued under the 7th sustainable development goal (hereinafter referred as SDG 7), is reflected under the provisions of the EU Directive 2018/2001 on the use of energy from renewable sources and, respectively, the new Governance Regulation (EU) 2018/1999.

Against this framework, Romania has recently updated the national Strategy on Energy for the period 2018–2030 [1], which identifies and promotes eight fundamental goals to sustain the growth of the energy sector, emphasizing the importance of the renewable sources of energy and bioenergy, so as to build up new energetic capacities, develop new technologies for clean energy in terms of efficiency, improve the transport and distribution system, support the growth of the internal efficient consumption, provide electricity and thermal energy for all consumers, insure the protection of the vulnerable consumer and, last but not least, increase the volume of exports. The energy growth from renewable sources constitutes an important part of the EU legislative measures adopted by the European forum in 2018 towards the mitigation of the climate change by decreasing the emissions of greenhouse gas emissions until 2030 by at least 40% below the level existent in the year 1990 in order to meet the objectives of the Agreement on Climate Change signed in Paris, in 2015, on the occasion of the 21st Conference of the United Nations. The energy and environmental policies implemented within the European Union with the support of the European institutions essentially contributes to the achievement of SDG 7. Moreover, this goal is targeted even by the Treaty on the Functioning of the European Union in article 194, paragraph (1), which provides for the responsible consumption of energy from renewable forms of energy. As one can note, the treaty introduces an obligation for all the EU Member States which becomes one of the EU political priorities. As such, EU could be regarded as a model of commitment for all the United Nations' parties.

We may note that the measures which are intended to stimulate the sustainable consumption of bioenergy and, in parallel, reduce the greenhouse emissions of gas [2–4] are of particular relevance for the background of our research. As such, at the EU level, the stakeholders are looking at the available sources of biomass laid down for the production of bioenergy and give consideration to the environment priorities to avoid unsustainable consumption, by virtue of the principles enshrined in the circular economy model [5–8].

The process of transforming the advanced biofuels and biogas into bioenergy with low emissions of greenhouse gas should be regarded in a cost effective manner, paying attention to the need for development of the corresponding high-tech bioenergy infrastructure [9–14]. To streamline the process, the European legislators thought of conceiving thresholds to keep a balance between the need to produce clean energy and biodiversity demands. As such, two types of thresholds were defined: minimum and maximum levels, respectively. We may note that all the EU Member States require fuel suppliers to use a minimum share of certain advanced biofuels and biogas in the production of gasoline [15]. In addition, a maximum level is imposed on the producers of bioenergy to refrain from exceeding a certain level of the amount of the biofuels and bioliquids produced from cereal and other starch rich crops, sugars and oils to reduce the impact on biodiversity and land use changes, to respond to the most vehement critics. Keeping the right balance with the support of clear-cut rules represents the solution adopted by the European Union, to counteract any excessive unsustainable consumption, against the increase of the ecological footprint, to support the natural biocapacity [16,17]. In this regard, Romania made progress related to its increased ecological agricultural areas [18–20]. In consideration of this aspect, the current paper evaluates the bioenergy factors of Romania which have a potential impact on the sustainable economic development. The factorial analysis is developed with the support of an econometric model. The disparities between the EU developed and developing countries with respect to the bioenergy macroeconomic indicators are revealed with data provided by the European Statistical Office (Eurostat) [21].

2. Materials and Methods

The Romanian agri-food sector plays an important role in creating a new industry based on the use of biomass as a raw material [22,23] and its conversion into value-added products, according to the latest country report drawn up by the Bio-Based Industries Consortium (BIC). BIC represents the private sector within the public-private partnership with the European Commission, i.e., the Bio-Based Industries Joint Undertaking (BBIJU). Report [24] identifies the main local biomass sources that could be used as sustainable raw materials for bio-industries as well as the main players in the relevant sectors and the opportunities for the development of industries based on these activities. According to the BIC report, agriculture and forestry, in conjunction with other industries such as food processing, wood industry, paper and pulp industry, can produce large amounts of waste used for bioenergy [25–30]. In addition, the agriculture sector employs 23.1% of the labor force [24].

According to BBIJU [24], Romania should develop an industry based on utilization of biomass as raw material for bioenergy. The petrochemical and agro-food industries in Romania might play an important role in creating a new industry based on the use of biomass as a raw material and its transformation into value-added products, according to the latest country report by the Bio-Based Industries Consortium (BIC).

The BBIJU report also states that agriculture and forestry, jointly with other industries such as food processing, wood industry, paper and pulp industry, may produce large amounts of waste and other unused or less used materials, being available as a raw material for biomass processing industries. Regarding the wood industry, Romania has an international trade surplus for timber and timber products, both in terms of value and volume. Approximately 61,500 employees work in this sector in 3000 companies [31].

To better understand the correlation between the production of bioenergy and its potential to generate sustainable economic development, we will look into the economic literature review and, based on the consecrated economic theory, we will exemplify the econometric model with empirical evidence from the Romanian bioeconomy.

The current research paper studies the correlations between the bioenergy use in conditions of efficiency and the overall sustainable economic development, the latter exogenous variable being determined by independent variables, known as bioenergy determinants. The input provided, i.e. bioenergy, is obtained as a result of biomass pre-processing, which implies complex production facilities, storage, bio-refinery and transport system. The whole process of production is known as the management of biomass supply chain, which is optimized based on different objective functions, either to minimize costs [32], to maximize profits [33] or to maximize the net present value [34] of the biomass supply chain.

If the sustainable production refers to the key economic sectors such as agriculture, energy, industry and transport, the sustainable consumption takes into account the demand for the goods and services needed to meet the basic needs and improve the quality of life, namely food and health, housing, clothing [35–37]. From this perspective, the organic agricultural area, the energy consumption from renewable sources, as percentage in the final energy consumption (%), the consumption of electricity from renewable sources, as percentage of the total electricity consumption (%), the share of recycled and recovered packaging waste (%), the passenger transport by rail (1000 million passengers / km) fall into the category of indicators used to measure the sustainability of the country production and consumption. For example, organic farming-human activity that does not adversely affect the environment-responds to the need and demand of the population for food and healthy clothing. As a result, according to Stanciu et al. [38], the ecologically cultivated agricultural area is growing everywhere in the world.

In Germany, communities are in charge of the energy production, following the principle of collective energy supply. In their research paper [39], the authors describe the qualitative assessment process using the interview as the main method to identify the success factors to produce bioenergy and use it in villages. Dincer [40] identifies potential solutions to the environmental problems along with the renewable energy technologies. The relations between sustainable development and renewable energy are depicted with illustrative examples and practical cases.

Bioenergy influences on sustainable development phenomenon are reflected in many research papers. Buchholz et al. [41] propose a multi-criteria analysis (MCA) as an effective tool to apply integrated modeling to assess the sustainability of an energy system. Other researchers [42,43] argue that the current expansion of bioenergy with a view to both mitigate climate change and provide more sustainable energy solutions portends to have significant implications on land and water use.

Transitions for sustainable development of bioenergy use were carefully examined by many researchers. In their paper [44], the authors provide discussion on social acceptance in biofuel context and conclude that biofuel development will be constraint if social acceptance issues remain neglected.

According to several research papers [45–47], the energy programes include a wide range of socio-economic determinants, representing the basic elements for the development of well-being. The neo-classic economic theory promoted by Keynes presents the economic cycles, with specific and adequate tools and strategies to be applied for the periods of regression and sustainable economic development. The positive externalities reside in new jobs and additional income formation. The promoter of the sustainable economic development theory and welfare should be found in the 18th century being no one else than Adam Smith, known as the father of economics and the one who introduced the concept of capitalism.

The classical Keynesian model was later developed by Harrod [48] and Domar [49] and represents the precursor of the exogenous growth model of Solow-Swan, derived in the Appendix A, the latter being considered a complex model which counteracts the imperfections of the previous economic models.

Solow [50] and Swan [51] have introduced the long-term economic growth concept in a macroeconomic model, which became classic, by extending the Cobb-Douglas growth function to a model which underlines the efficiency and utility of the productivity and labor force. Cass [52] and Koopmans [53] improved the neoclassical growth model by introducing the optimization analysis of the final consumer, which permitted the determination of the saving rate. The developing countries tend to recover the gap from developed countries through positive economic growth rates, influenced by human capital [54–57].

The Econometric Model

Starting with the research studies mentioned before, we target the object of our research paper and try to find the answer to the following question: "What is the impact of biofuels production, productivity of the resources and bioenergy productivity on sustainable economic development of Romania?". On top of what has been done in this research area, we will try to estimate which of the three exogenous factors mentioned before has the greatest impact on the endogenous variable in the multilinear regression model.

The impact of the bioenergy on sustainable economic development has been studied by many researchers. Some economists [58,59] demonstrated that bioenergy productivity and labor productivity have a direct impact on sustainable economic development, while other authors [60,61] argued that there is a strong connection between productivity of the resources and sustainable economic development. Thus, the three statistical hypotheses tested in our analysis are the following:

- H_1: Bioenergy labor productivity has a positive impact on sustainable economic development.
- H_2: Bioenergy productivity has a positive impact on sustainable economic development.
- H_3: Productivity of the resources has a positive impact on sustainable economic development.

To test the three research hypothesis above, an econometric model is built, derived from the Solow-Swan growth model, which will be presented in the next subsection. Based on this function, we will then create a multilinear regression model. Although the model has a linear parametric structure, it is projected to accommodate a large range of applications, parametric constrains and mean and covariance structures.

The model will be estimated starting with the derivative of the production function (see Equation (A8)), with respect to the capital variable [62]:

$$\mathrm{MPC} = \delta\mathrm{P}/\delta\mathrm{C} = \mathrm{aB}^{1-\mathrm{a}}/(\mathrm{C}/\mathrm{F})^{1-\mathrm{a}} \quad (1)$$

By small percentages increase, the derivative of the production function could be approximated by the first difference. Thus, the above equation is equivalent to:

$$\Delta\mathrm{P}/\Delta\mathrm{C} = \mathrm{aB}^{1-\mathrm{a}}/(\mathrm{C}/\mathrm{F})^{1-\mathrm{a}} \quad (2)$$

To linearize this exponential equation, we will take logarithm on both sides of the equality, and get:

$$\ln(\Delta\mathrm{P}/\Delta\mathrm{C}) = \ln[\mathrm{aB}^{1-\mathrm{a}}/(\mathrm{C}/\mathrm{F})^{1-\mathrm{a}}] \quad (3)$$

which is equivalent to:

$$\ln(\Delta\mathrm{P}/\Delta\mathrm{C}) = \ln\mathrm{a} + (1-\mathrm{a})\ln\mathrm{B} - (1-\mathrm{a})\ln(\mathrm{C}/\mathrm{F}) \quad (4)$$

To get the rate of increase of P/F, we will compute the first order differential in the previous equation, and get:

$$\Delta\ln(\Delta\mathrm{P}/\Delta\mathrm{C}) = \Delta\ln\mathrm{B} + \mathrm{a}[\Delta\ln(\mathrm{C}/\mathrm{F})] \quad (5)$$

In order to control the convergence effect of the states with a lower level of income, which have rapid growing rates, we will include in our model the base value of P/F.

Hence, the above equation becomes:

$$\Delta \ln(\Delta P/\Delta C) = \beta_0 + \beta_1 \cdot \Delta \ln(B) + \beta_2 \cdot \ln(P/F) + \beta_3 \cdot [\Delta \ln(C/F)] \quad (6)$$

where P = Gross Domestic Product (GDP); F = Active labor force; C = Capital input; B = Number of people employed in bioenergy sector.

When the data is analyzed in SPSS, we will use: $\Delta\ln(\Delta P/\Delta C)$ is the percentage increase of $\ln(\Delta P/\Delta C)$ and $\Delta\ln(C/F)$ percentage increase of $\ln(C/F)$.

We use economic growth in our model as a proxy variable for sustainable economic development [63]. The three independent variables in the model are: the active labor force, the capital input and the number of people employed in the bioenergy sector. The active labor force is defined as the section of working population in the age group of 16–64 years old in the economy currently employed or seeking employment [64]. In addition, we will use marginal capital rate of bioenergy sector as a proxy variable for the capital input [65].

3. Results and Discussion

Estimating a Model for Economic Growth Based on Productivity of Bioenergy

A description of the variables used in the econometric model could be seen in Table 1, while the correlation matrix is presented in Table 2.

Table 1. A description of the variables used in the model.

Variable	Mean	Minimum	Maximum	Standard dev.
Y	273.345	62.215	483.351	73.234
X_1	17,234.542	6143.251	29,765.239	4276.841
X_2	16,845.263	2876.123	30,345.241	5276.230
X_3	1123.467	109.272	2034.101	367.324

Source: Author's values determined using the SPSS 22 software package (Version 22.0, IBM Corp., Armonk, NY, USA).

Table 2. The Pearson correlation coefficients matrix.

Variable	Y	X_1	X_2	X_3
Y	1	0.645	0.712	0.804
X_1	0.645	1	0.089	0.127
X_2	0.712	0.089	1	0.245
X_3	0.804	0.127	0.245	1

Source: Author's values determined using the SPSS 22 software package.

The correlation table (Table 2) reveals the fact the between the independent variable on one side and dependent variables on the other side-used in the econometric model-there is a strong and direct correlation. Moreover, the independent variables are low correlated between each other.

The multiple linear regression model derived in the previous section (see Equation (6)) represents a multiple linear econometric model [66], which points out the evolution of the dependent variable with respect to the three independent variables:

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3 + \varepsilon \quad (7)$$

where, $y = \Delta\ln(\Delta P/\Delta C)$ – explained variable; $x_1 = \Delta\ln(B)$ – explanatory variable; $x_2 = \ln(P/F)$ – explanatory variable; $x_3 = \Delta\ln(C/F)$ – explanatory variable; β_0, β_1, β_2, β_3-parameters of the model and ε – residual variable (white noise).

The multiple linear econometric model is estimated by the ordinal least square (OLS) method to compute the production function based on the GDP, the active labor force, the fixed capital and the number of people employed in the bioenergy sector. Data was collected from the European Statistical Office (Eurostat), reflecting the values corresponding to the indicators of Romania's economy, between 2005 and 2017. We could note the Model Summary in Table 3, while Table 4 is the ANOVA Table and Table 5 represents the Multifactorial regression model.

Table 3. The econometric model (Model Summary [a]).

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.843 [b]	0.711	0.684	1.213

Notes: [a] Dependent Variable: Y; [b] Predictors: (Constant), X_3, X_2, X_1.

Table 4. ANOVA table.

Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.312	3	8.342	7.211
	Residual	4.176	4	1.157	-
	Total	26.488	7	-	-

Notes: [a] Dependent Variable: Y; [b] Predictors: (Constant), X_3, X_2, X_1

Table 5. Multifactorial regression model.

Model		Unstandardized Coefficients	Standardized Coefficients		t	Sig.	Collinearity Statistics	
		B	Std. err.	Beta			Tolerance	VIF
1	(constant)	−4.165	304.804	-	0.703	0.028	-	-
	X_1	0.134	0.034	0.120	0.203	0.045	0.893	1.189
	X_2	0.213	0.065	0.234	0.120	0.029	0.875	1.106
	X_4	0.206	0.046	0.305	0.368	0.016	0.793	1.345

Notes: [a] Dependent Variable: Y. Source: Author's values determined using the SPSS 22 software package

As we could observe from Table 4, the regression model is statistically significant (F = 7.211; Sig. = 0.38). Also, the correlation coefficient (R = 0.843) reveals the fact that the dependent variable is highly correlated with the independent variables and the coefficient of determination (R-square = 0.711) shows that 71.1% of the dependent variable is explained by the variation of the independent variables. Moreover, the Durbin-Watson test (DW = 1.942) has a value close to 2, which means that the regression equation does not have any autocorrelation problems.

We could see from Table 5 that the all independent variables in the model are significant (Sig. < 0.05). Moreover, as all variance inflection factors (VIF) related to the exogenous variables are less than 3, we conclude that there is no collinearity between the exogenous variables. Also, the positive values of the three beta coefficients confirms the convergent effect of the production function with the labor productivity, energy productivity, productivity rate and capital rate, respectively.

The multiple linear regression equation obtained using the SPSS software is:

$$\Delta\ln(\Delta P/\Delta C) = -4.165 + 0.134 \cdot \Delta\ln(B) + 0.213 \cdot \ln(P/F) + 0.206 \cdot [\Delta\ln(C/F)] \quad (8)$$

Thus, we could conclude that the first derivative of the production function in terms of the capital variable, could be written as a function of labor productivity, rate productivity and bioenergy productivity. Hence, the Solow-Swan model indicates a high potential of economic growth determined by bioenergy productivity, capital and labor.

4. Discussion and Conclusions

The Solow-Swan model starts from the premise that the economic growth is dependent on the work productivity and productivity of the resources. All the research hypotheses were confirmed and we conclude that productivity of the resources, bioenergy productivity and capital have significant impact on economic growth. Our results are in line with other research papers in this area [67–69].

The data collected for 27 EU countries, between 2007 and 2017, was used to test, by means of a multiple linear regression model, the existence of a relationship between bioenergy production and sustainable economic development. Therefore, three hypotheses were made concerning the relationships between the variables used in our model, which were validated through the regression analyses. As such, we have found a positive relationship between bioenergy productivity and sustainable economic development.

The econometric model reveals the fact that an increase of 1 percentage point (pp) in labor productivity would lead to 0.134 pp increase in economic growth, whereas an increase of 1 pp in capital input would lead to an increase of 0.213 pp in economic growth and an increase of 1 pp labor force would generate an increase of 0.206 pp in economic growth. Moreover, the multiple linear regression model revealed the fact that the labor force, the capital input and the number of people employed in the bioenergy sector are significant factors with strong and positive impact on sustainable economic development. Moreover, we observe that the strongest correlation is between the labor force and the sustainable economic growth.

The macroeconomic indicators presented in the results section underline the fact that the biofuels production, the production of resources, the labor productivity and the bioenergy production is higher in the developed EU countries and lower in the developing EU countries. In this view, the EU directives have an important role in converging the bioenergy productivity in the all EU member states.

Given that the macroeconomic indicators used in our analyses covered a period of ten years, the main limitation of our research is based on the restricted database used in our analyses. Other limitation of this research is related to the fact that only three independent factors were used in the regression analysis. Thus, further research should be made on extended time periods, a fact which could give a better view of the Solow-Swan model applied on the Romanian macroeconomic indicators.

This study may be supplemented by using different variables to quantify the features of the sustainable economic development, to better understand and evaluate the effects resulted from the European Commissions' decisions and measures planned in this regard in the EU countries. The research results could be further developed by expanding the analyzed period, adding more explanatory variables to the model, according to the availability of the data and using other econometric methods. The research could be also developed in the area of dynamic models of the economies [70] or it could refine the calibration methodology along several important dimensions [71]. The novelty of our research comes from a fresh outlook on the perspectives of bioenergy and its impact on the sustainable development of the EU countries, with the main focus on Romania.

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Appendix A

The Solow-Swan production function [72] in the economic growth model would be developed as follows:

$$P(t) = C(t)^{a}\ (B(t)F(t))^{1-a} \quad \text{(A1)}$$

where, t – time interval; a – elasticity of production due to capital, $0 < a < 1$; P(t) – Cobb-Douglas type function – here represents total production; C(t) – Capital; B(t) – Bioenergy labor; F(t) – Labor force; B(t)F(t) – Effective bioenergy labor force.

Now we assume that all production factors are employed, and the rate growth for each production factor B(t) and F(t) would be denoted by m, respectively q. The initial values for technology, capital and labor are: B(0), C(0) and F(0):

$$\{F(t) = F(0) \cdot e^{mt}; B(t) = B(0) \cdot e^{qt} \quad (A2)$$

In these conditions, the actual work at a given point in time will be B(t)F(t), with an exponential rate increase (m + q). The depreciation of capital or the depreciation rate is denoted by d. Consumption is $c \cdot P(t)$ with $0 < c < 1$, where c represents the share of consumption, and $r = 1 - c$ represents the saving rate required for investments. It is obtained [73]:

$$C'(t) = r \cdot P(t)\ d \cdot c(t) \quad (A3)$$

Now, we determine the production as a function of effective work, and get:

$$p(t) = P(t)/B(t)F(t) = c(t)^a \quad (A4)$$

What is interesting for us is the dynamics of the capital function k per actual work unit. The investor's behavior on the market follows the Solow-Swan model as follows [74]:

$$c'(t) = r \cdot c(t)^a - (m + q + d) \cdot c(t) \quad (A5)$$

in which $s \cdot c(t) = s \cdot p(t)$: is the investment on the effective labor unit; $(m + q + \delta) \cdot c(t)$: is the minimum level at the point which the investment became profitable.

c(t) converges to c*, defined by $r \cdot c(t)^a - (m + q + d) \cdot c(t)$, which represents the equilibrium level or the saving minimum beyond which the investment can become profitable [75]:

$$c^* = [r/(m + q + \delta)]^{1/(1-a)} \quad (A6)$$

Assuming the growth rates of production factors as constant, the increase in per capita production is determined by the rate of technological progress. If $C(t)/P(t) = c(t)^{1-a}$, where c* represents the equilibrium level then:

$$c(t)/p(t) = s/(m + q + d) \quad (A7)$$

Therefore, in equilibrium, the capital factor depends only on saving, growth rate and depreciation rate. Drawing the function of production by the capital variable, we obtain:

$$MPC = \delta P/\delta C = aB^{1-a}\ /\ (C/F)^{1-a} \quad (A8)$$

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