

Sustainability of Biodiesel Production and Usage: The Case of Romania

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Abstract

Background: This paper aims to evaluate the sustainability of biodiesel, a renewable fuel used as a blending component in diesel fuel. This study describes the current situation in Romania where the European Union (EU) settlement regarding the blending ratio of biodiesel and compliance with environmental protection specifications are applied. The evaluation covers the whole biodiesel value chain, from rapeseed production through biodiesel synthesis and combustion.

Results: Our evaluation process takes into account three elements of sustainability: economic, environmental, and social. The overall result of this research is that, despite Romania's high potential for biodiesel production and use, the sustainability of biodiesel is low as a result of the Romania's government strategy, combined with biodiesel prices on the international market and the interests of Romanian refinery owners.

Conclusions: Our prediction is that the current situation will remain over the next decade, owing to economic factors such as the decline in rapeseed crops, a key raw material for biodiesel manufacturing, and the higher cost of biodiesel produced in Romania. Another factor could be Romania's implementation of EU regulations aimed at replacing diesel engines with electric ones. If this decision is implemented, diesel fuel and, implicitly, biodiesel will be phased out of the vehicle fuel market.

1. Introduction

Climate change is a phenomenon exacerbated by human activities that increase greenhouse gas (GHG) emissions. It is observed every year to a greater and greater extent in the form of uncontrolled atmospheric turbulence and the melting of the polar ice caps, the latter of which are causing the global sea level to rise with dangerous speed. One of the main contributors of GHG emissions is the transportation sector: in 2018 it was responsible for 15% of total GHG emissions and this percentage is expected to increase in the next decade [1]. However, this increase will be the result of the growing number of vehicles in Asia and South America, while a European Union (EU) forecast indicates that diesel-engine cars in the latter region will decline, being replaced by hybrid and electric engines. By 2024, the reduction in diesel-engine cars will be reflected in a lower consumption of diesel and biodiesel fuel; as a result, the International Energy Agency predicts that biodiesel production will decline with at list 2.1 billion litres [2].

In order to reduce GHG emissions from transportation activities, society needs to follow a multiple step strategy where the first and the most important step is to replace a proportion of petroleum fuels with biofuels (e.g. alcohol, hydrotreated vegetable oil, biodiesel, biogas); another step is to replace petroleum-fuelled cars with hybrid cars; and the final step is to replace all fuel-engine cars with fully electric cars [3].

1.1 History of Biodiesel in Romania

Romania became an EU member state on the 1 January 2007, but even before this time it was interested in promoting biofuels for usage in the transportation sector. In 2008, the Romanian government decided to introduce biofuels in the stock of transportation fuels, the approved content being a 2.5% volume of biodiesel into diesel fuel and ethanol into gasoline. At that time, biodiesel production facilities were rapidly developed. A study that formed part of the Bionic project [4] identified more than 100 small plants working on biodiesel production, through the transesterification of rapeseed/sunflower oil with methanol or ethanol. This significant development of the biodiesel sector was encouraged by a very permissive taxation policy, which exempted biofuels from excise duties. After 1 January 2009, biofuels were included in the new fiscal code, in the category of energetic products for which excise duties must be paid through the creation of a tax warehouse. This political decision destroyed the small biofuel industry, because after its application, almost 90% of these small entrepreneurs closed their businesses. Today in Romania there are around 20 enterprises whose object of activity is biofuel production and the total biofuels production capacity is around 350 kt/year.

Regarding the political strategy, Romania applied the recommendations of the EU concerning the content of biofuels blended with petroleum fuels for the transportation sector. The first directive applied in Romania was Directive 2003/30/EC [5], which fixed the content of biodiesel into diesel fuel at 5.75% volume, with a term of application up to 31 January 2010. This directive was replaced by Directive 2009/28/CE (Renewable Energy Directive) [6], which after six years was updated by EU Directive 2015/1513 of the European Parliament [7]. This directive recommended a mixing ratio of a minimum biodiesel content of 10% into diesel fuel for 2020, a contribution that will remain frozen at 2020 consumption levels [8]. Today, Romania has a mixing ratio of 7% volume specified by OUG 80/2018 [9], which makes the modifications and updating of Law 211/2008 promoting of renewable resources for energy production [10].

Taking into account that the EU will not increase the mixing ratio of biodiesel in the coming years, we consider this a good moment to undertake an assessment of its sustainability in Romania.

This paper's aim is to evaluate the sustainability of biodiesel produced from rapeseed oil along the entire chain, from feedstock production all the way to combustion in diesel engines in the transportation sector. Our methodology seeks to eliminate the subjective factors that may affect the facts by using a system of numerical indicators for each of the analyzed sustainability factors.

2. Methodology For Biodiesel Sustainability Assessment

In the literature there are different definitions of sustainability, but importantly, these recognize that the term is more complex than merely referring to the ability of society to satisfy its needs by preserving natural resources for future generations [11]. Indeed, sustainability also involves the realization of a favourable economic balance for the entity, outcome or process being evaluated [12]. Furthermore, sustainability is validated by the efficient protection of environmental factors (i.e. the air, water and soil) without damaging biodiversity [13]. Finally, sustainability is demonstrated in the form of positive social

effects, through increasing the standard of living, or at least not affecting the current standard. According to Mensah [11], there are three pillars of sustainable development: economic growth, environmental protection and social equity. Taking into consideration this classification, in this study we evaluate the sustainability of biodiesel in Romania and attempt to develop a methodology of evaluation using a mathematical model in order to eliminate subjective factors. This numerical evaluation is applied to the following three factors:

1. Economic sustainability (EcoS);
2. Environmental sustainability (EnvS);
3. Social sustainability (SocS).

Moreover, biodiesel sustainability ($S_{\text{Biodiesel}}$) is calculated using a mathematical equation, where each factor is adjusted with a coefficient of impact, as follows:

$$S_{\text{Biodiesel}} = F_1 \cdot \text{EcoS} + F_2 \cdot \text{EnvS} + F_3 \cdot \text{SocS} \quad (1)$$

The coefficients of impact (F_i) were chosen as the ratio between the impact of each sustainability factor and total sustainability, thus taking the subunit values and their sum as equal to 1. Each sustainability factor is measured with four achievement levels and each level is given a score, as presented in Table 1.

3. Results And Discussion

3.1. Economic sustainability

The economic sustainability of a product or activity is evaluated by finding a balance between the total costs of production, distribution and consumption for the analyzed product or activity and the benefits obtained after that product is activity used. This balance is used to create a range of grades of sustainability: high, medium, low or no sustainability.

Romania has a very high potential for biodiesel production. A report published by the Ministry of Agriculture [14] shows that Romania has a total of 13.3 million ha agricultural land, with arable land representing 8.3 million ha. Taking into account that in Romania, biodiesel is solely produced from rapeseed oil, it is important to analyze the degree of arable land utilization for rape crops, the main feedstock for rapeseed oil production. The surfaces cultivated with rape crops are presented in Fig. 1.

Furthermore, total rapeseed production (yellow block) and price (blue line) on the internal market for the period 2017–2019 are shown in Fig. 2.

In 2018, the total land cultivated with rape crops was 1,610.9 thousand ha, but it dramatically decreased in 2019 to 798.2 thousand ha (Figure 1), representing a reduction of 50.45%. Taking into consideration that the entire quantity of rapeseed is used to extract rapeseed oil – the feedstock for the biodiesel

produced in Romania – we believe that this significant decline in rapeseed production was a reaction to the biodiesel market, which came to prefer importing biodiesel instead of producing it in Romania. This can be regarded as a negative indicator of biodiesel sustainability in Romania.

Another aspect that we deem very important when assessing biodiesel's economic sustainability is its cost of production. To calculate this cost, we need to take into consideration all costs, starting with the agricultural costs for rapeseed crops, followed by oil extraction and biodiesel synthesis. All these costs are then corrected with secondary activity costs, such as for fuel for transportation and distribution. Finally, we transform these costs into a production price of biodiesel for the internal market. The total costs of biodiesel production in Romania are presented in Table 2.

Considering that the excise duty to pay for biodiesel is the same as that for gas oil (almost 300 euro/t), the final price for the internal market exceeds 1,000 euro/t biodiesel. This price is far from competitive with the biodiesel purchased on the external market [16].

The calculated price for biodiesel production in Romania shows a low level of economic sustainability. Indeed, even though the agricultural potential for biodiesel production is quite high, the overall score for biodiesel sustainability is only 2, according to the data presented in Table 1.

3.2. Environmental sustainability

The environmental sustainability of biodiesel as a component of the Romanian fuel pool is evaluated by a methodology developed by Rojnavschi [17], based on calculating the Global Impact Index (GII). In our case, the GII is calculated by assessing biodiesel's impact on environmental factors (i.e. air, water and soil) as well as on the biodiversity of natural systems. This environmental impact assessment is based on quality indicators that accurately reflect the state of environmental factors. The quality of any environmental element or factor is estimated by transforming the qualitative aspects into quantitative parameters. This transformation is undertaken using a mathematical equation, as follows:

$$I_q = \frac{1}{\pm E}, \quad (2)$$

where: I_q = quality index;
 $\pm E$ = effect size (calculated with the evaluation matrix).

The quantification of the effect size (E) uses a combination of different elements that have following influences:

- +: positive influence;
- : negative influence;
- 0 : zero influence.

For the qualitative assessment, quality indicators of each environmental factor at a given moment are placed on a reliability scale with different grades expressing the proximity of the evaluated situation to the ideal state (Table 3).

Biodiesel's impact on the environment is assessed using an evaluation matrix, where the potential interactions between the effects of biodiesel usage and environmental components are quantified as effect sizes ($\pm E$) using the evaluation matrix. With these effect sizes, we can calculate the quality index (Iq) and then estimate the Reliability Grade (RG) of each environmental element. The RGs express the degradation of each environmental factor affected by biodiesel usage.

Recent studies [18, 19] have shown that biodiesel production via the transesterification of vegetable oils is realized in production units based outside urban areas and that the distribution of biodiesel does not pose a contamination risk for soil and water. Furthermore, the agricultural chain for rapeseed crops has a very low impact on the environmental factors of soil, water and air. In addition, we have already shown that in Romania, the terrain cultivated with rape crops constitutes only 2.25% of the total agricultural land, hence biodiversity is scarcely affected. Regarding the effects of biodiesel combustion, there are no reports of significant emissions of pollutants into the atmosphere. Compared with diesel fuel, biodiesel produces lower exhaust emissions of particulate matter (PM), carbon monoxide (CO) and volatile organic compounds (VOCs), but higher nitrogen oxide (NO_x) emissions [4, 20, 21]. Regarding the global warming potential of biodiesel from rapeseed oil, a value of 44 carbon dioxide (CO₂) eq. MJ⁻¹ has been reported, which is nearly half that of diesel fuel (94 CO₂ eq. MJ⁻¹) [3]. However, in the case of biodiesel blends, when the blending ratio is under 10%, the air quality impact can be considered negligible [20, 21]. More than that, Chauhan and Shukla [22] have shown that biodiesel blending at a volume below 10% has a minimal impact on the environmental factors of soil and water.

Nevertheless we assess the air quality that may be affected by exhaust emissions containing CO₂, CO, NO_x, PM and VOCs. Our procedure is to divide the assessment into a multi-directional analysis concerning the influence of each chemical compound emitted in the environment. The evaluation matrix for calculating the impact of biodiesel blended with diesel fuel at a 7% volume is presented in Table 4.

The environmental impact of biodiesel production and combustion was quantified in concordance with the environmental effects (Table 2) and the quality index calculated using equation 2. Furthermore, the environmental impact on the air is calculated in Table 5 and on all the environmental factors in Table 6.

The GII of biodiesel production and combustion in Romania is calculated by dividing the surface obtained by the RG for the ideal state of the environment (noted with SI) by the surface for the RG for the real state of the environment (noted with SR), as presented in Fig. 3 and calculated with Equation (3).

The equation for calculating the GII is as follows:

$$GII = \frac{SI}{SR}, \quad (3)$$

And the evaluation scale for GII has the following levels:

GII = 1 – natural environment not affected by human activity;

GII = 1 ÷ 2 – environment submitted to the effects of human activity within the allowable limits;

GII = 2 ÷ 3 - environment submitted to the effects of human activity causing a state of discomfort to all the

forms of life;

GII = 3 ÷ 4 - environment affected by human activity disturbing the life;

GII = 4 ÷ 6 - environment seriously affected by human activity;

GII > 6 – degraded environment unsuitable for the life.

For biodiesel production and combustion in Romania, the GII is calculated with Equation (3) using the RG values from Table 6, as: RG soil = 10; RG water = 10; RG air = 9; and RG biodiversity = 10. Thus, the area for the ideal state is SI = 200 units while for the real state it is SR = 190 units, resulting in a GII of 1.05, corresponding to an environment that is not significantly affected by biodiesel production and combustion.

All these data show the very high sustainability of biodiesel production and combustion in Romania, the score for which, according to Table 1, is 4.

3.3. Social sustainability

As stated by Kolk [23], the social sustainability of an activity or product refers to its ability to create favourable conditions for the community to ensure all that is necessary for living. Other studies [24, 25] have contended that social sustainability concerns more than basic necessities, such as human rights, gender equality, public participation and rule of law, all of which promote peace and social stability. Regarding biodiesel production, we have already shown the significant decline in Romanian interest in energy crops and especially rape crops, hence in this situation, the level of social sustainability is very low. Biodiesel synthesis is connected with the reduction in rapeseed oil production and so sustainability will remain at a low level. Because the combustion of biodiesel is only important for the environment (having no social effect), here we solely take into consideration biodiesel production for the social sustainability assessment. Finally, having in view the poor level of biodiesel production in Romania, we can see that social sustainability here is modest, yielding a score of 1 (Table 1).

3.4. Biodiesel sustainability calculation

Biodiesel sustainability will be calculated with equation 1, using the scores obtained for economic, environmental and social sustainability adjusted with the influence factors. The result is presented in Table 7.

The score obtained in Table 7 shows the low sustainability of biodiesel production and combustion in Romania, as a result of the very poor levels of economic and social sustainability. The total score corresponds to a low level of sustainability, even though the degree of environmental sustainability is high.

In analyzing this situation, we have identified a number of contributing factors that can be summarized as follows:

- The most important factor is the Romanian government's strategy, which has not supported the development of biodiesel production through granting fiscal aids to rapeseed producers and by reducing excise duties;
- The second factor is the influence of the international market, which offers large quantities of biodiesel at lower prices than the biodiesel produced in Romania. Countries such as Russia, China, Malaysia and Indonesia, which use palm oil for biodiesel synthesis, offer very attractive biodiesel prices, causing production in Romania to decline;
- A final factor that is specific to Romanian industry is the fact that all the refineries in the country are owned by foreign companies. Thus, there is little Romanian participation in the industry, with the result that each refinery purchases biodiesel from its owner's zone of influence. Therefore, Petrotel Lukoil Refinery (owner: Lukoil, Russia) purchases biodiesel from Eastern European countries like Russia, Ukraine and Moldova, but also from the above-mentioned Asian countries. Rompetrol Refinery (owner: KazMunayGas, Kazakhstan) applies a similar strategy to import biodiesel from the Asian market. A third refinery, Petrobrazi (owner: OMV, Austria), looks abroad to seek the cheapest price in order to increase its profits.

The future of biodiesel in Romania is connected to the EU strategy regarding the utilization of renewable fuels. Even if the biodiesel blending ratio were to be maintained or increased, the prognosis is not favourable, because the Romanian agricultural strategy is to reduce energy croplands so that they can be used instead for food products to satisfy the growing demand of the national and international markets. Support for this prognosis is provided by Eurostat statistics [26] indicating that Romania is the biggest producer of maize in Europe, a position that will be sustained in the coming years. Another aspect of the future of biodiesel, not only in Romania but also worldwide, is the rise of electric cars, which will replace diesel engines and thus have a direct effect on biodiesel consumption. All these aspects support our forecast that biodiesel production and consumption will remain at a very low level in Romania in the next decade.

4. Conclusions

Despite of its very high potential, Romania is a very small contributor to the biodiesel production. Even though the arable land per capita here is 0.41 ha, almost double the EU27 average (0.212 ha), Romanian rapeseed production is very low. As a result, the production sector remains underdeveloped without an internal feedstock for biodiesel synthesis and, we believe that the current situation will remain over the

next decade. Furthermore, due to Romania's implementation of EU regulations aimed at replacing diesel engines with electric ones, the future of biodiesel looks gloomy. Diesel fuel and, indirectly, biodiesel will be phased out of the vehicle fuel market if this decision will be applied.

Declarations

Ethics approval and consent to participate: All authors agree and consent to participate to this publication procedure.

Consent for publication: Both authors have read and agreed to the published this version of the manuscript.

Availability of data and materials: The data used in this paper are available in attached references.

Competing interests: The authors declare no conflict of interest.

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Nomenclature: Already presented in text.

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Tables

Table 1. Score given to sustainability factors for different achievement levels.

Achievement level	Score
No sustainability	1
Low sustainability	2
Medium sustainability	3
High sustainability	4

Table 2 - Total cost calculation for biodiesel production in Romania [15].

Code	Data used to calculate the cost for biodiesel production	2017	2018	2019
A	Cost of rapeseed crops on arable land ¹ (euro/ha)	350	350	355
B	Rapeseed productivity (t/ha)	2.79	2.55	2.26
C	Cost of rapeseed crops on rapeseed produced: $C = A / B$; (euro/t _{rapeseed})	125.45137	137.25157	157.08
D	Productivity of rape seed oil extraction (t _{oil} /t _{rape seed})	0.42	0.42	0.42
E	Cost of rape seed oil production: $E = C / D$ (euro/t _{oil})	298.69326	78.374	374.0
F	Average cost for oil production by extraction (euro/t _{oil})	125	123	120
G	Total cost for rape seed oil production: $G = E + F$ (euro/t _{oil})	423.69449	78.494	494.0
H	Productivity of Biodiesel synthesis by transesterification (t _{biodiesel} /t _{oil})	0.98	0.98	0.98
I	Cost of Biodiesel production: $I = G / H$ (euro/t _{biodiesel})	432.33458	96.504	504.08
J	Average cost for Biodiesel synthesis (euro/t _{biodiesel})	245	239	230
K	Total cost for Biodiesel produced in Romania: $K = I + J$ (euro/t _{biodiesel})	677.33697	96.734	734.08
L	Average cost for Biodiesel distribution to the refineries (euro/t _{biodiesel})	25.67	25	25
M	Price of Biodiesel without taxes: $M = K + L$ (euro/t _{biodiesel})	703	723	759

¹- The cost is calculated for the next agricultural operations: Plowing + Harrowing + Preparation of germination bed + Sowing
+ Harvesting + Transportation of the rapeseed from the field + Transportation of bales obtained as secondary production

Table 3. Reliability scale.

Reliability Grade	Iq (equation 2) $E \neq 0$	Environmental effects
10	Natural environment	- Environment is not affected by the activity/project;
10 ÷ 9	$Iq = 0 \div 0.25$ $E > 0$	- Environment is affected within allowable limits (Level A1); - the sum of positive effects is significant; - the activity/project generates a positive impact;
9 ÷ 8	$Iq = 0.25 \div 0.5$ $E > 0$	- Environment is affected within allowable limits (Level A2); - the positive and negative effects compensate each other; - the activity/project generates low impact;
8 ÷ 7	$Iq = 0.5 \div 1$ $E > 0$	- Environment is affected within allowable limits (Level A3); - the negative effects can be measured; - the alert threshold is reached;
7 ÷ 6	$Iq = -1$ $E < 0$	- Environment is affected over allowable limits (Level B1); - the negative effects are significant; - the intervention threshold is reached;
6 ÷ 5	$Iq = -1 \div -0.5$ $E < 0$	- Environment is affected over allowable limits (Level B2); - the negative effects cause discomfort to all the forms of life;
5 ÷ 4	$Iq = -0.5 \div -0.25$ $E < 0$	- Environment is affected over allowable limits (Level B3); - the negative effects are emphasized; - the impact is major;

Table 4. Evaluation matrix for effect size (E) calculation.

Type of activity	Environmental effects							
	Soil and subsoil	Surface and underground water	Air				Biodiversity	
			CO ₂	CO	NO _x	PM		VOC
Biodiesel production	0	0	+	0	0	0	0	0
Biodiesel combustion	0	0	+	+	-	+	+	0
Effect size (E)	0	0	+2	+1	-1	+1	+1	0

Table 5. Calculation of environmental impact on air.

Environmental impact parameters	CO ₂	CO	NO _x	PM	VOC
Effect size (E)	+2	+1	-1	0	0
Quality index (I _q)	+0.5	+1	-1	+1	+1
Reliability grade (RG)	9 - 8	8 - 7	7 - 6	8 - 7	7 - 6
Environmental effect level	A2	A3	B1	A3	A3

Table 6. Calculation of environmental impact for biodiesel production and combustion in Romania.

Environmental impact parameters	Soil	Water	Air	Biodiversity
Effect size (E)	0	0	+1	0
Quality index (I _q)	-	-	+1	-
Reliability grade (RG)	10	10	9 - 8	10
Environmental effect level	No effect	No effect	A2	No effect

Table 7. Biodiesel sustainability calculation.

Sustainability pillars	Sustainability score	Influence factor	S x F
Economic (EcoS)	2	0.5	1
Environmental (EnvS)	4	0.3	1.2
Social (SocS)	1	0.2	0.2
TOTAL (equation 1)			2.4

Figures

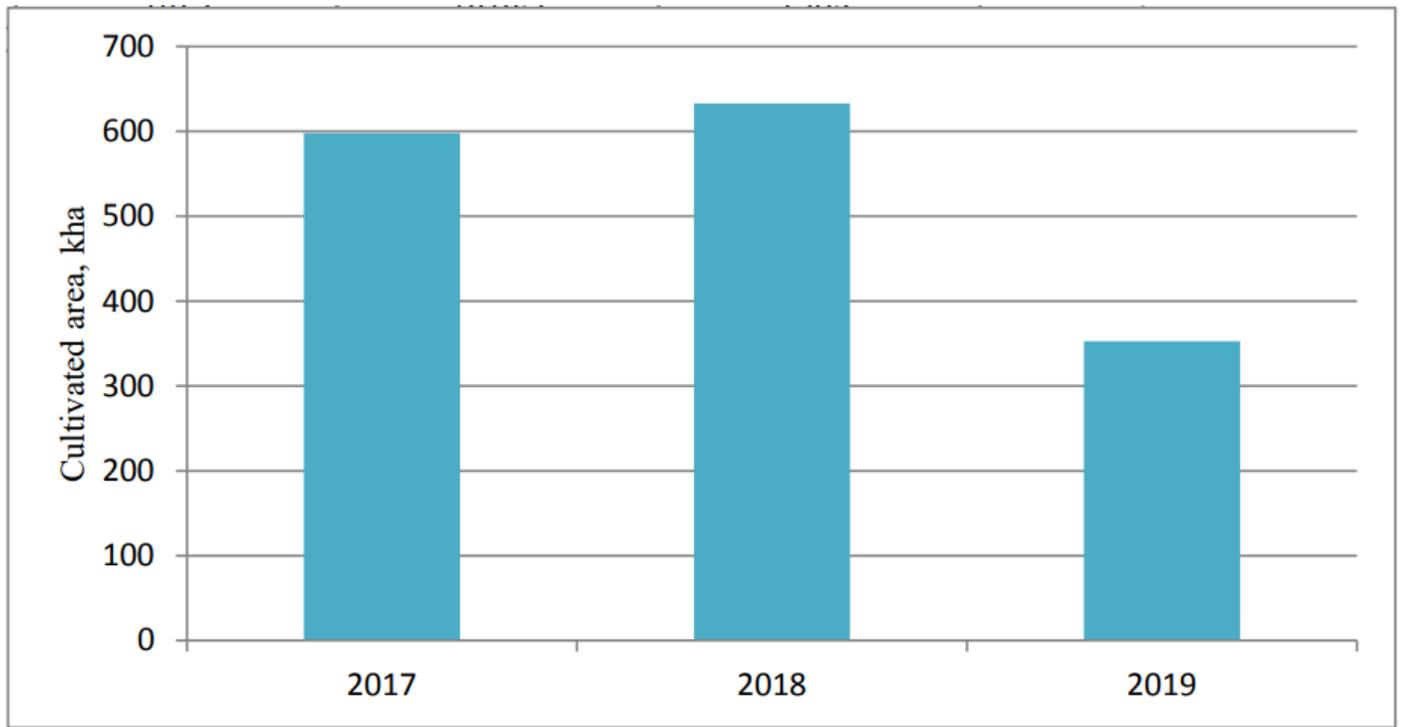


Figure 1

Area cultivated with rape crops in Romania

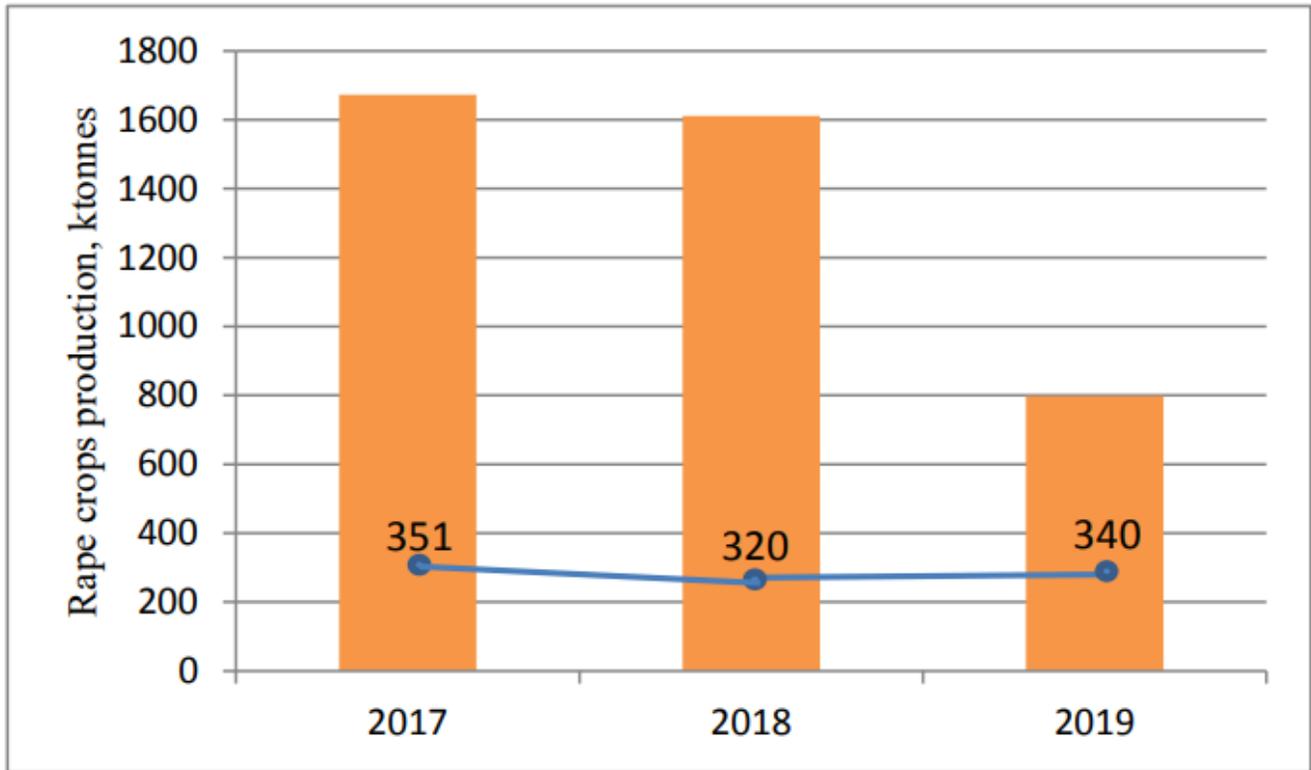


Figure 2

Total rape crops production in Romania and the evolution of the rape seed price (euro/t)

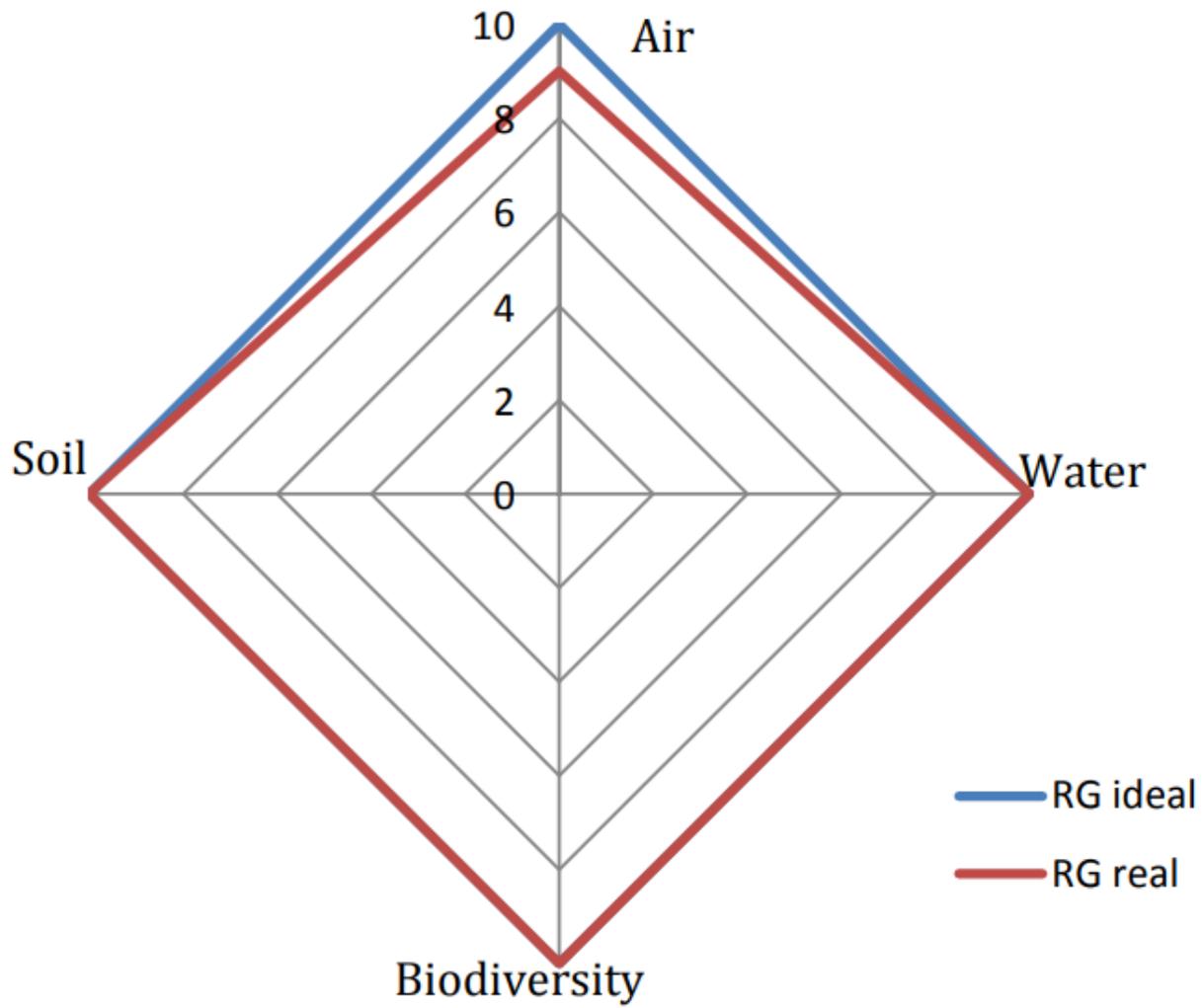


Figure 3

Global Impact Index graphical calculation.