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BIODIESEL PRODUCTION POTENTIAL FROM OILSEED CROPS IN SERBIA



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SUMMARY

This study aims to investigate the potential for biodiesel production from oilseed crops in Serbia, using a novel assessment method. The method involves calculating the arable land area that can be utilized for raw material production for the biodiesel industry. The available land for the production of biodiesel feedstocks is determined by subtracting the land required to meet the food needs of the domestic population and livestock from the maximum oilseed production area, which is defined as 20% of the total arable land area in Serbia. The findings reveal that approximately 353,000 hectares of land are available for producing raw materials for biodiesel production without compromising the domestic food supply. This land can provide enough raw materials to produce up to 324,000 tonnes of biodiesel annually, equivalent to 15.2% of the total domestic diesel fuel consumption for transportation in 2021.

Key words:

fatty acid methyl esters, fossil diesel, raw materials, substitution, vegetable oils

INTRODUCTION

Biodiesel is a liquid fuel that can be used in diesel engines with little or no modifications to the engine or its equipment (Tešić et al., 2008). Its primary advantage over fossil diesel is that it is produced from renewable and locally available raw materials, typically from crude or used cooking oils. Adopted in 2015, the Energy Sector Development Strategy of Serbia aimed to increase the use of biofuels in the transport sector, targeting a 10% share of biofuels in the final consumption of transportation fuels by 2020. The plan was to supply around 255,000 tonnes of biodiesel to the domestic market of transportation fuels, partly from domestic production (about 100,000 tonnes) and also from imports (the Ministry of Energy, Development and Environmental Protection, 2013). Despite having the industrial capacity to produce around 130,000 tonnes of biodiesel annually (Đurišić-Mladenović et al., 2018), Serbia has not yet met these targets, and the Serbian biodiesel production in recent years has been reduced to several smaller plants installed within agricultural companies for their own fuel needs.

High production costs have been identified as a significant hindrance to a greater market share of biodiesel in Serbia (Furman, 2005). However, changes in the market prices of fossil fuels and vegetable oils or state incentives, such as exempting biodiesel from excise taxes, could make biodiesel price-competitive with fossil diesel in the future (Tešić et al., 2008). In this context, production cost is not the most important limiting factor for a complete transition of the transportation sector to the use of biofuels, but rather the availability of raw materials, i.e. the inability of agriculture to provide sufficient quantities of raw materials for a complete replacement of fossil diesel with biodiesel.

In 2008, a comprehensive analysis of the agricultural potential for biodiesel feedstock production was conducted (Tešić et al., 2008), using the data from the previous decade (1996-2005). Thereafter, significant changes have occurred in the values of certain input parameters of the model. These changes are most noticeable in the yields of oilseed crops (which have significantly increased) and in the consumption of edible oils and fats (which have consistently declined in recent years). Additionally, the previous estimate did not consider the needs of livestock in oilseed meal.

This study aims to re-evaluate the potential of Serbian agriculture to supply the biodiesel industry with the necessary feedstock, using the latest data available and an improved approach. The focus of this research is on biodiesel produced from fresh vegetable oils, whereas the previous study (Đurišić-Mladenović et al., 2018) estimated the potential for biodiesel production in Serbia using alternative feedstocks such as used cooking oils, non-edible oils, and industrial wastes.

MATERIAL AND METHODS

The assessment of biodiesel production potential from oil crops in Serbia is based on determining the size of agricultural land available for biodiesel feedstock production. This study assumes that the maximum land available for this purpose is constrained by the following conditions and requirements:

- oilseed crop production takes place exclusively on already utilized arable land,
- the maximum proportion of land devoted to oilseed crops in the total arable land is conditioned by biological constraints such as crop rotation requirements, etc., and
- domestic oilseed production prioritizes food production and the supply of livestock feed.

The assessment method utilized in this study is illustrated in Fig. 1 and involves a series of steps. As the starting point, the total arable land area in Serbia is determined, which is illustrated as area A in Fig. 1. Subsequently, the maximum area of arable land suitable for cultivating oilseed crops is determined, considering biological limitations and recommended crop rotation practices, which is represented as area B in the figure. A portion of area B, specifically C, is reserved for meeting Serbia's annual food needs and for supplying unprocessed oilseeds to the animal husbandry sector. The remaining part of area B, excluding D_s and C_s, represents the potential area for growing oilseed crops intended for biodiesel production, represented as area D. Accordingly, the size of area D can be determined based on the following equation (eq. 1):

$$D = B - C - (C_s + D_s) \quad (\text{eq. 1})$$

Fig. 1 shows that the production of meal does not require additional land as it is a by-product of oil extraction used for food and biodiesel production. Consequently, a certain amount of meal is produced as a by-product during the processing of grain from areas C and D. It is assumed that the entire amount of seeding material for oilseed production in Serbia is provided domestically, for which C_s (the seeding material requirements of area C) and D_s (the seeding material requirements of area D) areas need to be reserved. After the size of area D is estimated, the possible production of biodiesel in Serbia is estimated quantitatively by multiplying the size of the D area by the specific biodiesel yield per unit area, which is dependent on the assumed cropping structure on D and oilseed yields.

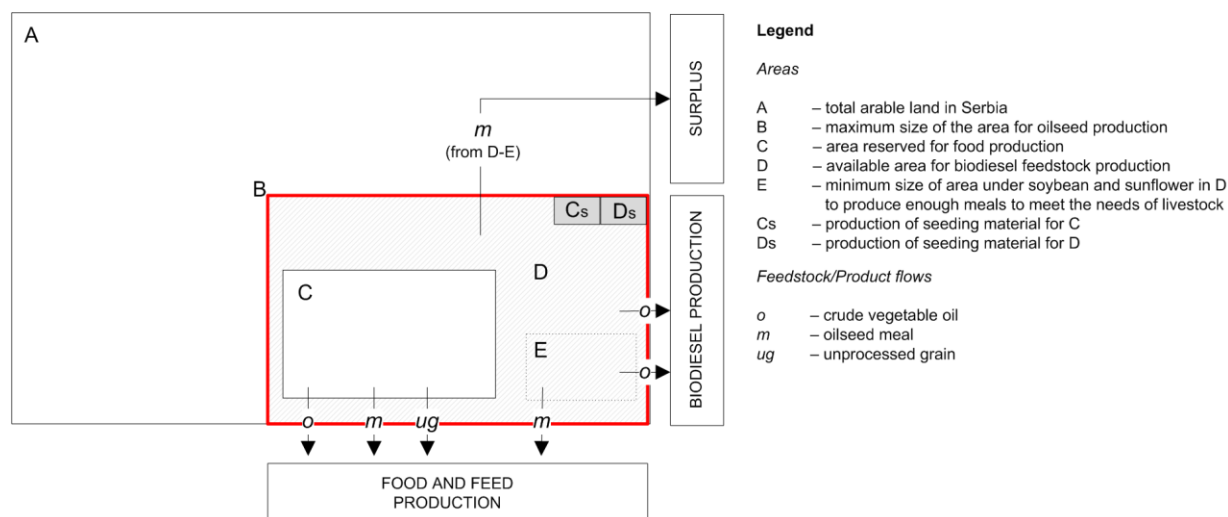


Figure 1. Schematic representation of the method for estimating the available land for biodiesel feedstock production
 Note: Proportions of the areas in the diagram are not accurate in relation to each other.

Some input parameters used in the method are accessible from published sources or can be easily determined based on the literature or statistical data, such as the size of areas A, B, Cs, and Ds, and the average yields of oil crops in Serbia. However, certain data, such as those required to estimate the size of the area C, were not readily available and had to be estimated in this study. The size of the area C is primarily dependent on the annual demand for oilseed-based food products, such as edible oil and vegetable fat, and the demand for oilseed-based feed in Serbia. The annual domestic demand for unprocessed sunflower and soybean grain, as well as their oils, is estimated based on the indicative balances of oilseeds and related products compiled annually by the Ministry of Agriculture, Forestry, and Water Management (MAFWM). These indicative oilseed balances determine the domestic consumption of a product by accounting for the difference between the domestic production and imports on one hand, and the exports of that product on the other, with adjustments made for the expected losses and changes in inventory levels at the beginning and end of the observed period (Milanović, 2011). As the MAFWM does not publish indicative balances for rapeseed, this study relies on the data on the quantities of domestically produced, imported, and exported rapeseed grain and rapeseed oil available from the Statistical Office of the Republic of Serbia (SORS) to create one. The amounts of sunflower and soybean meals and cakes consumed in Serbia are estimated based on the annual indicative balance sheets from the MAFWM. The information obtained from the Institute of Field and Vegetable Crops in Novi Sad suggests that the consumption of rapeseed meal is relatively insignificant compared to sunflower and soybean meal. Therefore, this study does not consider any potential demand for rapeseed meal. To verify the reliability of estimates regarding the quantity of oilseeds and oilseed-based products consumed in Serbia, the results are compared with the findings from a household consumption survey conducted by the Statistical Office of the Republic of Serbia (SORS). Additionally, they are compared with the estimated domestic consumption, calculated as the difference between the domestic production and net exports of a particular oilseed-based product (e.g., edible oil, margarine). Once the domestic demand for oilseeds and oilseed-based products is determined, the size of area C is determined by considering the average yields of oilseed crops and oilseed-based products per unit area in Serbia, a metric obtainable from the data sourced from the MAFWM and SORS. Given the potential variability of certain factors across different years, such as oilseed yields and net exports of crude vegetable oils, this study predominantly relies on average annual quantities over the ten-year period from 2012 to 2021.

RESULTS AND DISCUSSION

Production of sunflower, soybean and rapeseed in Serbia in the period 2012-2021

Sunflower, soybean, and rapeseed are Serbia's most extensively cultivated oilseed crops, and they also constitute the primary domestic feedstocks for biodiesel production. These oil crops were cultivated on an average area of about 417,000 hectares annually in the period from 2012 to 2021 (Tab. 1), which represents 16% of the 2,604,295 ha of arable land in Serbia (Statistical Office of the Republic of Serbia, 2022a). Sunflower and soybean dominate in terms of harvested areas, comprising approximately equal percentages of 47-49% in the total oilseed areas, whereas rapeseed areas make up about 5% of the total oilseed areas in Serbia (Tab. 1).

An analysis of the size of harvested areas in terms of their stability indicates significant fluctuations in the rapeseed areas (CV = 60%, Tab. 1), whereas the areas devoted to soybeans and sunflowers show greater stability over the observed ten-year period. During the observed period, the oilseed areas in Serbia increased at average annual rates of 1.9%, 4.6%, and 19.1% for sunflowers, soybeans and rapeseed, respectively. The growth of areas devoted to sunflowers and soybeans is more pronounced in Central Serbia, whereas the rapeseed areas increased at a higher annual rate in Vojvodina (22.3% compared to 9.9% in Central Serbia, Tab. 1).

From 2012 to 2021, the average yields of sunflowers, soybeans, and rapeseed in Serbia were 2.8 t/ha, 2.75 t/ha, and 2.84 t/ha, respectively (Tab. 1). The crop yields show a tendency to increase at annual rates of 5.6% for sunflower, 7.9% for soybean, and 4.1% for rapeseed during the same period (Tab. 1). The soybean yields in Serbia are comparable to those in the European Union (EU), whereas the rapeseed yields are 9% lower, and sunflower yields are 31% higher than the average yields achieved in the EU in the same period (the average yields of oilseed crops in the EU were calculated using the data from Ritchie et al., 2022). The Vojvodina region is characterized by higher yields compared to the Central Serbia region, by 28% in the case of sunflower and rapeseed, and by 13% in the case of soybean. During the observed period, the rapeseed and sunflower yields were relatively stable (CV $\leq$ 13%), whereas the soybean yields were characterized by greater variability, as confirmed by the high coefficient of variation (CV = 21%) (Tab. 1).

Regarding the regional distribution, it is noteworthy that 90% of the total area devoted to sunflowers and soybeans, and 80% of the total area devoted to rapeseed, are located in Vojvodina (Tab. 1). In the period under consideration, oil crops were grown on an average area of about 376,000 hectares in Vojvodina (Tab. 1), which represents 26% of the arable land in the province (Statistical Office of the Republic of Serbia, 2022a). In Central Serbia, this group of oil crops was grown on only about 41,000 hectares (Tab. 1) or about 4% of the available arable land in the region (Statistical Office of the Republic of Serbia, 2022a).

Table 1. Average harvested areas, yields, and production of oilseed crops in the period 2012-2020

Crop	Vojvodina			Central Serbia			Total
	avg.	CV	GR	avg.	CV	GR	avg.
Sunflower							
Harvested area (ha)	182,732	10.8%	+1.4%	20,042	22.3%	+7.3%	202,774
Yield (t/ha)	2.85	13.8%	+5.9%	2.22	14.0%	+6.1%	2.80
Production (t/year)	523,953	20.2%	+7.5%	45,443	33.0%	+15.6%	569,396
Soybean							
Harvested area (ha)	177,183	15.0%	+4.2%	17,341	30.3%	+9.5%	194,524
Yield (t/ha)	2.76	21.8%	+8.1%	2.44	22.0%	+8.1%	2.75
Production (t/year)	491,589	26.2%	+10.4%	42,590	39.0%	+15.5%	534,179
Rapeseed							
Harvested area (ha)	16,098	64.8%	+22.3%	3,563	40.1%	+9.9%	19,661
Yield (t/ha)	2.98	9.1%	+4.0%	2.33	14.4%	+2.0%	2.84
Production (t/year)	48,610	67.2%	+28.4%	8,083	35.0%	+11.9%	56,693

Legend: avg. - average value; CV - coefficient of variation; GR - average annual growth rate (%).

Source: Authors' calculations based on data from the SORS on achieved yields and harvested areas of soybean, sunflower, and rapeseed in the period 2012-2021.

Domestic needs for unprocessed grains, vegetable oils and fats, and oilseed meals

According to MAFWM data, the average annual domestic consumption of unprocessed sunflower and soybean seed in the period from 2012 to 2021 was around 10,000 tonnes and 35,600 tonnes, respectively (Tab. 2). In the same period, the average domestic consumption of crude sunflower oil was 82,600 tonnes, whereas the consumption of soybean oil was 22,400 tonnes annually (Tab. 2). During the investigated period, the average annual exports of rapeseed seeds and oil were 51,066 tonnes and 9,600 tonnes, respectively, whereas the imports of these products remained relatively low (see Table 2). To maintain this level of exports, the domestic production of rapeseed cannot be lower than 75,399 tonnes (Tab. 2), which is approximately 35% higher than the production reported by SORS for the same period (Tab. 1). Given the lack of reliable data on the consumption of unprocessed rapeseed and rapeseed oil in Serbia, and the results of the balancing exercise, which suggest that a significant portion of domestic production is likely exported, this study assumes that the domestic consumption of unprocessed rapeseed and rapeseed oil is negligible. Therefore, rapeseed will not be taken into consideration when estimating Serbia's total

requirements for oilseed crops, particularly considering its relatively small share in the total production of oilseed crops in Serbia (see Tab. 1).

Table 2. Indicative balances of sunflower, soybean, and rapeseed (average annual quantities in the period 2012-2021)

		SUNFLOWER ^(a)	SOYBEAN ^(a)	RAPESEED ^(b)
GRAIN	TOTAL AVAILABLE QUANTITIES	590,700	587,600	75,399
	Domestic production	569,500	534,300	75,091
	Import	21,200	53,300	308
	CONSUMPTION	591,500	579,600	75,399
	Total domestic consumption	492,200	494,500	24,332
	Industrial processing	468,000	432,200	22,449
	Other purposes (mostly animal feed)	10,000	35,600	0
	Losses	14,200	26,700	1,883 ^(c)
	Export	99,300	85,100	51,066
	NET STOCKS	800	-8,000	0
CRUDE VEGETABLE OIL	TOTAL AVAILABLE QUANTITIES	215,300	78,200	9,562
	Domestic production	206,000	77,900	9,204 ^(d)
	Import	9,300	300	357
	CONSUMPTION	212,200	77,900	9,600
	Total domestic consumption	82,600	22,400	0
	Consumption as food for humans	76,600	21,400	0
	Consumption for other purposes	6,000	1,000	0
	Export	129,600	55,500	9,600
	NET STOCKS	-3,100	-300	0

Explanation: ^(a) Authors' calculations based on annual indicative balances of sunflower and soybean (Ministry of Agriculture, Forestry and Water Management, 2022); ^(b) Authors' calculations based on foreign trade statistics of the SORS; ^(c) It is assumed that the reduction in the harvested mass of the rape seeds and sunflower during transport and storage was the same, i.e., 2.5%. ^(d) It is assumed that the yield of crude rapeseed oil is 0.41 kg/kg seed.

According to the data obtained from household surveys conducted in 2021, the average household in Serbia consumes 29.2 litres of edible oil and 4.4 kg of other vegetable fats annually (Statistical Office of the Republic of Serbia, 2022b). With an average household size of 2.69 members (Statistical Office of the Republic of Serbia, 2022b), this translates to a per capita consumption of approximately 10.8 litres of edible oil and 1.6 kg of vegetable fats. Therefore, the households in Serbia consume an estimated 68,209 tonnes of edible oil and 11,172 tonnes of vegetable fats annually (Tab. 3). It is further estimated that the production of these quantities requires processing around 81,200 tonnes of crude vegetable oil per year (Tab. 3).

Table 3. Consumption of edible oil and other vegetable fats in households in Serbia (data for 2021)

Food product	Consumption per capita, kg	Total consumption ^(a) , t/year	Conversion coefficients to equivalents of crude vegetable oil	Required amount of crude vegetable oil, t/year
Edible oil	10.0	68,209	1.053 ^(b)	71,799
Other vegetable fats	1.6	11,172	0.842 ^(c)	9,408
Total				81,206

Note: ^(a) The population is 6,830,000, ^(b) Losses during refining of crude vegetable oil are around 5% (Fišteš et al., 2022), ^(c) It is assumed that 0.8 kg of edible oil is needed to produce 1 kg of product (e.g. margarine).

Based on the indicative balances of MAFWM analysis, it was found that around 98,000 tonnes of crude sunflower and soybean oil is processed into food products and consumed in Serbia (Tab. 2). The household survey approach, which was also used in some previous studies, including Đurišić-Mladenović et al. (2018) and Čurović (2019), estimates the oilseed-based food consumption at around 81,200 tonnes of crude vegetable oil equivalents (Tab. 3). However, it is important to note that the actual consumption of vegetable oils and fats in Serbia is higher than both of these estimates. The approach based on the indicative balances does not include the consumption of refined palm oil, which is imported at an average of around 28,500 tonnes per year and mostly used for food purposes (Tab. 4). Conversely, the household survey approach, does not take into account the quantities of edible oils and fats consumed outside households. It is difficult to obtain reliable data on the consumption of edible oils and fats outside households in Serbia. However, the European and global statistics show that 40-50% of total edible oil and vegetable

fat consumption in a country is used in the HORECA sector (hotels, restaurants, and cafes) and industry, whereas the remainder is used in households (Jurac, 2011). Assuming that households account for 60% of total vegetable oil and fat consumption in Serbia, the total annual consumption expressed in crude oil equivalents is about 135,300 tonnes per year. If we were to increase the estimated domestic consumption of crude oil based on the balance sheet (76,600 tonnes of sunflower oil, 21,400 tonnes of soybean oil, Tab. 2) by the equivalents of sunflower and soybean oil that could replace the imported refined palm oil (an average of around 28,500 tonnes per year, Tab. 4), we would come to a slightly lower demand of around 128,000 tonnes of crude vegetable oil.

The analysis of data on the domestic production and foreign trade statistics of imported and exported vegetable oils and fats indicates that the average annual demand for these products in the period 2012-2021 was around 136,000 tonnes of crude vegetable oil equivalents (Tab. 4). This figure encompasses not only the quantities of crude vegetable oils used for food consumption, but also those used for non-food purposes such as the production of cosmetic products, paints, and varnishes. The MAFWM data reveals that approximately 7,000 tonnes of sunflower and soybean oil are used outside of the food industry (Tab. 2), whereas no data is available for palm oil. Therefore, the results based on foreign trade statistics indicate that the total consumption of oilseed-based food in Serbia was around 129,000 tonnes of crude vegetable oil equivalents, assuming that palm oil is used exclusively for food purposes. This estimate is in close agreement with the value obtained through balancing, differing by only about 1%. Considering that there are no precise data on the share of the HORECA sector and industry in the total consumption of vegetable oils and fats in Serbia, and that the results of estimates based on the indicative balances and foreign trade statistics are based on the official SORS and MAFWM data, and almost coincide, the latter are adopted as authoritative.

Table 4. Estimate of domestic needs in raw oil equivalents based on the foreign trade

	Average amount (2012–2021), t/year	Conversion coefficients (^c)	Equivalent amount of crude vegetable oil, t/year
A) AVAILABLE QUANTITIES			313,851
Production of crude sunflower oil (^a)	206,000	1.000	206,000
Production of crude soybean oil (^a)	77,900	1.000	77,900
Import of refined palm oil (^b)	28,453	1.053	29,951
B) NET EXPORT (^b)			177,952
Net export of margarine	-7,074	0.842	-5,957
Net export of other vegetable fats	787	0.842	663
Net export of crude sunflower and soybean oil	115,979	1.000	115,979
Net export of refined sunflower and soybean oil	63,904	1.053	67,267
DIFFERENCE (A-B)			135,899
Explanation: (^a) Data from the indicative balance of oilseed crops (Tab. 2); (^b) Authors' calculation based on data from the foreign trade statistics of the SORS; (^c) see Tab. 3.			

In addition to unprocessed oilseeds and crude vegetable oil, significant amounts of oilseed meal are also consumed in Serbia, primarily as livestock feed. According to MAFWM, the annual demand for sunflower meal is around 135,000 tonnes, whereas the soybean meal demand is around 310,000 tonnes (Ministry of Agriculture, Forestry, and Water Management, 2022). Although there is no reliable data on the consumption of rapeseed meal, the estimated domestic production (around 12,000 tonnes of meal produced as a by-product of 9,600 tonnes of oil, see Tab. 2) and exports of meal (averaging around 5,000 tonnes per year between 2012 and 2021 according to SORS) suggest that it cannot exceed 7,000 tonnes. According to unpublished estimates from the Institute of Field and Vegetable Crops in Novi Sad, the annual consumption of rapeseed meal in Serbia is projected to be approximately 1,000-2,000 tonnes. Given the absence of official estimates and its relatively minor significance compared to sunflower and soybean meal, this study does not account for any potential demand for rapeseed meal.

The production of the defined quantities of crude sunflower and soybean oil for food purposes (Tab. 5) results in approximately 100,000 tonnes of sunflower meal, which largely fulfils domestic livestock needs. However, the resulting amount of soybean meal, about 116,000 tonnes, falls significantly short of the domestic demand. As oilseed meal is also generated during the production of oil feedstocks for biodiesel, this shortage could be compensated for by the quantities that arise in the production chain of biodiesel. To address the shortage of approximately 34,000 tonnes of sunflower meal and 194,000 tonnes of soybean meal (Tab. 5), it is necessary to include sunflower and soybean in the cropping structure on the area designated for the cultivation of oilseed crops as feedstocks for the biodiesel industry. Based on the assumed meal yield of around 0.76 kg per kg of grain for soybean and 0.42 kg for sunflower (Ministry of Agriculture, Forestry, and Water Management, 2022), it is estimated that at least 97,631 ha

and 29,774 ha of land should be allocated for soybean and sunflower, respectively, to compensate for the meal shortage.

Table 5. Estimated annual needs of Serbia in unprocessed oilseeds, crude oil, and oilseed meal (average quantities in the period 2012-2021)

PRODUCT	Sunflower	Soybean
UNPROCESSED GRAIN	10,000	35,600
consumption of unprocessed grain (mostly for livestock feed) ^(a)	10,000	35,600
CRUDE OIL	100,561	27,390
consumed as food ^(a)	76,600	21,400
for replacement of imported palm oil ^(b)	23,961	5,990
OILSEED MEAL	134,700 ^(c)	309,500 ^(c)
	(34,139) ^(d)	(193,853) ^(d)

Explanation: ^(a) Data obtained from the indicative balance sheets of oilseeds (as in Tab. 2); ^(b) Authors' calculations based on the assumption that 80% of imported palm oil is replaced by sunflower oil, and the remaining 20% by soybean oil; ^(c) Authors' calculations based on annual indicative balance sheets of sunflower and soybean meal in the period 2012-2021 (Ministry of Agriculture, Forestry, and Water Management, 2022); ^(d) The quantities in parentheses represent the difference between the total annual needs and the quantities of meal generated as a by-product from the production of crude oil at amounts defined in this table.

Estimating the available land area in Serbia for producing biodiesel feedstocks

The total area of used agricultural land in Serbia is 3,504,290 hectares, out of which 2,604,295 hectares are arable land (Statistical Office of the Republic of Serbia, 2022a). However, only a portion of this area is suitable for oilseed production, as oilseed crops do not tolerate monoculture cultivation. It is recommended to grow oilseed crops such as soybeans, sunflowers, and rapeseed on the same land after four or five years (Marinković et al., 2011). The same period must be allocated between two oilseed crops due to specific diseases and common pests. Therefore, this study assumes that the area devoted to oil crops should not exceed 520,859 hectares, which is 20% of the total arable land in Serbia (Tab. 6).

Table 6. Estimate of available land for the production of raw materials for biodiesel

Description of the area	In Fig. 1:	Size of the area (ha)
Total arable land in Serbia	A	2,604,295 ^(c)
Potential area for growing oilseed crops (20% of area A)	B	520,859
Land area required for production of unprocessed grain to meet domestic demand of the animal husbandry ^(a)		3,663 ^(d)
Land area required for production of crude vegetable oil-based food products to meet domestic demand ^{(a) (b)}	C	13,627 ^(e)
		87,703 ^(d)
		58,244 ^(e)
Land area for the production of seeding material	Cs	653 ^(d)
		3,953 ^(e)
Available land area for the production of biodiesel feedstocks and associated seeding material	D+Ds	353,016

Explanation: ^(a) Calculated using the average yields from the period 2017-2021 and assuming an average reduction in the harvested mass of sunflowers and soybeans of 2.5% and 5.0%, respectively, in the pre-processing stage, e.g. during storage and transport of the seeds (Ministry of Agriculture, Forestry, and Water Management, 2022); ^(b) It is assumed that 0.42 kg of oil can be produced from one kg of sunflower and 0.18 kg of oil can be produced from one kg of soybean (Ministry of Agriculture, Forestry, and Water Management, 2022); ^(c) Statistical Office of the Republic of Serbia (2022a); ^(d) area devoted to sunflower; ^(e) area devoted to soybean.

To ensure sufficient supply of unprocessed grain and crude vegetable oil-based food products for domestic consumption, a portion of the total area designated for oilseed production must be reserved. Based on the annual need for these products (as provided in Tab. 5), the average grain yields (as presented in Tab. 1) adjusted for estimated losses (explained below Tab. 6), and the typical oil content of sunflower and soybean grain, it is estimated that around 163,000 hectares of land must be set aside for this purpose.

In this study, it is assumed that all the required seeding material for growing oilseed crops is produced in Serbia, which leads to an additional 4,606 hectares of land being set aside for this purpose (Tab. 6). This estimation is based on the literature data indicating that approximately 5,500 ha is required to produce seeding material sufficient to

establish 100,000 ha devoted to soybeans (Milošević & Kobiljski, 2011), and the data from the Institute of Field and Vegetable Crops in Novi Sad indicating that the production of sunflower or oilseed rape on an area of 100,000 ha requires seeding materials from 714 ha and 233 ha, respectively.

The total land area available for cultivating oilseed crops to produce biodiesel, as well as the necessary seeding material, is estimated to be 353,016 hectares, as presented in Tab. 6. This figure was obtained by subtracting the area required for producing unprocessed oilseed and oilseed-based food products for domestic consumption, along with the necessary seeding material (167,843 ha, Tab. 6), from the total area of land suitable for oilseed production (520,859 ha, Tab. 6).

Potential biodiesel production from oilseed crops cultivated on the designated land area in Serbia

The available area for biodiesel feedstock production can support the growth of various oilseed crops, with sunflower and oilseed rape being the most promising due to their high oil yields per unit area. However, to meet domestic demand for oilseed meals, soybean must also be grown on at least 97,631 hectares, while sunflower should occupy at least 29,774 hectares. Three scenarios were considered for oilseed production on the available land. The first two aim to maximize biodiesel output by prioritizing rapeseed and sunflower as primary oilseed crops, while keeping soybean's share of the cropping structure at a minimum. The third scenario assumes that oilseed crops will be incorporated into the cropping structure based on their average share in the total areas under oilseed crops in Serbia from 2012 to 2021.

It is estimated that the designated area for biodiesel feedstock production can provide sufficient raw materials to produce from 280,498 to 323,922 tonnes of biodiesel annually, depending on the assumed cropping structure (Tab. 7). This amount of biodiesel could substitute up to 15.2% of the 1,939,355 tonnes of fossil diesel (Statistical Office of the Republic of Serbia, 2023) consumed in the transport sector of Serbia in 2021 (on energy basis).

Table 7. Possible biodiesel production from available land (353,016 ha) depending on crop structure

	Crop structure	Area (ha) ^(a)	Grain yield (t/ha) ^(b)	Crude oil yield (kg/kg grain)	Biodiesel production (t/year) ^(c)	Possible replacement of fossil diesel (in 2021) ^(d)
I	28% Soybean	97,631	2.61	0.18	44,994	15.2%
	72% Sunflower	248,230	2.73	0.42	278,928	
	Total	345,861			323,922	
II	28% Soybean	97,631	2.61	0.18	44,994	15.1%
	9% Sunflower	29,774	2.73	0.42	33,457	
	63% Rapeseed	219,515	2.77	0.41	244,229	
	Total	346,921			322,680	
III	46% Soybean	157,346	2.61	0.18	72,514	13.1%
	49% Sunflower	168,108	2.73	0.42	188,898	
	5% Rapeseed	17,155	2.77	0.41	19,086	
	Total	342,609			280,498	

Note: ^(a) The area is adjusted to account for the portion that needs to be reserved for the production of seeding material; ^(b) The average yield for the period of 2017-2021 is adjusted to account for expected losses in grain mass before the oil mill stage (further details can be found in the explanation below Tab. 6); ^(c) It is assumed that 98 kg of biodiesel is obtained from 100 kg of crude vegetable oil; ^(d) The calculation is based on an energy basis, assuming that the lower heating values of biodiesel and fossil diesel are 37 MJ/kg and 43 MJ/kg, respectively (Government of the Republic of Serbia, 2019).

The results of the analysis of the exported and imported quantities of oilseed crops and oil crop-based products confirm previous estimates (Tab. 8). Between 2012 and 2021, an average of 259,283 tonnes of sunflower, soybean, and rapeseed oil were net exported from Serbia (calculated from Tab. 8). This amount includes not only the net export of crude and refined oil but also the amounts of oil contained in the net exported quantities of oilseeds (Tab. 8). During the same period, an average of 28,500 tonnes per year of refined palm oil was imported, whereas the average annual net import of margarine and other vegetable fats was about 6,300 tonnes (Tab. 8). This means that the average net export of vegetable oils expressed in crude oil equivalents was approximately 224,000 tonnes annually (Tab. 8). This surplus of vegetable oil could have been kept in Serbia and processed into roughly the same amount of biodiesel. Considering that this surplus was achieved using only 16% of arable land, the estimated theoretical potential (Tab. 7), which is based on the assumed 20% share of oilseed crops, appears to be realistic.

Table 8. Average net exports of oilseeds and vegetable oil from Serbia in the period 2012-2021

Oil crop	Product	Average net export (2017-2021) ^(a) (t)	Conversion coefficients ^(b)	Amount in crude oil equivalents (t)
Soybean	Grain	66,103	0.18	11,899
	Crude oil	56,624	1.00	56,624
	Refined oil	1,446	1.05	1,522
Sunflower	Grain	81,140	0.42	34,079
	Crude oil	59,355	1.00	59,355
	Refined oil	62,458	1.05	65,746
Rapeseed	Grain	50,758	0.41	20,811
	Crude oil	8,381	1.00	8,381
	Refined oil	823	1.05	866
Oil Palm	Refined oil	-28,453	1.05	-29,951
Mix	Margarine and other vegetable fats	-6,287	0.85	-5,295
Total				224,037

Explanation: ^(a) Calculated based on the data from the SORS foreign trade database; ^(b) see Tab. 3.

Table 7 shows the theoretical potential for biodiesel production from oilseeds in Serbia, but the ability to realize this potential is subject to various limitations and conditions, such as economic, social, technical, organizational, logistical, and environmental factors, as well as political and strategic interests (National Research Council, 2011). In Serbia, high production costs and limited profitability of the domestic biodiesel industry are the major constraints to achieve the full biodiesel potential (Furman, 2005; Tešić et al., 2008). As a result, raw materials are often exported or diverted to other industries, as biodiesel production is less profitable than some alternative uses of raw materials, such as processing oilseeds into edible oil. Furthermore, the increasing stringency of greenhouse gas emission standards and sustainability criteria in the life cycle of biofuels presents a significant challenge, particularly for biodiesel produced from conventional raw materials like edible vegetable oils (Dusser, 2019). This paper will comprehensively analyse another limitation that may impede the full potential of biodiesel production, i.e. the challenge of reaching the 20% share of oilseed crops in Serbia's total arable land.

Over the past decade, approximately 16% of the Serbian arable land has been used for oil crops. Achieving the 20% target would require an additional 100,000 hectares to be dedicated to oilseed crops. An analysis of the regional distribution of oilseed production in Serbia has shown that in Vojvodina, oil crops have been grown on areas that already exceed the optimal share considered in terms of yield sustainability (20% of the total area). Therefore, it is likely that any future expansion in the area devoted to oil crops would occur mainly in Central Serbia, where less than 5% of arable land is currently used for this purpose.

Expanding oilseed cultivation in Central Serbia faces several limitations. The areas with suitable edaphic-climatic conditions for oilseed cultivation are limited. In some areas of Central Serbia, there is a decades-long tradition of cultivating sunflower, especially in Eastern Serbia (primarily in Braničevo, Bor, and Podunavlje Districts). There, the climate and soil quality favour sunflower, considering better adaptation to drought during the summer vegetation period than other crops traditionally grown in this region (Miklić et al., 2018). Furthermore, the only oil mill in Central Serbia is located in this region (Čurović, 2021). Rapeseed cultivation also has a long tradition in Eastern Serbia, as evidenced by descriptions of cultivation technology in agricultural handbooks from the early 20th century (Klajn, 1938). Although rapeseed can be grown successfully in hilly-mountainous areas up to 750 m above sea level (Marjanović Jeromela & Prodanović, 2021), most cultivation areas are currently limited to the Braničevo district and the Belgrade region. In the Mačva district, where there are larger plots of deep, fertile soil, soybean is grown, and they achieve high yields and good seed quality. High air humidity during flowering and fertilization is essential for this species, so soybean can also be grown in the valleys of major rivers outside Vojvodina (Đukić et al., 2021). Other areas in Central Serbia are less suitable for growing oilseed crops, and their share in the cropping structure is currently insignificant (Statistical Office of the Republic of Serbia, 2013).

The second challenge facing oilseed production is the high cost of capital equipment, particularly for crops such as soybean and rapeseed, which require precision planters and combine harvesters (Milošević & Kobiljski, 2011). To recoup the significant investment in expensive machinery, a high utilization rate is essential. Consequently, oilseed production is concentrated in regions with large agricultural farms, where the distance between plots does not hinder

the efficient use of machinery (Popović et al., 2010). This challenge is particularly pronounced in Central Serbia, where the average farm size is approximately half that of Vojvodina (Statistical Office of the Republic of Serbia, 2022a), and arable plots are frequently situated further apart. As a result, the use of costly equipment can be financially unfeasible for the vast majority of farms in Central Serbia, posing an obstacle to the growth of the oilseed industry in this region.

The third obstacle to increased production of oilseed crops in Central Serbia arises from the uneven regional distribution of processing facilities in the country. Out of the nine oil mills in the country, eight are situated in Vojvodina, along with the majority of oilseed storage capacities (Čurović, 2021). After harvest, oilseed crops require cleaning and drying to achieve a moisture content that enables safe storage and optimal yields of oil and by-products later in the processing stage (Milošević & Kobiljski, 2011). However, in many parts of Central Serbia, adequate storage and processing facilities are either unavailable or located too far away, rendering oilseed production financially unviable.

To overcome these challenges, it is crucial to invest in the education of farmers, development of oilseed varieties that are specifically adapted to the unique edaphic and climatic conditions in Central Serbia (Miklić et al., 2018; Marjanović Jeromela & Prodanović, 2021), and the construction of essential infrastructure, such as adequate storage and processing facilities. However, accomplishing these objectives will require substantial time and investment, which may not be immediately feasible, given the current state of domestic agriculture and the limited funds allocated from the Serbian agrarian budget. Therefore, it is unlikely that oilseed cultivation will attain the targeted 20% share of total arable land in the region in the foreseeable future.

CONCLUSION

This study proposes an improved method for assessing Serbia's potential for domestic biodiesel production from oilseed crops. The new approach offers a more comprehensive evaluation of the annual demand for oilseed-based food products, resulting in a more robust assessment. Additionally, it highlights the importance of considering domestic demand for oilseed meals in the assessment of biodiesel production potential. Although the demand for oilseed meal does not affect the overall size of the area available for biodiesel raw material production, it does impact the crop structure on this land, which in turn influences the selection of raw materials for biodiesel production.

The results of this study indicate that the total domestic demand for edible oil and vegetable oil-based food products is approximately 128,000 tonnes of crude oil equivalents annually. It is estimated that roughly 163,000 hectares are needed to meet domestic needs for vegetable oil-based food products and the needs of livestock in unprocessed oilseed grains based on average yields of oilseeds from 2012 to 2021. The study shows that Serbia has an available arable land of around 353,000 hectares for biodiesel feedstock production, which can provide enough raw materials to produce up to 324,000 tonnes of biodiesel per year. This amount of biodiesel production can substitute up to 15% of fossil diesel used for transportation in Serbia, without jeopardizing food supply, and ensuring that livestock receives oil meal from domestic production.

Achieving the 20% share of oilseed cultivation in Serbia's total arable land area remains a significant challenge in fully realizing the potential of agriculture to produce raw materials for the biodiesel industry. Nevertheless, a closer analysis of foreign trade statistics shows that Serbia has exported an average of 224,000 tonnes of crude vegetable oil equivalents annually between 2012 and 2021, including net exported quantities of oilseeds and oil crop-based products. If this amount of vegetable oil were processed locally, it could yield a comparable quantity of biodiesel. These findings indicate that, even with the current level of oilseed production, the country has considerable potential for biodiesel production.

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