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RESEARCH ARTICLE

Application of mathematical model for design of an integrated biodiesel-petroleum diesel blends system for optimal localization of biodiesel production on a Bulgarian scale

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ABSTRACT

This paper proposes a mixed integer linear programming (MILP) model for optimal design and planning of biodiesel supply chain for Bulgarian case study. Sunflower and rapeseed are used as raw materials for biodiesel production. The country has been divided into twenty-seven regions corresponding to its districts. The existing in each region crops, oil and biodiesel plants and potential ones are represented as discrete variables in the model. The mathematical model is developed using GAMS software and represents a complete decision-making tool. The proposed strategy can be applied for other countries or regions by adjusting the required for the modeling data

Keywords: Integrated biofuel supply chain, optimal design, MILP model, minimum total GHG emission, minimum annualized total cost, Bulgarian scale

1. INTRODUCTION

To replace the increasing amount of fossil-based diesel by biodiesel is one of the targets of the sustainable development, because the biodiesel production can ensure significant economical and environmental benefits. Each country has to analyze the needs of the economical and environmental feasibility in order to produce its own biodiesel. The analysis has to include a complete production chain starting from the availability of raw materials, their intermediate transformations up to the end products and also the storing and the distribution of the products to internal and external markets. The development of a large network with several stages and possible different alternatives in each stage is required, according to the availability of the biomass crops, the location of products storage, conversion facilities, way of transportation of biomass and products between the regions, etc.

With the aim of mitigating emissions, diversifying the energy supply and reducing the dependence on imported fossil fuels, the European Union (EU) has set ambitious targets for a transition to renewable energy [1]. An integrated energy and climate change policy adopted in 2008 requires the following general targets: 20% greenhouse gas reduction, 20% reduced energy use through increased energy efficiency and a 20% share of renewable energy by 2020 [2]. As a key to reach these targets the increased production and use of bioenergy is promoted [3]. It is expected the biomass to replace the fossil fuels in stationary applications, such as heat or electricity production, as well as in the transport sector. In order to explicitly stimulate a shift to renewables in transportation, the European Commission has, in addition to the overall 20% renewable energy target, set a mandatory target of 10% renewable energy in transport by 2020 [4], with a transitional target of 5.75% for 2010 an achievement of 10% up to 2020 [5].

It can be achieved using biofuels (biodiesel and bioethanol) as a tool for decreasing the emissions of [6]. Study [7] emphasis on the main biofuels sources used for first generation biofuels production as well as global biofuel projections for coming decades.

Other research works are devoted of development of mixed integer linear programming (MILP) modeling approaches for optimal design and planning of the supply chains activities in the biodiesel [8] production.

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In Ref. [9], an approach for optimal design of integrated biodiesel-petroleum diesel blend system is proposed. It is based on mixed integer linear programming (MILP) model.

Recently, (2013-2015) a variety of research works have been published which deal with the problems associated with biofuel supply chains.

In some of them new methods of synthesis and optimization have been proposed [10]. Other works [11], [12] are focused on sustainability at operation of biofuel supply chain as well as the problems solution considering different aspects of sustainable development [13].

In Ref. [14] an effective method for the synthesis of biofuel supply chain is proposed. Its efficiency has been proved on a specific numerical example. As a case study a biofuel supply chain in North Dakota, USA is considered. The problem is solved using MATLAB and GAMS software on a Sony Vaio Laptop of 5 GB RAM, and processor's speed of 3.5 GHz.

In [15] a modeling approach for design of biofuel supply chain is presented. In order to demonstrate its performance in the presence of data uncertainty it has been proved on a hypothetical case study. The proposed model could be used for design of biofuel supply chain, which results in optimization of the total life cycle cost uncertainty. The designed model is complicated with multiple variables representing uncertainty of the yield of crops for biofuel production, the price of raw materials (grains for biofuel production), unit cost of each mode of transport, the production capacity of each plant and office price, etc.

In [16] a supply chain integration strategy for simultaneously consideration of selection and production planning based on mixed integer linear programming model accounting for uncertainty of supply and demand has been proposed. The model is solved using tailored algorithm optimization. County level cases in Illinois are analyzed and compared to show the advantage of the proposed framework for optimization.

Ref. [17] addresses the optimal design and planning of sustainable industrial supply chains considering three key performance indicators: total cost, total GHG emission, and total lead time. A multi-objective optimization framework, incorporating these sustainability indicators has been developed and applied to an industrial case study drawn from a Dow business.

The proposed mathematical programming model in Ref. [18] optimizes the numbers, locations and capacities of Jatropha CurcasL (JCL) cultivation centers and Waste Cooking Oil (WCO) collection centers, bio-refineries, and distribution centers. The proposed approach is implemented in Iran for 10 years planning horizon. The obtained results show the usefulness and efficiency of the proposed method in assisting the policymakers to make suitable strategic and tactical decisions related to biodiesel supply chain planning.

Supply chain (SC) analysis and optimization have been extensively reported in the literature applied to different process industries. However, biofuel production is mainly focused on such individual aspects of supply chain, as plantation or transportation and there are only a few papers that address analysis and optimisation of the entire biofuel supply chain. A mathematical model to solve the problem of designing and managing the biofuel supply chain (BSC) for biodiesel, based on the theoretical method of MILP of crop rotation has been proposed in the first part of Ref. [9]. The aim of this study is application of the mathematical model developed in Ref. [9] for the case of integrated biodiesel-petroleum diesel blends system at the real conditions in Bulgaria.

2. CASE STUDY: POTENTIAL BIODIESEL PRODUCTION IN BULGARIA FOR 2010-2020

The model described in Ref. [9] has been applied to a case study of biodiesel production in Bulgaria. Two major types of biomass resources in this case, sunflower and rapeseed for production of first generation biodiesel (B100) are used.

The demand scenario that is investigated in this paper is based on both the Bulgaria domestic target for 2010 (5.75% by energy content) [19] and the EU target for 2020 10% by energy content) [4] to promote the use of biofuels.

2.1. Input data

2.1.1. Territorial division of Bulgaria and data on energy consumption of petroleum diesel for transport

According to the Geodesy, Cartography and Cadastre Agency at the Ministry of Regional Development and Public Works, the total area of the Republic of Bulgaria as of 31.12.2000, is 111001.9 square kilometers of which 63764.8 square kilometers is used for agriculture. From this land arable land and utilized agricultural area for 2011 is 3,162,526 hectares [20], [21]. The main energy crops for biodiesel (B100), which are suitable for growing in Bulgaria are sunflower and rapeseed. These crops are now grown mainly for ensuring food security. Areas that are employed for this purpose for 2011 are: 734,314 [ha] for sunflower and 209,347 [ha], for industrial oleaginous crops including rapeseed. Bulgaria has almost 0.7 [ha] per inhabitant agricultural land, compared to an average of 0.4 [ha] in the EU-25 [22]. Therefore, to produce required feedstock internally in Bulgaria is not difficult. The correlation between feedstock availability and land availability is positive and significant and this factor is crucial and important for feedstock amount.

A. Territorial Division of Bulgaria, current cultivated area and the region's population

Bulgaria comprises 27 regions (see Fig. 1) [23]. In this case study, each region in Bulgaria is considered to be a feedstock production region, a potential location of a biorefinery facility and a demand zone. In other words, the biofuel supply chain network consists of 27 areas for feedstock production, 27 potential biorefinery locations, 27 costumer zones and 3 refineries for petroleum diesel. We assume a 10-year service life of biorefineries in the present study, and the fixed cost parameter for building refineries is amortized into annual cost to be consistent with other cost components.

For the purposes of this study, data on population, cultivated area, as well as the free cultivated area, which in principle can be used for the production of energy crops for biodiesel (B100) production are taken from Ref. [20].

Table 1 presents data on the distribution of cultivated area for each region and population size.

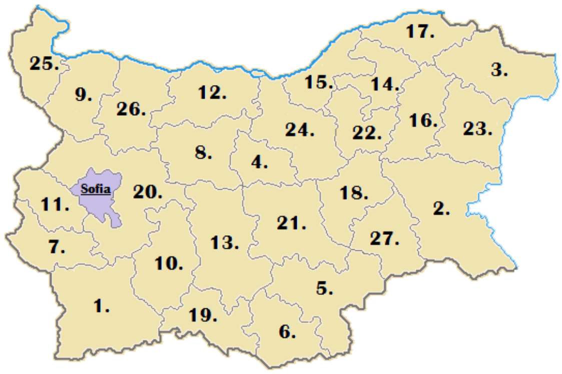

Fig 1. Map of the administrative territorial division of Bulgaria used for the purposes of the study [24]

Table 1. Cultivated area by region and population **[20], [25]**

No	**Name of regions**		**Population**	**Cultivated area**
	Units			**[ha]**
1	Region-1	Blagoevgrad	322 025	20 512
2	Region-2	Bourgas	414 947	177 572
3	Region-3	Dobrich	188 088	329 809
4	Region-4	Gabrovo	121 389	21 507
5	Region-5	Haskovo	243 955	116 657
6	Region-6	Kardjali	152 009	12 751
7	Region-7	Kyustendil	134 990	18 537
8	Region-8	Lovech	139 609	66 834
9	Region-9	Montana	145 984	130 243
10	Region-10	Pazardjik	273 803	57 675
11	Region-11	Pernik	131 987	33 980
12	Region-12	Pleven	266 865	289 355
13	Region-13	Plovdiv	680 884	179 416
14	Region-14	Razgrad	123 600	140 215
15	Region-15	Ruse	233 767	170 072
16	Region-16	Shtumen	179 668	140 824
17	Region-17	Silistra	118 433	146 411
18	Region-18	Sliven	196 712	85 021
19	Region-19	Smolyan	120 456	5 095
20	Region-20	Sofia	1 542 231	68 201
21	Region-21	St.Zagora	331 135	173 465
22	Region-22	Targovishte	119 865	98 038
23	Region-23	Varna	474 344	160 786
24	Region-24	V.Tarnovo	256 279	168 194
25	Region-25	Vidin	99 481	90 853
26	Region-26	Vratsa	184 662	175 528
27	Region-27	Yambol	130 056	149 686
		Total	**7 327 224**	**3 162 526**

B. Data on the energy consumption of petroleum diesel for transport for the period 2010 to 2020

In setting national indicative targets for the consumption of biofuels in Bulgaria the indicative targets set out in Directive 2003/30/EC and adopted by the European Council (8-9 March 2007) are considered. These targets for biofuels are 5% for 2010 and 10% for the total consumption of petrol and petroleum diesel for transport in the EU by 2020. These targets have to be achieved in a cost effective way.

Produce biodiesel (B100) is used as a component in mixtures of petroleum diesel oil produced in a specific proportion [26]. In Bulgaria in 2011 this proportion is a biodiesel–petroleum diesel blend of 6% biofuel (B100) and 94% petroleum diesel.

Table 2 shows the diesel consumption for transport over the period 2010-2012 we know it from Ref [20] while the estimated diesel consumption for the period 2013 to 2020 is taken from Ref. [27].

For the purposes of this study we assume that the consumption of petroleum diesel fuel for each region is taken approximately proportional to its size.

Table 2. Petroleum diesel consumption for transport and energy crops for food security in 2010-2020 [27]

No	Year	2010	2012	2014	2016	2018	2020
Status	**Units**	**Diesel consumption**		**Estimated diesel consumption**			
Proportion biodiesel/diesel	[%]	5%	6%	7%	8%	9%	10%
Petroleum Diesel	[ton year^{-1}]	1891300	2050000	2219000	2401000	2583000	2775500
Sunflower for food security		1321765	1321765	1321765	1321765	1321765	1321765
Rapeseed for food security		376824	376824	376824	376824	376824	376824

2.1.2. Potential feedstock's for biodiesel (B100) for production in Bulgaria

Vegetable oils are the main raw material for producing biodiesel (B100) and the oils are derived from the seeds or the pulp of a range of oil-bearing crops. The most suitable oil crops for Bulgarian climate are sunflower and rapeseed. Rapeseed oil was the first type used for biodiesel (B100) production and is still the main feedstock for biodiesel (B100) production in Bulgaria. This is because the climate is more suitable for its growth throughout the country, while sunflower seed crops are grown mainly in the warmer south areas. Rapeseed and sunflower have been traditionally cultivated in Bulgaria and both of these crops have great potential for the future. This is the reason rapeseed and sunflower to be discussed as main energy crops, in this study for biodiesel (B100) production.

2.1.3. Data for emission factor for cultivation of biomass and yields

GHG emissions in the agronomy phase for cultivation of sunflower and rapeseed lifecycle phases include soil preparation, seeding, tillage, fertilization, and finally harvest.

For different regions in Bulgaria GHG emissions aggregation for the entire life cycle of growing energy crops vary greatly depending on terrain, weather conditions, the technology of growing crops and imported fertilizer to increase yields. Table 3 gives GHG emissions in the agronomy phase to rapeseed and sunflower and the yield cultivation for different regions of the Bulgaria.

2.1.4. Data for the production cost of energy crops produced in Bulgaria

Unit biomass cultivation cost includes all costs associated with the cultivation of biomass, and a final selling price in the region (not including shipping costs for delivery to biorefineries). Cultivation cost is variable and is a function of the regional climate, the technology of cultivation of the species on earth and bio cultures.

At Table 3 is shown the specific annual yield of sunflower and rapeseed as raw material for biodiesel (B100) production. The specific annual yield of each raw material per hectare of cultivated area differs significantly between regions because of the climate, soil, rainfall, etc. The maximum biomass production from each region in Bulgaria is shown in Table 4. The minimum biomass production from each region in Bulgaria is 250 ton year^{-1}.

2.1.5. Potential locations of biodiesel and petroleum diesel refineries

The most appropriate possible locations for biorefinery throughout the regions are chosen on the basis of the accessibility to the transportation infrastructures, urban planning and zoning conditions. All 27 regions have been selected as candidate biorefinery locations, which are therefore dispersed across the Bulgarian territory. Refineries for the production of petroleum diesel are located in the regions of Bourgas, Ruse and Sofia.

Table 3. GHG emissions in the agronomy phase and potential yields from rapeseed and sunflower in the regions in Bulgaria **[20]**

No	**Regions**	**GHG emissions in the agronomy phase**		**The yield cultivation in regions**	
	Units	[kg CO_2 – eq ton^{-1} biomass]		[ton ha^{-1}]	
	Energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed
1	Region-1	1700	1350	1.5	1.8
2	Region-2	1425	1120	2.8	2.8
3	Region-3	600	430	3.4	3.5
4	Region-4	1425	1120	1.8	2.2
5	Region-5	1425	1120	1.8	2.2
6	Region-6	1700	1350	1.5	1.8
7	Region-7	1700	1350	1.5	1.8
8	Region-8	1425	1120	1.8	3.2
9	Region-9	1150	890	2.2	2.6
10	Region-10	1700	1350	2.2	3.2
11	Region-11	1425	1120	1.8	2.2
12	Region-12	600	430	2.8	3.5
13	Region-13	1425	1120	1.8	2.2
14	Region-14	875	660	2.8	3.0
15	Region-15	600	430	3.3	3.5
16	Region-16	875	660	2.8	3.0
17	Region-17	875	660	2.8	3.0
18	Region-18	1150	890	2.4	2.6
19	Region-19	1700	1350	1.5	1.8
20	Region-20	1700	1350	1.5	1.8
21	Region-21	875	660	2.8	3.0
22	Region-22	1150	890	2.2	2.6
23	Region-23	875	660	2.8	3.0
24	Region-24	875	660	2.4	3.0
25	Region-25	1425	1120	2.8	2.2
26	Region-26	875	660	1.8	2.0
27	Region-27	1150	890	2.6	2.6

2.1.6. The technology of biodiesel (B100) production used in this study

In our case, we assume that classical esterification technology [29] will be used for the production of biodiesel (B100) from raw sunflower and rapeseed.

The average price of glycerin by Ref. [30] is 1.088 \$ kg^{-1}. Another co-product is the residue seed cake from him crushing of the oilseeds, which is rich in protein and is used for animal feed. According to Ref. [29] approximately 1.575 ton of seed cake is produced per ton of biodiesel (B100). The average price of seed cake for sunflower by [31] is 115 \$ ton^{-1}.

The technology for extraction oil from oilseeds has not changed significantly during the last 10-15 years. The process of biodiesel production from the oil is a relatively simple and the expectations for efficiency improvement are small, but utilization of co-products has improved significantly in this time.

2.1.7. Biomass to biodiesel (B100) conversion factor

The feedstock conversion ratio of the process is defined here as the amount of the feedstock input divided by the amount of the main product. It is a measure of how much biomass is needed for a unit mass of biofuel.

Conversion efficiency of rapeseed and sunflower biodiesel (B100) ranges from 454 L ton^{-1} to 422 L ton^{-1}. We use a conversion efficiency of 422 L ton^{-1} in the Aglink model [32], which is the average of the lowest and highest conversion efficiency found in literature.

In Table 5, are given the differentiated value of the conversion factor for sunflower and rape, applicable to conditions in Bulgaria under traditional method to extract biodiesel (B100). In this study the used value of the conversion factor is 371 kg ton^{-1} biomass for sunflower and 303 kg ton^{-1} biomass rapeseed applicable to the conditions in Bulgaria by the traditional method for extracting biodiesel (B100).

Table 4. Unit biomass cultivation cost and maximum amount of biomass that can be produced in the regions of Bulgaria [28]

No	**Regions**	**Cultivation costs per unit of**		**Maximum biomass production**	
	Units	[\$ ton^{-1} biomass]		[ton year^{-1}]	
	Energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed
1	Region-1	227	239	10768	9230
2	Region-2	213	236	93225	79907
3	Region-3	192	227	173150	148414
4	Region-4	213	233	11291	9678
5	Region-5	213	236	61245	52496
6	Region-6	227	239	6694	5738
7	Region-7	227	239	9732	8342
8	Region-8	213	236	35087	30075
9	Region-9	198	233	68378	58609
10	Region-10	227	239	30279	25954
11	Region-11	213	236	17839	15291
12	Region-12	192	227	151911	130210
13	Region-13	213	236	94193	80737
14	Region-14	195	230	73613	63097
15	Region-15	192	227	89287	76532
16	Region-16	195	230	73932	63370
17	Region-17	195	230	76866	65885
18	Region-18	198	233	44636	38259
19	Region-19	227	239	2675	2293
20	Region-20	227	239	35806	30690
21	Region-21	195	230	91069	78059
22	Region-22	198	233	51469	44117
23	Region-23	195	230	84412	72353
24	Region-24	195	230	88301	75687
25	Region-25	213	236	47698	40884
26	Region-26	195	230	92152	78987
27	Region-27	198	233	78585	67358

Table 5. Biomass to biodiesel (B100) conversion factor

	Type of Energy Crops	**Conversion factor γ_{ij}**	**Energy equivalent of biomass**
	Units	**(ton biofuel) (ton biomass)$^{-1}$**	**GJ ton $^{-1}$**
1	Sunflower	0.371	14.023
2	Rapeseed	0.303	11.453

2.1.8. Biorefinery costs and capacity

The refinery capital cost consists of fixed and variable capital cost. If the plant technology is considered mature, the variable capital cost of biomass-to-biodiesel (B100) plants are depending only on the size of the plant. The variable capital costs are scaled using the general relationship [33].

$$\frac{Cost_p}{Cost_{base}} = \left(\frac{Size_p}{Size_{base}}\right)^R \qquad (1)$$

where $Cost_p$ and $Size_p$ represent the investment cost and plant capacity respectively for the new plant, $Cost_{base}$ the known investment cost for a certain plant capacity $Size_{base}$, and R is the scaling factor. The scaling factor R for biomass systems is generally between 0.6 and 0.8 [34].The fixed capital cost varies by the refinery locations.

Capital cost of biorefinery for each region is determined by the equation:

$$Cost_{pf}^{F} = M_f^{cost}\, Cost_p, \forall p \in P, \forall f \in F \qquad (2)$$

where M_f^{cost} is a correction factor in the price of biorefineries in the region $f \in F$ according to its installed $M_f^{cost} \geq 1$. The value of this coefficient is a different for geography region. It reported indicators such as, land prices, labor costs, etc.

According to Ref. [32] capital costs biorefinery size about 1000 ton year^{-1} are within 334 – 412 \$ ton^{-1}. In biorefinery with basic performance $Size_{base} = 8500$ *ton year*$^{-1}$ and then adopted base price *412 \$ ton*$^{-1}$, $Cost_{base} = 3.5M$ \$ and a $R = 0.8$ capacity shown in Table 6 are the values of certain capital expenditures for each of them.

In our case it is assumed that for all 27 regions $M_f^{cost} = 1, \forall f \in F$.

The capacity of the refinery at all appointed locations can be up to 10000 ton year^{-1} and they are ordered down into discrete order shown in Table 6.

2.1.9. Biodiesel(B100) production costs

Production costs per unit of biodiesel (B100) biorefinery installed in the region in case the Keys to Manufacturing Operating expenses such as: Chemicals and catalysts, gas, electricity, make-up water, wastewater treatment and disposal, administrative and operating costs and direct labor and Benefits. As discussed in Ref [28] average cost are respectively 125 \$ ton^{-1} for each region of biodiesel (B100) (not including the costs of raw materials).

In the present case study, we accept a 10 year service life of biorefineries, and the fixed cost parameter for building refineries is amortized into annual cost to be consistent with other cost components.

2.1.10. Data for petroleum diesel plants

In the present study we examine three bases in Bulgaria for diesel fuel supply over the regions. Two central fuel depots are in Region-20 (Sofia) and Region-15 (Ruse) and one fuel depot is in Region-2 (Bourgas). The three basic fuel depots are supplied with diesel fuel by the refinery Lukoil – Bourgas and also with imported fuel by other sources. The minimum annual capacity of the fuel depots is 100000 ton year^{-1} and the maximum capacity is 1200000 ton year^{-1} for Region-20 and 900000 ton year^{-1} for Region-15 and Region-2.

Table 6. Total specific investment cost of biodiesel (B100) production plants as a function of the size of the plant [35], [36]

Size of biodiesel (B100) plant	Capital cost of biodiesel (B100) plant $Cost_p$	MIN capacity of biodiesel (B100) plant PB_p^{MIN}	MAX capacity of biodiesel (B100) plant PB_p^{MAX}	Average capital costs per unit of biodiesel (B100)
Units	[$M\$$]	[ton year^{-1}]		[\$ ton^{-1}]
Size-1	3.5000	1000	8500	411.76
Size-2	4.3018	6000	11000	391.07
Size-3	6.3790	8000	18000	354.39
Size-4	8.0297	10000	24000	334.57
Size-5	10.8589	14000	35000	310.25
Size-6	14.4447	25000	50000	288.89
Size-7	18.4731	30000	68000	271.66
Size-8	19.7660	38000	74000	267.11
Size-9	22.0835	44000	85000	259.81
Size-10	25.1497	55000	100000	251.50

2.1.11. Data for biodiesel (B100) and petroleum diesel

Table 7. Emission coefficient of fuel and energy equivalent

Type of fuel	Emission coefficient	Energy equivalent	Energy equivalent	Density (average)	Price of biofuel
Source	Ref. [37]		Ref. [38]		Ref. [39]
Unit	[kg CO_2 – eq ton^{-1}]	[GJ ton^{-1}]	[MWh ton^{-1}]	[ton m^{-3}]	[\$ ton^{-1}]
Petroleum Diesel	3623	42.80	11.880	0.840	1192.70
Biodiesel(B100)	1204	37.80	7.720	0.880	

2.1.12. Data for cost transportation, and emission factors for biomass and biodiesel (B100)

A GIS-based transportation network has been used for cost estimation of transporting feedstock and fuels in the entire supply chain system, introduced. This network contains local, rural, urban roads and major highways. The shortest distances between feedstock fields, refineries, and demand cities have been calculated based on this network. Since only in-state production and delivery are considered, we assume that all transportations are performed by tractor, truck and rail for transporting biomass (Sunflower and Rapeseed) and for transportation biodiesel (B100) with truck and rail. Transportation costs include three components: loading/unloading cost, time dependent travel cost, and distance dependent travel cost. Time dependent cost includes labor and capital cost of trucks, while distance dependent cost includes fuel, insurance, maintenance, and permitting cost.

The biomass transportation cost is described by Ref. [9], and summarized in Table 8 and Table 9, for transportation by tractor, truck and train for biomass (Sunflower and Rapeseed) and biodiesel (B1000). They include the fixed cost and the variable cost. The loading and unloading costs, which are not dependent on distance of transport, are included in fixed costs. The costs for fuel, driving, maintenance, etc. are included in variable costs.

The biomass transportation cost UTC_{igfl} is described by [9], for transportation by tractor, truck and train UTC_{ftb}. They are composed of a fixed cost (IA_{il}, OA_b) and a variable cost (IB_{il}, OB_b). Fixed costs include loading and unloading costs. They do not depend on the distance of transport (ADG_{gfl}, ADF_{fcb}, ADD_{dcb}). Variable costs include fuel cost, driver cost, maintenance cost etc. They are dependent on the distance of transport [40].

$$\left.\begin{aligned}
UTC_{igfl} &= IA_{il} + \left(IB_{il} ADG_{gfl}\right)\\
UTB_{fcb} &= OA_b + \left(OB_b ADF_{fcb}\right)\\
UTD_{dcb} &= OAD_b + \left(OBD_b ADD_{dcb}\right)
\end{aligned}\right\}$$

IA_{il} and IB_{il} is fixed and variable cost for transportation biomass type $i \in I$, (OA_b, OB_b) is fixed and variable cost for transportation biodiesel (B100) and (OAD_b, OBD_b) is fixed and variable cost for transportation petroleum diesel.

The simplest approach to estimating emissions from road and rail transport is based on the amounts of each fuel consumed. The approach for CO_2 - *eq* is indicated in Table 10. This is based directly on the carbon content of the fuel. The default average emission factors used in this guideline are based on the average emission factors recommended by Refs. [41], [42].

Table 8. Unit transportation cost for each mode of transport and type of the biomass [9]

	Energy crops	**Fixed cost IA_{il} [44]**			**Variable cost IB_{il} [44]**		
	Unit	**[$\$\ \mathrm{ton}^{-1}\mathrm{km}^{-1}$]**					
	Type of transport	Tractor	Truck	Train	Tractor	Truck	Train
1.	Sunflower	2.486	9.28	19.63	0.14	0.209	0.029
2.	Rapeseed	2.486	9.28	19.63	0.14	0.209	0.029

Table 9. Unit costs for each transport mode and biodiesel (B100) [9]

		Fixed cost OA_b, OAD_b [44]		**Variable cost OB_b, OBD_b [44]**	
	Unit	**[$\$\mathrm{ton}^{-1}\mathrm{km}^{-1}$]**			
	Type of transport	Truck	Train	Truck	Train
1.	Biodiesel(B100)	24.11	7.86	0.436	0.173
2.	Petroleum diesel	24.11	7.86	0.436	0.173

2.1.13. Data for actual delivery distance between regions in Bulgaria

Distances in kilometers between different locations in Bulgaria for the purpose of this survey are taken by the National Transport Agency for each type of transport (tractor, truck and rail).

The distance between regions will be the average distance of the feedstock being transported to the factory (assuming it is installed in a certain place of the region). In order to calculate the transport distance, the coordinates of each biomass site and the potential biorefinery location have been determined. The data used in this case study are taken at the county level, therefore the coordinates of the center point of a county are used to calculated the geographical distances between locations. The average distance can be calculated using the following equation:

$$d_{gg}{}' = \frac{\sum_{m\in M_g}\left(S_{gm} d_m^{Plant}\right)}{\sum_{m\in M_g} S_{gm}} \tag{3}$$

where d_{gg} the average distance which is supposed to be transported feedstock produced in the region $g \in G$, $g = g'$ to the factory installed in place *Plant* (Fig. 2.), which is installed in the specified location in this region, S_{gm} is the area of $m \in M_g$ these sub-region, and d_m^{Plant} the distance landmark center sub region $m \in M_g$ and places in which it is permissible to install biorefinery. For our case, the distances calculated according to equation 3 for the individual regions are shown in Table 11.

Table 10. Emission factor of transportation for mode $l \in L$

	Type of transport	Emission factor of transportation biomass	Emission factor of transportation biofuel
	Unit	[kg CO$_2$ – eq km^{-1}ton^{-1}]	
1.	Tractor	0.591	
2.	Truck(average)	0.228	0.228
3.	Van < 3.5 t	1.118	1.118
4.	Truck, 16 t	0.304	0.304
5.	Truck, 32 t	0.153	0.153
6.	Train, freight	0.038	0.038

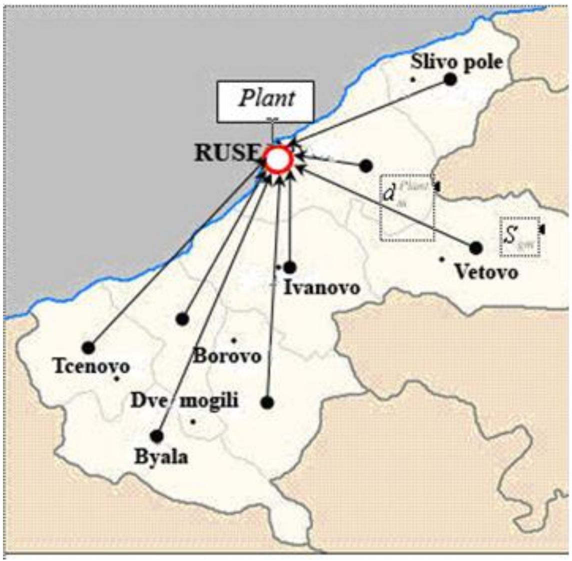

Fig 2. The actual delivery distance between sub regions

2.2. *Computational results and analysis*

The results from the case study described above, determining the optimal system design, the system costs, and the feedstock supply strategies are presented in this section.

Two possible scenarios for synthesis of the structure of the integrated biofuel supply chain (IBSC) are used in the present study. According to the proposed model [9] in the first scenario it is presumed that for a given time interval a factory with a given capacity is chosen to be built in particular geographic region and it will be the same factory with either the same or a bigger capacity is chosen in that region in the current and in the subsequent time interval. Applying the first scenario is presumed that for a given time interval a factory with a given capacity is chosen to be build in particular geographic region and it will be the same factory with either the same or a bigger capacity chosen in that region in the current and in the subsequent time interval. Applying the second scenario is presumed that for a given time interval a factory with a given capacity is chosen the same factory with the same capacity in the same region will remain in the current and all subsequent time intervals.

The proposed models in Ref. [9] has been solved by GAMS 22.8 [43] using CPLEX 11.1 solver on an Intel Core 2 Duo P8600 2.4 GHz with 4 GB RAM on a 32-bit platform. The mixed integer linear model is formed by 6843 binary and 10368 positive continuous variables and includes 18453 constraints, which represent the investment possible decisions and required management.

Table 11. The actual delivery distance between regions in different models of transport

No	Name of regions Type of transport	Tractor or Truck or Rail
	Unit [km]	
1	Blagoevgrad to Blagoevgrad	44
2	Bourgas to Bourgas	44
3	Dobrich to Dobrich	32
4	Gabrovo to Gabrovo	13
5	Haskovo to Haskovo	40
6	Kardjali to Kardjali	26
7	Kyustendil to Kyustendil	36
8	Lovech to Lovech	38
9	Montana to Montana	27
10	Pazardjik to Pazardjik	25
11	Pernik to Pernik	17
12	Pleven to Pleven	35
13	Plovdiv to Plovdiv	33
14	Razgrad to Razgrad	22
15	Ruse to Ruse	25
16	Shumen to Shumen	31
17	Silistra to Silistra	24
18	Sliven to Sliven	27
19	Smolyan to Smolyan	39
20	Sofia to Sofia	46
21	St.Zagora to St.Zagora	33
22	Targovishte to Targovishte	18
23	Varna to Varna	27
24	V.Tarnovo to V.Tarnovo	36
25	Vidin to Vidin	25
26	Vratsa to Vratsa	27
27	Yambol to Yambol	21

2.2.1. Biomass cultivation

The total amount of two kinds of biomass used to produce biofuels allocated per year in regions is given on Table 12 and Table 12a.

The results of the optimal synthesis for second scenario using the two basic evaluation criteria show that the regions with concentrated production of sunflower and rapeseed for biodiesel (B100) production are in considerably narrow bounds. Using the evaluation criteria „Minimum Total GHG Emissions“, the production of sunflower and rapeseed is concentrated in 3 basic regions in Bulgaria. At the same time the sown areas ensure the yield sustainability.

Using the criteria "Minimum Annualized Total Cost" for optimal synthesis of the structure of the integrated biofuel supply chain the number of the regions for sunflower and rapeseed production are increases to 7 with additional new 4 regions.

The basic bioculture for biodiesel (B100) production ensuring the „Minimum Total GHG Emissions“ is the rapeseed, while using the evaluation criteria "Minimum Annualized Total Cost" for optimal synthesis of IBSC the basic feedstock is sunflower.

2.2.2. Distribution of land

One of the most significant conclusions obtained from applying the mathematical model for optimal synthesis of IBSC [9] concerns the area of land in Bulgaria required to produce the national biofeedstock needs in 2020.

Using the "Minimum Total GHG Emission" criterion to model the quantity of biofeedstock required (see Fig. 3) for 10 % component of biodiesel (B100) it is predicted that 3% of available agriculture land would be required for production of biodiesel (B100) from sunflower and and 12% of available agriculture land for production of biodiesel (B100) from rapeseed.

Using the "Minimum Annualized Total Cost" criterion the predictions for areas of agricultural land required to produce the necessary biofeedstock (see Fig. 4) for biodiesel (B100) is 14% for sunflower and 2% for rapeseed cultivation.

For ensuring Minimum Total GHG Emissions the basic biofeedstock is rapeseed, while for ensuring the Minimum Annualized Total Cost the sunflower has to be used as a bioculture.

Comparing the cases we reach the conclusion that when the Minimum Annualized Total Cost criterion is used, sunflower cultivation is indicated whereas use of the Minimum Total GHG Emission criterion indicates that rapeseed cultivation is more efficient.

Table 12. Biomass cultivation per years in regions to produce biofuels for second scenario in case (a) – Minimum Total GHG emissions

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Sunflower [ton year^{-1}]						
Region-3	250	250	500	500	3750	3750
Region-12	500	500	7221	22040	48869	173524
Region-15	250	5157	500	500	9584	7407
Rapeseed [ton year^{-1}]						
Region-3	74483	65647	159732	236099	288583	288487
Region-12	214786	233326	236954	236954	253186	253186
Region-15	19804	97916	104246	131449	148813	148813

Table 12a. Biomass cultivation per years in regions to produce biofuels for second scenario in case (b) – Minimum Annualized Total Cost

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Sunflower [ton year^{-1}]						
Region-3	70460	87439	113597	134566	134950	157273
Region-12	182351	23819	235744	239146	194126	253186
Region-14	0	0	0	0	40613	40227
Region-15	0	0	67181	104867	90500	148813
Region-21	0	0	0	0	22706	22706
Region-24	0	0	0	0	0	1491
Region-26	0	0	0	22706	122869	122869
Rapeseed [ton year^{-1}]						
Region-3	250	250	250	250	500	500
Region-12	500	5158	500	500	500	500
Region-14	0	0	0	0	40613	0
Region-15	0	0	250	17925	250	250
Region-21	0	0	0	0	250	250
Region-24	0	0	0	0	0	250
Region-26	0	0	0	250	23532	750

Table 13. Distribution of arable land for biodiesel (B100) planted with sunflower and rapeseed for second scenario in case: (a) - Minimum Total GHG emission

Years		**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Land for biodiesel (B100) busy with sunflower and rapeseed [ha]							
Region-3	Sunflower	71	71	142	142	1071	1071
	Rapeseed	21281	18756	45637	67457	82452	82424
Region-12	Sunflower	142	142	2063	6297	13962	49578
	Rapeseed	61367	66664	67701	67701	72339	72339
Region-15	Sunflower	71	1473	142	142	2738	2116
	Rapeseed	5658	27976	29784	37556	42518	42518

Table 13a. Distribution of arable land for biodiesel (B100) planted with sunflower and rapeseed for second scenario in case: (b) - Minimum Annualized Total Cost

Years		**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Land for biodiesel (B100) busy with sunflower and rapeseed [ha]							
Region-3	Sunflower	20131	24982	32456	38447	38557	44935
	Rapeseed	71	71	71	71	142	142
Region-12	Sunflower	52100	68055	67355	68327	55464	72339
	Rapeseed	142	1473	142	142	142	142
Region-14	Sunflower	0	0	0	0	14504	14366
	Rapeseed	0	0	0	0	0	0
Region-15	Sunflower	0	0	19194	29962	25857	42518
	Rapeseed	0	0	71	5121	71	71
Region-21	Sunflower	0	0	0	0	8109	8109
	Rapeseed	0	0	0	0	83	83
Region-24	Sunflower	0	0	0	0	0	532
	Rapeseed	0	0	0	0	0	83
Region-26	Sunflower	0	0	0	8109	43882	43882
	Rapeseed	0	0	0	83	7844	250

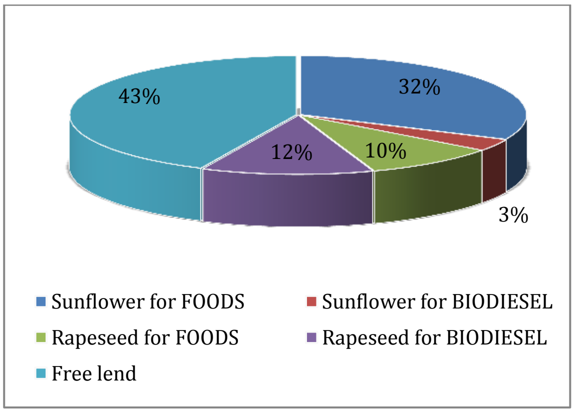

Fig 3. Distribution of arable land for various purposes for Sunflower and Rapeseed for 2020 year for second scenario for case: (a)-Minimum Total GHG emissions

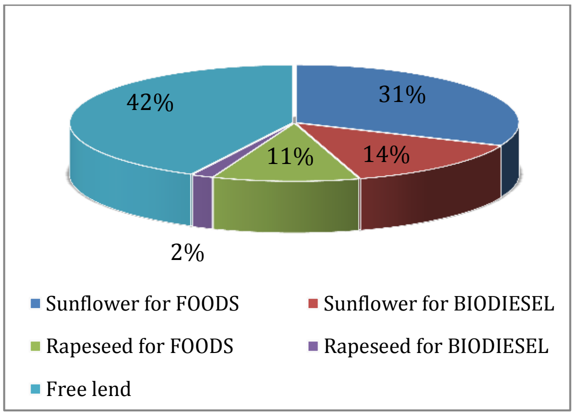

Fig 4. Distribution of arable land for various purposes for Sunflower and Rapeseed for 2020 year for second scenario for case: (b) - Minimum Annualized Total Cost

2.2.3. Biomass supply

The optimal biomass flows are given in Table 14 and Table 14a.

The analysis of the results of the optimal design of a system for IBSC in respect to the logistics show that the optimal delivery transport of the biomass from the region of production to the biorefineries is by train for both sunflower and rapeseed for all time intervals in the period (2010-2020). The railway transport can be suggested also from optimization results using the criteria "Minimum Total GHG emissions" and "Minimum Annualized Total Cost" [9]. For the transport of biodiesel (B100) and diesel from refineries to the centers of mixing and consumption is suggested also railway for both kind of fuels for the whole time period and for both criteria "Minimum Total GHG emissions" and "Minimum Annualized Total Cost" [9].

Table 14 Flow rate biomass from grow region to biodiesel (B100) plants for second scenario in case (a) – Minimum Total GHG emissions

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
Regions	**Sunflower [ton day^{-1}]**					
Region-3 to Region-3	0	0	1.00	1.00	5.00	0
Region-3 to Region-16	0	0	0	0	5.00	5.00
Region-3 to Region-23	1.00	1.00	1.00	1.00	5.00	0
Region-12 to Region-4	0	0	0	0	0	75.13
Region-12 to Region-8	1.00	1.00	1.00	1.00	5.00	5.00
Region-12 to Region-12	1.00	1.00	27.89	86.16	108.55	246.47
Region-12 to Region-20	0	0	0	0	0	181.46
Region-12 to Region-24	0	0	0	1.00	52.70	5.00
Region-12 to Region-26	0	0	0	0	5.00	181.04
Region-15 to Region-14	0	19.63	1.00	1.00	5.00	19.63
Region-15 to Region-15	1.00	1.00	1.00	1.00	5.00	5.00
Region-15 to Region-22	0	0	0	0	28.34	5.00
Regions	**Rapeseed [ton day^{-1}]**					
Region-3 to Region-3	0	0	394.82	576.33	569.96	568.31
Region-3 to Region-14	0	0	37.65	52.46	134.58	0
Region-3 to Region-16	0	0	0	0	139.09	110.32
Region-3 to Region-22	0	0	0	0	0	164.61
Region-3 to Region-23	297	262.59	206.46	315.61	310.71	310.71
Region-12 to Region-4	0	0	0	0	0	92.83
Region-12 to Region-8	427	422.98	427.82	427.82	422.92	389.92
Region-12 to Region-12	431	510.33	520.00	520.00	520.00	520.00
Region-12 to Region-20	0	0	0	0	0	5.00
Region-12 to Region-26	0	0	0	0	69.83	5.00
Region-15 to Region-14	0	306.00	306.00	306.00	189.34	306.00
Region-15 to Region-15	79	85.67	110.99	108.81	105.58	106.09
Region-15 to Region-22	0	0	0	0	295.34	159.30
Region-15 to Region-24	0	0	0	110.99	5.00	23.86

Table 14a Flow rate biomass from grow region to biodiesel (B100) plants for second scenario in case (b) - Minimum Annualized Total Cost

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
Regions	**Sunflower [ton day^{-1}]**					
Region-3 to Region-3	0	0	0	0	50	90
Region-3 to Region-23	281	349	454	538	489	538
Region-12 to Region-8	320	345	349	349	349	349
Region-12 to Region-12	408	607	593	607	426	607
Region-12 to Region-26	0	0	0	0	0	56
Region-14 to Region-15	0	0	0	0	162	160
Region-15 to Region-12	0	0	0	0	0	56
Region-15 to Region-15	0	0	268	357	357	357
Region-15 to Region-20	0	0	0	0	0	58
Region-15 to Region-24	0	0	0	0	0	84
Region-15 to Region-26	0	0	0	0	0	38
Region-21 to Region-21	0	0	0	0	90	90
Region-26 to Region-9	0	0	0	0	46	90
Region-26 to Region-20	0	0	0	90	76	32
Region-26 to Region-26	0	0	0	0	368	368
Regions	**Rapeseed [ton day^{-1}]**					
Region-3 to Region-3	0	0	0	0	1	1
Region-3 to Region-23	1	1	1		1	1
Region-12 to Region-8	1	1	1	1	1	1
Region-12 to Region-12	1	19	1	1	1	1
Region-15 to Region-15	0	0	1	71	0	0
Region-26 to Region-9	0	0	0	0	42	0
Region-26 to Region-20	0	0	0	1	1	0
Region-26 to Region-26	0	0	0	0	51	0

2.2.4. The optimal system design

Table 15 and Table 15a show the results from the optimal synthesis of an IBSC using the "Minimum Total GHG emissions" criterion. The case where it is possible to increase the size of the biorefinery optimal size and use capacity and the petroleum diesel plant capacity in the subsequent time intervals (scenario 1) are given in Table 15 and the case when it is not possible (scenario 2) in Table 15a. It is possible to satisfy the EC requirements for the period (2010-2020) by increasing factory size (scenario 1) in 9 Bulgarian regions (regions 3, 4, 8, 12, 14, 15, 20, 22, 23, 26). Using the policy of not changing the installed power of the factories (scenario 2) whilst satisfying the EC criteria and the predicted diesel fuel consumption for the same period it will be necessary to build new factories with different capacity in 12 Bulgarian regions (3, 4, 8, 12, 14, 15, 16, 20, 22, 23, 24, 26) in 2020. At the same time the total investments which have to be done for building and enlargements of biorefineries (2010-2020) are 1 % more using the scenario 2 (127.257M$) comparing with scenario 1 (125.685M$). Regarding the criteria "Minimum Total GHG emissions" using both scenarios the results are equivalent towards the total investment expenditures for the whole period (2010-2020). The advantage of using the scenario 1 is that the investment loading after the first year is less while using the scenario 2 is bigger in the first time interval. The investment expenses for the first year are equal for both scenarios but for the following years are different.

Table 15 Optimal size / optimal used capacity and location of biodiesel (B100) and optimal used petroleum diesel plants for first scenario in case (a) – Minimum Total GHG emissions

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
REGIONS/ Total Investment [M$]	**Biorefinery optimal size/**optimal used capacity **[ton year^{-1}]x10^3**					
Region-3/	-	-	-	**Size 5/**	**Size 5/**	**Size 8/**
19.788				25.729	35.000	42.984
Region-4/	-	-	-	-	-	**Size 1/**
3.500/0						3.686
Region-8/	**Size 7/**	**Size 7/**	**Size 7/**	**Size 7/**	**Size 7/**	**Size 7/**
18.473	32.500	32.377	32.483	32.500	30.758	32.500
Region-12/	**Size 7/**	**Size 8/**	**Size 8/**	**Size 8/**	**Size 10/**	**Size 10/**
25.149	32.765	39.755	43.515	39.482	55.000	62.250
Region-14	-	-	**Size 1/**	**Size 6/**	**Size 6/**	**Size 6/**
14.444			8.500	25.000	25.000	28.750
Region-15	**Size 1/**	**Size 4/**	**Size 4/**	**Size 6/**	**Size 6/**	**Size 6/**
14.444	6.093	23.847	24.000	25.000	25.000	26.973
Region-20	-	-	-	-	-	**Size 1/**
3.500						5.002
Region-23	**Size 4/**	**Size 6/**	**Size 6/**	**Size 9/**	**Size 9/**	**Size 9/**
22.083	22.661	26.467	46.334	44.000	53.566	64.586
Region-26	-	-	-	-	**Size 1/**	**Size 2/**
4.301					8.000	11.000
TOTAL USED CAPACITY	**94.020**	**1224.49**	**154.833**	**191.712**	**232.324**	**277.734**
Investment in years [M$]	**48.475**	**12.237**	**3.500**	**35.857**	**8.883**	**16.708**
MIN and MAX capacity of each of size of biodiesel (B100) plant is given in table 6						
Regions diesel plant / MAX capacity	**Petroleum diesel plant used capacity**					
	[ton year^{-1}]x10^3					
Region-2/ **1200000**	474.850	550.060	654.902	766.488	848.746	938.999
Region-15/ **900.000**	433.397	491.782	527.339	565.184	629.057	691.197
Region-20/ **900.000**	900.000	900.000	900.000	900.000	900.000	900.000
TOTAL USED CAPACITY	**1808.248**	**1941.843**	**2082.241**	**2231.672**	**2377.804**	**2530.196**

Table 15a Optimal size / optimal used capacity and location of biodiesel (B100) and optimal used petroleum diesel plants for second scenario in case (a) – Minimum Total GHG emissions

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
REGIONS/ Total Investment [M$]	**Biorefinery optimal size/**optimal used capacity **[ton year^{-1}]x10^3**					
Region-3/ 18.473	-	-	**Size 7/** 30.000	**Size 7/** 43.750	**Size 7/** 43.638	**Size 7/** 43.513
Region-4/ 10.858	-	-	-	-	-	**Size 5/** 14.000
Region-8/ 18.473	**Size 7/** 32.500	**Size 7/** 32.133	**Size 7/** 32.500	**Size 7/** 32.500	**Size 7/** 32.500	**Size 7/** 30.000
Region-12/ 18.473	**Size 7/** 32.765	**Size 7/** 38.749	**Size 7/** 41.976	**Size 7/** 47.381	**Size 7/** 49.458	**Size 7/** 62.250
Region-14/ 14.444	-	**Size 6/** 25.000	**Size 6/** (26.124	**Size 6/** 27.245	**Size 6/** 25.000	**Size 6/** 25.000
Region-15/ 3.500	**Size 1/** 6.093	**Size 1/** 6.581	**Size 1/** 8.500	**Size 1/** 8.335	**Size 1/** 8.461	**Size 1/** **8.500**
Region-16/ 4.301	-	-	-	-	**Size 2/** 11.000	**Size 2/** 8.820
Region-20/ 6.379	-	-	-	-	-	**Size 3/** 17.209
Region-22/ 14.444	-	-	-	-	**Size 6/** 25.000	**Size 6/** 25.000
Region-23 8.029	**Size 4/** 22.661	**Size 4/** 19.983	**Size 4/** 15.732	**Size 4/** 24.000	**Size 4/** 24.000	**Size 4/** 24.000
Region-24/ 3.500	-	-	-	**Size 1/** 8.500	**Size 1/** 5.266	**Size 1/** 2.271
Region-26/ 6.379	-	-	-	-	**Size 3/** 8.000	**Size 3/** 17.170
TOTAL USED CAPACITY	**94.020**	**122.449**	**154.833**	**191.712**	**232.324**	**277.734**
Investment in years [M$]	**48.475**	**14.444**	**18.473**	**3.500**	**25.125**	**17.237**
MIN and MAX capacity of each of size of biodiesel (B100) plant is given in table 6						
Regions diesel plant / MAX capacity	**Petroleum diesel plant used capacity**					
[ton year^{-1}]x10^3						
Region-2/ **1200000**	474.850.	550.060	654.902	766.488	848.746	938.999
Region-15/ **900.000**	433.397	491.782	527.339	565.184	629.057	691.197
Region-20/ **900.000**	900.000	900.000	900.000	900.000	900.000	900.000
TOTAL USED CAPACITY	**1808.248**	**1941.843**	**2082.241**	**2231.672**	**2377.804**	**2530.196**

Table 16 Optimal size / optimal used capacity and location of biodiesel (B100) and optimal used petroleum diesel plants for first scenario in case (b) - Minimum Annualized Total Cost

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
REGIONS/ Total Investments [M$]	**Biorefinery optimal size/**optimal used capacity **[ton year^{-1}]x10^3**					
Region-3/ 3.5000	-	-	-	**Size 1/** 6.116	**Size 1/** 8.468	**Size 1/** 3.979
Region-8/ 10.8589	**Size 5/** 29.803	**Size 5/** 32.146	**Size 5/** 32.500	**Size 5/** 32.500	**Size 5/** 32.500	**Size 5/** 32.500
Region-9/ 3.5000	-	-	-		**Size 1/** 8.500	**Size 1/** 8.500
Region-12/ 19.7660	**Size 8/** 38.000	**Size 8/** 53.879	**Size 8/** 56.748	**Size 8/** 62.169	**Size 8/** 41.940	**Size 8/** 57.246
Region-14/ 14.4447	-	-	-		**Size 6/** 28.579	**Size 6/** 28.750
Region-15/ 3.5000	-	**Size 1/** 7.975	**Size 1/** 8.500	**Size 1/** 8.500	**Size 1/** 8.500	**Size 1/** 8.500
Region-17/ 10.8589	-	-	-			**Size 5/** 14.000
Region-20/ 3.5000				**Size 1/** 8.500	**Size 1/** 8.500	**Size 1/** 8.500
Region-21/ 3.5000	-	-	-			**Size 1/** 8.500
Region-23/ 19.7683	**Size 6/** 26.216	**Size 6/** 28.447	**Size 8/** 57.084	**Size 8/** 73.926	**Size 8/** 57.335	**Size 8/** 64.258
Region-26/ 19.7660	-	-	-		**Size 8/** 38.000	**Size 8/** 43.000
TOTAL USED CAPACITY	**94.020**	**122.449**	**154.833**	**191.712**	**232.324**	**277.734**
Investments over years [M$]	**45.0696**	**3.5000**	**5.3213**	**7.000**	**37.7107**	**14.3589**
MIN and MAX capacity of each of size of biodiesel (B100) plant is given in table 6						
Region diesel plant/ **MAX capacity**	**Petroleum diesel plant used optimal capacity**					
	[ton year^{-1}]x10^3					
Region-2/ **1200000**	474.850	550.060	654.902	766.488	848.746	938.999
Region-15/ **900.000**	433.397	491.782	527.339	565.184	629.057	691.197
Region-20/ **900.000**	900.000	900.000	900.000	900.000	900.000	900.000
TOTAL USED CAPACITY	**1808.248**	**1941.843**	**2082.241**	**2231.672**	**2377.804**	**2530.196**

Table 16a Optimal size / optimal used capacity and location of biodiesel (B100) and optimal used petroleum diesel plants for second scenario in case (b) - Minimum Annualized Total Cost

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
REGIONS/ Total Investments [M$]	**Biorefinery optimal size/**optimal used capacity **$[ton\ year^{-1}]x10^3$**					
Region-3/ 3.500	-	-	-	-	**Size 1/** 4.713	**Size 1/** 8.500
Region-8/ 10.858	**Size 5/** 29.803	**Size 5/** 32.146	**Size 5/** 32.500	**Size 5/** 32.500	**Size 5/** 32.500	**Size 5/** 32.500
Region-9/ 3.500	-	-	-	-	**Size 1/** 7.500	**Size 1/** 8.500
Region-12/ 19.766	**Size 8/** 38.000	**Size 8/** 57.786	**Size 8/** 55.112	**Size 8/** 62.169	**Size 8/** 40.136	**Size 8/** 61.622
Region-15/ 14.444	-	-	**Size 6/** 25.000	**Size 6/** 38.543	**Size 6/** 48.255	**Size 6/** 48.111
Region-20/ 3.500	-	-	-	**Size 1/** 8.500	**Size 1/** 7.215	**Size 1/** 8.500
Region-21/ 3.500	-	-	-	-	**Size 1/** 8.500	**Size 1/** 8.500
Region-23/ 14.444	**Size 6/** 26.216	**Size 6/** 32.515	**Size 6/** 42.220	**Size 6/** 50.000	**Size 6/** 45.504	**Size 6/** 50.000
Region-24/ 3.500	-	-	-	-	-	**Size 1/** 8.500
Region-26/ 19.766	-	-	-	-	**Size 8/** 38.000	**Size 8/** 43.000
TOTAL USED CAPACITY	**94.020**	**122.449**	**154.833**	**191.712**	**232.324**	**277.734**
Investments over years [M$]	**45.069**		**14.444**	**3.500**	**30.266**	**3.500**
MIN and MAX capacity of each of size of biodiesel (B100) plant is given in table 6						
Region diesel plant/ **MAX capacity**	**Petroleum diesel plant used optimal capacity**					
	$[ton\ year^{-1}]x10^3$					
Region-2/ **1200000**	474.850	550.060	654.902	766.488	848.746	938.999
Region-15/ **900.000**	433.397	491.782	527.339	565.184	629.057	691.197
Region-20/ **900.000**	900.000	900.000	900.000	900.000	900.000	900.000
TOTAL USED CAPACITY	**1808.248**	**1941.843**	**2082.241**	**2231.672**	**2377.804**	**2530.196**

On the Table 16 and Table 16a are shown the results from the optimal synthesis of an IBSC using the criteria „Minimum Annualized Total Cost". The cases when it is possible to increase the size of the factory in the subsequent time intervals (the first scenario) the biorefinery optimal size/optimal used capacity and the petroleum diesel plant used capacity are given on Table 16 and the case when it is not possible (the second scenario) on Table 16a. To reach the EC requirements for the period (2010-2020) using the first scenario if increasing of the factory size is possible the number of Bulgarian regions with changed power of the factories is 11 (regions 3, 8, 9, 12, 14, 15, 17, 20, 21, 23, 26) at 2020. Using the policy without changing of the installed power of the factories (second scenario) during the exploitation, keeping the requirements EC criteria and the prognoses for diesel fuel consumption it is necessary to build factories with different power in 10 Bulgarian regions (3, 8, 9, 12, 15, 20, 21, 23, 24, 26) at 2020. For scenario 1 the total investments for building and enlargement of biorefineries for the period 2010-2020 figure out at 112.960 M$ while using scenario 2 the total investments are 96.780M$ respectively. The investment expenditures are equal for both scenarios for the first year, but for the next years the investment loading will be less for scenario 1 comparing with scenario 2.

2.2.5. Distribution of greenhouse gases stages of the life cycle of biodiesel(B100)

The results of optimal synthesis shown on Fig. 5 and Fig. 6 indicate that carbon dioxide emissions increase when the "Minimum Annualized Total Cost" criterion is used in comparison with the case when the Minimum Total GHG Emission is used. This is mainly because of increased emissions from the transport of raw materials and biodiesel. At the same time the increased emissions of carbon dioxide in the case in Fig. 6 is because of the technology used for growing sunflowers, which are predominantly used for the production of biodiesel (B100) in this case.

The analysis of the distribution of GHG emissions show that the "Minimum Total GHG emissions" is realized basically by optimization of transport emissions and appropriate choice of the places for necessary biomass production. When using the "Minimum Annualized Total Cost" criterion for synthesis of optimal IBSC is used, an increase of the emissions is observed as a result of the transportation of biofeedstock and fuels. In both the "Minimal Total GHG" and "Minimum Annualized Total Cost" cases the source of GHG emissions is the biodiesel (100) production technology and the relevant technology for cultivation of sunflower and rapeseed. Use of rapeseed as biofeedstock for biodiesel (100) production gives better indicators for GHG emissions at the biomass growth stage than use of sunflower biofeedstock.

The conclusion made from Fig. 7 is that the "Total GHG Emissions" with criteria "Minimum Annualized Total Cost" are with 9.55% more comparing with the emissions using the criteria "Minimum Total GHG Emissions" referred to 2020.

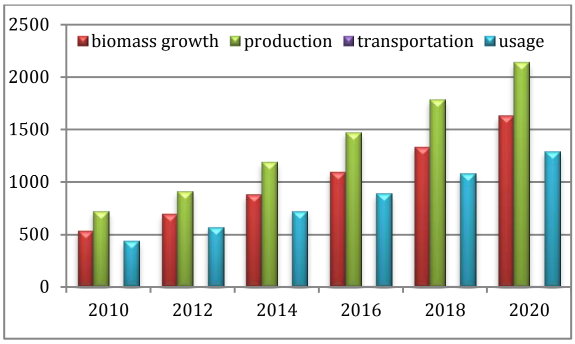

Fig 5. Distribution of GHG emissions for different stages of the life cycle of biodiesel (B100) for second scenario in case (a) – Minimum Total GHG emissions

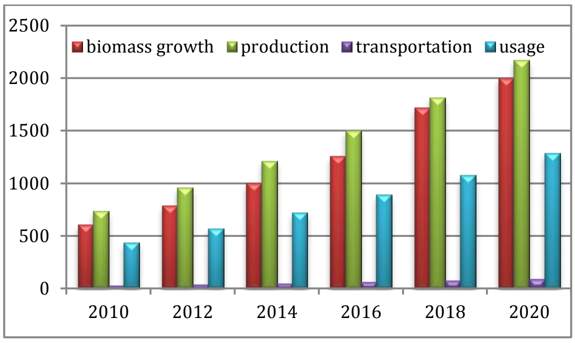

Fig 6. Distribution of GHG emissions for different stages of the life cycle of biodiesel (B100) for second scenario in case (b) - Minimum Annualized Total Cost

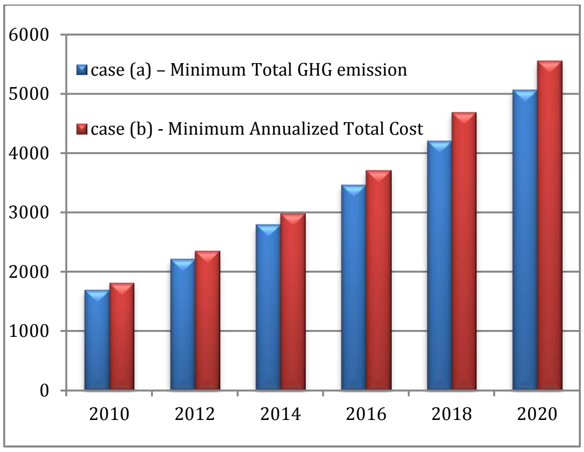

Fig 7. Total GHG emissions of the life cycle of biodiesel (B100) for second scenario in case (a) – Minimum Total GHG emissions and (b) - Minimum Annualized Total Cost

2.2.6. Biodiesel(B100) supply chain cost structures

The analysis of the structure of the expenses using both criteria shows that there is a significant value in the byproducts such as glycerin and seed cake remaining after oil extraction. For example the inclusion of glycerin and seed cake value leads to a decrease in the net process cost by 29.77% using the "Minimum Total GHG emission" criterion and by 37.03% using the "Minimum Annualized Total Cost" criterion over the time interval 2010-2020.

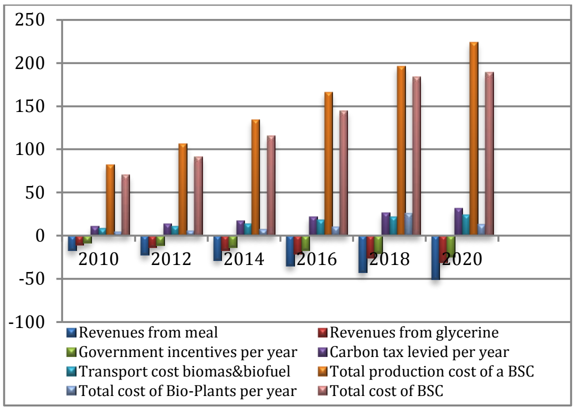

Fig 8. Biodiesel (B100) supply chain cost structures ($ year^{-1})10^6 for second scenario in case (a) – Minimum Total GHG emissions

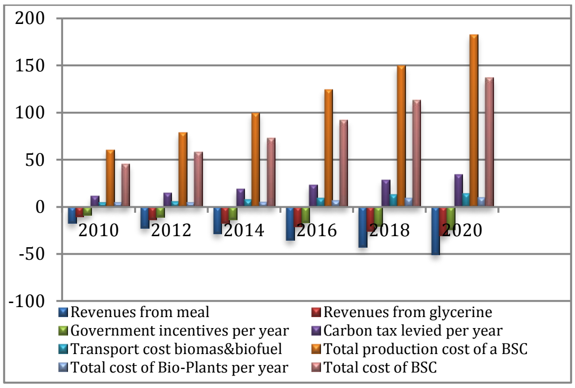

Fig 9. Biodiesel (B100) supply chain cost structures ($ year^{-1})10^6 for second scenario in case (b) - Minimum Annualized Total Cost

Figure 10 shows the Annualized Total Cost for the first and second scenario for different objective functions used for optimal synthesis of IBSC for different time intervals. It is seen that factory size has a relatively small influence on the total price of the IBSC, whereas choice of the criteria for synthesis, Minimum Cost or "Minimum GHG Emission", has a significant influence on the Annualized Total Cost. For example the cost of the "Minimum Annualized Total Cost" system has a 22.56% lower price compared with the Minimum Total GHG Emission based approach. At the same time using the "Minimum Annualized Total Cost" criterion the total emissions of greenhouse gases is only 9.55% bigger than that produced using the "Minimum Total GHG emission" approach.

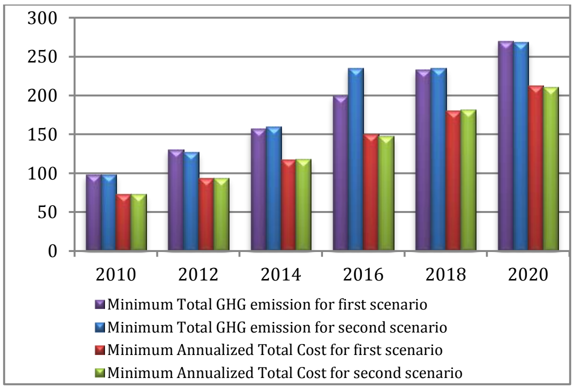

Fig 10. Annualized Total Cost ($ year^{-1})10^6 for first and second scenario using different objective functions for optimal synthesis of IBSC

2.2.7. Biodiesel(B100) production plant locations

The solutions obtained in the case of an optimal synthesis of BSC using the criterion "Minimum Total GHG Emissions" (case (a)) and using the criteria "Minimum Annualized Total Cost" (case (b)) showed that GHG emissions (Table 19) is only 6.6% lower in case (a) than case (b), while the price of biodiesel (B100) (Table 18) is 32% higher in case (a) than case (b). This is due to the increased capital and operational costs in case (a). Furthermore, the reduction of GHG emissions at the expenses of optimization of transport emissions in case (a) and use as rapeseed feedstock at case (b) instead of sunflower seeds in case (b). In case of design of an IBSC by using minimum greenhouse gas emissions as objective function, the best parameters are obtained if the used bio-resource for the Bulgarian conditions is rapeseed. However, it results in production of biodiesel (B100) with highest price (see Table 17 and Table 17a).

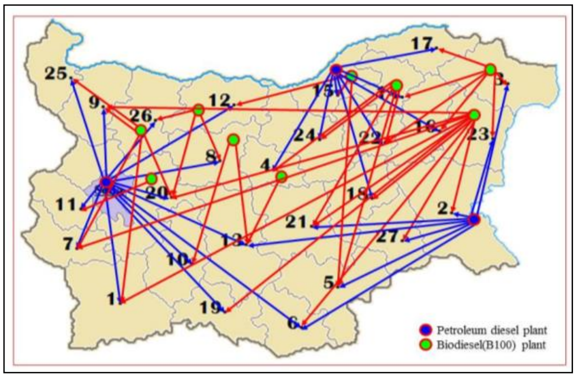

Fig 11. Optimal BG biodiesel (B100) supply chain configuration for 2020 year for first scenario in case: (a) – Minimum Total GHG emissions

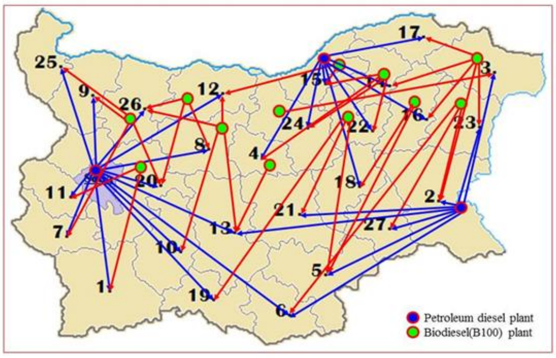

Fig 12. Optimal BG biodiesel (B100) supply chain configuration for 2020 year for second scenario in case:(a) – Minimum Total GHG emissions

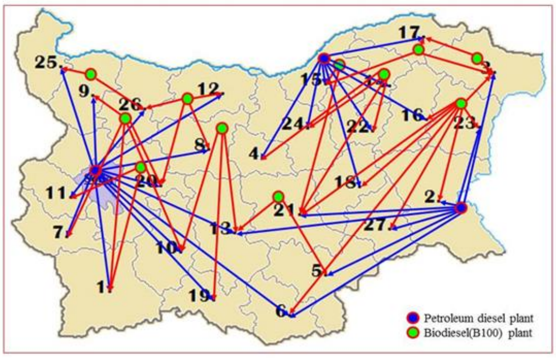

Fig 13. Optimal BG biodiesel (B100) supply chain configuration for 2020 year for first scenario in case: (b) – Minimum Annualized Total Cost

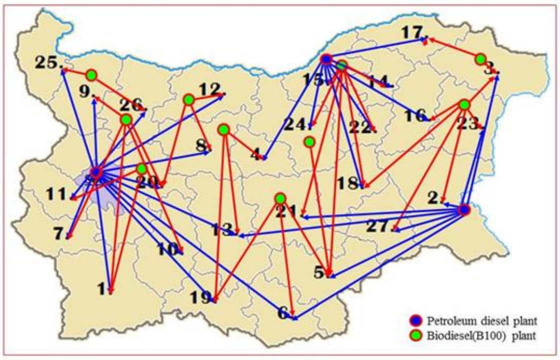

Fig 14. Optimal BG biodiesel (B100) supply chain configuration for 2020 year for second scenario in case: (b) – Minimum Annualized Total Cost

Table 17. Summary of computational results for the second scenario in case: **(a)**-Minimum Total GHG emissions

Years	**2010**	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	5%	6%	7%	8%	9%	10%
Cost of a Biodiesel plants per year (M$ year^{-1})						
Cost of a Biodiesel per year	**98.270**	**127.101**	**159.84**	**195.67**	**235.53**	**268.93**
Cost of a Diesel and Transport per year (M$ year^{-1})						
Cost of a Diesel&Transport	**1173.58**	**1261.37**	**1353.79**	**1452.15**	**1548.39**	**1648.79**
Transport cost Diesel	34.38	38.01	41.98	46.20	50.37	54.77
Total Greenhouse gases (tonCO2-eq. year^{-1})x10^{6}						
GHG on a Biodiesel&Diesel	**6.98**	**7.5930**	**8.248**	**8.969**	**9.68**	**10.44**
GHG emissions from Biodiesel	0.4240	0.5528	0.699	0.867	1.05	1.27
GHG for Diesel and transportation	6.55	7.0352	7.543	8.082	8.61	9.17
Greenhouse gases per day for BSC (tonCO2-eq. day^{-1}) x10^{6}						
GHG emissions on a BSC	**0.1696**	**2.2113**	**2.79**	**3.48**	**4.22**	**5.07**
Total Biodiesel and Diesel usage per year (ton year^{-1}) x10^{6}						
Biodiesel usage	0.094	0.122	0.154	0.192	0.232	0.278
Diesel usage	1.808	1.942	2.082	2.232	2.378	2.530
Distribution of arable land (ha)x10^{3}						
Total SUM Land	3227.23					
BIOFUELS Land	88.59	115.08	145.17	177.62	215.08	250.05
RESERVATION Land	1613.61					
FOOD Land	668.09					
FREE Land	856.93	830.91	800.36	767.92	731.21	695.48
BIOFUELS Land all regions for (ha)x10^{3}						
Sunflower	0.285	1.68	2.349	6.582	17.772	52.743
Rapeseed	88.306	113.34	143.123	172.715	197.309	197.281
FOODS&BIOFUELS Land all regions (ha)x10^{3}						
Sunflower	515.215	516.62	518.609	529.008	536.071	567.673
Rapeseed	241.470	266.56	294.657	316.701	346.347	350.472

Table 17a. Summary of computational results for second scenario in case: (b) - Minimum Annualized Total Cost

	Years					
	2010	**2012**	**2014**	**2016**	**2018**	**2020**
Proportion biodiesel/diesel	5%	6%	7%	8%	9%	10%
Cost of a Biodiesel plants per year (M$ year^{-1})						
Cost of a Biodiesel per year	**72.760**	**93.723**	**11.8459**	**147.730**	**181.510**	**211.051**
Cost of a Diesel and Transport per year (M$ year^{-1})						
Cost of a Diesel&Transport	**1173.57**	**1261.37**	**1353.78**	**1452.15**	**1548.39**	**1648.79**
Transport cost Diesel	34.38	38.01	41.98	46.20	50.37	54.77
Total Greenhouse gases (tonCO2-eq./year)x10^6						
GHG on a Biodiesel&Diesel	**7.008**	**7.630**	**8.289**	**9.02**	**9.76**	**10.56**
GHG emissions from Biodiesel	0.452	0.589	0.745	0.928	1.138	1.387
GHG for Diesel and transportation	6.551	7.035	7.544	8.085	8.615	9.167
Greenhouse gases per day for BSC (ton CO_2-eq. day^{-1}) x10^3						
GHG emissions on a BSC	**1.809**	**2.35**	**2.98**	**3.71**	**3.90**	**5.55**
Total Biodiesel and Diesel usage per year (ton year^{-1}) x10^6						
Biodiesel usage	0.094	0.122	0.155	0.192	0.232	0.278
Diesel usage	1.808	1.941	2.082	2.231	2.377	2.530
Distribution of arable land (ha)x10^3						
Total SUM Land	3227.23					
BIOFUELS Land	72.446	94.583	119.43	150.26	194.66	227.45
RESERVATION Land	1613.61					
FOOD Land	657.46					
FREE Land	883.72	861.58	826.10	781.65	731.84	689.87
BIOFUELS Land all regions for (ha)x10^3						
Sunflower	72.231	93.038	119.00	144.84	186.37	226.68
Rapeseed	0.214	1.545	0.285	5.419	8.284	0.773
FOODS&BIOFUELS Land all regions (ha)x10^3						
Sunflower	576.53	597.34	633.33	668.48	719.04	756.20
Rapeseed	153.38	154.71	154.19	163.50	165.85	174.44

Table 18. Summary of computational results for price of biodiesel (B100) for second scenario

Price of biodiesel (B100) ($ ton^{-1})							
Criterion	**Average**	**Years**					
		2010	**2012**	**2014**	**2016**	**2018**	**2020**
(a) - MIN Total GHG emissions	**1019** **(132%)**	1045 (135%)	1041 (136%)	1032 (135%)	1020 (132%)	1013 (129%)	968 (127%)
(b) - MIN Annualized Total Cost	**769** **(100%)**	774 (100%)	765 (100%)	765 (100%)	770 (100%)	781 (100%)	759 (100%)

Table 19. Summary of computational results for total GHG emissions for the second scenario

Total Greenhouse gases emissions (tonCO2-eq./year)x10^6							
Criterion	**Average**	**Years**					
		2010	**2012**	**2014**	**2016**	**2018**	**2020**
(a) - MIN Total GHG emissions	**(93.42%)**	1.696 (93.7%)	2.211 (93.8%)	2.798 (93.8%)	3.465 (93.4%)	4.216 (92.2%)	5.083 (93.6%)
(b) -MIN Annualized Total Cost	**(100%)**	1.809 (100%)	2.356 (100%)	2.981 (100%)	3.712 (100%)	4.696 (100%)	5.558 (100%)

3. CONCLUSIONS

The underlying conclusions of the present investigation are that in order to achieve a "smart" system design for biodiesel production and dissemination it is necessary to take into account the interactions between all components included in the production and distribution of biodiesels produced from different types of biomass. At the same time, the requirements of EC Directive 20/20/20 need to be met. Analyzing the results of the investigation, we found that the economically competitive production of biodiesel depends on the optimization of the whole integrated supply chain over the entire planning horizon for Bulgaria in the period 2010-2020. Optimization of only parts of the supply chain will not achieve an understanding of the compromises in time, in geographical location of the production and in necessary supply elements required for the optimization of biodiesel production. The approach proposed in this investigation can be applied in different geographic regions that have the capacity to produce various bio-resources for example - sunflower and rapeseed. The model can also be take into account changing policy standards and changing biodiesel production technologies in over extended system planning periods.

The results from this investigation are giving the possibility to make the following substantial conclusions:

1. The available agricultural land in Bulgaria is giving an opportunity for producing sufficient amount of biological feedstock (sunflower and rapeseed) for production of the needed quantity of biodiesel (B100) in order to satisfy the Bulgarian needs and to reach the required quota of 10 % for liquid biofuel at 2020.
2. The optimal area required for cultivation of sunflower and rapeseed is concentrated in a small number of country regions chosen independently of the objective criteria for the optimal synthesis of the IBSC.
3. The optimum mixture of biocultural feedstock using the "Minimum Annualized Total Cost" approach for synthesis of IBSC required in 2020 requires 14% of agricultural land to be used to for sunflower cultivation and 2% to be used for rapeseed cultivation. The use of the "Minimum Total GHG Emissions" criterion requires 12% of agricultural land to be used for rapeseed cultivation and 3% to be used for sunflower cultivation.
4. An important conclusion for the logistics is that the railway is an optimal type of transport which should be used as for bio-resources (sunflower and rapeseed), as well as for fuels (biodiesel (B100) and petroleum diesel).
5. The average cost of biodiesel (B100) in the period of (2010-2020) using the "Minimum Annualized Total Cost" synthesis model is 769 \$ t^{-1} whilst the "Minimum Total GHG Emission" model under the the same circumstances yields a cost of 1019 \$ t^{-1}, i.e. 32.5% higher than the "Minimum Annualized Total Cost" approach. The total GHG emissions for the Minimum Annualized Cost approach are 6.6% higher when minimization of the cost of production rather than minimization of GHG emissions the primary objective.
6. The estimated cost of capital investment for the whole period (2010-2020) is 96.779 M\$ for the "Minimum Annualized Total Cost" and 127.257 M\$ for "Minimum Total GHG Emission" using the same input data for each calculation.

We intend also in the future to include in the model uncertainties in optimal decision-making procedures in order to improve the system reliability against uncertainties as demand variations, technological uncertainty and unexpected circumstances caused by human or natural adversity.

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