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Optimal design and planning of biodiesel supply chain considering crop rotation model. Part 2. Location of biodiesel production plants on the Bulgarian scale

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The mixed integer linear programming (MILP) model for optimal design and planning of Bulgarian biodiesel supply chain proposed in Part 1 is applied in this paper. The given feed stocks are sunflower and rapeseed. The country has been divided into twenty seven regions corresponding to its provinces, each one including existing crops, oil and biodiesel plants and potential ones associated to binary variables. The mathematical model has been implemented in GAMS providing a complete decision tool that can be applied to other regions or countries by adjusting the system-specific data.

Key words: Biodiesel Supply Chain, Crop rotation, Optimum design, Bulgarian scale

INTRODUCTION

Biodiesel production is been explored throughout the world to ensure economical and environmental profits in replacing increasing percentages of fossil-based diesel by biodiesel. In order to produce its own biodiesel, each country needs analyzing the economical and environmental feasibility of the complete production chain beginning from the availability of raw materials, their transformation in intermediate and final products and the storing and distribution of these one to internal and external markets. The result is a large network combining several stages with different options in each stage extending from alternative biomass crops to the location of product storage and conversion facilities, modes of transportation and flows of biomass and products between regions.

The EU Strategy for Biofuels (2006), the Biomass Action Plan (2005), and the adoption of the Biofuels Directive (2003/30/EC) by the EU Commission all sent a clear signal that the EU wishes to establish and support the bioenergy industry (Commission of the European Communities, 2003). Furthermore, biofuels have been required to account for at least 2% of the total transportation fuels used in EU member states since 2005. That minimum level increases to 5.75% in 2010 and 10 percent by 2020.

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 individual aspects of supply chain, as plantation or transportation and there are only a few papers that address the entire biofuel supply chain analysis and optimization. A mathematical model to solve the problem of designing and managing the BSC for biodiesel, based on the method of MILP of crop rotation was proposed in the first part of this work.. The aim of this study work is to apply the mathematical model for the case of biodiesel production at the real conditions in Bulgaria.

CASE STUDY: POTENTIAL BIODIESEL (B100) PRODUCTION IN BULGARIA

The model described in part 1 has been applied to a case study of biodiesel (B100) production in the Bulgaria. Two major types of biomass resources in this case, namely, sunflower and rapeseed for production of first generation biodiesel (B100) is used.

A demand scenario has been investigated based on Bulgarian domestic target for 2010 (5.75% by energy content) [16].

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Model input data

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 'Territorial balance of the Republic of Bulgaria as of 31.12.2000'. Bulgaria's total area is 111001.9 square kilometers out of which 63764.8 square kilometers is agricultural land. From this land, arable land and utilized agricultural area for 2011 is 3,162,526 hectares (STATISTICAL YEARBOOK 2011 [17]). The main energy crops for biodiesel (B100) that 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. The agricultural land of Bulgaria is almost 0.7 ha per inhabitant, compared to 0.4 ha at the average of EU-25 [1]. Hence, producing the feedstock required internally becomes easier. In general, feedstock availability is directly related to land availability. Therefore, land availability is an important and critical factor affecting the feedstock amount.

*Territorial division of Bulgaria.*Bulgaria comprises 27 regions. In this case study, each region in Bulgaria is considered to be a feedstock production region, a potential location of a biorefinery facility and also a demand zone. In other words, the biofuel supply chain network consists of 27 areas for feedstock production, 27 potential biorefinery locations and 27 demand zones. In the case study, we assumed 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.

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 STATISTICAL YEARBOOK-2011 [17]. The consumption of petroleum diesel fuel for transportation in the country is known and for the year 2011 it amounted to 1,711,000 tons. For the purposes of this study, the consumption of petroleum diesel fuel for each region is assumed to be approximately proportional to its size.

Data on energy consumption of petroleum diesel for transport by regions. **Table 1** presents the data on cultivated area distribution corresponding to each region, population size and fixed consumption of petroleum diesel fuel for transport.

Petroleum Diesel[*]**.** The values for the used amount of petroleum diesel corresponding to for each region is assumed to be proportional to their population in the total set for Bulgaria in 2011, according to [17].

Feedstock supply chain components for biodiesel(B100) production in Bulgaria. Biodiesel (B100) is produced from vegetable oils that are derived from seeds or pulp of a range of oil-bearing crops. Such oil crops for Bulgarian climate are rapeseed and sunflower. Oil from sunflower was the first type used for biodiesel (B100) production. Today, in Bulgaria, sunflower is still the main feedstock for biodiesel (B100) production. It is grown throughout Bulgaria and sunflower seed crops are grown mainly in the warmer areas. Bulgaria has great potential and traditions for rapeseed and sunflower cultivation. Therefore the main energy crops that will be discussed in this study are, as follows: rapeseed and sunflower for biodiesel (B100) production.

Emission factor for cultivation of feedstock and yields. Greenhouse gas 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 aggregate Green House Gases (GHG) emissions 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 2** gives GHG emissions in the agronomy phase to rapeseed and sunflower for different regions of Bulgaria.

Data for the production cost of energy crops (sunflower and rapeseed) 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 Regions, the technology of cultivation of the species on earth and bio cultures

The specific annual yield of each raw material per hectare of cultivated area differs significantly from one region to the other, depending on various parameters, such as climate, soil, etc. **Table 3** show the specific annual yield of each raw material (Sunflower and Rapeseed) for biodiesel(B100) production, respectively, as well as the available land in each region in Bulgaria

Table 1. The distribution of set-aside land per regions in Bulgaria

No	Name of regions	Population [17]	Current cultivated area [4]	Land reserved for food [4]	Petroleum Diesel*
	Units		ha		$ton/year$
1	Region-1 ⇒ Vidin	99481	90 853	45426	23230
2	Region-2 ⇒ Montana	145984	130 243	65121	34089
3	Region-3 ⇒ Vratsa	184662	175 528	87764	43120
4	Region-4 ⇒ Sofia	1542231	68 201	34100	360130
5	Region-5 ⇒ Pernik	131987	33 980	16990	30820
6	Region-6 ⇒ Kyustendil	134990	18 537	9268	31521
7	Region-7 ⇒ Blagoevgrad	322025	20 512	10256	75196
8	Region-8 ⇒ Pazardjik	273803	57 675	28837	63936
9	Region-9 ⇒ Lovech	139609	66 834	33417	32600
10	Region-10 ⇒ Pleven	266865	289 355	144677	62316
11	Region-11 ⇒ V.Tarnovo	256279	168 194	84097	59844
12	Region-12 ⇒ Gabrovo	121389	21 507	10753	28345
13	Region-13 ⇒ Plovdiv	680884	179 416	89708	158995
14	Region-14 ⇒ Smolyan	120456	5 095	2547	28128
15	Region-15 ⇒ Kardjali	152009	12 751	6375	35496
16	Region-16 ⇒ Haskovo	243955	116 657	58328	56966
17	Region-17 ⇒ St.Zagora	331135	173 465	86732	77324
18	Region-18 ⇒ Yambol	130056	149 686	74843	30369
19	Region-19 ⇒ Sliven	196712	85 021	42510	45934
20	Region-20 ⇒ Targovishte	119865	98 038	49019	27990
21	Region-21 ⇒ Rouse	233767	170 072	85036	54587
22	Region-22 ⇒ Razgrad	123600	140 215	70107	28862
23	Region-23 ⇒ Shumen	179668	140 824	70412	41954
24	Region-24 ⇒ Silistra	118433	146 411	73205	27655
25	Region-25 ⇒ Dobrich	188088	329 809	164904	43920
26	Region-26 ⇒ Varna	474344	160 786	80393	110765
27	Region-27 ⇒ Bourgas	414947	177 572	88786	96895
	Total	7327224	3162526	1613611	1711000

Table 2. Greenhouse gas emissions in the agronomy phase and potential yields from rapeseed and sunflower in the regions in Bulgaria

No	Regions [5]	GHG emissions in the agronomy phase		The yield cultivation in regions	
	Units	$kg\,CO_2-eq\,ton^{-1}\,biomass$		ton/ha	
	Energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed
1	Region-1 ⇒ Vidin	1425	1120	2.8	2.2
2	Region-2 ⇒ Montana	1150	890	2.2	2.6
3	Region-3 ⇒ Vratsa	875	660	1.8	2.0
4	Region-4 ⇒ Sofia	1700	1350	1.5	1.8
5	Region-5 ⇒ Pernik	1425	1120	1.8	2.2
6	Region-6 ⇒ Kyustendil	1700	1350	1.5	1.8
7	Region-7 ⇒ Blagoevgrad	1700	1350	1.5	1.8
8	Region-8 ⇒ Pazardjik	1700	1350	2.2	3.2
9	Region-9 ⇒ Lovech	1425	1120	1.8	3.2
10	Region-10 ⇒ Pleven	600	430	2.8	3.5
11	Region-11 ⇒ V.Tarnovo	875	660	2.4	3.0
12	Region-12 ⇒ Gabrovo	1425	1120	1.8	2.2
13	Region-13 ⇒ Plovdiv	1425	1120	1.8	2.2
14	Region-14 ⇒ Smolyan	1700	1350	1.5	1.8

15	Region-15 $\Rightarrow$ Kardjali	1700	1350	1.5	1.8
16	Region-16 $\Rightarrow$ Haskovo	1425	1120	1.8	2.2
17	Region-17 $\Rightarrow$ St.Zagora	875	660	2.8	3.0
18	Region-18 $\Rightarrow$ Yambol	1150	890	2.6	2.6
19	Region-19 $\Rightarrow$ Sliven	1150	890	2.4	2.6
20	Region-20 $\Rightarrow$ Targovishte	1150	890	2.2	2.6
21	Region-21 $\Rightarrow$ Rouse	600	430	3.3	3.5
22	Region-22 $\Rightarrow$ Razgrad	875	660	2.8	3.0
23	Region-23 $\Rightarrow$ Shumen	875	660	2.8	3.0
24	Region-24 $\Rightarrow$ Silistra	875	660	2.8	3.0
25	Region-25 $\Rightarrow$ Dobrich	600	430	3.4	3.5
26	Region-26 $\Rightarrow$ Varna	875	660	2.8	3.0
27	Region-27 $\Rightarrow$ Bourgas	1425	1120	2.8	2.8

Table 3. Unit biomass cultivation cost and maximum amount of biomass that can be produced in the regions of Bulgaria

No	Regions	Cultivation costs per unit biomass [7,10]		Maximum biomass production	
	Units	$\$\,ton^{-1}\,biomass$		$ton\ year^{-1}$	
	Energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed
1	Region-1 $\Rightarrow$ Vidin	213	236	47698	40884
2	Region-2 $\Rightarrow$ Montana	198	233	68378	58609
3	Region-3 $\Rightarrow$ Vratsa	195	230	92152	78987
4	Region-4 $\Rightarrow$ Sofia	227	239	35806	30690
5	Region-5 $\Rightarrow$ Pernik	213	236	17839	15291
6	Region-6 $\Rightarrow$ Kyustendil	227	239	9732	8342
7	Region-7 $\Rightarrow$ Blagoevgrad	227	239	10768	9230
8	Region-8 $\Rightarrow$ Pazardjik	227	239	30279	25954
9	Region-9 $\Rightarrow$ Lovech	213	236	35087	30075
10	Region-10 $\Rightarrow$ Pleven	192	227	151911	130210
11	Region-11 $\Rightarrow$ V.Tarnovo	195	230	88301	75687
12	Region-12 $\Rightarrow$ Gabrovo	213	233	11291	9678
13	Region-13 $\Rightarrow$ Plovdiv	213	236	94193	80737
14	Region-14 $\Rightarrow$ Smolyan	227	239	2675	2293
15	Region-15 $\Rightarrow$ Kardjali	227	239	6694	5738
16	Region-16 $\Rightarrow$ Haskovo	213	236	61245	52496
17	Region-17 $\Rightarrow$ St.Zagora	195	230	91069	78059
18	Region-18 $\Rightarrow$ Yambol	198	233	78585	67358
19	Region-19 $\Rightarrow$ Sliven	198	233	44636	38259
20	Region-20 $\Rightarrow$ Targovishte	198	233	51469	44117
21	Region-21 $\Rightarrow$ Rouse	192	227	89287	76532
22	Region-22 $\Rightarrow$ Razgrad	195	230	73613	63097
23	Region-23 $\Rightarrow$ Shumen	195	230	73932	63370
24	Region-24 $\Rightarrow$ Silistra	195	230	76866	65885
25	Region-25 $\Rightarrow$ Dobrich	192	227	173150	148414
26	Region-26 $\Rightarrow$ Varna	195	230	84412	72353
27	Region-27 $\Rightarrow$ Bourgas	213	236	93225	79907

Data for the biodiesel production cost Unit biodiesel production cost from Sunflower and Rapeseed for biorafinery of all scale p for each 27 regions is $214\$\,/\mathrm{ton}$ biodiesel

Required feedstock (rapeseed and sunflower) to ensure food security in Bulgaria

Table 4. Value of biological resources to ensure food security in Bulgaria

	Type of Energy crops	Total bio-resources amount for food security	Cultivated area used for food security
	Units	*ton/year*	*ha*
1	Sunflower	1321765	734314
2	Rapeseed	376824	209347

Table 4 presents data taken from the STATISTICAL YEARBOOK-2011 [17]. It describes cultivated area in 2011 for production of sunflower and rapeseed to ensure food security of Bulgaria. In this work, we assume the data as basis that ensures food security to all regions of Bulgaria.

Potential sites for locations of biorefineries in Bulgaria. Suitable potential biorefinery locations throughout the state have been chosen based on a set of criteria considering the accessibility to water and transportation infrastructures and zoning requirements. In total, all 27 regions were selected as candidate refinery locations and they are dispersed across the Bulgarian territory.

The technology of biodiesel (B100) production used in this study. It is based on the use of technology for producing biodiesel (B100) by esterification of vegetable oils. It is assumed that pure vegetable oil is obtained from rapeseed oil or sunflower by mechanical pressing or solvent extraction.

Production route is as follows: Oilseeds are crushed to produce oil, which after filtering is mixed with ethanol or methanol at about 50°C. The resultant esterification reaction produces fatty acid methyl esters (FAME), which are the basis for biodiesel (B100), and the co-product glycerine which can be used in soap manufacture. Approximately 100 kg of glycerine is produced per tone of biodiesel(B100). Another co-product is the residue "cake" from the crushing of the oilseeds, which is rich in protein and is used for animal feed.

This technology for extracting oil from oilseeds has remained the same for the last 10-15 years and is not likely to change significantly. Similarly, biodiesel(B100) production from the oil is a relatively simple process and so there is little potential for efficiency improvement. There is, however, ongoing research into the better utilisation of co-products.

Biomass to biodiesel(B100) conversion factor. Conversion efficiency of rapeseed and sunflower biodiesel(B100) ranges from $389 l/ton$ to $454 l/ton$ [15]. We use a conversion efficiency of $421 l/ton\,(371 kg/ton)$ for sunflower and $344 l/ton\,(303 kg/ton)$ for rapeseed, which is the average of the lowest and highest conversion efficiency found in literature.

Biorefinery costs and capacity. The refinery capital cost (as shown in Part 1) consists of fixed and variable capital cost. The fixed capital cost varies according to refinery locations while the variable capital cost of biomass-to-biodiesel plants, is mainly influenced by the plant size, since the technology is considered mature.

Variable capital cost is scaled using the general relationship [20]

$\dfrac{Cost_p}{Cost_{base}} = \left(\dfrac{Size_p}{Size_{base}}\right)^R$, where $Cost_p$ is variable capital cost and $Size_p$ represent the investment cost and plant capacity for the new plant, respectively $Cost_{base} = 3.5\, M\$$ for $Size_{base} = 8500\, ton/year$ and then adopted base price is $412\ \$/ton$ **a**ccording to [15]**.**

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

$$Cost_{pf}^{F} = M_f^{\cos t} Cost_p, \quad \forall p \in P, \forall f \in F\,,$$

where $M_f^{\cos t} = 1$; in our case it is assumed that all 27 regions $f \in F$.

The refinery capacity at all candidate locations can be up to $PB_p^{MAX} = 100000\, ton/year$ .They are broken down into discrete order shown in Table 5.

Biodiesel(B100) production costs. Production costs per unit of biodiesel (B100) in a biorefinery installed in the region in case the Keys to Manufacturing Operating expenses such as: Chemicals and catalysts, gas, electricity, makeup water, wastewater treatment and disposal, administrative and operating costs and direct labor and Benefits. As discussed in [7], the average costs are $125\ \$/ton$ for each region of biodiesel (B100), not including the costs of raw materials. In the case study, we assumed 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.

Data for biodiesel(B100) and petroleum diesel. The data necessary for the purposes of this study were taken from the literature [12,13,14] and the parameters of biodiesel and petroleum diesel are given in Table 6.

Table 5. Total specific investment cost of biodiesel(B100) production plants as a function of their size

Size of the biodiesel(B100) plant [9,10]	Variable capital cost of the biodiesel (B100) plant $Cost_p$	MIN capacity of the biodiesel (B100) plant PB_p^{MIN}	MAX capacity of the biodiesel (B100) plant PB_p^{MAX}	Average capital costs per unit of the biodiesel (B100)
Units	$M\$$	$ton/year$		$\$/ton$
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

Table 6. Emission coefficient of fuel and energy equivalent

Type of fuel	Emission coefficient	Energy equivalent	Energy equivalent	Density (average)	Price of biofuel
Source	[13]		[12]		[14]
Unit	$kgCO_2-eq/ton$	GJ/ton	MWh/ton	ton/m^3	$\$/ton$
Petroleum Diesel	3623	42.80	11.880	0.840	1192.70
Biodiesel(B100)	1204	37.80	7.720	0.880	-

Biodiesel (B100) and petroleum diesel proportion, subject of mixing. In order to set national indicative targets for the consumption of biofuels in any country, the European Concil's Directive 2003/30/EC (8-9 March 2007) has set out and adopted new targets for increasing the share of biofuels. In the above documents are targets for biofuels: indicative target of 5.75% for 2010; binding target for the share of biofuels of 10% for all states-states in the total consumption of petrol and petroleum diesel for transport in the EU by 2020 to be achieved in a cost effective manner. Production of biodiesel (B100) is used as a component in mixtures of petroleum diesel oil produced in a specific proportion [11]. Bulgaria in 2011 is to use biodiesel–petroleum diesel blend ratio of 6% biofuel (B100) and 94% petroleum diesel.

Data for cost transportation for biomass and biodiesel (B100). In order to estimate the costs of transportation of the feedstock and fuels in the entire supply chain system, a GIS-based transportation network was introduced. This network contains local, rural, urban roads and major highways. The shortest distances between feedstock fields, refineries, and demand cities were 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 biodiesel (B100) transportation by 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 Leduc [6], and detailed in Table 7 and Table 8., for transportation by tractor, truck and train for biomass (sunflower and rapeseed) and biodiesel (B100).

Table 7. Unit transportation cost for each mode of transportation and type of the biomass

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

Table 8. Unit costs for each transportation mode and biodiesel (B100), rcf. [6].

		Fixed cost OA_b		Variable cost OB_b	
	Unit	$\$ton^{-1}km^{-1}$			
	Type of transport	Truck	Train	Truck	Train
1	Biodiessel(B100)	24.11	7.86	0.436	0.173

Data for emission factors for transportation biomass and biodiesel(B100). The simplest approach for estimating emissions from road and rail transport is based on the amounts of each fuel consumed. The approach for CO_2 is indicated in **Table 9**. 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 in [2,3,8].

Table 9. Emission factor of transportation for mode l

	Type of transport [2,3,8]	Emission factor of transportation biomass	Emission factor of transportation biofuel
	Unit	$kg\ CO_2\text{-}eq.km^{-1}ton^{-1}$	
1	Tractor	0.591	-
2	Truck	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

Data for Actual delivery distance between regions in Bulgaria.

A/ Actual delivery distance between regions.

Distances in kilometers between settlements in Bulgaria for the purposes of this study were taken from the National Transport Agency for each type of transport (tractor, truck, rail).

B/ Average local delivery distance**.** While the distance between a region with them will be the average distance of the feedstock being transported to the factory (assuming it is installed in a certain place of the region). To calculate the transportation distance required, the coordinates of each biomass site, namely the potential biorefinery location was identified. The data used in this paper is given at the level of a county, therefore the coordinates of the center point of a county are used to calculate the geographical distances between locations. In general, the average distance can be determined according to the relationship:

$$d_{gg'} = \frac{\sum_{m \in M_g} \left(S_{gm} d_m^{Plant} \right)}{\sum_{m \in M_g} S_{gm}} \qquad (1)$$

where $d_{gg'}$ is the average distance that is expected for transport of the feedstock produced in region $g \in G$, $g = g'$ to the factory installed in place $Plant$ (Figure 1**)** installed in the specified location of this region, S_{gm} is the area of sub-region $m \in M_g$, and d_m^{Plant} indicates the distance between landmark center sub region $m \in M_g$ and places in which it is permissible to install biorefinery.

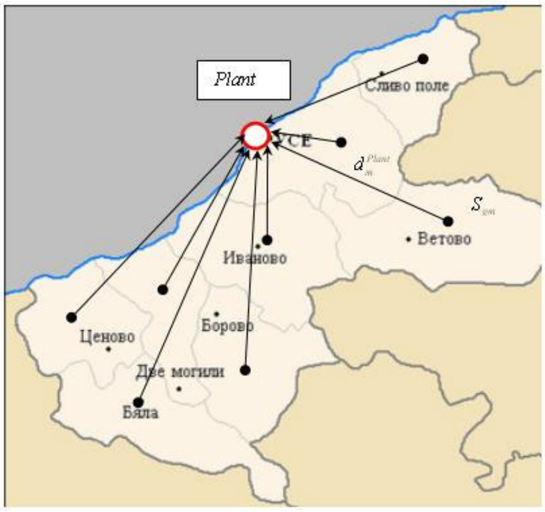

Fig. 1. Scheme to determine the average distance for the transport of feedstock in a region where the biorefinery is located in the same region

Table 10 presents the average distance for each of the 27 regions of Bulgaria. It is used in the method described above.

Computational results and analysis

In this section, we present the results from the case study described, identifying the optimal system design, the system costs, and feedstock supply strategies.

The mathematical model proposed in the first part of this work is used to solve the case study at the conditions at present in Bulgaria. The Software code is carried out by using GAMS intended for solving specific problems with real data.

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Table 10. Average distance for each region determined by (1).

	Type of transport	Tractor	Truck	Rail
	Name of regions		*km*	
1.	Region-1 to Region-1	25	25	25
2.	Region-2 to Region-2	27	27	27
3.	Region-3 to Region-3	27	27	27
4.	Region-4 to Region-4	46	46	46
5.	Region-5 to Region-5	17	17	17
6.	Region-6 to Region-6	36	36	36
7.	Region-7 to Region-7	44	44	44
8.	Region-8 to Region-8	25	25	25
9.	Region-9 to Region-9	38	38	38
10.	Region-10 to Region-10	35	35	35
11.	Region-11 to Region-11	36	36	36
12.	Region-12 to Region-12	13	13	13
13.	Region-13 to Region-13	33	33	33
14.	Region-14 to Region-14	39	39	39
15.	Region-15 to Region-15	26	26	26
16.	Region-16 to Region-16	40	40	40
17.	Region-17 to Region-17	33	33	33
18.	Region-18 to Region-18	21	21	21
19.	Region-19 to Region-19	27	27	27
20.	Region-20 to Region-20	18	18	18
21.	Region-21 to Region-21	25	25	25
22.	Region-22 to Region-22	22	22	22
23.	Region-23 to Region-23	31	31	31
24.	Region-24 to Region-24	24	24	24
25.	Region-25 to Region-25	32	32	32
26.	Region-26 to Region-26	27	27	27
27.	Region-27 to Region-27	44	44	44

Table 11. Flow rate biomass from grow region to biodiesel (B100) plants

No	Name of regions	Criterion 1 (a)-Min. GHG emission		Criterion 2 (b)-Min. Cost BSC	
	Type of transport	TRACTOR	RAIL	TRACTOR	TRACTOR
	Type of energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed
	Unit		*ton/day*		
1.	Region-10 to Region-9	1.00	405.76	257.94	1.00
2.	Region-10 to Region-10	1.00	517.42	590.43	1.00
3.	Region-21 to Region-21	1.00	77.98	0.00	0.00
4.	Region-25 to Region-26	1.00	384.55	193.25	1.00
5.	Region-25 to Region-25	0.00	0.00	90.83	1.00

Table 12. Distribution of greenhouse gases stages of the life cycle.

No.		Criterion 1 (a)-min. GHG emission		Criterion 2 (b)-min. cost BSC	
	Unit	*kg CO_2-eq/day*	%	*kg CO_2-eq/day*	%
1.	GHG emission to grow	598253.76	31.48	681193.39	33.58
2.	GHG emission for biodiesel prod.	809051.27	42.57	824122.93	40.63
3.	GHG emission of transportation	2914.98	0.15	32901.26	1.62
4.	GHG emission from biodiesel usage	490033.59	25.78	490033.59	24.16
5.	Total GHG emission for BSC	1900253.61	100	2028251.18	100

Biomass supply. The optimal biomass flows are given in **Table 11**.*Distribution of greenhouse gases stages of the life cycle of biodiesel (B100).* Table 12 shows the distribution of greenhouse gas life cycle stages of biodiesel (B100) relative to day work BSC

Solutions obtained in the case of optimal synthesis conforming to criterion (a) minimum total

GHG emission in the work of BSC and minimum annualized total cost of BSC showed that GHG emission is only 6.31% lower in case (a) than in case (b), while the price of biodiesel (B100) is 37.63% higher in case (a) than in case (b). This is due to the increased capital and operational costs (a). Furthermore, the reduction of GHG emission at the expense of optimization of transport emissions in (a) and use as canola feedstock at (a) instead of sunflower seeds in (b).

The cost structure for biodiesel (B100) in the supply chain. The total system cost consists of four components: feedstock procurement cost, refinery capital cost, production cost, and transportation cost. The refinery capital cost contains fixed and variable capital costs. The transport cost includes both the delivery cost of feedstock to refineries and fuel distribution cost from refineries to cities.

Table 12 shows the breakdown of cost for one-year work BSC throughout the planning period, send the optimal solution for the design of the supply chain for both evaluation criteria (economic and environmental).

The solutions obtained in the case of an optimal synthesis at criterion (a) Minimum Total GHG emission and Minimum Annualized Total Cost of BSC showed that emissions of greenhouse gases are only 6.31% lower in case (a) than case (b), while the price of biodiesel(B100) extracted is 37.63% higher in case (a) than in case (b). This is due to the increased capital costs of case (a) than of case (b). Furthermore, case greenhouse gas emissions are at the reduced expense of optimization of transport emissions in case (a) and use as feedstock rapeseed instead of sunflower seeds in case (b). The rapeseed shows less emissions and growing production in refineries compared sunflower, used in case (b). In genera, the cost of biodiesel produced is less competitive (i.e. in the range of $0.76-$1.05 per kg) over the year. Accounting for the largest portion in the total cost (between 67% and 70%) total biomass cost of in the range a BSC is identified as the major cost drive in the system.

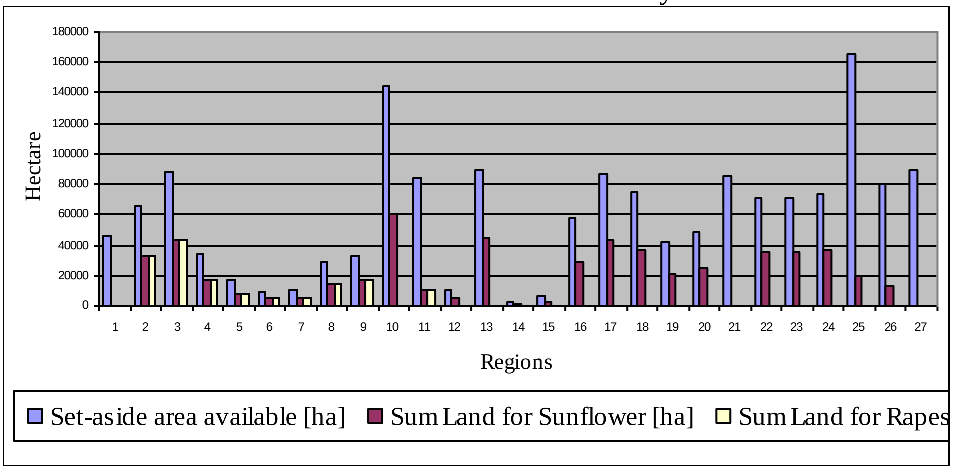

Fig. 2. Distribution of agricultural land by way of use for each of the regions in case (b)-Minimum Annualized Total Cost

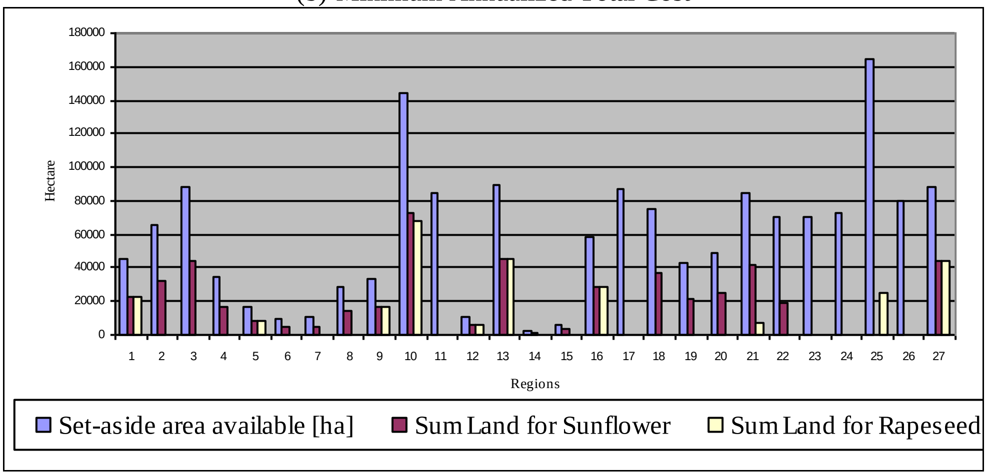

Fig. 3. Distribution of agricultural land by way of use for each of the regions in case (a)-Minimum Total GHG emission.

Table 13. Biodiesel (B100) cost structures in case (a)-Minimum Total GHG emission and (b) Minimum Annualized Total Cost.

No		Criterion 1 (a)-Min. GHG emission		Criterion 2 (b)-Min. Cost BSC	
	Unit	$\$/year$	%	$\$/year$	%
1.	Total inv. cost a BSC per year	6681600.00	6.00	4365600.00	5.40
2.	Total production cost of a BSC	13167282.72	11.83	13167282.72	16.29
3.	Total biomass cost of a BSC	78830839.68	70.88	54584871.32	67.55
4.	Total transport cost of a BSC	9713152.54	8.73	5066114.10	6.27
5.	Carbon tax levied per year	11876585.08	10.67	12676569.85	15.69
6.	Government incentives per year	9059090.51	8.14	9059090.51	11.21
7.	**Total cost BSC**	**111210369.50**	**100**	**80801347.49**	**100**
8.	**Price of biodiesel(B100)**	**1055.745** $\$/ton$		**767.065** $\$/ton$	

Distribution of land.

Table 14. Distribution of arable land for different purposes and in the regions in case (b) -Minimum Annualized Total Cost

No	Regions	Land for biodiesel (B100)		Land for food security		FREE Land	All Land
	Type of energy crops	Sunflower	Rapeseed	Sunflower	Rapeseed		
	Unit	*ha*					
1	Region-1 ⇒ Vidin	0	0	22713	0	22713	45426
2	Region-2 ⇒ Montana	0	0	32561	0	32561	65121
3	Region-3 ⇒ Vratsa	0	0	43882	0	43882	87764
4	Region-4 ⇒ Sofia	0	0	17050	0	17050	34100
5	Region-5 ⇒ Pernik	0	0	8495	0	8495	16990
6	Region-6 ⇒ Kyustendil	0	0	4634	0	4634	9268
7	Region-7 ⇒ Blagoevgrad	0	0	5128	0	5128	10256
8	Region-8 ⇒ Pazardjik	0	0	14419	0	14419	28837
9	Region-9 ⇒ Lovech	0	0	16708	11572	5136	33417
10	Region-10 ⇒ Pleven	52356	142	19982	72196	0	144677
11	Region-11 ⇒ V.Tarnovo	0	0	8491	0	75605	84097
12	Region-12 ⇒ Gabrovo	0	0	5377	0	5377	10753
13	Region-13 ⇒ Plovdiv	0	0	44854	44854	0	89708
14	Region-14 ⇒ Smolyan	0	0	1274	0	1274	2547
15	Region-15 ⇒ Kardjali	0	0	3188	0	3188	6375
16	Region-16 ⇒ Haskovo	0	0	29164	0	29164	58328
17	Region-7 ⇒ St.Zagora	0	0	0	0	86733	86732
18	Region-18 ⇒ Yambol	0	0	37421	0	37421	74843
19	Region-19 ⇒ Sliven	0	0	21255	0	21255	42510
2	Region 20 ⇒ Targovishte	0	0	24509	0	24509	49019
21	Region-21 ⇒ Rouse	0	0	42518	0	42518	85036
22	Region-22 ⇒ Razgrad	0	0	35054	0	35054	70107
23	Region-23 ⇒ Shtumen	0	0	0	0	70412	70412
24	Region-24 ⇒ Silistra	0	0	0	0	73206	73205
25	Region-25 ⇒ Dobrich	28591	71	0	0	136241	164904
26	Region-26 ⇒ Varna	0	0	40196	0	40196	80393
27	Region-27 ⇒ Bourgas	0	0	44393	0	44393	88786

Table 15. Distribution of arable land for different purposes

No	Unit	Criterion 1 (a)-Min. GHG emission	Criterion 2 (b)-Min. Cost BSC
		ha	
1.	BIOFUELS Land	99264	81175
2.	RESERVATION Land	1613611	1613611
3.	FOOD Land	668093	657463
4.	FREE Land	846267	874986

Biodiesel (B100) production plant locations.

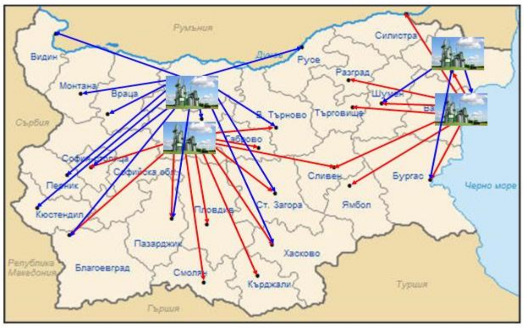

Fig. 4. Optimal BG biodiesel(B100) supply chain configuration in case (b)–Minimum Annualized Total Cost for BSC.

Table 16. Optimal biorefinery locations, Min/Max capacity and annual production of biodiesel (B100) for different criteria.

No	Biodiesel production plant locations	MIN Capacity of Plants	MAX Capacity of Plants	Annual Biodiesel produced in factories
	Units	*ton/year*		
		Minimum Total GHG emission		
1.	Region-9	30000	68000	30829
2.	Region-10	30000	68000	39286
3.	Region-21	1000	8500	6000
4.	Region-26	25000	50000	29222
		Minimum Annualized Total Cost		
1.	Region-9	10000	24000	24000
2.	Region-10	30000	68000	54838
3.	Region-25	1000	8500	8500
4.	Region-26	8000	18000	18000

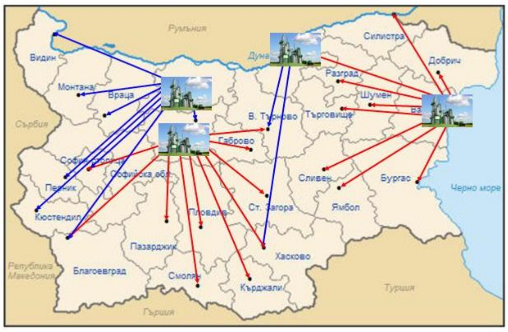

Fig. 5. Optimal BG biodiesel(B100) supply chain configuration in case (a)–Minimum GHG emission for BSC.

Table 16 presents the results of the optimization for optimal locations of biorefineries (their minimum and maximum capacity) and the annual quantities of biodiesel to be produced, in order to meet the needs of all regions.

Biodiesel (B100) distribution. The main mode preferred for biodiesel (B100) transportation from biodiesel (B100) plants to customer zones is rail with its lower unit cost and higher capacity compared to road transport.

Table 17. Flow rate of biodiesel from biodiesel plants to costumer zones in case: (a)–Min. Total GHG emission and (b)–Min. Annualized Total Cost.

Name of regions	Transportation biodiesel from rail	
Unit	*ton/day*	
Variant of criterion	Case (a)-	Case (b)
Region-9 to Region-4	0	5.00
Region-9 to Region-7	13.52	0
Region-9 to Region-8	15.75	8.31
Region-9 to Region-11	5.00	5.00
Region-9 to Region-12	6.98	6.98
Region-9 to Region-13	39.15	39.15
Region-9 to Region-14	6.93	6.93
Region-9 to Region-15	8.74	8.74
Region-9 to Region-16	8.21	5.00
Region-9 to Region-17	19.04	5.00
Region-9 to Region-19	0	5.89
Region-10 to Region-1	5.72	5.72
Region-10 to Region-2	8.39	8.39
Region-10 to Region-3	10.62	10.62
Region-10 to Region-4	88.69	83.69
Region-10 to Region-5	7.59	7.59
Region-10 to Region-6	7.76	7.76
Region-10 to Region-7	5.00	18.52
Region-10 to Region-8	0	7.44
Region-10 to Region-9	8.03	8.03
Region-10 to Region-10	15.35	15.35
Region-10 to Region-11	0	9.74
Region-10 to Region-16	0	9.03
Region-10 to Region-17	0	14.04
Region-10 to Region-21	0	13.44
Region-21 to Region-11	9.74	0
Region-21 to Region-16	5.82	0
Region-21 to Region-21	8.44	0
Region-25 to Region-23	0	5.00
Region-25 to Region-25	0	5.82
Region-25 to Region-26	0	18.18
Region-25 to Region-27	0	5.00
Region-26 to Region-18	7.48	7.48
Region-26 to Region-19	11.31	5.42
Region-26 to Region-20	6.89	6.89
Region-26 to Region-21	5.00	7.11
Region-26 to Region-22	7.11	5.33
Region-26 to Region-23	10.33	6.81
Region-26 to Region-24	6.81	0
Region-26 to Region-25	10.82	5.00
Region-26 to Region-26	27.28	9.09
Region-26 to Region-27	23.86	18.86

Table 17 is a daily flow of biodiesel (B100) from biodiesel (B100) plants to costumer zones as optimal form of rail transport.

Table 18. Summary of computational results in case: (a)-Minimum Total GHG emission and (b)-Minimum Cost BSC

		Units	Criterion 1 (a)-Min. GHG emission	Criterion 2 (b)-Min. Cost BSC
Min. Total GHG emission	(a)	$kg\,CO_2-eq\,d^{-1}$	25347651.82	25475649.38
Min. Cost BSC	(b)	$\$/year$	111210369.50	80801347.49
Min. GHG emissions BSC		$kg\,CO_2-eq\,d^{-1}$	1900253.61	2028251.18
GHG emission for diesel		$kg\,CO_2-eq\,y^{-1}$	23447398.21	23447398.21
GHG emission to grow biomass		$kg\,CO_2-eq\,d^{-1}$	598253.76	681193.39
GHG emission for production:		$kg\,CO_2-eq\,d^{-1}$	809051.27	824122.93
GHG emission from transport:		$kg\,CO_2-eq\,d^{-1}$	2914.98	32901.26
GHG emission from biofuel:		$kg\,CO_2-eq\,d^{-1}$	490033.59	490033.59
Total cost biodiesel(B100) plants		$\$$	55680000.00	36380000.00
Total operating expenses for year		$\$/year$	45043178.40	37336187.02
Investment. cost a BSC per year:		$\$/year$	6681600.00	4365600.00
Total biomass&prod. cost of a BSC:		$\$/year$	91998122.40	67752154.04
Total production cost of a BSC:		$\$/year$	13167282.72	13167282.72
Total biomass cost of a BSC:		$\$/year$	78830839.68	54584871.32
Transport cost of a BSC:		$\$/year$	9713152.54	5066114.10
Carbon tax levied:		$\$/year$	11876585.08	12676569.85
Government incentives:		$\$/year$	-9059090.51	-9059090.51
Total Land all regions:		ha	3227237.00	3227237.00
Total BIOFUELS Land:		ha	99264.74	81175.40
Total RESERVATION Land:		ha	1613611.00	1613611.00
Total FOOD Land:		ha	668093.45	657463.95
Total FREE Land:		ha	846267.81	874986.65
Sunflower Land for biodiesel		ha	285.71	80889.69
Rapeseed Land for biodiesel(B100)		ha	98979.03	285.71
Sunflower Land for foods		ha	514930.25	504300.75
Rapeseed Land for foods		ha	153163.20	153163.20
FOOD&BIOFUEL(Sunflower)		ha	515215.96	585190.44
FOOD&BIOFUEL(Rapeseed)		ha	252142.23	153448.91
Diesel to meet the energy		$ton/year$	1710987.00	1710987.00
Biodiesel(B100) in regions		$ton/year$	105338.26	105338.26
Petroleum diesel in regions		$ton/year$	1617954.61	1617954.61
GHG emission by biodiesel(B100)		$\frac{kg\,CO_2-eq}{ton\,biodiesel}$	4509.80	4811.90
GHG emission by petroleum diesel		$\frac{kg\,CO_2-eq}{ton\,diesel}$	3623.00	3623.00
Price of biodiesel(B100)		$\$/ton$	**1055.745**	**767.065**

The model proposed was solved in GAMS 22.8 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 composed of 13510 constraints and 12123 variables (out of which 6102 are binary variables that represent the investment decisions and management). The solution was obtained in less than 539s using the simplex and barrier algorithms available in the CPLEX solver.

DISCUSSION AND CONCLUSIONS

The biofuel industry is anticipated to rapidly expand in the decades to come, and the impacts of the industry growth on agricultural industry and regional economy need to be investigated. In recent years the “food versus energy” competition has been heatedly debated. This paper studies the interactions of biofuel supply chain design with agricultural land use and local food market equilibrium. We focus on economic behavior of the stakeholders in the biofuel supply chain, and incorporate them into the supply chain design model.

In this paper, a systems optimisation framework has been introduced for the optimal design of a Bulgaria first generation biodiesel(B100) supply chain. The model proposed has been applied to a case study of biodiesel(B100) production in Bulgaria. Different instances have been investigated for years 2012 (5.75% by energy content) based on the domestic biofuel targets. For 2012, first generation technologies have been studied. The use of set-aside land for these two special energy crops has also been taken into account.

This paper presents the issues related to designing and managing the biomass-to-biorefinery supply chain. A mathematical model is proposed that can be used to design and manage this supply chain. Bulgaria is used, as a case study to show how this model can be used to identify potential location for biorefineries, and give insights about the factors that impact the delivery cost of biodiesel(B100).

The data used to validate the model and perform the computational analyses presented above is collected from a number of sources such as research articles and the statistical yearbook of Bulgaria. Due to data availability, only two major sources of biomass feedstock sunflower and rapeseed relevant to Bulgaria are considered.

A similar model could be used to design the supply chain of a biorefinery provided other biomass feedstock is being used.

Based on the inputs and outputs of the optimal synthesis in criterion for minimizing total annual costs (see **Table 18**), one could say that about 19.9% of the price for the supply of biodiesel(B100) are due to investment costs, approximately 20.5% are due operating costs, 35% are due to raw material costs for collection, approximately 35% are due to carbon tax collected approximately 14.47% are due to transportation costs and about -25% are due to government incentives for the production and use of biodiesel(B100). It is then understandable why our computational results indicate that changes due to raw material costs affect greatly the biodiesel delivery cost.

Improvements in the technology of biomass feedstock conversion to biodiesel(B100) have high impact on the cost of biodiesel(B100). This is due to the fact that less biomass will be required to produce the same amount of biodiesel(B100). As a result, less biomass will need to be harvested and transported. This in turn will decrease the cost of producing a ton of biodiesel(B100). The cost of biodiesel(B100) is also affected by factors such as the project life and Government incentives for biodiesel(B100) production and use.

Future research may be carried out in several directions. This study assumes that the production of biodiesel(B100) feedstock uses only sunflower and rapeseed. Future studies may consider other energy source such as waste oils from food or livestock. This paper suggests that the factories are specialized to produce only biodiesel(B100), but in fact arrivals intermediate is used for food purposes. Further studies should consider such combined plants. This paper suggests the use of local row materials. Inclusion in the model and the possibilities of imported raw materials wold enrich the study and may lead to another configuration of supply chain. To maximize net social benefits, the impact of biofuel supply chain design on food and fuel consumer surpluses could be considered as an objective of biofuel supply design problem. How to consider all these factors in the model will be a challenging topic that is worth exploring in future research. Finally, we have only considered one time investment of building biofuel refineries and static land use decision. A more realistic multi-year biofuel refinery location problem with dynamic land use choice may be worthy of investigation in the future. In the following developments approaches should be developed that account changing requirements demand for biofuels over time, leading to phased infrastructure development.

The experimental results indicate that the running time of CPLEX for these problems is relatively small. The minimum running time is 167 CPUs and the maximum 539 CPUs. Increasing the problem size (which would be the case when one uses this model to design and manage larger supply chains considering larger number of biomass feedstock options and larger number of biomass supply sources, etc.) may result in longer running times for CPLEX or failure of CPLEX to read the problem created. Therefore, future work include design of various solution approaches that would provide good quality solutions to these problems in a reasonable amount of time.

REFERENCES

1. E.M. Kondili, J.K. Kaldellis, *Renewable and Sustainable Energy Reviews* **11**, 2137 (2007).
2. G. Edwards-Jonesa *et al*., *Trends in Food Science & Technology* ,**19,** 265 (2008).
3. A. Zamboni, F. Bezzo, N. Shah, *Energy & Fuels*, **23**, 5134 (2009).
4. http://www.mzh.government.bg
5. A. Iriarte, J. Rieradevall, X. Gabarrell, *J. Cleaner Production,* **18,**336 (2010).
6. S. Leduc, PhD Thesis, Department of Applied Physics and Mechanical Engineering, Luleå University of Technology, Luleå, Sweden
7. http://www.biofuels.apec.org/pdfs/ewg_**2010**_biofuel-production-cost.pdf
8. European Commission, Well-to-wheels analysis of future automotive fuels and pow-ertrains in the European context. (2006) (online).
9. S. Giarola, A. Zamboni, F. Bezzo, *Computers & Chem. Eng.*, **35**, 1782 (2011).
10. O. Akgul, N. Shah, L.G. Papageorgion, *Computers & Chem. Eng.*, **42**, 101 (2012).
11. B.R. Moser, *Fuel*, **99,** 254 (2012).
12. http://www.evworld.com/library/energy_numbers.pdf
13. http://www.iea.org/stats/unit.asp
14. http://ekipbg.com/2012/05/25/gpricesbg/
15. http://igitur-archive.library.uu.nl/chem/2007-0320-200551/NWS-E-2005-141.pdf
16. http://eurlex.europa.eu
17. http://www.nsi.bg

ОПТИМАЛНО ПРОЕКТИРАНЕ И ПЛАНИРАНЕ НА РЕСУРСНО ОСИГУРИТЕЛНАТА ВЕРИГА ЗА ПРОИЗВОДСТВО И ДОСТАВКИ НА БИОДИЗЕЛ С ОТЧИТАНЕ НА СЕИТБООБРАЩЕНИЕТО. ЧАСТ 2. ОПРЕДЕЛЯНЕ НА МЕСТОПОЛОЖЕНИЕТО НА БИОРАФИНЕРИИТЕ ЗА ТЕРИТОРИЯТА НА БЪЛГАРИЯ

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(Резюме)

В тази част на работата се демонстрира използването на предложения в част 1 математичен модел за проектиране на ресурсно осигурителни вериги за производство и разпространение на биодизел за територичта на България. Биосуровините за производство на биодизел са слънчоглед и рапица. Територията на България е разделена на 27 области, съответстващи на съществуващото териториално деление. Решението на проблема за оптимално разполагане на биорафинериите е извършено с използване на пакета GAMS и математичния модел, предложен в част 1.