DESIGN AND MANAGEMENT OF BIOMASS PROCESSING NETWORK FOR BIODIESEL PRODUCTION BY USING MILP MODEL

PART 2. CASE STUDY: POTENTIAL BIODIESEL PRODUCTION FROM IN BULGARIA

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Abstract

In this work, we apply the proposed in part 1 MILP model for the optimal design and planning of Bulgarian biodiesel supply chain, given sunflower and rapeseed as feedstock. 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 specific data.

Keywords: *Biodiesel Supply Chain, Crop rotation, Optimal design, Bulgarian scale*

1 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 great network combining several stages with different options in each stage 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. In the first part of this work is proposed mathematical model to solve the problem of designing and managing the BSC for biodiesel, based on the method of MILP of crop rotation. The aim of this work is to apply the developed mathematical model for the case of biodiesel production in the conditions of Bulgaria with real data.

2 CASE STUDY: POTENTIAL BIODIESEL PRODUCTION IN BULGARIA

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

One demand scenario have been investigated based on the Bulgaria domestic target for 2010 (5.75% by energy content) [8] to promote the use of biofuels.

2.1 Model input data

2.1.1 Territorial division of Bulgaria

According to the Geodesy, Cartography and Cadastre Agency at the Ministry of Regional Development and Public Works, 'Territorial balance of the Republic of Bulgaria as of 31.12.2000'. Bulgaria's total area is 111001.9 square kilometers of which is agricultural 63764.8 square kilometers. From this land Arable land and utilized agricultural area for 2011 is 3,162,526 hectares under (STATISTICAL YEARBOOK 2011 [9]). The main energy crops for biodiesel, 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 have almost 0.7 ha per inhabitant agricultural land, compared to 0.4 ha in the average of EU-25 [1]. Hence, producing required feedstock 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.

Bulgaria comprises 27 regions. In this case study, each region in Bulgaria is considered to be a feedstock production region, a potential location of an 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 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 production are taken from STATISTICAL YEARBOOK-2011 [9]. For 2011 we known consumption of petroleum diesel fuel for transportation for the country which amounted to 1,711,000 tons. 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.

2.1.2 Data on energy consumption of diesel for transport by regions

Table 1 presents data on the distribution of cultivated area for each region, population size [9] and fixed consumption of petroleum diesel fuel for transport.

2.1.3 Feedstock supply chain components for biodiesel production in Bulgaria

Biodiesel is produced from vegetable oils, which are derived from the seeds or the pulp of a range of oil-bearing crops. These oil crops for Bulgarian climate is rapeseed and sunflower. Oil from the sunflower was the first type used for biodiesel production. Today, in Bulgaria, sunflower is still the main feedstock for biodiesel 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 main energy crops, which will be discussed in this study are the following: rapeseed and sunflower for biodiesel production.

2.1.4 Emission factor for cultivation of rapeseed and sunflower

Greenhouse gas emissions in the agronomy phase for cultivation of sunflower and rapeseed lifecycle phases include soil preparation, seeding, tillage, fertilization, and finally harvest [4].

For different regions in Bulgaria aggregate 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.

This study was used for all regions averages for emission factor for one ton sunflower is $EFBC_{ig} = 1100\ kg\ CO_2 - eq$ and for one ton rapeseed is $EFBC_{ig} = 850\ kg\ CO_2 - eq$ respectively.

2.1.5 Yield cultivation in regions for rapeseed and sunflower

Yields from rapeseed strongly depend on the region in which they are grown, as well as the technology of cultivation [4]. For the purposes of this study were adopted averages which for sunflower is $\beta_{ig} = 2.2\ ton/ha$ and for rapeseed is $\beta_{ig} = 2.6\ ton/ha$ and is equal for all 27 regions.

2.1.6 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 $214\$/ton$ biodiesel

Table 1 The distribution of set-aside land and population of each region in Bulgaria

No	Name of regions	Population [9]	Cultivated area [10]	Reserved land [10]	Petroleum diesel
	Units		*ha*		*ton / year*
1	Region-1 ⇒ Vidin	99481	90853	45426	25677,99
2	Region-2 ⇒ Montana	145984	130243	65121	37681,33
3	Region-3 ⇒ Vratsa	184662	175528	87764	47664,88
4	Region-4 ⇒ Sofia	1542231	68201	34100	398080,02
5	Region-5 ⇒ Pernik	131987	33980	16990	34068,43
6	Region-6 ⇒ Kyustendil	134990	18537	9268	34843,56
7	Region-7 ⇒ Blagoevgrad	322025	20512	10256	83120,96
8	Region-8 ⇒ Pazardjik	273803	57675	28837	70673,92
9	Region-9 ⇒ Lovech	139609	66834	33417	36035,82
10	Region-10 ⇒ Pleven	266865	289355	144677	68883,08
11	Region-11 ⇒ V.Tarnovo	256279	168194	84097	66150,63
12	Region-12 ⇒ Gabrovo	121389	21507	10753	31332,88
13	Region-13 ⇒ Plovdiv	680884	179416	89708	175749,49
14	Region-14 ⇒ Smolyan	120456	5095	2547	31092,05
15	Region-15 ⇒ Kardjali	152009	12751	6375	39236,50
16	Region-16 ⇒ Haskovo	243955	116657	58328	62969,56
17	Region-17 ⇒ St.Zagora	331135	173465	86732	85472,43
18	Region-18 ⇒ Yambol	130056	149686	74843	33570,00
19	Region-19 ⇒ Sliven	196712	85021	42510	50775,22
20	Region-20 ⇒ Targovishte	119865	98038	49019	30939,50
21	Region-21 ⇒ Rouse	233767	170072	85036	60339,84
22	Region-22 ⇒ Razgrad	123600	140215	70107	31903,58
23	Region-23 ⇒ Shtumen	179668	140824	70412	46375,83
24	Region-24 ⇒ Silistra	118433	146 411	73205	30569,88
25	Region-25 ⇒ Dobrich	188088	329 809	164904	48549,20
26	Region-26 ⇒ Varna	474344	160 786	80393	122437,48
27	Region-27 ⇒ Bourgas	414947	177 572	88786	107105,95
	Total	**7327224**	**3162526**	**1613611**	**1891300**

2.1.7 Feedstock that is required to ensure food security in Bulgaria

Table 2. presents data taken from STATISTICAL YEARBOOK-2011 [9] for use in cultivated area in 2011 for the production of sunflower and rapeseed to ensure food

security of Bulgaria. In this work we take as a basis for ensuring food security of the data that are common to all regions of Bulgaria.

Table 2 Value of biological resources to ensure food security in Bulgaria

	Type of Energy crops	Total bio-resources amount for food security [9]	Cultivated area used for food security
	Units	*ton / year*	*ha*
1	Sunflower	1321765	734314
2	Rapeseed	376824	209347

2.1.8 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. Total all 27 regions were selected as the candidate refinery locations, which are dispersed across the Bulgarian territory.

2.1.9 The technology of biodiesel production used in this study

This study is based on the use of technology for producing biodiesel by esterification of vegetable oils. It is assumed that pure vegetable oil 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, and the co-product glycerine which can be used in soap manufacture. Approximately 100 kg of glycerine is produced per tone of biodiesel. Another co-product is the residue "cake" from he 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 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.

2.1.10 Biomass to biodiesel conversion factor

Conversion efficiency of rapeseed and sunflower biodiesel ranges from $389 l / ton$ to $454 l / ton$ [7]. 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.

2.1.11 Data for biodiesel and petroleum diesel

The data necessary for the purposes of this study were taken from the literature and the parameters of biodiesel and petroleum diesel are given in **Table 3**.

Table 3 Emission coefficient of fuel and energy equivalent

Type of fuel	Emission coefficient [5]	Energy equivalent [8]	Density (average)	Price of biofuel[6]
Unit	$\frac{kgCO_2 - eq}{ton}$	GJ / ton	kg / m^3	$\$ / ton$
Diesel	3623	42.80	853.97	1192.70
Biodiesel	1204	37.80	864.42	-

2.1.12 Biodiesel and petroleum diesel proportion, subject of mixing

In setting national indicative targets for the consumption of biofuels in the country are considered indicative targets set out in Directive 2003/30/EC and adopted by the European Council (8-9 March 2007). 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. Produce biodiesel is used as a component in mixtures of petroleum diesel oil produced in a specific proportion [3]. In Bulgaria in 2011 is to use biodiesel–petroleum diesel blend ratio of 6% biofuel (B100) and 94% petroleum diesel.

2.1.13 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.

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 distance traveled, we identified the coordinates of each biomass site; potential biorefinery location. The data used in this paper is given at the county level, therefore the coordinates of the center point of a county are used to calculated the geographical distances between locations. In general, the average distance can be determined according to the relationship:

2.2 Computational results and analysis

In this section, we present results from the case study described above, 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 on the conditions of Bulgaria. Software code is carried out by using the packet **GAMS** [2] for solving specific problems with real data.

2.2.1 Biomass supply

The optimal biomass flows are given in **Table 4.**

Table 4 Flow rate biomass from grow region to biodiesel plants

No	Name of regions	**Criterion 1** Minimum Cost BSC	
	Type of transport	TRACTOR	TRACTOR
	Type of energy crops	Sunflower	Rapeseed
	Unit	ton/day	
1.	Region-10 to Region-10	538.49	1.00
2.	Region-25 to Region-26	473.58	1.00

2.2.2 The cost structure for biodiesel in the supply chain

Table 5 shows the breakdown of the cost of one year of work BSC throughout the planning period, then the optimal solution for the design of the supply chain for economic criteria

Table 5 Biodiesel(B100) cost structures in case Minimum Cost BSC

No		**Criterion 1** Minimum Cost BSC	
	Unit	$\$/year$	**%**
1.	Total inv. cost a BSC per year	4184000	5.72
2.	Total production cost of a BSC	11752554	16.07
3.	Total biomass cost of a BSC	48692572	66.57
4.	Total transport cost of a BSC	5151012	7.04
5.	Carbon tax levied per year	11443396	15.64
6.	Government incentives per year	8085757	11.05
7.	**Total cost BSC**	**73137778**	**100.00**
8.	**Price of biodiesel(B100)** $\$/ton$	**777.896**	

2.2.3 Distribution of land

Table 6 Distribution of arable land

		Criterion 1 - Minimum Cost BSC
1.	Sunflower for biofuel all regions	72290.29 *ha*
2.	Rapeseed for biofuel all regions	142.86 *ha*
3.	Sunflower for foods all regions	486552.43 *ha*
4.	Rapeseed for foods all regions	141041.00 *ha*
5.	FREE Land all regions	913599.43 *ha*
6.	RESERVATION Land all regions	1613611 *ha*

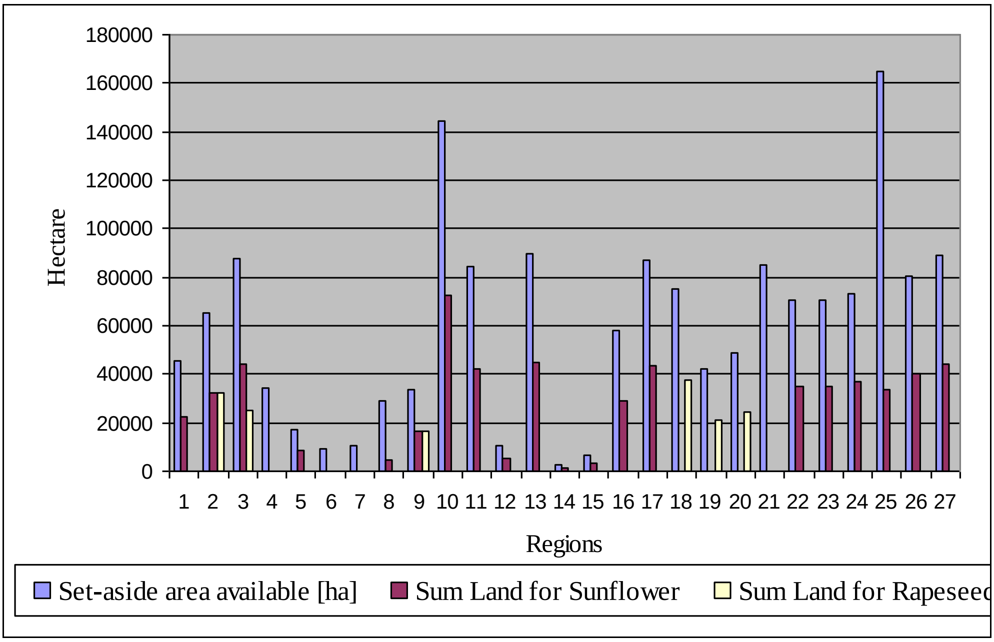

Figure 1 Distribution of agricultural land by way of use for each of the regions

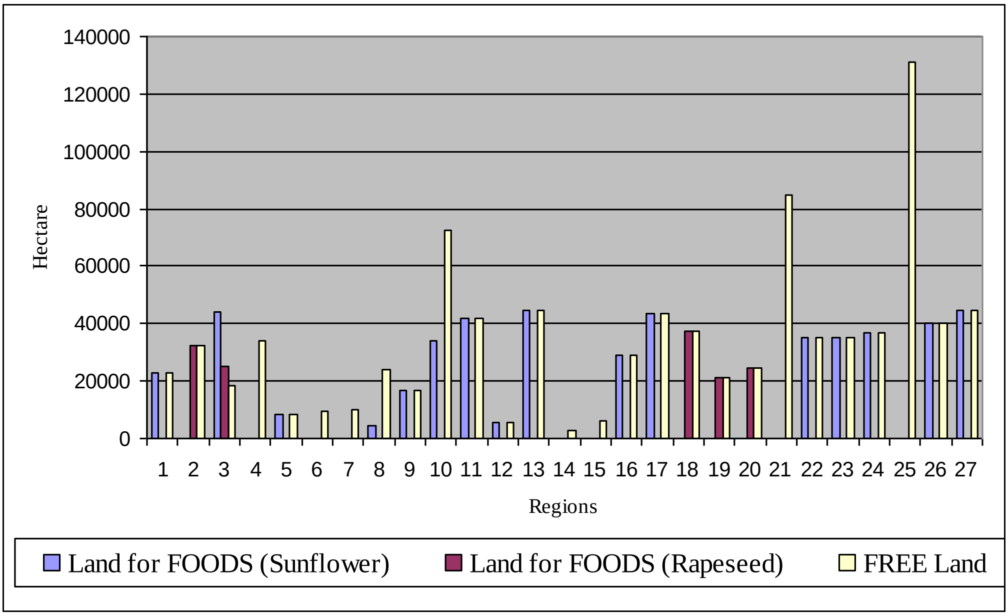

Figure 2 Distribution of land used for the production of sunflower and rapeseed for food security and free arable land for each region

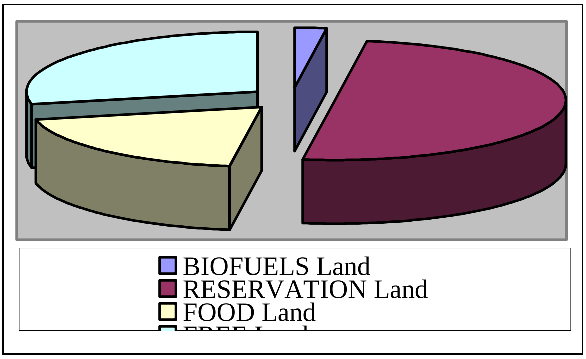

Figure 3 Distribution of arable land for various purposes

2.2.4. *Biodiesel production plant locations*

Table 7 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 to meet the needs of all regions

Table 7 Location of biorefinery, Min/Max capacity and annual production

No	Biodiesel production plant locations	MIN Capacity of Plants	MAX Capacity of Plants	Annual Biodiesel produced
	Units	*ton / year*		
Biodiesel rafinery				
1.	Region-10 ⇒ Pleven	38000	74000	**39286**
2.	Region-26 ⇒ Varna	44000	85000	**29222**
Petroleum diesel rafinery				
1.	Region-4 ⇒ Sofia	0.0	900000	**900000**
2.	Region-21 ⇒ Rouse	0.0	600000	**433397**
3.	Region-27 ⇒ Bourgas	0.0	900000	**474850**

2.2.4 Biodiesel and diesel distribution

The main preferred mode of transportation of biodiesel from biodiesel plants to costumer zones is rail with its lower unit cost and higher capacity compared to road transport.

Table 8 shows a daily flow of biodiesel plants to mixing&costumer zones as the optimal form of rail transport.

Table 8 Flow rate biodiesel from biodiesel plants to mixing&costumer zones

Name of regions	Transportation biodiesel	Name of regions	Transportation biodiesel
Region-10 to Region-1	5.11	Region-26 to Region-13	6.25
Region-10 to Region-2	7.49	Region-26 to Region-14	6.18
Region-10 to Region-3	9.48	Region-26 to Region-15	7.80
Region-10 to Region-4	79.16	Region-26 to Region-16	12.52
Region-10 to Region-5	6.77	Region-26 to Region-17	17.00
Region-10 to Region-6	6.93	Region-26 to Region-18	6.68
Region-10 to Region-7	16.53	Region-26 to Region-19	10.10
Region-10 to Region-8	14.05	Region-26 to Region-20	6.15
Region-10 to Region-9	7.17	Region-26 to Region-21	12.00
Region-10 to Region-10	13.70	Region-26 to Region-22	6.34
Region-10 to Region-11	5.00	Region-26 to Region-23	9.22
Region-10 to Region-13	28.70	Region-26 to Region-24	6.08
Region-26 to Region-11	8.15	Region-26 to Region-25	9.65
Region-26 to Region-12	6.23	Region-26 to Region-26	24.35

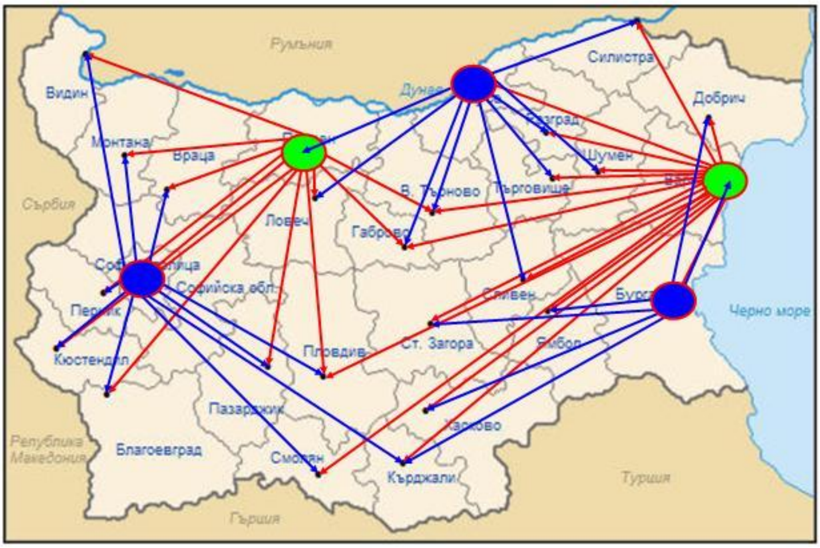

Figure 3 Optimal BG biodiesel-diesel supply chain configuration

Table 9 is a daily flow of petroleum diesel plants to mixing&costumer zones as the optimal form of rail transport.

Table 9 Flow rate diesel from diesel plants to mixing&costumer zones

Name of regions	Transportation biodiesel	Name of regions	Transportation biodiesel
Region-4 to Region-1	98.20	Region-21 to Region-12	119.83
Region-4 to Region-2	144.11	Region-21 to Region-19	194.18
Region-4 to Region-3	182.29	Region-21 to Region-20	118.32
Region-4 to Region-4	1522.41	Region-21 to Region-21	230.76
Region-4 to Region-5	130.29	Region-21 to Region-22	122.01
Region-4 to Region-6	133.25	Region-21 to Region-23	177.36
Region-4 to Region-7	317.88	Region-21 to Region-24	116.91
Region-4 to Region-8	270.28	Region-27 to Region-15	139.80
Region-4 to Region-13	672.13	Region-27 to Region-16	240.82
Region-4 to Region-14	118.91	Region-27 to Region-17	326.88
Region-4 to Region-15	10.26	Region-27 to Region-18	128.38
Region-21 to Region-9	137.81	Region-27 to Region-25	185.67
Region-21 to Region-10	263.43	Region-27 to Region-26	468.25
Region-21 to Region-11	252.98	Region-27 to Region-27	409.61

The proposed model 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 (of which 6102 are binary variables, which represent the investment decisions and management). The solution was obtained in less than 539s using the simplex and barrier algorithms, available in the solver CPLEX [2].

3 DISCUSSION AND CONCLUSIONS

This paper studies the interactions among biodiesel supply chain design, agricultural land use and local food market equilibrium. .

We first develop a model that includes problem crop rotation. Tray we believe it is important for the practical application this model in practice.

Systems optimization framework has been introduced for the optimal design of a Bulgaria biodiesel supply chain. The proposed model has been applied to a case study of biodiesel production in the Bulgaria. Different instances have been investigated for years 2012 (5.75% by energy content) based on the domestic biofuel targets, respectively. 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.

We propose a mathematical model that can be used to design and manage this supply chain. We use the Bulgaria 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.

Table 10 Summary of computational results in case: Minimum Cost BSC

	Units	**Criterion 1** Minimum Cost BSC
Minimum Total Cost of BSC	$\$/\,year$	**1246716068.56**
Total cost biodiesel(B100) plants	$	73137778.29
Total operating expenses for year	$\$/\,year$	41840000.00
Investment. cost a BSC per year:	$\$/\,year$	4184000.00
Total biomass&prod. cost of a BSC:	$\$/\,year$	60445126.72
Total production cost of a BSC:	$\$/\,year$	11752554.54
Total biomass cost of a BSC:	$\$/\,year$	48692572.18
Transport cost biomas&biofuel of BSC	$\$/\,year$	5151012.38
Transport cost fuel(Diesel)	$\$/\,year$	34381886.80
Carbon tax levied:	$\$/\,year$	11443396.71
Government incentives:	$\$/\,year$	-8085757.53

Total Land all regions:	*ha*	**3227237.00**
Total BIOFUELS Land:	*ha*	72433.14
Total RESERVATION Land:	*ha*	1613611.00
Total FOOD Land:	*ha*	627593.43
Total FREE Land:	*ha*	913599.43
Sunflower Land for biodiesel(B100)	*ha*	72290.29
Rapeseed Land for biodiesel(B100)	*ha*	142.86
Sunflower Land for foods	*ha*	486552.43
Rapeseed Land for foods	*ha*	141041.00
FOOD&BIOFUEL(Sunflower)	*ha*	558842.71
FOOD&BIOFUEL(Rapeseed)	*ha*	141183.86
Biodiesel(B100) in regions	$ton/year$	94020.44
Petroleum diesel in regions	$ton/year$	1808248.26
Price of biodiesel(B100)	$\$/ton$	**777.896**

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 statistical yearbook in Bulgaria . Due to the availability of data, we consider only two major sources of biomass feedstock sunflower and rapeseed are relevant to Bulgaria.

Improvements in the technology of converting biomass feedstock to biodiesel have a high impact on the unit cost of biodiesel. This is due to the fact that less biomass will be required to produce the same amount of biodiesel. As a result, less biomass will need to be harvested and transported.

Future research may be conducted in a few directions. This study assumes that the production of biodiesel feedstock used only sunflower and rapeseed. Future study could consider more involvement feedstock other energy source such as waste oils from food or livestock.

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