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STRATEGIC DESIGN OF INTEGRATED SUPPLY CHAINS FOR PRODUCTION AND DISTRIBUTION OF BIOETHANOL[1]

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Abstract: *Today, energy consumption is steadily rising, but global energy sources are in limited reserves of oil, gas and coal. Their extraction and exploitation is often associated with a number of negative environmental impacts by obtaining the conventional fuels needed for the heat and transport systems. Continuous alternative sources of energy, constantly renewable sources, low prices and ecologically clean are sought. Biofuels are alternative sources of petroleum fuels. The article presents a method for optimal design of resource- supply chains for production and distribution of bioethanol. The problem of optimal design and management of supply chains is formulated as a task of mixed linear programming under the criterion of minimum capital and operating costs. The optimal scheme of the resource - insurance chain for the territory of the Republic of Bulgaria is presented*

Keywords: *Bioethanol supply chain, mathematical model, economic, environmental and social aspects.*

INTRODUCTION

Biofuel production and use is promoted worldwide. Its use could potentially reduce emissions of greenhouse gases and the need for fossil fuels (IEA, 2007). Accordingly, the European Union has imposed a mandatory target of 10% biofuel production by the year 2020 (European Communities, Commission, 2003). Biofuels are produced from biomass feedstocks. Their use for energy purposes has the potential to provide important benefits. Burning biofuel releases as much CO_2 as the amount that has been absorbed by the biomass in its formation. Another advantage of biomass is its availability in the world due to its variety of sources. Despite its advantages, increasing quantities of biofuels to achieve EC objectives is accompanied by growing quantities of waste products. These wastes are related to the biofuels lifecycle from crop cultivation, transportation, and production up to distribution and use. The main liquid biofuels are bioethanol and biodiesel. Depending on the raw material used, production is considered in two generations.

The first generation used as feedstock crops containing sugar and starch to produce bioethanol (Rosegrant et al., 2006). In the production of bioethanol, the advantage of these materials is that they can be grown on contaminated and saline soils, as the process does not affect the fuel production. The drawback is that they raise issues related to their competitiveness in the food sector. Excessive use of fertilizers, pesticides and chemicals to grow them also leads to accumulation of pollutants in groundwater that can penetrate into water courses and thus degrade water quality.

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Referring to the second generation, bioethanol is produced by using as raw material waste biomass (agricultural and forest waste) (Heungjo et al., 2011), i.e. lignocellulose which is transformed into a valuable resource as bioethanol.

The main technologies for production of bioethanol are fermentation, distillation and dehydration (Akgul et al., 2011). The wastes of biofuels are divided into production and performance. The technological waste is produced mainly in generation of products that occur as waste. The management of such waste is related to their reduction, recovery and disposal.

The present study deals with the issue of designing an optimal Integrated Bioethanol Supply Chains (IBSC) model for waste management in the process of biofuel production and use. Tools have been developed for the formulation of a mathematical model for the description of the parameter, the restrictions and the goal function.

MODEL FORMULATION

The role of the optimization model is to identify what combination of options is the most efficient approach to supply the facility. The problem for optimal location of bioethanol production plants and the efficient use of the available land is formulated as a MILP model with the following notation.

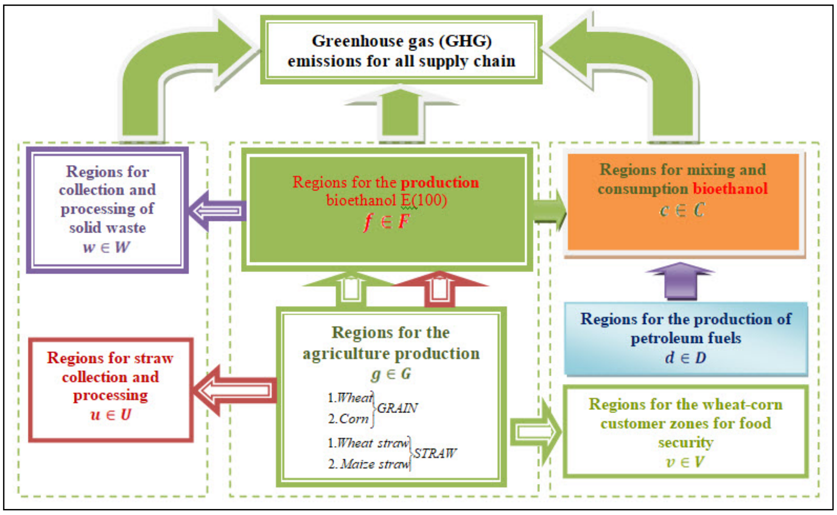

Figure 1: Superstructure of an IBS

Mathematical model description

To start with the description of the MILP model, we first introduce the parameters, that are constant and known a priori, and the variables that are subject to optimization. Then we describe step by step the mathematical model by presenting the objective function and all constraints. First of all, the set of time intervals of the planning horizon $t=\{1,2,...,T\}$ is introduced.

The following sets and subsets are introduced:

Sets/indices

I Set of biomass types indexed by i;

LF Set of transport modes indexed by lf ;

P Set of plant size intervals indexed by $p=\overline{1,N_p}$;

S Set of utilization plant size intervals indexed by $s=\overline{1,N_s}$;

GF Set of regions of the territorial division indexed by gf ;

K Set of proportion of bioethanol (E100) and gasoline subject of mixing for each of the customer zones indexed by k;

T Set of time intervals, indexed by t.

Subsets/indices

B Set of transport modes for bioethanol and gasoline is a subset of LF indexed by b;

L Set of transport modes for biomass is a subset of LF ($L \subset LF$) indexed by l;

M Set of transport modes for solid wastes is a subset of LF ($M \subset LF$) indexed by m;

E Set of transport modes for straw is a subset of LF ($E \subset LF$) indexed by e;

Z Set of transport modes for wheat-corn for food security is a subset of $Z \subset LF$ indexed by z;

F Set of candidate regions for bioethanol plants established, which is a subset of GF ($F \subset GF$) indexed by f;

C Set of bioethanol mixing and customer zones, which is a subset of $C \subset GF$ indexed by c;

D Set for delivery and production gasoline, which is a subset of GF ($D \subset GF$) indexed by d;

W Set for regions for collection and processing of solid waste, which is a subset of GF ($W \subset GF$) indexed by w;

U Set for regions for straw and corn cobs collection and processing, which is a subset of GF ($U \subset GF$) indexed by u;

V Set for regions for the wheat-corn customer zones, which is a subset of GF ($V \subset GF$) indexed by v;

Input parameters for the model.

Parameters that are constant, or may change very slowly over time, are listed below:
Environmental parameters:

$EFBP_{ip}$ Emission factor for bioethanol(E100) production from biomass type $i \in I$ using technology $p \in P$, [$kg\,CO_2 - eq / ton\,biofuel$];

$EFDP_d$ Emission factor for gasoline production in region $d \in D$, [$kg\,CO_2 - eq / ton$ gasoline];

$EFTRA_{il}$ Emission factor for biomass $i \in I$ supply via mode $l \in L$, [$kg\,CO_2 - eq / ton\,km$];

$EFTRB_b$ Emission factor for bioethanol (E100) supply via mode $b \in B$, [$kg\,CO_2 - eq / ton\,km$];

$EFTRV_z$ Emission factor for transport of wheat-corn for food security with transport $z \in Z$;

ECB Emissions emitted during the combustion of CO_2 unit bioethanol (E100);

ECG Emissions emitted during the combustion of CO_2 unit gasoline.

Monetary parameters:

$CosB_p$ Capital investment of bioethanol plant size $p \in P$, [\$];

C_{CO_2} Carbon tax per unit of carbon emitted from the operation of the IBSC, [$\$ / kg\,CO_2 - eq$];

IA_{il} Unit transport fixed cost for biomass $i \in I$ via mode $l \in L$, [$\$ / ton$];

IB_{il} Unit transport variable cost for biomass $i \in I$ via mode $l \in L$, [$\$ / ton\,km$];

OA_b Unit transport fixed cost for bioethanol(E100) via mode $b \in B$, [$\$/ton$];

OB_b Unit transport variable cost for bioethanol(E100) via mode $b \in B$, [$\$/ton\,km$];

OAD_b Unit transport fixed cost for gasoline via mode $b \in B$, [$\$/ton$];

OAV_z Unit transport variable cost for wheat-corn for food security via mode $z \in Z$ [$\$/ton$].

The assessment of the production and distribution of IBSC will be based on three criteria, namely economic, environmental and social.

The model includes the following objectives:

Model of total environmental impact of IBSC

The environmental impact of the IBSC is measured in terms of total GHG emissions ($kg\,CO_2 - eq$) stemming from supply chain activities and the total emissions are converted to carbon credits by multiplying them with the carbon price at the market.

The environmental objective is to minimize the total annual GHG emission resulting from the operations of the IBSC. The formulation of this objective is based on the field-to wheel life cycle analysis, which takes into account the following life cycle stages of biomass-based liquid transportation fuels:

- biomass cultivation, growth and acquisition,
- biomass transportation from source locations to facilities,
- transportation of bioethanol facilities to the demand zones,
- solid waste transportation from bioethanol facilities to utilization plants,
- local distribution of liquid transportation fuels in demand zones,
- emissions from bioethanol and gasoline usage.

Ecological assessment criteria will represent the total environmental impact at work on IBSC through the resulting GHG emissions for each time interval t. These emissions are equal to the sum of the impact that each of the stages of life cycle has on the environment. The GHG emission rate is defined as follows:

$$TEI_t = ELS_t + ELB_t + ELD_t + ETA_t + ETE_t + ETD_t + ETW_t + ETU_t + ETV_t + ECAR_t + ESW_t, \forall t \qquad (1)$$

where

TEI_t Total GHG impact at work on IBSC for each $t \in T$. [$kg\,CO_2 - eq\,d^{-1}$],

ELS_t GHG impact of growing biomass,

ELB_t GHG impact of production of bioethanol,

ELD_t GHG impact of production of petroleum gasoline,

ETA_t GHG impact of Transportation biomass,

ETE_t GHG impact of Transportation bioethanol,

ETD_t GHG impact of Transportation gasoline,

ETW_t GHG impact of Transportation of solid waste,

ETU_t GHG impact of Transportation of straw,

ETV_t GHG impact of Transportation of wheat-corn for food security,

$ECAR_t$ GHG impact of Usage bioethanol and gasoline

ESW_t GHG impact of utilization solid waste.

Model of total cost of a IBSC TDC_t, [$\$\ year^{-1}$]

The annual operational cost includes the biomass feedstock acquisition cost, the local distribution cost of final fuel product, the production costs of final products, and the transportation costs of biomass, and final products. In the production cost, we consider both the fixed annual operating cost, which is given as a percentage of the corresponding total capital investment, and the net variable cost, which is proportional to the processing amount. In the transportation cost, both distance-fixed cost and distance-variable cost are considered. The economic criterion will be the cost of living expenses to include total investment cost of bioethanol production facilities and operation of the IBDS. This price is expressed through the dependence is**:**

$$TDC_t = TIC_t + TIW_t + TPC_t + TPW_t + TTC_t + TTAXB_t - TL_t, \quad \forall t \tag{2}$$

where

TDC_t Total cost of a IBSC for year [$\$\ year^{-1}$];

TIC_t Total investment costs of production capacity of IBSC per year [$\$\ year^{-1}$];

TIW_t Total investment costs of solid waste plants per year [$\$\ year^{-1}$];

TPC_t Production cost for biorefineries [$\$\ year^{-1}$];

TPW_t Production cost for solid waste plants [$\$\ year^{-1}$];

TTC_t Total transportation cost of a IBSC [$\$\ year^{-1}$];

$TTAXB_t$ A carbon tax levied according to the total amount of CO_2 generated in the work of IBSC;

TL_t Government incentives for bioethanol production and use [$\$\ year^{-1}$].

Model of social assessment of a IBSC Job_t, [$Number\ of\ Jobs$]

The IBSC Social Assessment Model is to determine the expected total number of jobs created (Job_t) as a result of the operation of all elements of the system during its operation.

$$Job_t = NJ1_t + LT_t NJ2_t + LT_t NJ3_t, \quad \forall t \tag{3}$$

where the components of Eq(3) are defined according to the relations for each time interval,

$NJ1_t$ number of jobs created during the installation of bioethanol refineries and solid waste plants,

$NJ2_t$ number of jobs created during the operation of bioethanol refineries and solid waste plants,

$NJ3_t$ number of jobs created by cultivation bioresources for bioethanol production,

LT_t Duration of time intervals [$year$]

Optimization problem formulation

The optimization procedure finds the set of decision variables, both binary and continuous, that minimize of the objective function. The identified decision variables are:

- SC network structure, which includes: number, size and location of biorefineries,

- biomass cultivation rate for each biomass feedstock type and bioethanol(E100) production,
- locations of bioethanol(E100) production facilities and biomass cultivation sites,
- flows of each biomass type and bioethanol(E100) between cells,
- modes of transport of delivery for biomass and bioethanol(E100),
- greenhouse gas emissions for each stage of the life cycle,
- transportation amount for each transportation link and transportation mode,
- distribution processes for biofuel to be sent to mixing and demand zones.

In the following model, two objective functions are considered:

- Economic sustainability **(** $COST$ **):** Minimize the total logistics cost of the supply chain considering fixed, variable, and emissions costs **[** $\$$ **]**.

$$COST = \sum_{t \in T} \left(LT_t TDC_t \right) \tag{4}$$

- Environmental sustainability **(** ENV or $Cost_{ENV}$ **):** Minimize the total quantity of GHG emissions calculated in units of [kg or $\$$] of carbon dioxide equivalent [$kg\ CO_2 - eq$].

$$ENV = \sum_{t \in T} \left(LT_t\ TEI_t \right) \tag{5}$$

$$Cost_{ENV} = C_{CO_2} ENV \tag{6}$$

- Social sustainability **(** JOB **):** Maximize the social impact of the system work of the supply chain [$Number\ of\ Jobs$].

$$JOB = \sum_{t \in T} \left(LT_t\ Job_t \right) \quad (7)$$

In Fig. 2. and Fig. 3. the optimal configuration of the supply chain is shown in case of: (a)-Minimum GHG emission and (b)-Minimum Annualized Total Cost.

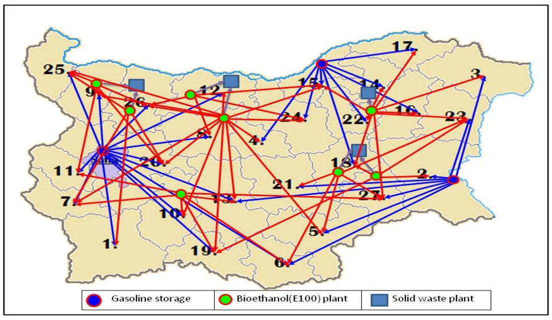

Fig. 2: Optimal IBSC configuration for 2020 in case: (a)-Minimum GHG emission

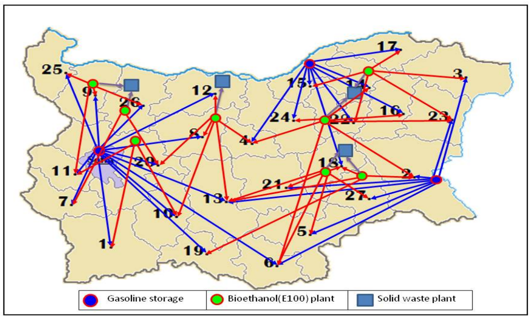

Fig. 3: Optimal IBSC configuration for 2020 in case: (b)-Minimum Annualized Total Cost

CONCLUSIONS

The main findings of this study are that, in order to achieve "intelligent" design of the bioethanol production and distribution system, it is necessary to take into account the interactions between all components involved in the production and distribution of biofuel produced from different types of biomass. At the same time, the requirements of EU Directive 20/20/20 must be met. The available agricultural land in Bulgaria allows for the production of enough organic raw materials to produce the necessary amount of bioethanol to meet Bulgarian needs.

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