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MULIPARAMETER OPTIMIZATION FOR GENERATION OF TECHNOLOGICAL AND LOGISTIC SOLUTIONS FOR PRODUCTION AND USE OF BIODIESEL

Eng. Yunzile Dzhelil, PhD
Laboratory "Process System Engineering", Institute of Chemical Engineering,
Bulgarian Academy of Sciences, Sofia. Bulgaria
E-mail: unzile_20@abv.bg

Eng. Evgeniy Ganev, PhD-student
Laboratory "Process System Engineering", Institute of Chemical Engineering,
Bulgarian Academy of Sciences, Sofia. Bulgaria
E-mail: evgeniy_ganev@abv.bg

Prof. Boyan Ivanov, DSc
Laboratory "Process System Engineering", Institute of Chemical Engineering,
Bulgarian Academy of Sciences, Sofia. Bulgaria
E-mail: bivanov1946@gmail.com

Assoc. Prof. Dragomir Dobrudzhaliev, PhD
Laboratory "Process System Engineering", Institute of Chemical Engineering,
Bulgarian Academy of Sciences, Sofia. Bulgaria
E-mail: dragodob@yahoo.com

Abstract: The problem discussed in this article can generally be expressed as follows. We have a set of energy crops that should be converted into biodiesel, which include crops such as sunflower, rapeseed and more. We envisage a ten-year planning horizon that includes government regulations, manufacturing, construction and carbon tax. For the purposes of the study, we rely on the superstructure of an integrated biofuel supply chain, including a range of collection points and a range of search areas, as well as potential locations for individual facilities and biorefineries.

Keywords: Biodiesel, Spply chain, Multi ciriteria decision making.

INTRODUCTION

The problem addressed in this work can generally be expressed as follows. We have at our disposal a set of energy crops that should be converted into biodiesel. A ten-year planning horizon is envisaged, including government regulations, manufacturing, construction and carbon tax.

The aim is to determine the number, location and scale of biodiesel refineries as well as bioresources to be transported between the different nodes of the designed network so that the total net present value is kept to a minimum while respecting demand constraints of products. This means that biodiesel refineries will operate in the upcoming time interval, while there will be an opportunity for upgrades related to increasing production capacity.

EXPOSITION

Biofuels supply chain consists of a network of raw material producers (biomass), biorefineries, storage facilities, mixing plants and end users. The main elements of the biofuels supply chain are: (1) farms, (2) storage facilities, (3) bio-refineries, (4) blending facilities, (5) retail outlets, and (6) transportation. In general, biomass raw materials are transported by truck from neighboring farms to biofuel refineries organized by farmers' cooperatives. Cooperatives act as a link between producers and buyers. To this end, storage facilities between farms and bio-refineries are required. It is also necessary to take into account pre-treatment prior to storage in order to improve the quality of storage and adaptability for further processing (Iddrisu & Jun, 2012).

The objective is to determine the number, location, and size of the biodiesel refineries and bioresources to be transported between the various nodes of the designed network so that the overall net present value is minimized while respecting the constraints associated with product demands. This means that biodiesel refineries built on a stage will operate in the next time interval, while allowing renovations to increase capacity to manufacturing.

We look at IBDSC for a long planning horizon H (e.g. 10 years). The whole time horizon H is subdivided in a set of discrete time intervals t. This time interval is divided into several equal time subintervals $t=\{0,1,2,\dots,T\}$, each of which lasts Δt. During the planning horizon is assumed that diesel consumption will change with an estimate value. At the same time it is assumed that the annual increase in consumption of biodiesel in order to reach the requirements of the directives adopted by the state is also known.

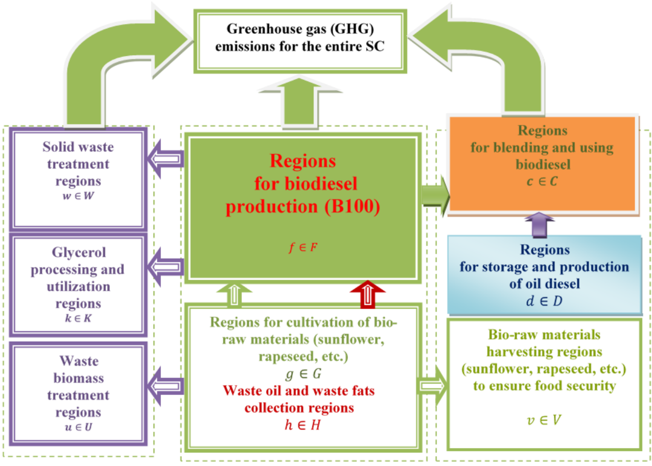

Fig. 1. Superstructure of integrated biodiesel- petroleum diesel supply chain

MODEL FORMULATION

This mathematical model can be used to assist decision makers in the design and planning of sustainable SC based on the LCA methodology. The model establishes the link with the emission trading scheme to achieve sustainability objectives. Although SC sustainability recognizes the link between the economic, ecological, and social performance, an examination of social performances (labour equity, healthcare, safety) shows that they are dependent on the context of operation of the SC, the government policies, and cultural norms. Thus, without loss of generality, we do not include the social performance in the mathematical formulation.

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 the constraints. First of all, we introduce the set of time intervals of the horizon of planning $t=\{0,1,2,\dots T\}$**.** The subscript $\boldsymbol{t}$ indicates the variable or parameter corresponding to the $\boldsymbol{t}$ the interval of the planning.

Sets/indices

I Set of bioresources (sunflower / rapeseed), indexed by i;
Y Set of for waste bioresources (waste oil and animal waste fat), indexed by y;
LF Set of transport modes, indexed by lf;
P Sets for types of capacities and technologies of biodiesel (B100) plants, indexed by $p = \overline{1, N_p}$;
S Sets for the typical capacity of the plants for the treatment of solid waste generated, indexed by $s = \overline{1, N_s}$;
GF Sets of regions of the territorial division, indexed by gf;
K Sets for proportion of biodiesel (B100) and diesel subject of mixing for each of the customer zones, indexed by k;
T Sets of time intervals, indexed by t.

Subsets/indices

B Sets of transport modes for biodiesel (B100) and diesel is a subset of $LF\,(B \subset LF)$, indexed by b;
L Set of transport modes for biomass is a subset of $LF\,(L \subset LF)$, indexed by l;
LC Set of transport modes for waste cooking oils and animal fats is a subset of $LF\,(LC \subset LF)$, indexed by l_c;
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 sunflower / rapeseed for food is a subset of $LF\,(Z \subset LF)$, indexed by z;
F Set of candidate regions for biodiesel (B100) plants established, which is a subset of $GF\,(F \subset GF)$, indexed by f;
C Sets of biodiesel mixing and customer zones, which is a subset of $GF\,(C \subset GF)$, indexed by c;
D Sets delivery and production diesel, which is a subset of $GF\,(D \subset GF)$, indexed by d;
W Sets regions for collection and processing of solid waste, which is a subset of $GF\,(W \subset GF)$, indexed by w;
U Setsта of for regions for waste biomass collection and processing, which is a subset of $GF\,(U \subset GF)$, indexed by u;
V Sets of regions for the sunflower / rapeseed customer zones, which is a subset of $GF\,(V \subset GF)$, indexed by v;
H Sets of regions for collection of waste cooking oil and animal fat, which is a subset of $GF\,(H \subset GF)$, indexed by h;

Environmental parameters:

$EFBP_{ip}$ Emission factor for biodiesel production (B100) of biomass type $i \in I$ through technology $p \in P$, [$kg\,CO_2 - eq / ton\,biofuel$];
$EWCO_{yp}$ Emission factor for production of biodiesel (B100) from waste oil and animal fats type $y \in Y$ by technology $p \in P$, [$kg\,CO_2 - eq / ton\,biofuel$];
ESU_i Emission factor for biomass waste $i \in I$, if not used for other purposes, [$\frac{kg\,CO_2 - eq}{ton\,solid\,waste}$];
$ESF1_{ft}$ Separate emissions from solid waste utilisation, if carried out at the plant $f \in F$, [$\frac{kg\,CO_2 - eq}{ton\,solid\,waste}$];

$ESW1_{wst}$ Emission factor for solid waste when utilised of at a plant $w \in W$ by technology $s \in S$, if not used for other purposes, [$\frac{kg\,CO_2 - eq}{ton\ solid\ waste}$];

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

$EFTRA_{il}$ Biomass emission factor $i \in I$, transported using transport $l \in L$, [$kg\,CO_2 - eq / ton$ km];

$EFTWA_{ylc}$ Emission factor for WCO $y \in Y$, which is transported using transport $lc \in LC$, [$kg\,CO_2 - eq / ton$ km];

$EFTWC_y$ Emission factor for WCO $y \in Y$, leading to environmental pollution if not used for biodiesel production (B100), [$\frac{kg\,CO_2 - eq}{ton\,WCO}$];

$EFTB_b$ Emission factor for transport of biodiesel (B100) and petroleum diesel for transport use $b \in B$, [$kg\,CO_2 - eq / tonkm$];

$EFTRW_m$ Emission factor for the transport of solid waste by type $m \in M$ transport, [$kg\,CO_2 - eq / tonkm$];

$EFTRU_e$ Emission factor for the transport of waste biomass with type $e \in E$ transport, [$kg\,CO_2 - eq / tonkm$];

$EFTRV_z$ Emission factor for the transport of sunflower / rapeseed for food of type $z \in Z$ transport, [$kg\,CO_2 - eq / tonkm$];

ECB Emissions from (CO_2), emitted during combustion of a biodiesel (B100) unit, [$kg\,CO_2 - eq / tonbiodiesel$];

ECG Emissions from (CO_2), emitted during combustion of an oil-diesel unit, [$kg\,CO_2 - eq / tondiesel$].

Monetary parameters:

PO The price of oil, [$\$/ton$];

$cost\_Gl$ Price of glycerol, [$\$/ton$];

$cost\_Ml$ Price of the oil cake, as animal feed, [$\$/ton$];

C_{CO_2} Carbon tax to emit one equivalent of CO_2 when operating IBDSC, [$\$/kg\,CO_2 - eq$];

IA_{il} Fixed costs of transporting a unit of biomass $i \in I$ via type $l \in L$ transport, [$\$/ton$];

IB_{il} Variable costs of transporting a unit of biomass $i \in I$ via type $l \in L$ transport, [$\$/ton$ km];

IAW_{yl_c} Fixed costs of transporting a WCO $y \in Y$ unit through type $l_c \in LC$ transport, [$\$/ton$];

IBW_{yl_c} Variable cost of transportation of a WCO $y \in Y$ unit by type $l_c \in LC$ transport, [$\$/ton$];

OA_b Fixed costs for transporting a unit of biodiesel (B100) via type $b \in B$ transport, [$\$/ton$];

OB_b Variable cost of transporting a unit of biodiesel (B100) by type $b \in B$ transport, [$\$/ton$ km];

OAD_b	Fixed costs of transporting a unit of oil diesel through type $b \in B$ transport, $[\$/ton]$;
OBD_b	Variable cost of transport per unit of oil-diesel via type $b \in B$ transport, $[\$/ton\,km]$;
OAW_m	Fixed costs for the transport of a solid waste unit via type $m \in M$ transport, $[\$/ton]$;
OBW_m	Variable costs of transporting a unit of solid waste through type $m \in M$ transport, $[\$/ton\,km]$;
OAU_e	Fixed costs of transporting a unit of biomass waste through type $e \in E$ transport, $[\$/ton]$;
OBU_e	Variable transport costs per unit of biomass waste through type $e \in E$ transport, $[\$/ton\,km]$;
OAV_z	Fixed costs for transporting a unit of sunflower / rapeseed for food via type $z \in Z$ transport, $[\$/ton]$;
OBV_z	Variable cost per unit of sunflower / rapeseed for food via type $z \in Z$ transport, $[\$/ton\,km]$.

The production and distribution of biodiesel (B100) and petroleum diesel will be done on three criteria, economic, environmental and social. The optimal solution would be a compromise between these three criteria.

Model of total environmental impact of IBDSC (Integrated biodiesel - petroleum diesel supply chain), TEI$_t$ [$kg\,CO_2 - eq$]:

Environmental assessment criteria will be understood as the overall environmental impact during the operation of the IBDSC by the resulting greenhouse gas emissions at each time interval $t \in T$. These emissions are equal to the sum of the environmental impacts of each stage of the life cycle. Greenhouse gas emissions are usually determined as follows for each time interval $t \in T$:

$$TEI_t = ELS_t + ELB_t + ELD_t + ETT_t + ESW_t + ESTRAW_t + ECAR_t + EWCO_t, \forall t \qquad (1)$$

ELS_t, ELB_t, ELD_t, ETT_t	Environmental impact of life cycle stages;
ESW_t	Emissions from solid waste recovery at each time interval $t \in T$;
$ESTRAW_t$	Emissions generated from the utilization of plant solid residue in the regions for each time interval $t \in T$;
$EWCO_t$	Emissions from WCO utilization if not used for biodiesel production.

Model of total cost of a IBDSC 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 biodiesel (B100) production facilities and operation of the IBDS. This price is expressed through the dependence (Ozlem A. et al., 2012) for each time interval $t \in T$:

$$TDC_t = TIC_t + TIW_t + TPC_t + TPW_t + TTC_t + TTAXB_t - TL_t - TA_t + TWCO_t, \quad \forall t \qquad (2)$$

TDC_t IBSC total expenses for the year, $[\$\, year^{-1}]$;

TIC_t Total investment cost for the production capacity of IBSC compared to the operating period and the purchase of the plant per year, $[\$\, year^{-1}]$;

TIW_t Total investment costs for IBSC solid waste treatment plants compared to the operating period and purchase of the plant per year, $[\$\, year^{-1}]$;

TPC_t Production costs for biodiesel production (B100), $[\$\, year^{-1}]$;

TPW_t Production costs for solid waste disposal, $[\$\, year^{-1}]$;

TTC_t Total shipping costs of IBSC, $[\$\, year^{-1}]$;

$TTAXB_t$ Carbon tax calculated on the total amount CO_2, generated by the operation of the IBDSC, $[\$\, year^{-1}]$;|potential customer conflicts;

TL_t Government incentives for biodiesel production and consumption (B100), $[\$\, year^{-1}]$;

TA_t Total value of by-products (glycerol, oil cake), $[\$\, year^{-1}]$;

$TWCO_t$ The cost of unused WCO for the production of biodiesel (B100), which is a penalty function. (This unused residual of WCO is considered an environmental pollutant that should be minimized).

Model of social assessment of a IBDSC Job$_t$, [$Number\ of\ Jobs / year$] Yunzile et al (2018)

The IBDSC Social Assessment Model defines the expected total number of jobs created (J_t) as a result of the operation of all elements of the system during its operation:

$$Job_t = NJ1_t + LT_t NJ2_t + LT_t NJ3_t, \quad \forall t \qquad (3)$$

$NJ1_t$ the number of jobs created during the installation of biodiesel (B100) facilities and solid waste;

$NJ2_t$ the number of jobs created during the operation of biodiesel facilities (B100) and solid waste;

$NJ3_t$ number of jobs created during biodiesel production (B100).

- **Economic sustainability ($COST$):** Minimize the total logistics cost of the supply chain considering fixed, variable, and emissions costs **[$]**.*Yunzile et al (2018):*

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

- **Environmental sustainability (ENV or $Cost_{ENV}$):** Minimize the total quantity of GHG emissions calculated in units of [kg or $\$$] of carbon dioxide equivalent [$kg\, CO_2 - eq$].*Yunzile et al (2018):*

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

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

- **Social sustainability (JOB):** Maximize the social impact of the system work of the supply chain [*Number of Jobs*].*Yunzile et al (2018):*

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

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.

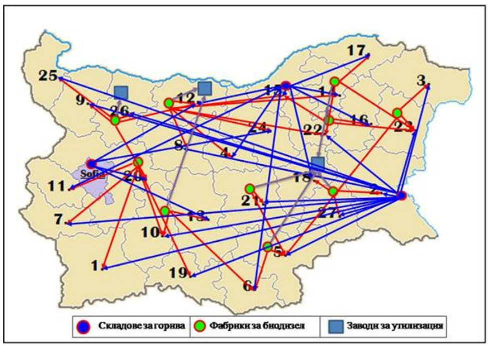

Fig. 2: Optimal IBSC configuration for 2020 in case: (a)-Minimum GHG emission

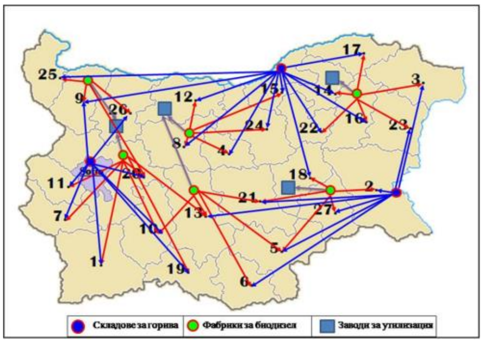

Fig. 3: Optimal IBSC configuration for 2020 in case: (b)-Minimum Annualized Total Cost

CONCLUSION

The solution obtained in the case of optimal SC synthesis using the criterion (A) Minimum total greenhouse gas emissions and using the criteria (B) The minimum annual cost showed that the greenhouse gas emissions were 6.6% lower than the criterion (A) than criterion (B), while the price of biodiesel is 14% higher than criterion (A). This is due to the increased capital and operating costs in case of criterion (A). In the case of designing SCs by using minimum greenhouse gas emissions as a target function, the best parameters are obtained if the bioresources used for the Bulgarian conditions are sunflower, rapeseed, animal fat and waste oils.

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