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RESEARCH ARTICLE

Method for synthesis and control of biofuel supply chains integrated with the relevant systems for utilization of production-generated waste by-products

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ABSTRACT

Last decade has seen reduction of amount of fossil raw materials for production of conventional fuels that in turn has been accompanied by deepening of the environmental problems. There is a trend of biofuel production rise accompanied by increase of the amount of waste produced. The waste is classified as productive (i.e. technological) one and operational one (for utilization of biofuels and their value). The study is focused on the creation of tools for supply chains (SC) by description/formulation of optimal management of production and operational waste. Tools are developed for production and use of biofuels that include a mathematical model and its optimization. The procedures are based on the following criteria/conditions: known production technology, spatial distribution logistics and production units and environmental pollution by waste fuel gases containing prevailingly CO_2. The SC building also aims to provide the necessary fuel quantities for heating and transport systems as well as to foresee their optimization in terms of the environmentally-friendly aspect.

Keywords: Biofuels, synthesis and management, supply chain, greenhouse gas, solid waste

1. INTRODUCTION

Production and use of biofuels are promoted worldwide. Their use could potentially reduce emissions of greenhouse gases and the need for fossil fuels [1]. Accordingly, the European Union imposes a mandatory target of 10% biofuels by 2020 [2]. These fuels are produced from biomass. Their use for energy purposes has the potential to provide important benefits. Burning them releases such amount of CO_2 as was absorbed by the biomass in its formation [3]. Another advantage of biomass is its availability in the world due to its variety of sources (energy and oilseeds, algae, wood, agricultural, municipal, industrial and animal waste). Despite the advantages of biomass with increasing quantities of biofuels to achieve the objectives of the European Union, this is accompanied by growing quantities of waste products. These wastes are related to the lifecycle of biofuels from crop cultivation, transportation, production to distribution and use. The main liquid biofuels are bioethanol and biodiesel. Depending on the raw material used, production is considered in three generations.

The first generation used as feedstock crops containing sugar and starch (corn, wheat, sugarcane, etc.) to produce bioethanol, and oilseed crops (sunflower, canola, soybean oil, etc.) to produce biodiesel [4]. In the production of biodiesel, 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. These materials also have a negative impact in terms of the quantity of water consumed. This is related to their cultivation that requires significant amounts of water resources. 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.

According to the second generation, bioethanol is produced by using as raw material waste biomass (agricultural and forest waste) [5], i.e. lignocellulose which is transformed into a valuable resource as bioethanol. In this case, biodiesel can be produced by using as energy crops raw material obtained from

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kitchen, animal, organic industrial waste and sewage. Many European countries have a problem with overproduction of organic wastes from industry and households. Biofuel production second generation is an excellent way to deal with increasingly restrictive national and European regulations in this area and the use of organic waste for energy production and fertilizer as a byproduct. Logistics and use of these materials can be challenging due to the fact that they are usually dispersed. Another disadvantage from an environmental perspective is the need for further purification and processing.

The third generation comprises production from microalgae which occur as promising feedstock for biofuel production. The advantage of this biomass is that it is a year-round production and does not compete with the food industry [6].

The main technologies for production of bioethanol are fermentation, distillation and dehydration. In the preparation of biodiesel using the transesterification method, as a result of these technologies receives the fuel and waste. The wastes of biofuels are divided into production and performance. The technological waste is produced mainly in the creation of products that occur as waste production. The management of these wastes is related to their reduction, recovery and disposal. These guidelines are united in the idea of acquiring more sophisticated production processes. Efforts are focused on the use of new sources of raw materials, new processes, and new ways of realization of the side products. The use of by-products as raw materials for other production closes cycle in the supply chain, reducing the price of obtaining fuel. Operational waste associated with gases and emissions released during operation and the burning of biofuels.

2. PROBLEM STATEMENT

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

The problem addressed in this work can be formally stated as follows. Given are a set of biofuel crops that can be converted to biofuel. These include agricultural feedstock's e.g. sunflower, energy crops, etc. A planning horizon of one year for government regulations including manufacturing, construction and carbon tax is considered. A Biofuel Supply Chain (BSC) network superstructure including a set of harvesting sites and a set of demand zones, as well as the potential locations of a number of collection facilities and bio refineries are set. Data for biofuel crops production and harvesting are also given. For each demand zone, the biofuel demand is given, and the environmental burden associated with biofuel distribution in the local region is known. For each transportation link, the transportation capacity, available transportation modes, distance, and emissions of each transportation type are known.

2.1. General Formulation of the Problem

The overall problem can be summarized, as follows:

- Potential locations of fuel demand centers and their biofuel demand,
- Demand for petroleum fuel for each of the demand centers for fuel,
- The minimum required ratio between petroleum fuel and biofuel for blending,
- Biomass feedstock types and their geographical availability,
- Specific Green House Gas (GHG) emission factors of the biofuel life cycle stages,
- Potential areas where systems for utilization of solid waste from production can be installed.

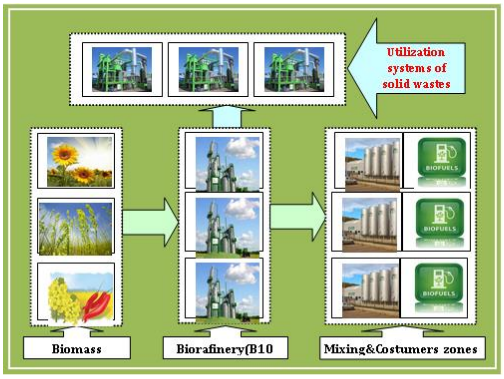

Fig 1. Superstructure integrated biofuel supply chain

The objectives are to maximize the environmental performances of the BSC by optimizing the following decision variables:

- Supply chain network structure,
- Locations and scales of biofuel production facilities and biomass cultivation sites,
- Flows of each biomass type and biofuel between regions,
- Modes of transport for delivery for biomass and biofuel (B100),
- The GHG emissions for each stage in the life cycle,
- Supply strategy for biomass to be delivered to production facilities,
- Distribution processes for biofuel to be sent to demand zones.

2.2. Mixed Integer Linear Programming (MILP) 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 the optimal location of biofuel (B100) production plants and the efficient use of the available land is formulated as a MILP model with the following notation:

The input sets, input parameters and the decision variables are given in Table 1, Table 2 and Table 3, respectively.

Table 1. Input sets used in the model

Sets/Indices	Index
Set of biomass types	I
Set of transport modes for biomass	L
Set of transport modes for solid wastes	M
Set of transport modes for biofuel and petroleum fuel	B
Set of life cycle stages of a BSC	ST
Set of plant size intervals	P
Set of utilization plant size intervals	S
Set of regions of the territorial division	GF
Set of candidate regions for biomass production, which is a subset of GF	G
Set of candidate regions for biofuel plant established, which is a subset of GF	F
Set of biofuel customer zones, which is a subset of GF	C
Set of utilization waste zones, which is a subset of GF	W

Table 2. Input parameters for the problem

Symbol	Description	Units
$EFBP_i$	Emission factor for biofuel (B100) production from biomass type $i \in I$	$\frac{kg\ CO_2-eq}{ton\ biofuel}$
$EFBC_{ig}$	Emission factor for cultivation of biomass type $i \in I$ in region $g \in G$	$\frac{kg\ CO_2-eq}{ton\ biomass}$
$EFTRA_{il}$	Emission factor for transport of biomass per unit of type $i \in I$ with transport type $l \in L$	$\frac{kg\ CO_2-eq}{ton\ km}$
$EFTRB_b$	Emission factor for transport of biofuel (B100) with transport $b \in B$	$\frac{kg\ CO_2-eq}{ton\ km}$
$EFTRW_m$	Emission factor for transport of solid waste with transport $m \in M$	$\frac{kg\ CO_2-eq}{ton\ km}$
$EFTM_l$	Emission factor of transportation for mode $l \in L$	$\frac{kg\ CO_2-eq}{ton\ km}$
ESW	Emission factor of pollution caused by one tone of solid waste if not used	$\frac{kg\ CO_2-eq}{ton\ solid\ waste}$
ECB	Emissions emitted during the combustion of $\boldsymbol{CO_2}$ unit biofuel (B100)	$\frac{kg\ CO_2-eq}{ton\ biofuel}$
ECG	Emissions emitted during the combustion of $\boldsymbol{CO_2}$ unit petroleum fuel	$\frac{kg\ CO_2-eq}{ton\ biofuel}$
$GHGB$	GHG emission from biofuel supply chain	$\frac{kg\ CO_2-eq}{ton\ km}$
ADD_{gfl}	Actual delivery distance between regions producing biomass and regions producing biofuel (B100) via model $l \in L$	km
ADF_{fcb}	Actual delivery distance between regions producing biofuel (B100) and demand regions $c \in C$ via model $b \in B$	km
ADW_{fwm}	Actual delivery distance between regions producing biofuel(B100) and utilization systems of solid wastes $w \in W$ via mod $m \in M$	km
γ_i	Biomass to biofuel (B100) conversion factor for biomass type $i \in I$ to biofuel (B100)	$\frac{ton\ biofuel}{ton\ biomass}$
YO_c	Years demands of petroleum fuel in the customer zones $c \in C$	ton/year
ENO	Energy equivalent unit of petroleum fuel	GJ/ton
ENB	Energy equivalent unit of biofuel (B100) from biomass	GJ/ton
PB_p^{MAX}	Maximum annual capacity of the plant of size $p \in P$	ton/year
PB_p^{MIN}	Minimum annual capacity of the plant of size $p \in P$	ton/year
PW_s^{MIN}	Minimum annual capacity of the utilization systems of solid wastes size $s \in S$	ton/year
PW_s^{MAX}	Maximum annual capacity of the utilization systems of solid wastes size $s \in S$	ton/year
QI_{ig}^{MAX}	Maximum flow rate of biomass $i \in I$ from region $g \in G$	ton/year
QB_f^{MAX}	Maximum flow rate of biofuel (B100) from region $f \in F$	ton/year
PBI_{ig}^{MAX}	Maximum biomass of $i \in I$ produced in the region $g \in G$ per year	ton/year
PBI_{ig}^{MIN}	Minimum biomass of $i \in I$ produced in the region $g \in G$ per year	ton/year
α_f	Operating period for the region $g \in G$ in a year	ton/year
αf_f	Operating period for plants in region $f \in F$in a year	ton/year
αc_c	Operating period for the region $c \in C$ in a year	day/year
αw_w	Operating period for region $w \in W$ within a year	day/year
A_g^S	Set-aside area available in region $g \in G$	ha
A_g^{Food}	Set-aside area available in region for food $g \in G$	ha
$TEIF^{MAX}$	Max. permissible values for the environmental impact of biofuel network of supply chain and fossil fuel in the regions	kg CO_2 – eq / day
B_{ig}	The yield per hectare of type $i \in I$ biomass in the region $g \in G$	ton/ha
QB_i^{Food}	The total amount of bio-resources of type $i \in I$ which must be provided for all regions $g \in G$ for food security	ton
QT_l^{MIN}	Optimal capacity of transport $l \in L$ for transportation of biomass	ton
QTB_b^{MIN}	Optimal capacity of transport $b \in B$ for transportation biofuel	ton
K_c^{MIX}	Proportion of biofuel (B100) and petroleum fuel subject of mixing for each of the customer zones $c \in C$	Dimensionless
SW	The total amount of solid waste generated for production of 1 ton biofuel	$\frac{ton\ solid\ waste}{ton\ biofuel}$

Table 3. Decision variables for the problem

Symbol	Description	Units	Type
PBB_{ig}	Production rate of biomass $i \in I$ in region $g \in G$	*ton/day*	*Continuous*
QI_{igfl}	Flow rate of biomass $i \in I$ via mode $l \in L$ from region $g \in G$ to $f \in F$	*ton/day*	*Continuous*
QB_{fcb}	Flow rate of biofuel via mode b from region $f \in F$ to $c \in C$	*ton/day*	*Continuous*
QW_{fwm}	Flow rate of solid waste via mode $m \in M$ from region $f \in F$ to $w \in W$	*ton/day*	*Continuous*
QEO_c	Quantity of petroleum fuel to be supplied to meet the energy needs of the region $c \in C$	*ton/year*	*Continuous*
QEB_c	Quantity of biofuel (B100) to be supplied to meet the energy needs of the region $c \in C$	*ton/year*	*Continuous*
QW_{fwm}	Flow rate of solid waste via mode m from region $f \in F$ to $w \in W$	*ton/day*	*Continuous*
A_{ig}	Land occupied by crop $i \in I$ in region $g \in G$	*ha*	*Continuous*
A_{ig}^F	Land occupied by crops $i \in I$ needed for food security	*ha*	*Continuous*
X_{igfl}	0-1 variable, equal to 1 if a biomass type $i \in I$ is transported from region $g \in G$ to $f \in F$ using transport $l \in L$ and 0 otherwise	*0 or 1*	*Binary*
Y_{fcb}	0-1 variable, equal to 1 if a biofuel is transported from region $f \in F$ to $c \in C$ using transport $b \in B$ and 0 otherwise	0 or 1	*Binary*
Z_{pf}	0-1 variable, equal to 1 if a plant size $p \in P$ is installed in $f \in F$ and 0 otherwise	0 or 1	*Binary*
W_{fwm}	0-1 variable, equal to 1 if a solid waste is transported from region $f \in F$ to $w \in W$ using transport $m \in M$ and 0 otherwise	0 or 1	*Binary*
ZW_{sw}	0-1 variable, equal to 1 if a utilization plant size $s \in S$ is installed in region $w \in W$ and 0 otherwise	0 or 1	*Binary*

2.3. Basic Relationships

As noted above, the assessment of BSC production and distribution of biofuel (B100) will be made by environmental criteria.

The environmental impact of the BSC 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 (per *g CO_2-eq*) in the market.

The environmental objective is to minimize the total annual GHG emission resulting from the operations of the BSC. 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 processing facilities,
- transportation of biofuel (B100) facilities to the demand zones,
- local distribution of liquid transportation fuels in demand zones,
- emissions from biofuel (B100) usage in vehicle operations.

The ecological assessment criteria is the total environmental impact at work on BSC, estimated through the resulting greenhouse gas emissions as proposed in Akgul, O. et al. [7]. These emissions are equal to the sum of the impact of each stage of the life cycle:

$$TEI = EL_{BC} + EL_{BP} + EL_{TR} + EB_{CAR} + EW_{SW} \quad (1)$$

where;

TEI is total environmental impact on BSC (*kg CO_2 eq d^{-1}*);

$\left\{ \begin{matrix} EL_{BC} \\ EL_{BP} \\ EL_{TR} \end{matrix} \right\}$ are GHG impact of life cycle stages (*kg CO_2 eq d^{-1}*)

EB_{CAR} is emissions from biofuel (B100) usage in vehicle operations (*kg CO_2 eq d^{-1}*),

EW_{SW} is emissions from solid waste that are not processed in any of the utilization systems (*kg CO_2 eq d^{-1}*)

The evaluation of the environmental impact at every stage $st \in ST$ of the life cycle estimates:

- growing biomass;
- production of biofuel (B100);
- transportation resources (biomass and biofuel (B100));
- utilization of solid waste.

The greenhouse gases to grow biomass EL_{BC} *are;*

$$EL_{BC} = \sum_{i \in I} \sum_{g \in G} \left(EFBC_{ig}\, PBB_{ig} \right) \quad (2)$$

where, EL_{BC} denotes the total environmental impact (*kg CO_2 eq d^{-1}*) of biomass cultivation, which in general represents the production rate of resource $i \in I$ in region $g \in G$, in this equation it refers to the cultivation rate of biomass $i \in I$ in that region.

The total emissions from biofuel (B100) production EL_{BR} are determined by the equation:

$$EL_{BP} = \sum_{g \in G} \sum_{i \in I} \sum_{f \in F} \sum_{l \in L} \left(EFBP_i \gamma_i\, QI_{igfl} \right) \quad (3)$$

where EL_{BP} is total environmental impact of biofuel (B100) production (*kg CO_2 eq d^{-1}*).

The environmental impact of transportation EL_{TR} is calculated by:

$$EL_{TR} = EL_{TR}^{Biomass} + EL_{TR}^{Biofuel} + EL_{TR}^{Waste} \quad (4)$$

where;

$$EL_{TR}^{Biomass} = \sum_{i \in I} \sum_{g \in G} \sum_{f \in F} \sum_{l \in L} \left(EFTRA_{il} ADD_{gfl} QI_{igfl} \right)$$

$$EL_{TR}^{Biofuel} = \sum_{f \in F} \sum_{c \in C} \sum_{b \in B} \left(EFTRB_b\, ADF_{fcb}\, QB_{fcb} \right)$$

$$EL_{TR}^{Waste} = \sum_{f \in F} \sum_{w \in W} \sum_{m \in M} (EFTRW_m \, ADW_{fwn} \, QW_{fwm})$$

where $EL_{TR}{}^{Waste}$ is environmental impact of transportation of resources and solid waste (*kg CO_2 eq d^{-1}*)

Emissions from biofuel (B100) usage in vehicle operations EB_{CAR}:

$$EB_{CAR} = \sum_{f \in F} \sum_{c \in C} \sum_{c \in B} (ECB \, QB_{fcb}) \quad (5)$$

where EB_{CAR} is emissions from biofuel (B100) usage in vehicle operations (*kg CO_2 eq d^{-1}*)

Emissions from solid waste not treated in any of the waste recovery systems installed:

$$EW_{SW} = ESW \left(SW \sum_{f \in F} \sum_{c \in C} \sum_{b \in B} QB_{fcb} - \sum_{f \in F} \sum_{w \in W} \sum_{m \in M} QW_{fwm} \right) \quad (6)$$

2.4. Total Environmental Impact of the Used Fuels to Provide the Energy Balance of the Region

The environmental goal is to reduce the annual equivalent of GHG emission, resulting from the operations of SC of biofuel and petroleum fuel to meet the energy needs of the regions.

The annual equivalent of greenhouse gases by the used fuels is determined by the equation:

$$TEIF = TEI + EG_{CAR} \quad (7)$$

where *TEIF* is the total environmental impact of the used fuels (biofuel (B100) and petroleum fuel) to provide the energy balance of the region; *TEI* is the total environmental impact at work on BSC; and EG_{CAR} is the emissions from petroleum fuels usage in vehicle operations.

Emissions from fuel EG_{CAR} vehicles used, to supplement the energy balance:

$$EG_{CAR} = \sum_{c \in C} \left(\frac{ECG \, QEO_c}{\alpha c_c} \right) \quad (8)$$

2.5. Restrictions

Plants capacity limited by upper and lower constrains:

Plants capacity is limited by upper and lower bounds, where the minimal production level in each region is obtained by:

$$\sum_{p \in P} (PB_p^{MIN} \, Z_{pf}) \le \alpha f_f \sum_{c \in C} \sum_{b \in B} QB_{fcb} \le \sum_{p \in P} (PB_p^{max} Z_{pf}), \forall f \in F \quad (9)$$

Constraints balance of biofuel (b100) to be produced from biomass available in the regions:

$$\sum_{c \in C} QEB_c \le \sum_{i \in I} \sum_{g \in G} (\gamma_i \, \beta_{ig} \, A_g^S) \quad (10)$$

A condition that ensures that the total amount of solid waste generated by all bio-refineries can be processed in the plants built for this purpose:

$$\sum_{w \in W} \sum_{m \in M} QW_{fwm} \le SW \sum_{c \in C} \sum_{b \in B} QB_{fcb}, \forall f \in F \quad (11)$$

A restriction that ensures that the amount of solid waste processed at the plant is within its production capacity:

$$\sum_{s \in S} P_S^{MIN} \, ZW_{sw} \le \alpha w_w \sum_{f \in F} \sum_{m \in M} QW_{fwm} \le \sum_{s \in S} P_S^{MAX} \, ZW_{sw}, \forall w \in W \quad (12)$$

Restriction guarantees that a given region g ∈ G installed power plant with p ∈ P for biofuel (B100) production. Constraints (13) and (14) state that can be chosen only one size for each facility and for utilization systems of solid wastes, respectively.

$$\sum_{p \in P} Z_{pf} \le 1, \forall f \in F \quad (13)$$

$$\sum_{s \in S} ZW_{sw} \le 1, \forall w \in W \quad (14)$$

Limitation ensure the availability of at least one connection to a region of bioresources and region for biofuel:

$$\sum_{g \in G} \sum_{l \in L} X_{igfl} \ge \sum_{c \in C} \sum_{b \in B} Y_{fcb} \ge \sum_{p \in P} Z_{pf}, \forall i \in I, \forall f \quad (15)$$

Limit which guarantees that each region will provide only one plant with a biomass type i∈ I:

$$\sum_{f \in F} \sum_{l \in L} X_{igfl} \le 1, \forall i \in I, \forall g \in G \quad (16)$$

Limitation of assurance that at least one region $g \in G$ producing biomass is connected to a plant located in a region $f \in F$:

$$\sum_{b \in B} Y_{fcb} \le 1, \ \forall f \in F, \ \forall c \in C \quad (17)$$

Limitation of assurance that at least one region $f \in F$ producing biofuel is connected to a plant located in region $w \in W$:

$$\sum_{m \in M} W_{fwm} \le 1, \ \forall f \in F, \ \forall w \in W \quad (18)$$

Condition ensuring that the solid waste produced from a given bio-refinery will be processed in only one of the plants for use:

$$\sum_{m \in M} \sum_{w \in W} W_{fwm} = \sum_{p \in P} Z_{pf}, \ \forall f \in F \quad (19)$$

Condition ensuring that a plant used in a given region will be connected to at least one plant in which solid waste is generated:

$$\sum_{m \in M} \sum_{w \in W} W_{fwm} \ge \sum_{s \in S} ZW_{sw}, \ \forall w \in W \quad (20)$$

Restriction on transportation of biomass is;

$$PBI_{ig}^{MIN}\sum_{l\in L} X_{igfl} \le \alpha_g \sum_{l\in L} QI_{igfl} \le PBI_{ig}^{MAX}\sum_{l\in L} X_{igfl}, \forall i \in I, \forall g \in G, \forall f \in F \quad (21)$$

Restriction for total environmental impact of all regions:

$$TEIF \le TTEIF^{MAX} \quad (22)$$

where $TEIF^{MAX}$ are the maximum permissible values for the total environmental impact of the biofuel (B100) network of supply chain and fossil fuel in the regions ($kg\ CO_2\ eq\ d^{-1}$).

Mass balances between biofuel (b100) plants and biomass regions:

The connections between biofuel (B100) plants and biomass regions are given by:

$$\sum_{l\in L}\sum_{g\in G}\sum_{i\in I}(\gamma_i QI_{igfl}) \le \sum_{p\in P}(PB_p^{MAX} Z_{pf}), \ \forall f \in F \quad (23)$$

Mass balances between biofuel (b100) plants and biofuel customer zones:

$$\sum_{b\in B}\sum_{f\in F}(\alpha f_f QB_{fcb}) = QEB_c, \ \forall c \in C \quad (24)$$

Limitation guaranteeing crop rotation:

The crop rotation allows ensuring control of pests, improving soil fertility, maintenance of the long-term productivity of the land, and consequently increasing the yields and profitability of the rotation [8], [9]. The combination of crop rotation and fallowing is a common practice that is gaining momentum again due to environmental benefits and promoted reduction in the dependence on external inputs.

Crop rotation implemented in a region $g\in G$ means that the growing area of energy crops are rotated so that the next time the same area is used by other crops grown under are optimal scheme of crop rotation. This can be achieved if for land A_{ig} and A_{ig}^F inequalities are implemented:

$$(A_{ig} + A_{ig}^F)\, 2.0 \le (A_g^S + A_g^{Food}), \forall i \in I, \forall g \in G \quad (25)$$

Energy restriction:

Limitation ensuring that the overall energy balance in the region is provided by:

$$ENO\sum_{c\in C} QEO_c + ENB\sum_{c\in C} QEB_c = ENO\sum_{c\in C} YO_c \quad (26)$$

Limitation ensuring that each region will be provided in the desired proportions with fuels;

$$ENBQEB_c = K_c^{mix} ENOYO_c, \quad \forall c \in C \quad (27)$$

2.6. Optimization Problem Formulation

The problem for the optimal design of a BSC is formulated as a MILP model for the objective function of Minimizing GHG emissions. As discussed above the environmental objective is to minimize the total annual CO2 -equivalent greenhouse gas emissions resulting from the operations of the biofuel supply chain and oil, used to provide the energy balance of the regions. The formulation of this objective is based on total the GHG emissions in the supply chain and other fuels are estimated, throw Life Cycle Assessment (LCA) approach, where emissions are added for every life stage.

The task of determining the optimal location of facilities in the regions and their parameters is formulated as follows:

$$\begin{Bmatrix} Find: X[Decision\ variables]^T \\ MINIMIZE\ \{TEIF(X)\} \rightarrow (Eq.7) \\ s.t.: \{Eq.8 - Eq.27\} \end{Bmatrix} \quad (28)$$

The problem is an ordinary MILP and can thus be solved using standard MILP techniques. The present model was developed in the commercial software General Algebraic Modeling System(GAMS) [10] using the solver CPLEX. The model chooses the less costly pathways from one set of biomass supply points to a specific plant and further to a set of biofuel (B100) demand points. The final result of the optimisation problem would then be a set of plants together with their corresponding biomass and biofuel (B100) demand points.

3. DISCUSSION AND CONCLUSIONS

This paper studies the interactions among biofuel supply chain design, agricultural land use and local food market equilibrium. The study has been focused on the eco comparable behavior of the stakeholders in the biofuel supply chain incorporating them into the supply chain design model. The model includes the problem of crop rotation and solid waste utilization. The model is believed to be important for practical application and can be used for design and management of similar supply chains.

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