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Sobhan Razm, Nadjib Brahimi, Alexandre Dolgui, Ramzi Hammami

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Sobhan Razm[1], Nadjib Brahimi[2*], Alexandre Dolgui[1], Ramzi Hammami[2]

[1] IMT Atlantique, LS2N - UMR CNRS 6004, La Chantrerie, 4, rue Alfred Kastler - B.P. 20722, F-44307 Nantes Cedex 3, France
{sobhan.razm, alexandre.dolgui}@imt-atlantique.fr
[2] Rennes School of Business, Rennes, France
{ramzi.hammami, nadjib.brahimi}@ rennes-sb.com

Abstract. The use of renewable energy, as a clean alternative to fossil fuel, has become very attractive. It has environmental advantages and leads to regional development. This study proposes an optimization model for the design of bioenergy supply chains under social concerns. The social concerns involve the unemployment rate and the vulnerability to changes during an economic crisis. The areas that are mostly exposed to these social issues are chosen as initial potential locations for installing the biorefineries. Installing a biorefinery can generate jobs for the people of these areas. This leads to the sustainable development in the areas. The applicability of the developed model is shown through a case study. The results demonstrate that the proposed approach leads to the generation of a large number of job positions which has an important impact on the social development of these regions.

Keywords: Sustainable development; Biofuel production; Bioenergy supply chains; Biomass; Optimization; Social concerns.

1 Introduction

The design and management of bioenergy supply chains have gotten attention in the recent years [1]. However, the cost of the bioenergy supply chain (SC) network is one of the most significant obstacles in developing bioenergy supply chains [2]. For example, one of the major costs is incurred in the collection and transportation of biomass to the biorefineries. Collecting, processing, and transporting biomass feedstocks from supply sites to the biorefineries have also environmental and social impacts [3].

The location of the biorefinery is a critical issue [4] in terms of reducing these costs [5] as well as GHG emissions (e.g. because of less transportation). The location of the biorefinery is also important, since it can generate new jobs and lead to sustainable development in a given region [6]. As a result, it is important to incorporate the concepts of sustainability into the design and planning of the bioenergy supply chain networks. Consequently, this study is seeking to answer the following questions:

1. How to design and manage the bioenergy supply chains that transform biomass into biofuel and bioenergy?

2. How to determine the purchased biomass quantities, the output quantities of bioenergy and biofuel, and the inventory decisions in order to minimize the supply chain costs while considering social constraints?

Consequently, the contributions of this paper are as follows: 1) Developing a mathematical model for designing and managing the bio-refineries. 2) Incorporating the social concerns into the network design of the bioenergy supply chain. 3) Applying the developed model to a case study.

The remainder of the paper is organized as follows. The literature review is presented in Section 2. The definition of the problem is presented in Section 3. The model formulation is presented in Section 4. The results are described in Section 5. Finally, the conclusion and some suggestions to extend the study are presented in section 6.

2 Literature review

In recent years, modeling and optimization of the bioenergy supply chains have attracted the researchers. For example, some studies focused on the geographical dispersion to find biomass sources and supply capacities [7]. Some studies were more focused on the locations of bio-refinery and production capacities [8]. A group of studies considered the whole network (more integrated). They used different types of biomass (the agricultural and forest residues) to generate biofuel in the design of bioenergy supply chains [9, 10].

In terms of sustainability, a MILP model was proposed by [11] to design the bioenergy supply chain network. They used switchgrass as biomass feedstock. Three objectives (economic, environmental, and social objectives) were considered to optimize the following decisions: i) determining the amount of collected biomass, ii) determining the maximum capacity in the biomass collecting centers, iii) determining the locations of power plants and the capacities. The augmented ε-constraint and TOPSIS approach were used as a hybrid method to generated Pareto-optimal solutions for decision makers. However, their study focused only on generating electricity (power plant), and the generated jobs were not jobs with high impacts on the area. They did not pay attention very well to the important social concerns such as high unemployment rate, and high vulnerability to changes in the markets in an economic crisis.

Designing a biofuel supply chain could generate jobs for the local residents (in the territory), as well as protect the environment [12]. Nevertheless, in the literature, most of the researchers focused only on economic aspects, and less attention has been made to sustainability, especially the social aspects of the bioenergy supply chains. This is a gap in the bioenergy SC literature that needs to get more attention. In addition, in the real world, generating the jobs in a territory where has a very low unemployment rate could not be considered a very efficient design of the bioenergy SC (in terms of sustainable development). Generating the jobs which are not close (not relevant) to the skills of the local people, who may lose their jobs in the economic crisis, could not make a high social impact on the territory.

These are the factors which motivate this paper versus the state of the art. The outcomes of the bioenergy SC literature review are shown in Table 1. As shown in Table 1, there is an essential research gap in the literature to optimal design and planning of the bioenergy supply chains under social sustainability constraints such as high unemployment rate, and high vulnerability to changes in the markets in an economic crisis. This study tries to fill this research gap.

Table 1. The bioenergy SC literature vs. this study

Article	Modeling approach			Objective function	Social sustainability			Final products			
	Mathematical Programming				jobs with high impacts		Other indices				
	MoMILP	MILP	MINLP		High unemployment rate (index)	High vulnerability in an economic crisis (index)		Electricity	Pellet	Heat	Biofuel (bioethanol, bio-oil, biodiesel)
[13]		X		3							X
[14]		X		2			food versus fuel				X
[15]	X			3							X
[16]			X	1				X			
[17]	X			2,3				X			
[5]		X		2							X
[18]		X		1							X
[9]		X		3							X
[19]		X		2							X
[20]			X	1				X			
Proposed model		X		1	X	X		X	X	X	X

1= minimizing (expected) total cost/annual cost/unit cost. 2= maximizing (expected) total profit/annual profit/annual income/net cash. 3= maximizing (expected) net present value

3 Problem definition

The bioenergy supply chain network gets started with supplying raw materials (biomass) for the biorefineries and will end with the customers (markets). As shown in Fig. 1, biomass $r \in R$ is collected from the supply site $s \in S$. The biomass can be sent and processed by biorefinery at location $b \in B$ using technology $a \in A$. The biomass is converted to bioenergy $e \in E$ to sell in location $b \in B$, or is converted to biofuel $f \in F$ to sell in market $c \in C$.

The biomass feedstocks are forest residues and agricultural residues. Bioenergy refers to heat and electricity. Biofuel refers to bio-oil and pellet. These conversions of biomass can be done by different processes such as thermochemical, chemical, and biochemical. The generated biofuel is sent to different markets. The generated bioenergy is either used in the bio-refinery or sold to local heat grids/systems.

3.1 Social sustainability

Iran's Ministry of Economic Affairs and Finance proposed an index of agricultural and forest vulnerability based on the research done by Isfahan University of Technology's college of agricultural engineering. The index is used to resist against changes in the agricultural and forest commodity markets that is $\mathcal{V} = \mathfrak{D} \times (100 - \xi)$. In this equation, $\mathfrak{D}$ is the agricultural and forest dependency index. It is a part of employment revenue in the area that is obtained from the agricultural and forest parts. ξ is diversity index. It shows the economic diversity in the area. ξ takes value in (0,100). ξ=0 means that the society (the area) is completely dependent on a part. ξ=100 means that the society is equally dependent on each of the defined parts. After normalizing, $\mathcal{V}$ (The agricultural and Forest vulnerability Index) is obtained in (0,100) for each area. $\mathcal{V}$=100 means the area is highly vulnerable to changes in the markets (e.g., in an economic crisis). For example, the values of $\mathcal{V}$ for 23 territories are shown in Table 2. These values can be obtained from the statistics office of each country.

Table 2. The values of $\mathcal{V}$ for each territory.

territory	***b1***	***b2***	***b3***	***b4***	***b5***	***b6***	***b7***	***b8***	***b9***	***b10***
$\mathcal{V}$	18	62	14	23	19	17	15	53	50	43
territory	***b11***	***b12***	***b13***	***b14***	***b15***	***b16***	***b17***	***b18***	***b19***	***b20***
$\mathcal{V}$	16	42	44	48	30	41	12	23	49	13
territory	***b21***	***b22***	***b23***							
$\mathcal{V}$	55	22	20							

Concentrating on the high unemployment rate in the areas with high vulnerability could generate social impact. Consequently, when a job with a higher employment rate is generated in a territory with a higher vulnerability (job with a high impact), it can generate more social profit. Given the ruined jobs of the aboriginal people of the biorefinery's territory (caused by an economic crisis), various job categories are generated in the biorefineries that are close to the skills of the aboriginal people. For instance, the farmers who have lost their jobs can be employed in combustion stations. The individuals who have worked in the corporations relating to oil can be employed in the pyrolysis technology stations. According to the Iranian statistics office, a lot of farmers have lost their jobs in the last economic crisis, so their unemployment rate is high (equal to 11.23%). These farmers could be employed in the combustion stations. As a result, the social profit is generated by the social impact of the job generation.

The jobs generated for local people by installing the biorefinery could be defined into three main categories depending on the average unemployment rate (λ_w), consulting with Renewable Energy and Energy Efficiency Organization.Table 3 shows these categories.

Table 3. Jobs categories generated by installing the bio-refineries.

Class (w)	Description	Average unemployment rate (λ_w)
1. Combustion	This class of jobs has a revenue between $50,000 and $55,000 per year that the revenue is able to change in the specific range considering the technologies' capacity and the requested variable and fix work hours. For example, jobs related to burning of agriculture and forest biomass to generate heat and electricity, or periodic maintenance of combustion technology like the biomass boiler and steam turbine.	**11.23%**
2.Pelletizing	This class of jobs has a revenue between $55,000 and $60,000 per year that the revenue is able to change in the specific range considering the technologies' capacity and the requested variable and fix work hours. For example, working with technologies which are specific to generate pellets, or preprocesses which are requested in each period before performing the main process of generating pellets.	**6.55%**
3.Pyrolysis	This class of jobs has a revenue more than $60,000 per year that the revenue is able to change in the specific range considering the technologies' capacity and the requested variable and fix work hours. For example, the hourly jobs for the generating process with pyrolysis technologies or the jobs with fix hours for constant presence of the experts beside the facilities in each period.	**12.35%**

The unemployment rates can be determined by the statistics office of each country. Therefore, in another study, the values of the unemployment rate may change. The social impact ($\boldsymbol{\Pi}_{w,b}$) of the generated job in the category w in the territory b is calculated by $\boldsymbol{\Pi}_{w,b} = \lambda_w \times \boldsymbol{\mathcal{V}}_b$. Then, the territories with high vulnerability and high unemployment rates are chosen as candidate locations for the biorefineries (see Fig. 2), in order to maximize the social impact. The vulnerability rate and unemployment rate for each territory can be obtained from the statistics office of each country.

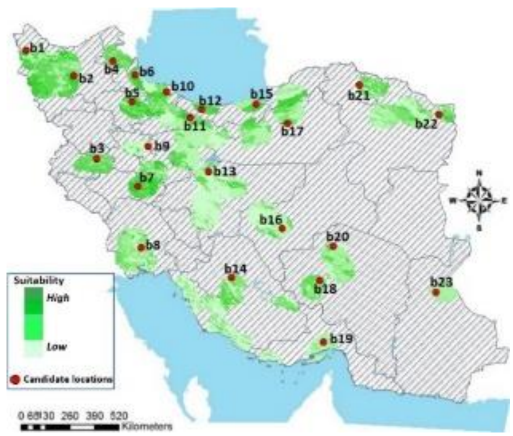

Fig. 2. Initial suggested locations for installing the bio-refineries

4 Model formulation:

The objective of the proposed model is to minimize the total costs of the supply chain. The decisions determined by this model are as follows: 1) determining the amount of the purchased and transported biomass to the bio-refineries, 2) selecting the biomass suppliers, 3) selecting the optimal locations of the bio-refineries, 4) determining the capacity and type of the technologies considered in each bio-refinery, 5) determining the amount of the assigned biomass to the technologies, 6) determine the amount of biofuel and bioenergy to sell to customers.

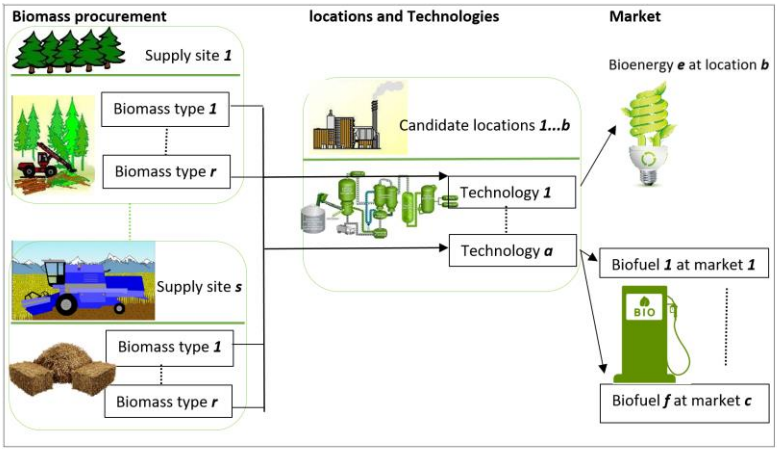

Fig. 1. General framework of the supply chain

Because of page limitation imposed by the conference, we opt for a verbal description of the proposed model. The detailed mathematical formulation is available from the authors upon request. It consists of a Mixed Integer Linear Programming formulation that can be described as follows:

Minimization of total costs = *Procurement biomass costs*
+*Biomass transportation cost* + *Biofuel transportation costs* + *Fixed opening costs*
+*Variable production costs* + *Energy purchase costs* + Inventory holding costs
Subject to:
Resource availability constraints, Biomass flow constraints,
Bioenergy and biofuel balance equations, Bioenergy and biofuel flow constraints,
Production capacity equations, Inventory balance equations,
Satisfaction of the demand, Binary limitations on the relative decision variables

5 Results and discussion

The proposed model was coded in GAMS 24 and solved using the CPLEX solver. Using the case study, the model was implemented with an Intel Core i3, 2.13 GHz processor with 4GB of RAM. The results are presented in the following.

5.1 Bioenergy supply chain structure

In this part, the optimal design obtained by the model is presented. The optimal locations of the biorefineries are presented in Fig. 3 that minimize the total cost of the bioenergy supply chain. The total cost of the bioenergy SC that was obtained from the model is equal to 637.5M$. Fig. 3 also shows the area of the customers and the amount of satisfied demand during the planning horizon. The satisfied biofuel demand is illustrated by yellow colors (pale to dark), and the satisfied pellet demand is shown by green colors (pale to dark). Table 5 shows the different types and capacities of the technologies that are optimally installed in the biorefineries.

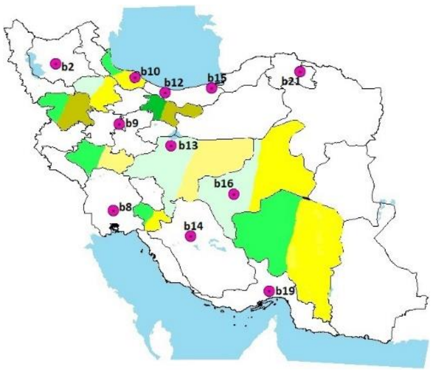

Fig. 3. Optimal structure of the bioenergy supply chain.

5.2 The social impacts of the bioenergy supply chain

This part investigates the effect of the bioenergy network on the territories (the society), where bio-refineries are installed. Therefore, first, the social profit ($\boldsymbol{\mathfrak{S}_{w,b}}$) of the generated job *w* (the work hours) in territory *b* is defined as follows:

$$\mathfrak{S}_{w,b} = \boldsymbol{\Pi}_{w,b} \times \mathfrak{T}_{w,b} \; ; \; \mathfrak{T}_{w,b} = (\mathfrak{H} + \mathfrak{I}) \tag{P1}$$

Where $\boldsymbol{\Pi}_{w,b}$ is the social impact of the installed biorefinery that was defined in Section 3.1. $\mathfrak{H}$ is the number of work hours (hourly work) within the job category *w* required to operate technology a. In other words, $\mathfrak{H}$ is corresponding to the work hours that are required to converting the biomass to bioenergy and biofuel (hours/tonne of biomass). $\mathfrak{I}$ is the number of work hours (salaried work) within job class *w* required to operate technology a (hours/year). $\mathfrak{I}$ is corresponding to the work hours that are required to keeping the bio-refinery open during the year (e.g., administrative staff). These work hours (Hourly-wage work and salaried work) can change by changing the type of technology and its capacity. Table 4 shows the assumptions of these work hours. They come from reports made by [21] and also from consulting with the Renewable Energy and Energy Efficiency Organization. In addition, work hours that are required for pyrolysis and pellet technologies come from different studies [22, 23].

Table 4: work hours (per year) required to each technology.

Kinds of technology	Hours needed for each job class					
	Salaried work			Hourly-wage work		
	combustion	pellets	pyrolysis	combustion	pellets	pyrolysis
pyrolysis (200 t/day)	-	-	10222	-	-	16422
pyrolysis (600 t/day)	-	-	10222	-	-	16802
pelletizing (15000 t/ year)	-	10222	-	-	26899	-
pelletizing (45000 t/ year)	-	10222	-	-	30152	-
Biomass boiler (heat only)(3MW)	2812	-	-	17102	-	-
Biomass boiler + steam turbine (CHP) (0.5MW)	3151	-	-	17122	-	-

Next, given the optimal design of the bioenergy supply chain obtained in Section 5.1, the social profit of the bioenergy SC can be calculated using equation (P1) and Table 5. If the social impact ($\boldsymbol{\Pi_{w,b}}$) in (P1) is substituted by value 1, the number of jobs is obtained. As shown in Table 5, the optimal design obtained from the model causes social profit (up to 48.84) by generating 262 jobs. These jobs have a high impact on the society, because they are generated in the territories with two features: i) high vulnerability in an economic crisis, and ii) high unemployment rate.

6 Conclusion

In this paper, a model was proposed to design bioenergy supply chains under social consideration. Unemployment rate and vulnerability to changes during an economic crisis were considered as social concerns. The areas that are mostly exposed to these social issues were chosen as initial potential locations for installing the bio-refineries. The applicability of the developed model was shown through a case study. The results demonstrated that the proposed approach leads to the generation of a large number of job positions which has an important impact on the social development of these regions. In the future studies, first, initial capacities can be considered, or instead of using old technologies, the new technologies can be considered in the model in order to increase the production yield (efficiency). Second, it would be interesting to consider product recycling inside the biorefinery after generating the products. Finally, carbon pricing policies or decisions corresponding to the carbon trading can be added to the model.

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Table 5: Optimal design and social profit of the bioenergy supply chain

Technologies	The installed technologies	Social profit
b2		
Biomass boiler + steam turbine (electricity only),(MW)	5	2839070
pellet plant, (t/year)	15000	3014968
pyrolysis plant, (t/day)	200	4080262
b8		
Biomass boiler + steam turbine (CHP), (MW)	0.5	2413257
pellet plant, (t/year)		
pyrolysis plant, (t/day)	400	3511530
b9		
Biomass oil heater + ORC(CHP or electricity only), (MW)	2	2240160
pellet plant, (t/year)	15000	2431426
pyrolysis plant, (t/day)		
⋮	⋮	⋮
b21		
Biomass oil heater + ORC(CHP or electricity only), (MW)	0.5	2340646
pellet plant, (t/year)		
pyrolysis plant, (t/day)	400	3644040
Total number of technologies	20	
Total social profit (M points)		48.84
Total number of Jobs (Jobs)		263