FINAL PROJECT

Industrial Engineering

Design of bioethanol green supply chain

Comparison between first and second generation biomass concerning economic, environmental and social impact

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1. Introduction

In recent decades it is highlighting that oil will run out in a relatively near future and some renewable energy source will have to replace it. Moreover, the world energy demand grows [1] and society is becoming more concerned about climate change. So, as oil resources are depleting, biofuels are becoming more important. Biofuels are being used to counteract disadvantages of oil as rise in its price, the large amount of greenhouse gas emission, air pollution and reliance of exporting countries. Biofuels are obtained from vegetal materials or waste and they can be used in the production of bioethanol, used as a gasoline additive. All this is contributing to create a biobased economy. This is also leading to the establishment and development of biorefineries, where biomass is converted into fuels, power, and chemicals. The emergence of biorefineries helps to reduce the environmental impacts by taking advantage from biomass feedstock.

There are many processes that can be used to transform biomass into bioethanol. Each process depends on the biomass feedstock and has its own cost [2]. However, an important part of the cost of the final product, such as bioethanol, comes from the supply chain. In fact, to minimise costs in a biorefinery, it is essential to have a biomass infrastructure where raw materials collection, storage and pre-processing are simultaneously optimised. Therefore, the establishment site of the biorefineries, the amount of the different kind of raw materials and where they are collected or the construction of stores are as important or more than choosing the most suitable conversion process [3].

Biorefineries are being implemented to replace the current oil refineries and it should be considered that their socio-economic impact seems to be really different. Biomass dependence and its collection and processing are key factors in the socio-economic impact. These factors are important in a large scale development because of the difference between biomass feedstock and fossil fuel feedstock [4].

Many studies concerning economic costs have been done about biorefineries [3] [5] [6] [7]; even some of them concerning also environmental terms [8]. However, few things have been written concerning economic, environmental and social terms in biorefineries supply chain. There is a need to balance economic, environmental and social effects of building and putting into operation biorefineries. This balance has nothing to do with current refineries because most of the economic costs, environmental costs and social aspects are related to the biomass production, processing and delivery. You et al. (2012) [9] considered economic, environmental and social criteria when optimising a biofuel supply chain. Santibañez-Aguilar et al. (2013) [10] also considered simultaneously economic, environmental and social criteria to design and plan biorefinery supply chains with several multiproduct processing plants located at different sites and supply different markets.

This article seeks to find a balance that optimizes simultaneously economic, environmental and social objectives in the supply chain of a biorefinery or a set of biorefineries located in southwest France. That supply chain extends from biomass feedstock to delivery of the final product, bioethanol, to the fuel depots. So the process includes the collection of the biomass feedstock, its transportation to the biorefineries, the treatment to convert it into bioethanol and the transportation to the fuel depot.

Social aspects in this paper are focused on job creation. These new jobs are divided into direct, indirect and induced jobs. Direct jobs are those that are taken by the plant's personnel. Indirect jobs are those related to subcontracting activities such as farmers, transporters and stock managers. Finally, induced jobs are those created in other sectors due to the activity of the biorefinery, for example local trade.

This is a multi-objective problem divided in 52 periods that represents the 52 weeks of the year. A mixed integer linear programming model is responsible for minimising the economic costs and the environmental impact of the implementation of the biorefineries and the entire supply chain as well as maximising the number of jobs created due to its implantation.

In this context, France wants to increase its number of biorefineries in the next years [11]. The goal is to achieve a production of 400,000 tons of bioethanol, by biorefineries working with corn or wood as raw materials, in southwest France. There is already one biorefinery that works with corn in Lacq, the only one of this kind in southwest. The choice of corn and wood as raw materials is based in its abundance in this region. France is the first European country in corn production and its yield is still rising [12]. The wood used as biomass feedstock in biorefineries is divided in softwood, that has long fibres, and hardwood, that has short fibres. In some cases this wood is similar to the one used in the paper industry and it is obtained from trees as pines, eucalyptus, poplars or willows. This wood feedstock is also characterized by its low price.

In the case of bioethanol, there are no differences in the resulting fuel between the first or second generation since in both cases ethyl alcohol is obtained. The difference is that the first generation ethanol, or conventional, is obtained from agricultural products that have nutritional value but its cost of production is lower. Meanwhile, the second generation ethanol is derived from biomass rich in cellulose and hemicellulose without nutritional value. However, the processing technology of these materials is more complex, so investment and associated production costs are high. In this paper corn (first generation) and wood (second generation) are compared as raw materials in bioethanol production.

The target of this study is to define the optimal establishment of biorefineries in southwest France in regard to economic, environmental and social terms. Different weights are imposed to the three criteria in order to compare the results when giving more importance to one of the criteria or another.

2. Superstructure model

The main objective of this project is to find a solution that reaches a compromise between three criteria (economic, environmental and social) to establish one or some biorefineries in southwest France. Using a Mixed Integer Linear Programming model, economic, environmental and social aspects are evaluated and compared in order to justify the reasons to choose how many refineries should be established and where. At first, only corn is considered as raw material because of its abundance in the region. The model is designed and solved to determine the economic cost, the eco-cost [13] and the number of jobs created to procure, harvest, store, transport and treat a flow of corn biomass to an optimally located set of biorefineries. In this case, the amount of corn collected is imposed so that it is proportional to the total crop in each region and bioethanol demand is met. Binary variables are included to enable the model to determine the most suitable plant locations to reach a balance between the three criteria. The model was solved using the program ILOG with the CPLEX solver.

A superstructure model is created to define the whole process from the harvest to the transport of the final product, bioethanol, to the fuel depots. This superstructure model is represented in figure 1.

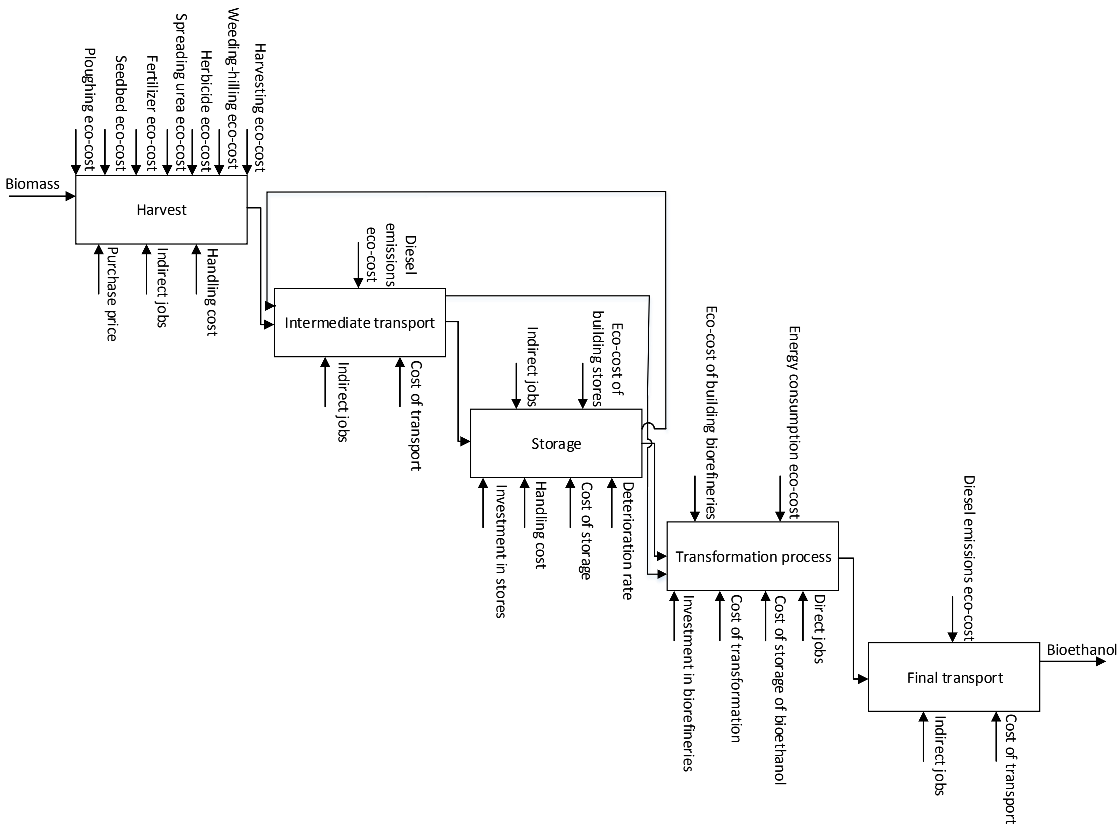

Figure 1

Superstructure of biomass supply chain model

3. Objectives

3.1. Economic

The part of the objective function associated with the minimization of the economic costs includes all costs of the supply chain, from the purchase of biomass feedstock to transportation of the final product, as well as the investment cost of biorefineries and stores. The costs of the supply chain are: the cost of raw material, transporting the raw material to the stores, the cost of handling and storage of biomass, the cost of transport to the biorefinery, the cost of transformation into bioethanol and the cost of final transport to the fuel tank.

3.1.1. Costs of transport

The distance considered between the departments is the distance between their capitals. Transport is carried out by trucks and its cost vary from 1 € to 1,25 € per kilometre according to the French average in 2007 [14] [15]. This price includes all transport costs. The selected value is the most penalising. Considering an inflation of 2% per year, the final value is 1,41 € per kilometre for a 30 tons capacity truck.

3.1.2. Investment in the plants

The investment corresponding to the construction of biorefineries is estimated by considering the price of a similar biorefinery that is already built and applying Chilton's law to define the prices of all sizes biorefineries. The considered biorefinery as example is:

- The corn biorefinery in Lacq (France) with a capacity of 200.000 tons of bioethanol/year and a price of 149 million euros in 2008.

To define the Chilton coefficient it is considered that to double the capacity production from 50 MGY to 100 MGY it is necessary to multiply the investment by 1,6 (Wallace et al., 2005).

Applying the following Chilton formula: $\frac{1{,}6\, I}{I} = (\frac{2P}{P})^C$

Then the Chilton coefficient is deduced: $C = \frac{\ln 1{,}6}{\ln 2} = 0{,}678$

The necessary investment is calculated through the Chilton formula $I = I_0(\frac{P}{P_0})^C$ considering a discount rate of 15%. The amortisation is considered in 20 years and the costs of operating are 24 million euros per year. The costs are summarised in table 1:

Table 1

Investment cost of corn biorefineries

Production capacity (tons of ethanol/year)	Investment (€)	Discounted investment + cost of operating (€/year)
50.000	58.208.927	33.299.544
75.000	76.626.584	36.241.976
100.000	93.129.642	38.878.528
150.000	122.596.425	43.586.185
200.000	149.000.000	47.804.459
400.000	238.388.118	62.085.236

The same is done for the plants using wood as raw material. The investment is based on two existing refineries: the plant in Mascoma (2012) that produces 78 million litres of bioethanol per year and its cost was 148 million euros and the plant in Bluefire (2012) that produces 73 million litres of bioethanol per year and its cost was also 148 million euros.

Table 2

Investment cost of wood biorefineries

Production capacity (tons of ethanol/year)	Investment (€)	Discounted investment + cost of operating (€/year)
50.000	136.181.902	45.756.621
75.000	179.275.908	52.641.383
100.000	217.891.044	58.810.594
150.000	286.841.453	69.826.212
200.000	348.625.670	79.696.950
400.000	557.657.304	113.092.151

To calculate the investment of a plant using corn and wood, it has been done a weighted average according to the amount of each material.

3.1.3. Price of the stores

The storage silos are composed of reinforced concrete cells with a capacity of 200 tons [16]. The price of each 200 tons capacity cell is 15.000 € [17]. Five sizes of stores are considered and represented in table 3:

Table 3

Investment cost of the stores

Capacity (tons)	Investment (€)	Discounted investment (€/year)
5.000	375.000	59.910
40.000	3.000.000	479.284
70.000	5.250.000	838.747
100.000	7.500.000	1.198.211
250.000	18.750.000	2.995.527

3.1.4. Price of biomass, conversion rate and cost of treatment and storage

The price of the corn is estimated in 220 €/ton by the price paid by farmers in 2012 and published in the journal FranceAgriMer (April 2012) [18].

The price of the wood feedstock is calculated from the French data in January 2014 [19]. It is 31 €/ton and corresponds to the average of sawdust from hardwood and softwood.

Taking the example of the plant in Lacq, it is assumed that 500.000 tons of corn are necessary to produce 200.000 tons of bioethanol, which means a rate conversion of 2,5 tons of corn per ton of bioethanol produced.

The Enerkem group, in Canada, operates many plants producing bioethanol from biomass. It is declared that the plant that uses wood as raw material needs 2,78 tons of wood to produce 1 m^3 of bioethanol (3,52 tons of wood/ ton of bioethanol).

The handling cost (unloading, loading…) for biomass is valued at 0,15 € per ton.

Looking again at the data from the plant in Lacq, the average cost of operation is 160 million euros. The 13% of these costs involve the conversion process, which are 20,8 million euros. As there are transformed 500.000 tons of corn in the plant, the cost is 41,6 € to transform one ton of corn into ethanol.

According to the sustainable forest management network [20], the current cost of producing bioethanol from wood is 310 €/ m^3 of ethanol. With a conversion rate of 2,78 tons of wood/m^3 of ethanol, it makes 112 €/ ton of wood.

Due to insects and foreign bodies, it is assumed a deterioration rate of 0,1% for corn biomass.

The cost of the storage of ethanol is 175 €/ ton and its calculation is available in the appendix.

3.1.5. Cost of storage of ethanol

The actual sale price of bioethanol in June 2013 was 0,9 €/L [21]. Considering a margin of 15%, the cost price is 0,76 €/L.

The cost price is includes:

- Purchase cost
- Production cost
- Administrative cost
- Storage cost

If the percentage of each cost is defined, the cost of storage can be calculated.

To calculate the cost of purchase it is necessary to know the amount of corn needed per month. Then, the total cost of purchase is calculated. Calculations are summarized in table 4:

Table 4

Purchasing cost of bioethanol

Production of bioethanol (L/year)	315.600.000
Production of bioethanol (L/month)	26.300.000
Amount of bioethanol produced per ton of corn (L/ton)	400
Purchase cost of 1 ton of corn (€/ton)	220
Corn purchased per month (ton/month)	65.750
Total purchase cost of corn (€)	14.465.000
Cost price (€)	20.119.500
Percentage of purchase cost	72%

The percentage of the cost of production and administration in the production chain of this kind of carburant can be estimated in 10%.

Then, the percentage of storage cost is 18%. That means a cost of storage of 0,14€/L (175 €/ton).

Table 5

Storage cost of bioethanol

Cost price = sale price – margin	
Sale price (€/L)	0,9
Margin	15%
Cost price (€/L)	0,765
Cost price = purchase cost + storage cost + production cost + administrative cost	
Percentage of purchase cost	72%
Percentage of production + administrative cost	10%
Percentage of storage cost	18%
Total	100%
Storage cost of bioethanol (€/L)	0,1385

3.2. Eco-costs

Eco-costs are a measure that expresses the environmental load of a product, from its production until the end of its utilisation. This indicator is presented as a price in euros (€). It takes into account several stages in the life of the product concerned [22]:

- It quantifies the impact of the product on the environment in terms of pollution by allocating a cost penalizing the use of an alternative that would reduce its impact on the environment and would be called sustainable solution.
- It takes into account the depletion of natural resources on Earth
- It takes into account the impact of energy costs required to manufacture the product.

The eco-cost is obtained by the addition of these three factors.

These are the main eco-costs with the product which is most of these emissions:

- Global warming (0,135 €/kg CO_2)
- Acidification: acid rain, soil acidification… (8,25 €/kg SO_x)
- Eutrophication: modification and degradation of aquatic environments (3,90 €/kg Phosphate)
- Eco-toxicity: pollution of the biosphere, heavy metals, toxins… (55 €/kg Zn)
- Carcinogenic particles (36 €/kg Benzopyrene)
- Fine particles (29,65 €/kg PM 2,5)
- Summer smog: atmosphere pollution (9,70 €/kg C_2H_4)

Eco-costs allow quantifying the environmental impact as a simple indicator easy to understand and compare with other criteria, for example economic. However, this indicator is changing over time and it is important to assure that it has been calculated properly.

The data used in this paper comes from a MS Excel file provided by the Delft University of Technology (Netherlands) for the year 2012 [13].

Eco-costs are applied to all the stages in the logistic chain. Most penalising conditions are applied in order to not underestimate the environmental impact. This is the logistic chain used in the process:

Cultivation → Biomass transport → Biomass storage → Cooperatives/refineries transport → Transformation → Transport to the fuel depots

The different eco-costs are divided into two groups depending on whether they are fixed or variable:

- Those that do not change depending on the solution chosen or have no influence on the solution are fixed eco-costs and are calculated preliminary.
- Those that can have an influence on the solution and depend on it are variable eco-costs and are evaluated through the model.

3.2.1. Fixed eco-costs

3.2.1.1. Cultivation of corn

The cultivation of corn is the beginning of the logistic chain and it is composed by many stages that all emit various pollutants [23].

Ploughing (1) → Seedbed (2) → Fertilizer (3) → Spreading urea (4) → Herbicide (5) → Weeding-hilling (6) → Harvesting (7)

- All steps need the use of an agricultural machine that emits mainly CO_2, but also fine particles, carbon monoxide, hydrocarbons and oxides of nitrogen. These emissions are based on the Euro 5 and 6 standards that regulate engine emissions.
- Steps 1,6 and 7, that are mechanics, emit fine particles to the atmosphere (PM 2,5 and PM 10).
- Steps 3 and 4 spread various chemicals in nature. The main interest is in NH_x molecules.
- Throughout its growth, corn needs to be irrigated. This irrigation mobilizes significant energy involving eco-costs, taking also into account the use of specific equipment for irrigation. These data are averages of all existing irrigation techniques.

Corn crop needs of one hectare are calculated to then estimate the eco-cost of the total environmental impact [24].

Table 1

Corn cultivation requirements

Yield (Tons/ha)	10
Water requirements (m^3/ha and month)	1.000
Time from seedbed to harvest (months)	6
Consumption of an agricultural machine (L of diesel/ha)	35
Number of passages per hectare	7
Nitrogen requirements (kg/ha)	220
Selective herbicide (prosulfocarb, L/ha)	1
PM 2,5 ploughing + harvesting (kg/ha)	0,1
PM 10 ploughing + harvesting (kg/ha)	7

Eco-cost related to the cultivation of wood biomass is zero since sawdust is a waste recovered directly in sawmills.

3.2.1.2. Energy consumption
As the project takes place in France, nuclear energy is considered to provide energy to the process. Heat is made with natural gas which is preferred to the use of coal that has a greater impact on the environment and is less interesting from an economic point of view.

It is chosen to use data related to a process called dry which represents 75% of existing bioethanol plants and is used for all refineries built after 2005.

Taking into account losses in upstream, that is to say between the energy production and use, here are the energies involved in the production of one cubic meter of bioethanol.

- 11,5 GJ of natural gas/m^3 (Eco-cost: 26,33 €/GJ)
- 2,7 GJ of electricity/m^3 (Eco-cost: 11,82 €/GJ)

The hypothesis that corn and wood process needs same energy is done.

3.2.1.3. Other fixed eco-costs
There are other eco-costs that can be calculated preliminary. It is mainly the use of denaturant added up to 5% ethanol product. Generally, the denaturant is the unleaded 95. This eco-cost is 0,64 €/kg of unleaded 95 used.

3.2.2. Variable eco-costs

3.2.2.1. Transports
Referring to the transport of biomass or ethanol, deliveries are only made by trucks. It is necessary then to evaluate the pollution of that means of transport. Trucks consume diesel and emissions of that type of transport are regulated by European standards. It is therefore necessary to establish the emissions of CO_2, hydrocarbons, nitrogen oxides and fine particles for a loaded truck for each journey. So a matrix containing the journeys eco-cost between each destination is created, the same way as the one containing the price of each journey.

CO_2 emissions for a truck over 30 tons are estimated in 500 g/km. For the other pollutant emissions, we rely on European standards. The standard used is EURO 6, which came into force on January 2014.

Table 2

Maximum authorized emissions according to EURO 6 European standards

g/kWh	CO	Hydrocarbons	NO_x	PM
Euro 6	1,5	0,13	0,4	0,01

Table 3

Data related to the diesel consumption of an over 30 tons truck

Consumption (L/100 km)	35
Energy (kWh/L)	10,5
Energy (kWh/km)	3,675

Table 4

Eco-costs of various emissions from diesel

Eco-costs	€/kg
CO	0,26
Hydrocarbons	3,4
NO_x	4,62
PM 10	14,5

Table 5

Results of eco-costs per km traveled

€/km	CO	Hydrocarbons	NO_x	PM	Total
Euro 6	0,00143	0,00162	0,00679	0,00053	0,01038

3.2.2.2. Cooperatives

Another source of pollution is the creation of storage cooperatives. The stores are composed by 200 tons capacity silos made of reinforced concrete. The silos are considered geometric cylinders with a wall's thickness of 30 cm. Knowing then the volume of reinforced concrete used, eco-costs can be defined.

Table 6

Eco-costs of cooperatives depending on their size

Capacity (T)	Eco-cost (€)
5.000	147.498
40.000	1.179.988
70.000	2.064.979
100.000	2.949.970
250.000	7.374.925

3.2.2.3. Refineries

The eco-cost of refineries is divided into two parts:

- The part concerning installations carrying out the material processing
- The part concerning the storage of biomass

The first part of the eco-cost is obtained from a cost calculated for a bioethanol refinery using corn and having a production capacity of 90.000 tons per year. Chilton's law is chosen to adapt this result to the different sizes of the plants. The Chilton coefficient used is 0,6. A quick rough estimation of the amount of material necessary for the construction of such a plant confirms that the use of this data is appropriate since figures obtained have the same order of magnitude.

The second part of the eco-cost depends on storage. Anyway, the storage solution in the refinery cannot be more complicated, more expensive nor have a greater environmental impact than cooperatives since they perform the same function. It is decided to evaluate the impact of these storages using Chilton's law, with a coefficient of 0,6, from data on industrial silos with a capacity of 2.165 tons of reinforced concrete. The same eco-costs are considered for biorefineries using corn and wood.

Table 7

Eco-costs of refineries depending on their annual production capacity

Refinery's capacity (T)	Eco-cost of installation (€)	Eco-cost of storage (€)	Total eco-cost (€)
50.000	1.943.929	65.191	2.009.120
75.000	2.479.335	412.880	2.892.215
100.000	2.946.446	717.107	3.663.553
150.000	3.757.969	1.021.335	4.779.304
200.000	4.465.977	1.521.137	5.987.114
400.000	6.769.155	2.520.741	9.289.897

3.3. Social aspects

Three types of jobs are generated by the implementation of biorefineries: direct, indirect and induced jobs. Direct jobs are those that are related to the plant's operation. That is the number of jobs of the enterprise. Indirect jobs are those related to subcontracting activities such as farmers, transporters and stock managers. Finally, induced jobs are those created in other sectors due to the activity of the biorefinery, for example local trade [25] [26] [27].

- Direct and indirect jobs

According to the existing data, it is decided to take direct and indirect jobs as the same data that depend only on the plant's size.

Nowadays, few enterprises produce ethanol from corn. To obtain consistent data, it has been taken into account all types of biomass used to produce bioethanol.

The information is taken from the list of all the companies included in the SNPAA (Syndicat National des Producteurs d'Alcool Agricole) [28]. The total number of jobs generated is not correlated with the amount of ethanol produced but with the tone of biomass transformed. This is because the bioethanol production is not the only activity of the enterprises included in the SNPAA.

The correlation between the number of jobs (direct and indirect) and the amount of biomass transformed, for the size of the refineries concerned, is modelled by the following equation:

$$\text{Numberof jobs } = 0.0006 * \text{quantity transformed} + 115.69$$

This equation has been obtained from four values concerning the dimensions of studied biorefineries. The number of jobs generated is then proportional to the consumption of biomass of the plant and consequently to its production of bioethanol. The figure 1, table 24 and table 25 can be found in the appendix.

- Induced jobs

The number of induced jobs varies depending on the region and the number or direct and indirect jobs generated. The following formula can be used to calculate the number of induced jobs generated:

$$Induced\ jobs = \frac{\sum DJ + \sum IJ}{Pop} \times F_a \times E_{cons}$$

$$With\ E_{cons} = E_{region} \times \%GDP_{cons}$$

Legend:

- DJ= Direct Jobs generated
- IJ= Indirect jobs generated
- Pop= Total population of the considered region
- F_a= Size of an average French family (number of people).
- E_{cons}= Number of jobs related to the consumption of direct and indirect jobs generated
- E_{region}= Number of total jobs in the considered region

- $\%GDP_{cons}$= Percentage of GDP related to household consumption in France

These data is available at INSEE site [29].

As results depend on each department, it is possible to obtain the ratio of each of them that will be multiplied by the number of direct and indirect jobs (table 23 in appendix) [30].

$$Ratio = \frac{F_a \times E_{cons}}{Pop}$$

It is assumed that only the refineries have an impact on the employment created. Therefore, the social model does not control the construction of storage and a risk is taken, for almost a dozen jobs, that if the storage is not located in the same area as the refinery, the number of induced jobs is very slightly distorted.

4. Play-off table

The main objective of this project is to find a solution that reaches a compromise between our three criteria (economic, environmental and social) to establish one or some refineries. Making a playoff table is the first step to obtain a balanced solution. To solve this part of the problem a new table has to be made to help finding the minimum and maximum of objective functions. In this table, each row represents the term that is being minimized/maximized and the result of each aspect is represented in columns. Then optimizing each objective function on its own table 13 is obtained, using corn as biomass feedstock.

Table 13

Play-off table using corn

Criteria	Economic (€)	Environmental (€)	Social (induced jobs)
Economic	$f_{min}^1 = 343{,}345{,}136$	$f_1^2 = 23{,}309{,}098$	$f_1^3 = 546$
Environmental	$f_2^1 = 414{,}707{,}930$	$f_{min}^2 = 19{,}052{,}661$	$f_2^3 = 1031$
Social	$f_3^1 = 620{,}142{,}561$	$f_3^2 = 147{,}718{,}939$	$f_{max}^3 = 1151$

In order to obtain a balanced solution as close as possible to desired solutions, the magnitude order of the three criteria have to be matched. For that reason, the objective functions and goals have to be normalized. The values in table X are used to normalize the objective functions and goals.

$$\mathrm{F}_{\mathrm{norm}}^{\mathrm{i}} = \frac{\mathrm{f}^{\mathrm{i}} - \mathrm{f}_{\mathrm{min}}^{\mathrm{i}}}{\mathrm{f}_{\mathrm{max}}^{\mathrm{i}} - \mathrm{f}_{\mathrm{min}}^{\mathrm{i}}}$$

$$\mathrm{goal}_{\mathrm{norm}}^{\mathrm{i}} = \frac{\mathrm{goal}^{\mathrm{i}} - \mathrm{f}_{\mathrm{min}}^{\mathrm{i}}}{\mathrm{f}_{\mathrm{max}}^{\mathrm{i}} - \mathrm{f}_{\mathrm{min}}^{\mathrm{i}}}$$

With i = economic, environmental and social

And f1 = Price (Economic costs)

f2 = Eco-cost + ECR + ECC (Eco-costs)

f3 = InducedJCreated (New induced jobs)

The goals for each criterion are the minimum value of table X multiplied by 1.01, in order to not getting zero but being close to the minimum, in economic and environmental cases; and the maximum multiplied by 0.99 in the case of social aspects to keep the same policy of being around 1% of the goal.

5. Goal programming

To find a compromise between three criteria, it is used the goal programming methodology. Goal programming is a multi-objective optimization methodology that allows working with ILOG. There are some different kinds of goal programming. The one that is used in this model is based on deviation variables. The aim of this methodology is to minimize the deviation of the different objective functions the model has. In order to do it, objective functions become constraints and deviation variables are added to them. So the value that restricts the constraint is the sum of the goal and the deviation. In this case, the goal value for each constraint is that one obtained when minimizing each objective function separately. Then, the objective function is the sum of all deviation variables [31]. The process is as follows:

- An initial vector of objective functions $\vec{F} \epsilon \ \mathbb{R}$ is chosen;
- Two new variables, called deviations (d_i^+ and d_i^-), are associated to each objective related to the initial objective functions $f_i(\vec{x}), i \ \epsilon \ \{1, \ldots, k\}$, obtaining the following problem:

$$
\begin{array}{ll}
\text{minimise} & (d_1^+ ou\ d_1^-, \ldots, d_k^+ ou\ d_k^-) \\
\text{with} & f_1(\vec{x}) = F_1 + d_1^+ - d_1^- \\
& \quad\quad . \\
& \quad\quad . \\
& \quad\quad . \\
& f_k(\vec{x}) = F_k + d_k^+ - d_k^- \\
& \vec{h}(\overrightarrow{x}) = 0 \\
\text{and} & \vec{g}(\vec{x}) \leq 0
\end{array}
$$

The deviation variables to be minimized must respect certain constraints:

$$d_i^+ et\ d_i^- \geq 0,$$

$$d_i^+ \cdot d_i^- = 0\ with\ i \ \epsilon \ \{1, \ldots, \mathrm{k}\}$$

- Then, one of these two deviation variables is minimised. The selection of the variable is based on the type of exceeding desired (above or below the objective that is set). Depending on the desired way to achieve the goal $\vec{\mathrm{F}}$, different combinations of minimizing d_i^+ and d_i^- are possible. These combinations are shown in table 14.

Table 84

Deviation variables

Type	Deviation value	Variable
The goal is desired to be reached by higher values	Positive	d_i^+
The goal is desired to be reached by lower values	Negative	d_i^-
The goal is desired to be reached without exceeding	No deviation	$d_i^+ + d_i^-$

For example, if all goals are desired to be reached by higher values, the following problem is obtained:

minimise $\quad (d_1^+, \ldots, d_k^+)$

with $\quad f_1(\vec{x}) = F_1 + d_1^+$

$$\vdots$$

$$f_k(\vec{x}) = F_k + d_k^+$$

$$\vec{h}(\overrightarrow{x}) = 0$$

and $\quad \vec{g}(\vec{x}) \leq 0$

This methodology allows a multi-objective optimisation problem being reduced to minimise a vector. This vector may minimise the weighted sum of deviations. For example:

$$\min(4 \cdot d_1^+ + 2 \cdot d_2^- + (d_3^+ + d_3^-)\,)$$

The different weights define a user selection in the relevance of objective functions.

6. Results and discussions

6.1. Corn as raw material

If corn is used as raw material, the results show the difficulty in finding a balance between the three criteria. On one hand, if balanced weights are applied to the model, acceptable eco-costs and employment are obtained but economic costs are high. On the other hand, if much bigger weight is applied to the economic cost, its result is acceptable but then eco-cost increases to the double and employment is reduced to a half.

Table 15

Results for corn as raw material

Category / Weights	Economic: 1 Eco-cost: 1 Social: 1	Economic: 0,6 Eco-cost: 0,3 Social: 0,1	Economic: 0,9 Eco-cost: 0,09 Social: 0,01	Goal
Economic cost (€)	402.086.150	396.069.774	358.500,376	343.345.136
Eco-cost variable (€)	21.117.759	25.892.930	51.030.707	19.052.661
Total jobs created	2.508	1.831	1.262	2.679
Capacity of refineries	800.000	550.000	400.000	-
Capacity of stores	80.000	420.000	1.580.000	-

This shows that working at full capacity with one biorefinery is economically more interesting than building two biorefineries. However, the fact of building a single biorefinery increases the eco-costs of transportation and storage, as well as reduces the creation of jobs. In the case of first generation biomass as corn, that is cultivated only during one season of the year, costs and eco-costs of transportation and storage become very relevant.

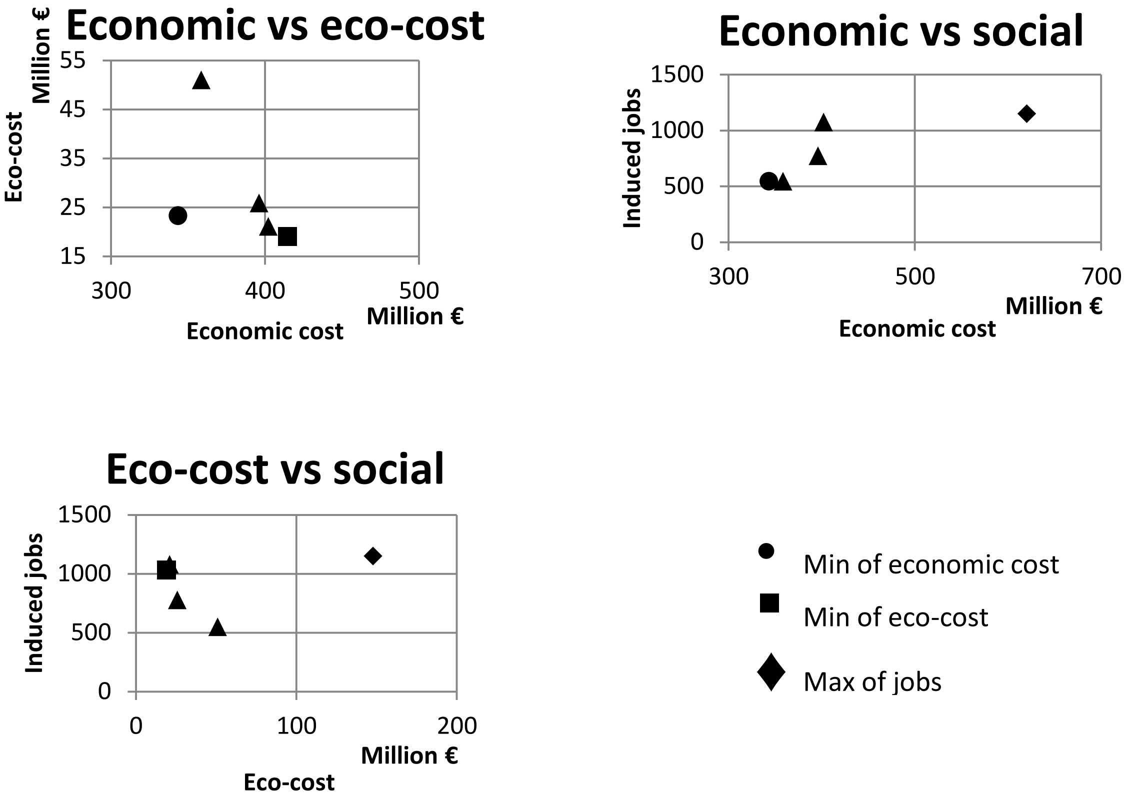

Figure 2

Comparison between economic cost, eco-cost and job creation in corn biorefineries

6.2. Wood as raw material

As no stores are required when using wood (because it can be collected during all year), when some simulations are done it can be observed that some solutions are very similar and all of them could be simplified in two main solutions.

In the first solution two refineries are built (Bordeaux and Toulouse), both of 400,000 tons of capacity. This solution is possible due to the absence of the total production capacity constraint in refineries used when maximizing employment. This constraint has not been considered because the minimisation of costs does not allow the building of many refineries. Moreover, as that constraint is not considered, more jobs than the goal (maximum applying the constraint) are created. Referring to economic costs and eco-costs, the fact of having two high-capacity refineries makes them very high.

On the other hand, in the second solution only one refinery is built (Bordeaux) and its economic costs and eco-costs are quite similar to the goal. However, the number of created jobs decreases considerably.

Table 16

Results for wood as raw material

Category / Solution	Solution 1: 2 refineries	Solution 2: 1 refinery	Goal
Economic cost (€)	435.529.490	330.327.439	325.706.706
Eco-cost variable (€)	19.170.718	10.316.633	10.061.406
Total jobs created	3.418*	1.725	3.113
Capacity of refineries	800.000	400.000	-
Capacity of stores	0	0	-

*Higher than maximum due to the absence of a constraint

If oversizing capacity of refineries is not a problem, it is not easy to choose a solution which balances the three criteria. Otherwise, if oversized refineries are not convenient, the best solution is the one that uses wood and establishes only one refinery in Toulouse. It has the minimum cost and eco-cost and employment creation is very close to the "non-oversized capacity solutions" maximum.

In this case of second generation biomass as wood, the fact that it can be collected all year makes the cost and eco-cost of storage decrease a lot. In fact, unlike corn, the less wood's biorefineries are built the lower is the eco-cost. Then in this situation, the only disadvantage found is the creation of jobs.

Second generation biomass has a lower purchasing price than first generation biomass but its transformation cost is higher. What will make a difference then are the amount processed or the plant yield and the cost of storage. Taking these terms into account, the use of second generation biomass like wood seems to be more advisable if a single biorefinery is established and works at full capacity since economic costs and eco-costs are lower than any possibility concerning corn.

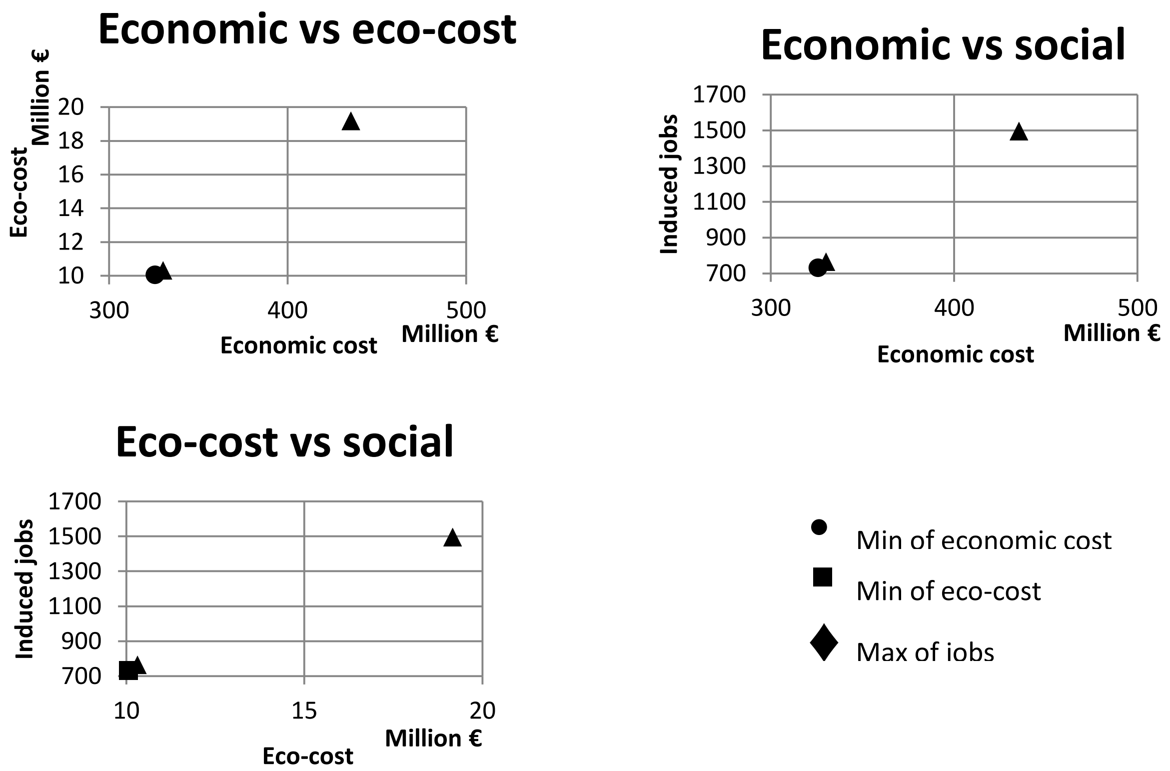

Figure 3

Comparison between economic cost, eco-cost and job creation in wood biorefineries

6.3. Corn and wood as raw materials

Looking at the results, it could be said that using both corn and wood at the same time improves the results obtained using only one of them. However, it does not lead to find a really good compromise between the three criteria. None of these solutions establishes stores because they are economically and environmentally expensive, not necessary when using wood and they do not contribute to job creation.

Table 17

Results using corn and wood as raw material

Category / Weights	Economic: 1 Eco-cost: 1 Social: 1	Economic: 0,6 Eco-cost: 0,3 Social: 0,1	Economic: 0,5 Eco-cost: 0,25 Social: 0,25	Economic: 0,55 Eco-cost: 0,3 Social: 0,15	Economic: 0,6 Eco-cost: 0,2 Social: 0,2	Goal
Economic cost (€)	425.850.112 (+31%)	329.264.839 (+1%)	396.286.458 (+22%)	428.620.732 (+32%)	385.806.931 (+19%)	325.268.655
Eco-cost variable (€)	101.256.687 (+9%)	93.849.931 (+1%)	99.399.355 (+7%)	100.458.277 (+9%)	102.839.133 (+11%)	92.570.833
Total jobs created	3.043 (-2%)	1.584 (-49%)	2.829 (-9%)	3.158 (-1%)	2.871 (-8%)	3.113
Capacity of refineries	Bordeaux (400.000) (100% wood) Toulouse (400.000) (85% corn / 15% wood)	Bordeaux (400.000) (25% corn / 75% wood)	Bordeaux (400.000) (65% corn / 35% wood) Toulouse (400.000) (70% corn / 30% wood)	Bordeaux (400.000) (55% corn / 45% wood) Toulouse (400.000) (5% corn / 95% wood)	Bordeaux (400.000) (45% corn / 55% wood) Toulouse (400.000) (80% corn / 20% wood)	
Capacity of stores	-	-	-	-	-	

In this case cultivation eco-costs are variable and that makes impossible to compare the eco-costs with the ones before. The environmental impact is lower when using more wood than corn due to the storage circumstances explained before. Also, the best economical solution is the one that establishes a single biorefinery and uses 75% of wood. However, the cheapest solution involving two biorefineries processes more corn than wood; but, again, it has the highest eco-cost due to the storage of corn. The solution that provides more employment processes more wood than corn.

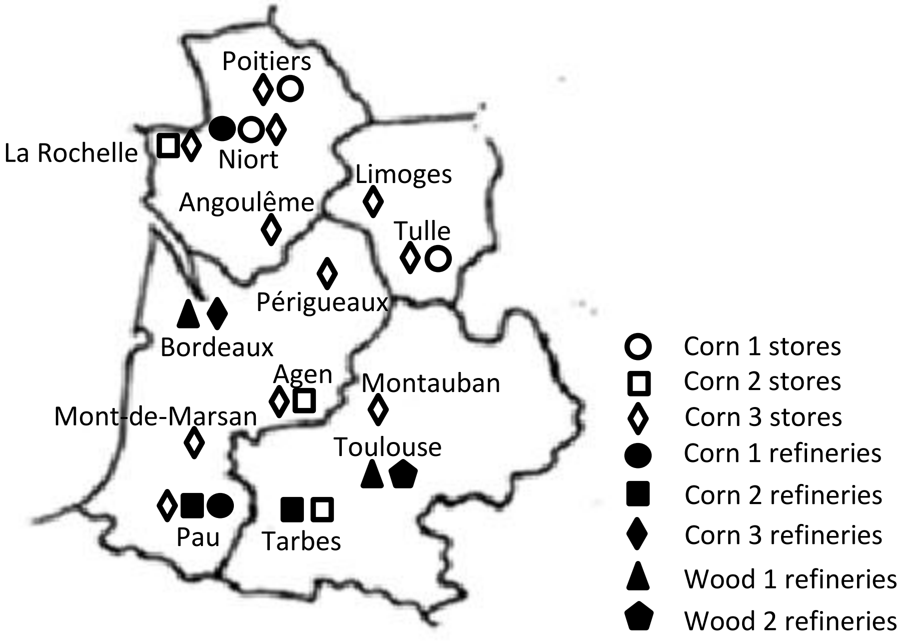

Figure 4

Location of biorefineries and stores depending on different corn and wood solutions

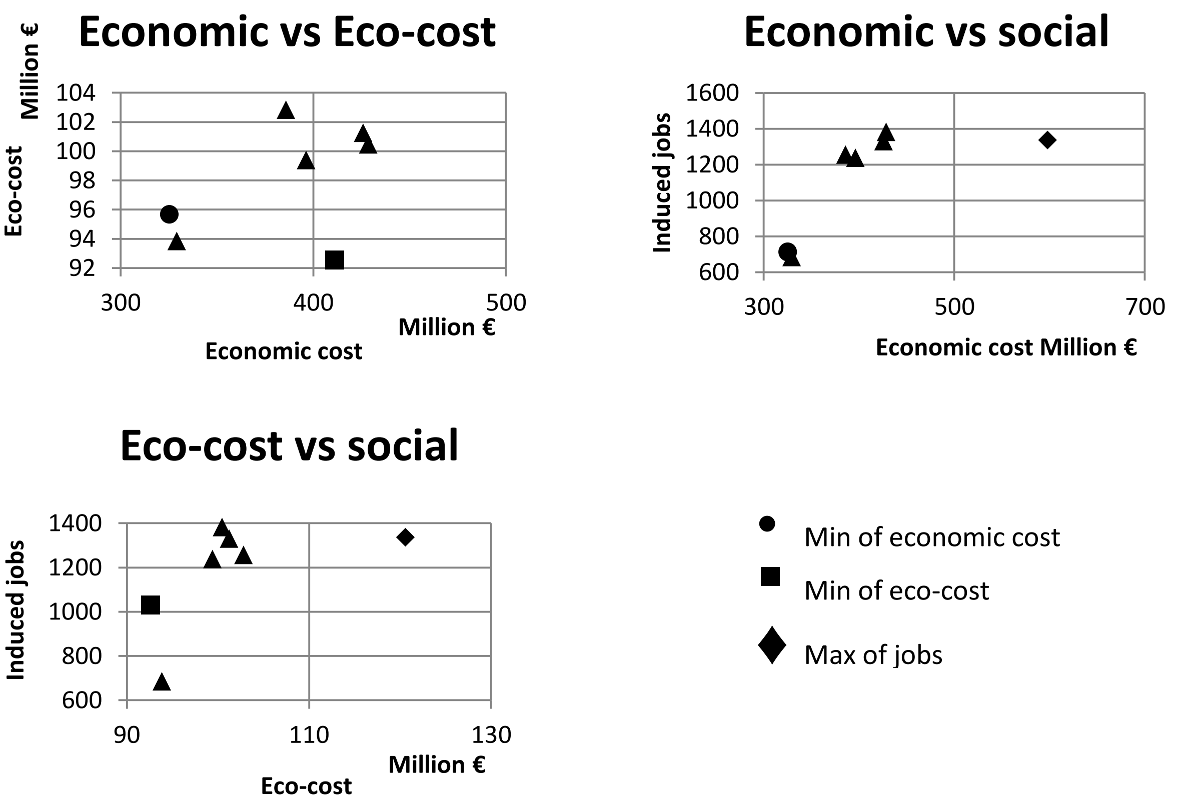

Figure 5

Comparison between economic cost, eco-cost and job creation in biorefineries using corn and wood

Economic costs and eco-costs rise as the number of refineries does while the number of jobs decreases. It is interesting then to analyse the economic and environmental cost as well as the number of jobs with different number of refineries established. There has to be done some simulations imposing the number of refineries to study the tendency of each criterion. So, eight simulations are done imposing from one refinery to eight refineries using goal programing.

The results show what is expected, economic cost and eco-cost increase as the number of refineries increases. On the other hand, the more refineries, the more new jobs are created. There is always one refinery in Toulouse due to its facility to create induced employment. The same happens with Bordeaux when there are two or more refineries. Most of the production is based on wood because it is economically better although job creation is less than with corn. Moreover, the more refineries are imposed, higher is the amount of wood used because the lack of jobs is supplemented with a greater number of refineries.

Table 18

Results using corn and wood as raw materials and imposing the number of biorefineries

Number of refineries	1	2	3	4
Economic cost (€)	330.584.166	367.796.563	402.163.096	435.428.172
Eco-cost (€)	93.929.578	94.809.325	96.310.691	97.397.906
Total jobs	1.614	1.752	1.981	2.192
Refineries (capacity in tons) {composition}	Toulouse (400.000) {25% corn, 75% wood}	Bordeaux (200.000) {40% corn, 60% wood} Toulouse (200.000) {35% corn, 65% wood}	Bordeaux (150.000) {30% corn, 70% wood} Toulouse (200.000) {40% corn, 60% wood} Niort (50.000) {35% corn, 65% wood}	Bordeaux, Pau (50.000) {5% corn, 95% wood} Toulouse (200.000) {40% corn, 60% wood} Niort (100.000) {35% corn, 65% wood}

Number of refineries	5	6	7	8
Economic cost (€)	469.922.119	505.441.826	537.939.552	569.233.037
Eco-cost (€)	100.444.598	100.611.639	102.329.839	102.770.191
Total jobs	2.482	2.656	2.891	3.088
Refineries (capacity in tons) {composition}	Bordeaux (50.000) {10% corn, 90% wood} Pau (50.000) {5% corn, 95% wood} Toulouse (200.000) {15% corn, 85% wood} Niort, Poitiers (50.000) {100% wood}	Bordeaux, Rodez (50.000) {5% corn, 95% wood} Toulouse (150.000) {35% corn, 65% wood} Tulle, Niort, Poitiers (50.000) {100% wood}	Bordeaux, Pau, Rodez, Tulle, Niort, Poitiers (50.000) {5% corn, 95% wood} Toulouse (100.000) {10% corn, 90% wood}	Bordeaux, Mont-de-Marsan, Pau, Rodez, Toulouse, Tulle, Niort, Poitiers (50.000) {5% corn, 95% wood}

Applying same weights to economic, environmental and social criteria and imposing the number of refineries, the processed amount of wood is always higher than the amount of corn. In fact, if more than four biorefineries are established, the amount of wood processed is at least 90% of the total amount.

These results clearly represent the different solutions obtained during the entire project. The difficulty is to find a compromise between economic and environmental aspects and social aspects. On one hand, if only one refinery was chosen, it would have low economic costs and eco-costs but only a half of all possible jobs would be created. On the other hand, if the maximum refineries were established (8), the objective of the number of jobs would be achieved but economic costs and eco-costs would be too much high. The point is to find some way to create the maximum number of jobs possible and at the same time try not to get that high costs.

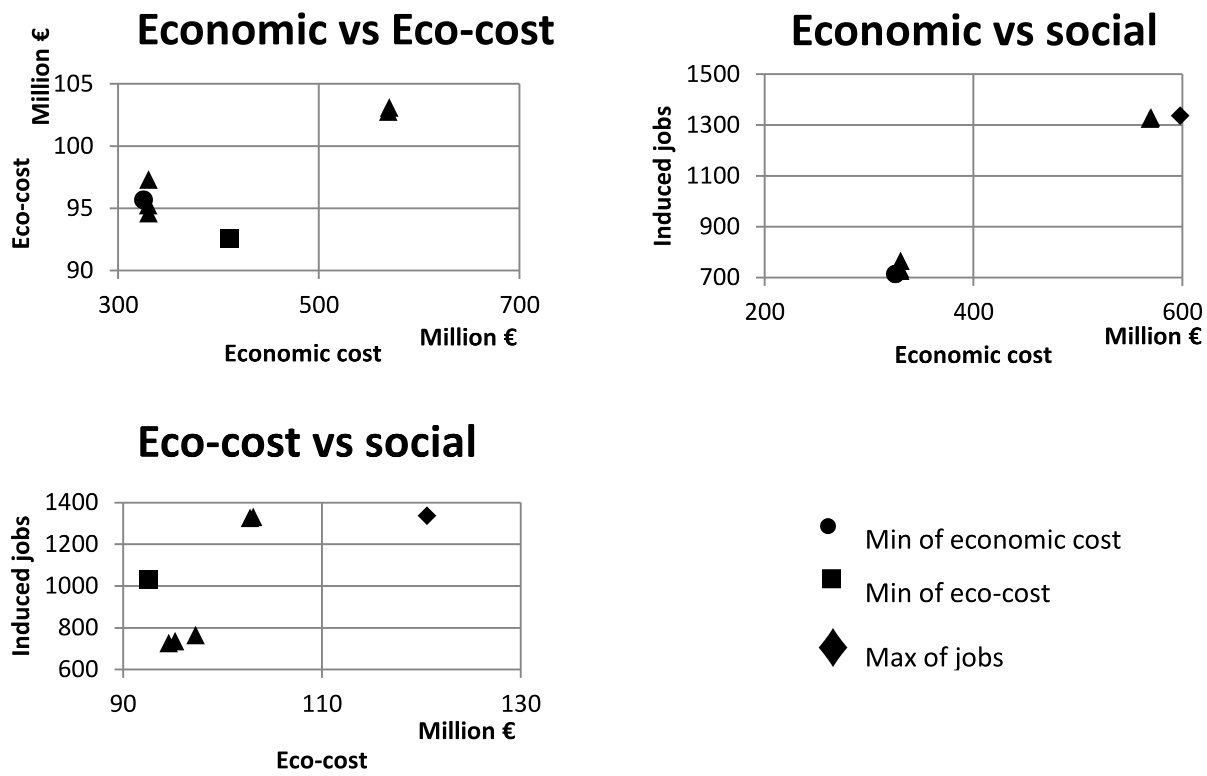

Figure 6

Comparison between economic cost, eco-cost and job creation with biorefineries capacity limit of 400.000 tonnes

7. Conclusions

Nowadays, biofuels are a key theme easily taken into account by policy makers and investors due to the strategic needs of French chemical industry and agricultural sectors. Policy decisions for sustainable development and energy policy will primarily support the development of biofuels. For this reason, French government wants to establish a set of biorefineries capable to produce 400.000 tons of bioethanol per year.

Biorefineries correspond to an industrial sector model maturity. The actors are then have highly competitive costs and all their parameters are optimized (procurement, logistics, treatment, etc.). At such a stage of development, the accumulated investment is considerable and there is a strong entry barrier for new entrants. This is what is required for biorefineries in order to provide a viable competition with oil refineries, fully mature in their model after 150 years of history.

Each workshop will represent significant investments and, once built, their profitability depends on their duty cycle. The image of the fully flexible biorefinery adapting its production to markets and raw materials available will probably be only a partial reality, simply for reasons of the importance of investments to be made and their profitability.

The necessary investment to carry out the project defined in this paper varies from 330 million euros to more than 500 million euros per year, depending on the number of biorefineries, including all costs. It should be necessary then to find some investment sources interested in biorefineries that is a heavy industry which must be concentrated to be competitive. It requires significant investments in R&D and in equipment, with horizons of return still uncertain, largely related to the respective changes in oil and agricultural commodities.

This investment in biorefineries would generate between 1500 and 3000 jobs directly related to the biorefinery as well as induced jobs, for example in local trade.

Being the price of bioethanol 0,73 €/liter the money from the sale of 400.000 tons of bioethanol would be around 370 million euros. That amount depends on the price of corn and other raw materials as well as the price of oil, gas or other fossil fuels. This supposed amount would allow the establishment of at most two biorefineries to make the project economically viable. These two biorefineries would be established in Toulouse and/or Bordeaux and they will generate between 1600 and 1700 jobs.

This model could be a help to the government to establish some subventions to manage the country by promoting renewable energies and ecological policies. However, the study will be continued using a biobutanol production, a third generation of bioethanol.

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9. Appendix

9.1. Variables and model

9.1.1. Variables

The really important variables of the model are those binary variables that indicate whether a biorefinery is built in different cities and what size is it. Also the binary ones that indicate the same referring to the stores are important to study the solutions. There are other variables that help the model with the biomass flow.

Table 19

Variables of the model

Variables	
y1[i][j][t]	Amount of corn/wood delivered from field i to cooperative j at period t
y2[i][j][t]	Amount of corn/wood delivered from field i to refinery j at period t
y3[i][j][t]	Amount of corn/wood delivered from cooperative i to refinery j at period t
y[i][j][t]	Amount of fuel delivered from refinery i to fuel depot j at period t
z1[i][t]	Amount of biomass stored in cooperative i at period t
z2[i][t]	Amount of biomass stored in refinery i at period t
z[i][t]	Amount of bioethanol stored in refinery i at period t
w[i][t]	Quantity of biomass transformed at period t in city i
e[i][t]	Quantity of bioethanol produced in city i at period t
xref[i][l]	Binary: presence or not of a refinery of size l in the city i
xsto[i][f]	Binary: presence or not of a cooperative of size f in the city i
NbrTruck'X'[i][j][t] (X=1,2,3)	Number of trucks that are necessary to transport corn/wood between 2 destinations at period t
NbrTruckEth[i][j][t]	Number of trucks that are necessary to transport fuel from refinery i to fuel depot j at period t
Ecocost	Eco-cost of transportation value
ECR	Eco-cost of refineries value
ECC	Eco-cost of cooperatives value
Price	Total economic cost of the solution
InducedJCreated	Induced jobs created by the solution
Deconpos	Positive deviation variable of economic cost

Deconneg	Negative deviation variable of economic cost
Decocostpos	Positive deviation variable of eco-cost
Decocostneg	Negative deviation variable of eco-cost
Dsocialpos	Positive deviation variable of number of jobs
Dsocialneg	Negative deviation variable of number of jobs

9.1.2. Objective function

Using goal programming, the objective function of the model focuses only the deviations of the considered economic, environmental and social goals and tries to minimise these deviations. This function includes also a weight for each criterion in order to obtain the desired balance.

$$min\left(w_{econ} * D_{econpos} + w_{ecocost} * \ D_{ecocostpos} + w_{social} * \ D_{socialneg}\right)$$

9.1.3. Constraints

Constraint 1: It cannot be transported more corn/wood than the amount that has been harvested.

$$\forall(Period\ t\ ; City\ i)\ \sum_{City\ j} y1[i][j][t] + \sum_{City\ j} y2[i][j][t] \leq Harvest[i][t]$$

Constraint 2: Balance of the biomass in each period.

$$\forall(Period\ t\ ; City\ i)(1-\propto) * z1[i][t-1] + \sum_{City\ k} y1[k][i][t] = z1[i][t] + \sum_{City\ j} y3[i][j][t]$$

Constraint 3: Balance of the biomass by refinery in each period t.

$$\forall(Period\ t\ ; City\ i)\ \sum_{City\ j} y2[j][i][t] + \sum_{City\ j} y3[j][i][t] + (1-\propto) * z2[i][t-1]$$
$$= w[i][t] + z2[i][t]$$

Constraint 4: The conversion rate must be respected.

$$\forall(Period\ t\ ; City\ i)\ e[i][t] \leq \frac{w[i][t]}{rate}$$

Constraint 5: Balance of the bioethanol produced.

$$\forall(Period\ t\ ; City\ i)\ e[i][t] + z[i][t-1] = \sum_{Depot\ l} y[i][l][t] + z[i][t-1]$$

Constraint 6: Respect the storage capacity of biomass in the cooperatives.

$$\forall(Period\ t\ ; City\ i)\ z[i][t] \leq \sum_{SizeStock\ f} Capa\_Sto\_Co[i][f] * xsto[i][l]$$

Constraint 7: Respect the storage capacity of biomass in the refineries.

$$\forall(Period\ t\ ; City\ i)\ z2[i][t] \leq \sum_{SizeRef\ f} Capa\_Sto\_Bio[i][f] * xref[i][l]$$

Constraint 8: Respect production capacity.

$$\forall(Period\ t\ ; City\ i)\ e[i][t] \leq \sum_{SizeRef\ f} \frac{Capa\_Bio[i][f]}{T} * xref[i][l]$$

Constraint 9: Respect the global demand of bioethanol.

$$\forall(Period\ t\ ; Depot\ a) \sum_{City\ i} y[i][a][t] = Demand[a][t]$$

Constraint 10: Only one cooperative in each city.

$$\forall(City\ i) \sum_{SizeStock\ f} xsto[i][f] \leq 1$$

Constraint 11: Only one refinery in each city.

$$\forall(City\ i) \sum_{SizeRef\ l} xref[i][l] \leq 1$$

Constraint 12: initial and final stocks.

$$\forall(City\ i)\ z1[i][0] = 0$$

$$\forall(City\ i)\ z2[i][0] = 0$$

$$\forall(City\ i)\ z[i][0] = 0$$

$$\forall(City\ i)\ z1[i][52] = 0$$

$$\forall(City\ i)\ z[i][52] = 0$$

Constraint 13: The number of trucks corresponds to the amount transported.

$$\forall(Period\ t, City\ i, City\ j)\ NbrTruck1[i][j][t] = \frac{y1[i][j][t]}{CapacityTruck}$$

$$\forall(Period\ t, City\ i, City\ j)\ NbrTruck2[i][j][t] = \frac{y2[i][j][t]}{CapacityTruck}$$

$$\forall(Period\ t, City\ i, City\ j)\ NbrTruck3[i][j][t] = \frac{y3[i][j][t]}{CapacityTruck}$$

$$\forall(Period\ t, City\ i, City\ j)\ NbrTruckEth[i][j][t] = \frac{y[i][j][t]}{CapacityTruck}$$

Constraint that allows calculating economic cost:

$$Price = \sum_{Period\ t} \sum_{City\ i} P * Harvest[i][t] +$$

$$\sum_{Period\ t} \sum_{City\ i} z1[i][t] * \frac{hm}{T} +$$

$$\sum_{Period\ t} \sum_{City\ i} z2[i][t] * \frac{hm}{T} +$$

$$\sum_{Period\ t} \sum_{City\ i} z[i][t] * \frac{he}{T} +$$

$$\sum_{Period\ t} \sum_{City\ i} w[i][t] * wb +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price\_log1[i][j] * \frac{y1[i][j][t]}{CapacityTruck} +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price\_log2[i][j] * \frac{y2[i][j][t]}{CapacityTruck} +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price\_log3[i][j] * \frac{y3[i][j][t]}{CapacityTruck} +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price\_log4[i][j] * \frac{y[i][j][t]}{CapacityTruck} +$$

$$\sum_{SizeRef\ l}\ \sum_{City\ i} EC[l] * x_{ref}[i][l] +$$

$$\sum_{SizeStock\ l}\ \sum_{City\ i} EC\_C[l] * x_{sto}[i][l]$$

Constraint that allows calculating eco-cost of transport:

$$Ecocost = \sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price1_{TransCO2}[i][j] * NbrTruck1[i][j][t] +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price1_{TransCO2}[i][j] * NbrTruck2[i][j][t] +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price1_{TransCO2}[i][j] * NbrTruck3[i][j][t] +$$

$$\sum_{Period\ t} \sum_{City\ i} \sum_{City\ j} Price2_{TransCO2}[i][j] * NbrTruckEth[i][j][t]$$

Constraint that allows calculating eco-cost of refineries:

$$ECR = \sum_{SizeRaf\ l}\ \sum_{City\ i} EcoCost\_Ref[l] * x_{ref}[i][l] +$$

Constraint that allows calculating eco-cost of cooperatives:

$$ECC = \sum_{SizeStock\ l}\ \sum_{City\ i} EcoCost\_Co[l] * x_{sto}[i][l]$$

Constraint that allows calculating induced jobs:

$$InducedJCreated = \sum_{SizeRaf\ l}\ \sum_{City\ i} InducedJ[i][l] * x_{ref}[i][l]$$

Constraints for goal programming:

Economic cost restriction:

$$\frac{Prix - f_{min}^{1}}{f_{max}^{1} - f_{min}^{1}} = goal_{norm}^{1} + D_{econpos} - D_{econneg}$$

Eco-costs restriction:

$$\frac{Ecocost + ECR + ECC - f_{min}^2}{f_{max}^2 - f_{min}^2} = goal_{norm}^2 + D_{ecocostpos} - D_{ecocostneg}$$

Number of created jobs restriction:

$$\frac{InducedJCreated - f_{min}^3}{f_{max}^3 - f_{min}^3} = goal_{norm}^3 + D_{socialpos} - D_{socialneg}$$

9.2. Data

To apply the model to biorefineries that use both corn and wood, it has been done to all the data that depends on the amount of each material or the size of the biorefinery a discretization 5 by 5 per cent according to the amount of each material transformed.

Table 20

Parameters of the model

Parameters	
P	Purchase price of corn/wood
hm	Average handling cost per ton of corn/wood
wb	Transformation cost of corn/wood
he	Storage cost of bioethanol
EC[l]	Economic cost of a refinery
T	Discretization time about 52 weeks
Rate	Conversion rate of corn/wood into bioethanol
α	Rate of deterioration of corn/wood
City	Cities that can accommodate a building
Depots	Fuel depots location
Harvest[i][t]	Amount of corn/wood harvested by city and period
Price_log'X'[i][j] (X=1,2,3,4)	Unit cost of transportations between 2 destinations
Capa_Bio[l]	Production capacity of a refinery
Capa_Sto_Bio[l]	Biomass storage capacity of a refinery
Capa_Sto_Co[f]	Storage capacity of a cooperative
EC_C[f]	Economic cost of a cooperative
Demand[i][t]	Fuel depots demand by period
Nbr_Size_Ref	Number of different types of refineries
Nbr_Size_Stoc	Number of different types of stores
CapacityTruck	Capacity of the trucks in tons

Period (1,..,T)	Duration of the study
Period1 (0,..,T)	Duration to define the initial storage
SizeRaf (1,..,Nbr_Size_Ref)	Discretization of the capacity of refineries
SizeStock (1,..,Nbr_Size_Stoc)	Discretization of the capacity of stores
Price'X'TransCO2[i][j] (X=1,2)	Eco-cost of transportation between 2 destinations by vehicle
EcoCost_Ref[l]	Eco-cost of a refinery depending on the size
EcoCost_Co[f]	Eco-cost of a store depending on the size
InducedJ[i][l]	Number of induced jobs depending on the zone
wecon	Weight of the economic cost
wecocost	Weight of the eco-cost
wsocial	Weight of the number of new jobs
goalnorm1	Normalized economic objective
goalnorm2	Normalized eco-cost objective
goalnorm3	Normalized social objective
fmin1	Minimum of the economic objective function
fmax1	Maximum of the economic objective function
fmin2	Minimum of the eco-cost objective function
fmax2	Maximum of the eco-cost objective function
fmin3	Minimum of the social objective function
fmax3	Maximum of the social objective function

Table 21

Demand of ethanol

City	Stock of fuel (m^3)	Percentage of the demand	Amount of bioethanol delivered per week (tons)
Toulouse	142.000	7,31%	562,02
Poitiers	33.000	1,70%	130,61
Mont-de-Marsan	33.000	1,70%	130,61
La Rochelle	493.700	25,40%	1.954,02

Tulle	26.150	1,35%	103,50
Bordeaux	1.204.680	61,98%	4.768,01
Pau	11.000	0,57%	43,54

Table 22

Amount of corn collected

Department	City	Total corn production (tons)	Max. collection dedicated to the refinery (tons)
Dordogne	Périgueux	179.750	40.162,20
Gironde	Bordeaux	281.230	62.836,24
Landes	Mont de Marsan	1.365.600	305.120,97
Lot-et-Garonne	Agen	387.950	86.681,08
Pyrénées-Atlantique	Pau	880.030	196.628,30
Ariège	Foix	10.706,5	2.392,19
Aveyron	Rodez	1.864	416,48
Haute-Garonne	*Toulouse*	5.397	1.205,87
Gers	*Auch*	16.380	3.659,84
Lot	*Cahors*	2.824,8	631,16
Hautes-Pyrénées	*Tarbes*	0	0,00
Tarn	*Albi*	6.981,9	1.559,99
Tarn-et-Garonne	*Montauban*	13.260,8	2.962,91
Corrèze	*Tulle*	20.400	4.558,05
Creuse	*Guéret*	8.425	1.882,43
Haute-Vienne	*Limoges*	20 .700	4.625,08
Charente	*Angoulême*	296.370	66.219,03
Charente-Maritime	*La Rochelle*	466.494	104.230,45
Deux-Sèvres	*Niort*	214.110	47.839,37
Vienne	*Poitiers*	390.016	87.142,69

Table 23

Amount of wood collected

Department	City	Total wood production (tons)	Max. collection dedicated to the refinery (tons)
Dordogne	Périgueux	1.222.732,32	134.500,56
Gironde	Bordeaux	1.502.976,53	165.327,42
Landes	Mont de Marsan	1.729.314,69	190.224,62
Lot-et-Garonne	Agen	394.638,81	43.410,27
Pyrénées-Atlantique	Pau	726.901,54	79.959,17
Ariège	Foix	749.931,85	82.492,50
Aveyron	Rodez	857.371,20	94.310,83
Haute-Garonne	Toulouse	406.399,59	44.703,96
Gers	Auch	249.486,50	27.443,52
Lot	Cahors	752.020,37	82.722,24
Hautes-Pyrénées	Tarbes	451.847,68	49.703,24
Tarn	Albi	547.488,62	60.223,75
Tarn-et-Garonne	Montauban	205.288,51	22.581,74
Corrèze	Tulle	772.469,09	84.971,60
Creuse	Guéret	495.042,93	54.454,72
Haute-Vienne	Limoges	474.086,27	52.149,49
Charente	Angoulême	401.908,03	44.209,88
Charente-Maritime	La Rochelle	336.846,06	37.053,07
Deux-Sèvres	Niort	147.212,34	16.193,36
Vienne	Poitiers	385.946,45	42.454,11

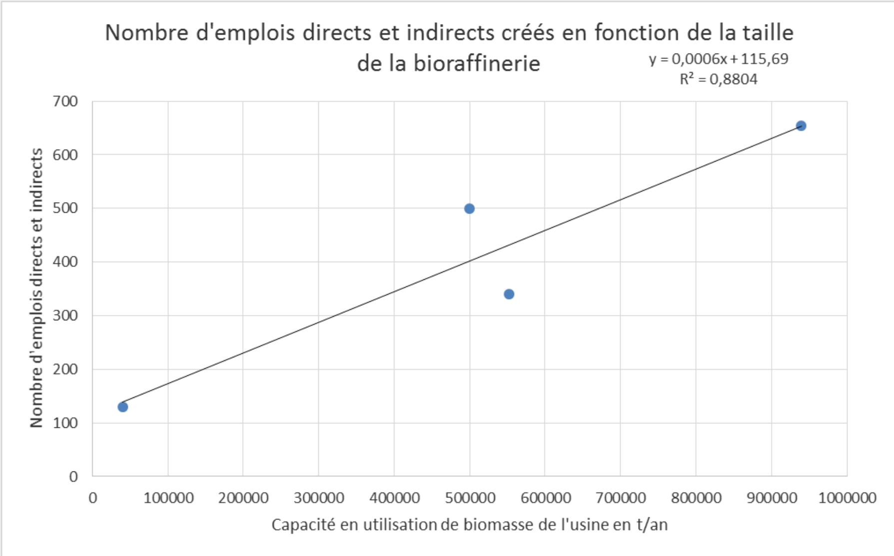

Figure7. Number of jobs depending on the amount of biomass transformed

Table 24

Value of the ratio for each county

Region	County	Ratio
Aquitaine	Dordogne	0,68465981
	Gironde	0,761526466
	Landes	0,718640433
	Lot-et-Garonne	0,692318686
	Pyrénées-Atlantiques	0,742884459
Midi-Pyrénées	Ariège	0,68625881
	Aveyron	0,73876812
	Haute-Garonne	0,794003364
	Gers	0,726406534
	Lot	0,697139914
	Hautes-Pyrénées	0,707143512
	Tarn	0,69263993
	Tarn-et-Garonne	0,706250048
Limousin	Corrèze	0,733751941
	Creuse	0,682609306
	Haute-Vienne	0,725678048
Poitou-Charentes	Charente	0,720589143
	Charente-Maritime	0,68737951

	Deux-Sèvres	0,759722123
	Vienne	0,744210715

Table 25

Number of direct and indirect jobs generated depending on the size of corn refineries

Capacity (T/year of bioethanol)	Capacity (T/year of biomass used)	Number of direct and indirect jobs
50.000	125.000	191
75.000	187.500	229
100.000	250.000	266
150.000	375.000	341
200.000	500.000	416
400.000	1.000.000	716

Table 26

Number of direct and indirect jobs generated depending on the size of wood refineries

Capacity (T/year of bioethanol)	Capacity (T/year of biomass used)	Number of direct and indirect jobs
50000	176105,4099	222
75000	264158,1148	275
100000	352210,8197	328
150000	528316,2296	433
200000	704421,6394	539
400000	1408843,279	961