Energy Supply Chain – Sourced by bioethanol and bio-power

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ABSTRACT

The growing concern about environmental issues has led the society to seek for solutions in order to replace fossil fuels. Part of this research is focused in the transport sector since it is a major contributor to the high emission levels of greenhouse gases. To reverse the situation two hypotheses are proposed in this article: change the type of fuel or the type of vehicle. Regarding the first hypothesis, bioethanol is currently the most exploited and that has the greatest potential for expansion solution. The other solution involves the development of the market for electric cars. Considering the two presented solutions, a mixed integer linear programming model was implemented with the aim of analyze a power and bioethanol supply chain in northern Italy. The referred model is built to optimize financially and concerning a spatially explicit layout of the supply chain finding the best solution to produce energy: ethanol or power. In a situation to encourage clean energy production, the production of electricity using combustion is the most profitable situation, followed by the production of bioethanol by DGP and, finally, by gasification. Analyzing a situation of selling the electricity produced without tax benefits, indications favor the production of bioethanol.

KEY WORDS:

Bio-power, Bioethanol, Energy supply chain, Optimization, Price

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1. Introduction

This paper attends the development of a spatially explicit mixed integer linear program for a strategic design of an energy supply chain structure. The supply chain is sourced by bioethanol and bio-power

Nowadays energy plays an outstanding role in our society and hence contributes to social and economic development. The growth of the world population and its economical expansion are the two main causes for the increase of energy demand.

The continuing growth of the energy consumption leads to an unsustainable environmental and economical situation caused, mostly, by the increase of the petroleum price and the limited lifetime of fossil fuels [1,2].

In the fossil fuels' market, petroleum is the major application and the industry (mostly petrochemical) and transports are the sectors that concentrate the bulk of it. In fact, estimates say that in 2040 these two sectors will represent a 92% of global liquid fuels demand. Considering that petroleum and its

derivates represent 93% of the liquid fuels, these two sectors will create a tremendous impact in the fossil fuel market [3].
Therefore, the transports sector is a good target to implement modification which can actually contribute to achieving a sustainable development. In this article are proposed two possible ways to transform the transports market: to substitute the type of fuel or the type of vehicle. In both situations renewable energies play the main role.

Regarding the solution of changing the type of fuel, biofuels appears as the best option driven, mostly, by bioethanol. Bioethanol can be used directly in cars or blended with gasoline and is, by far, the most widely used biofuel for transportation worldwide, with about 80% of the market share [4].
Bioethanol production grew from 40.9 millions of liters in 2004 to 87 million liters in 2010 representing an average annual growth of 17%. However, since 2010 the global production has slightly decreased but, the USA, Brazil and the EU, are still responsible for a huge amount of quantities produced. These three regions represent 54%, 35% and 5%, respectively, of the world production [4,5]. This market domination by these three regions is, partially, a consequence of the policies implemented by their governments. In the USA, for instance, there is a law that ensures a minimum volume of biofuels usage in the transports sector. Besides this law there are many incentives implemented by this country such as tax credits, import tariffs or use mandates[6,7].
In the case of Brazil, the investment in this alternative market is the most developed and is the only profitable, influenced by its ideal natural resource. In fact, in 2006, 86% of the automobiles sold were flex-fuel vehicles which proved that the commercialization can be a success. Nowadays, there are no direct subsidies for ethanol production but instead a policy of preferential treatment such as taxes reduction.[9] In the EU, several policies have been applied such as the establishment of a goal of 5.75% using of biofuels in the transports sector by 2010 and 10% by 2020 in all member states. Other measures were implemented regarding the limitation of the first generation production technologies and creating a new accountability technique. Both measures are based in bet to benefit the advanced production technologies [7].

Regarding the solution that considers the substitution of the type of vehicle; electric cars constitute the best option. There are three main types of electric cars: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles and all-electric vehicles (that can be fuel cell electric vehicle, FCEV, or battery electric vehicle, BEV). It is expected in the near future that the market share of hybrid vehicles will raise and that, in the long term, the market share of plug-in hybrid vehicles will be significant as the following figure shows[10]:

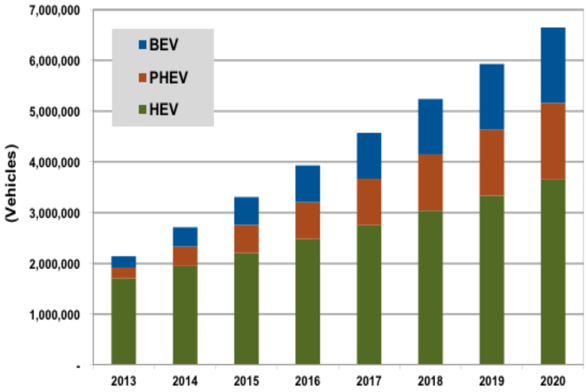

Figure 1 - World annual light duty electric vehicle sales [11].

In the context of this article, it is considerate the generation of power through renewable sources. In terms of renewable energies, the power generation sector was the one that presented the most significant growth reaching a global capacity of 1560 GW in 2013, which represents an increase of about 8% when compared to 2012 [4]. This growth can be associated with the role of the USA, Germany, China, Brazil and India and is expected to increase considering the new upper targets establish to 2015.

Considered as a promising substitute of gasoline, bioethanol has been the focus of several studies and numerous papers that analyze the all supply chain of this product. On the other hand, the studies about bio-power's supply chain are limited. Nevertheless, a new look on these supply chains is given in this paper where the two referred approaches are combine in one energy supply chain. In fact, the work developed focused on the data collection and model implementation of the bio-power part of the energy supply chain creating a new tool to analyze the most profitable solution between bioethanol and bio-power.

2. Assumptions and problem statement

This paper establishes a strategic design and planning of a general energy supply chain over a 15-year horizon. This energy supply chain can be sourced by bioethanol and/or bio-power and is located in the Northern Italy. The problem is formulated as a spatially explicit multi-period where an optimization is realized with the objective of maximization of the financial performance of the business (Net Present Value, NPV) in operating the system. The structure of the supply chain network elaborated is presented in figure 2.
The main variables to be optimized over the planning time horizon are:

- bioethanol facilities technology selection, location and capacity;
- bio-power facilities technology selection, location and capacity;
- biomass production rate and geographical location for each site;

- characterization of transport logistic in terms of biomass and bioethanol;
- economic performance of the supply chain over the time horizon.

Spatially explicit feature

In order to implement the spatially explicit part of the model, the North Italy region is divided considering that the whole region is approximated through a grid of 59 homogeneous squares of 50 km of length. Another fictional square (g=60) is added to represent the possibility of biomass import.

In terms of biomass production capacity, the cell 60 is considered to have unlimited production and the value of the other cells is estimated considering the specific geographical configuration of each square. All the values are taken from Zamboni, Shah, et al (2009), [12].

Production technologies

In the model there are two main types of technology: one to produce bioethanol (GDP) and two to produce bio-power (gasification and combustion).

- k=1 – Dry Grind Process with DDGS sale - first generation;
- k=7 – Corn-stover Gasification - second generation;
- k=8 – Corn-stover Combustion - second generation.

Each technology is linked to some technical and economic data. The data related with DGP is taken from Giarola et al., (2011) [12]. The data related with the technical parameters of each technology of bio-power is presented in table 1.

Table 1 – Conversion of biomass to bio-power by technology *k* (Mwh/t $_{\text{biomass}}$) [13,14].

Biomass	**Technology**	
	Gasification	Combustion
Corn	0	0
Stover	0.615	0.621

In table 4 is explicit the quantity and the type of biomass needed to produce 0.615 and 0.621 MWh of power using gasification and combustion process, respectively.

The economic data related with bio-power technologies is presented in tables 2 and 3.

Table 2 – Capital investment for each plant size *p* and for each technology *k,* (M€) [13,14].

Plant sizes	**Technology**	
	Gasification	Combustion
1	2.7	1.3
2	27.2	12.7
3	136.1	63.5
4	272.2	126.9
5	408.3	190.4
6	544.4	253.8

In table 2 is presented the value of the investment needed to build the bio-power plants. The different plant sizes considered, take into account minimum size feasibility in economic terms and are presented in table 3.

Table 3 – Coefficient for linear regression of production costs [13,14].

Coefficient	**Technology**	
	Gasification	Combustion
Slope (€/MWh)	9.827	1.179
Intercept (€/month)	59244	84097

In table 3 is exposed the data related with the production costs of bio-power technologies.

Demand

The definition of the demand is the step that allows the model to initialize its optimization. It is considered that the energy produced is supposed to feed existing blending terminals. This blending is imposed by the EU guidelines that set a minimum blending factor of bioethanol within gasoline of 5.75% by 2010 and 10% by 2020 and can be consulted in Giarola et al. [12]. To adapt these guidelines to the model it is considered that this bioethanol demand is, instead, an energy demand that can be satisfied either by bio-power or by bioethanol.

Transport

The transport between infrastructures can be provided by: trucks, rail, barges or ships. In the specific case of biomass trans-shipping is also an option. All the transport related data can be found in Zamboni et al. [15]. Regarding bio-power production it is assumed that the final product is directly sent to the grid. In this way, there is no cost associated to the transport of bio-power.

Price

There are three products contributing to the incomes of the process: bioethanol, DDGS and bio-power. In a first approach, market prices for these products are taken from Zamboni et al. [15] and consider equal to 710 €/t_{EtOH}, 300 €/t_{DDGS} and 180 €/MWh. However, these prices represent a higher value comparatively to the ones used in industries nowadays. This happens because incentives to a green energy production are taken into account [12].

For a more realistic approach, it is considered a second scenario in which the power price is fixed in 66.5 €/ MWh, corresponding to the price, taxes and levies excluded, for a consumption greater than 150 000 MWh defined by Eurostat [16].

Plant sizes

In terms of plant sizes the problem is divided in two: bioethanol plants and bio-power plants. In both cases six plant sizes are considered and they were defined based on the typical size plants installed. For bioethanol plants, the different values for

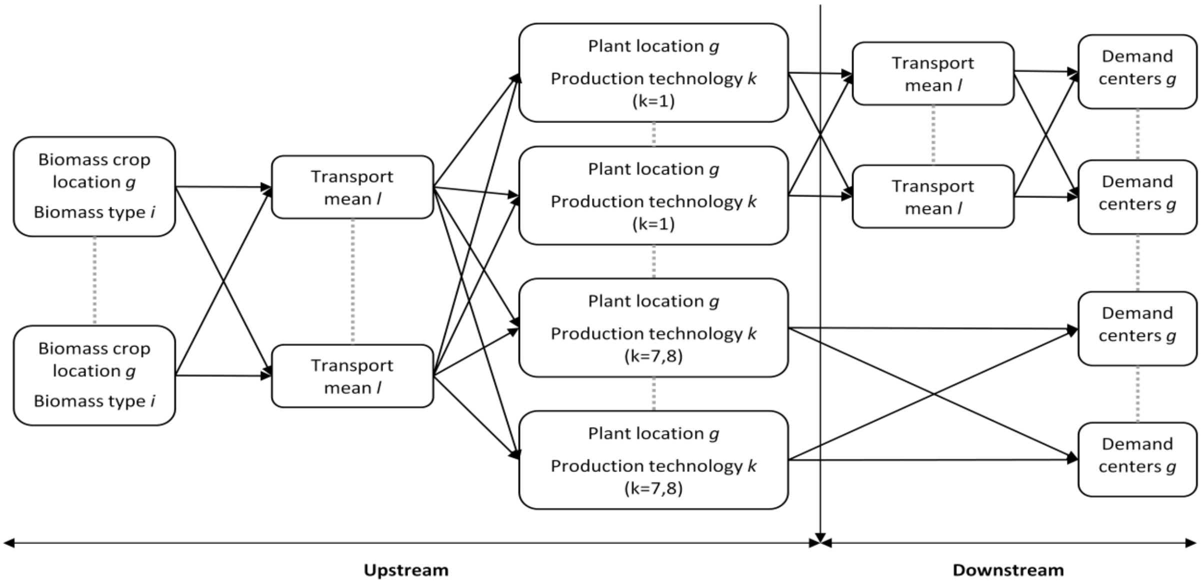

Figure 2 - Bio-power and bioethanol network supply chain.

the limits and the plant sizes are taken from S. Giarola et al. [12].

In bio-power plants the maximum capacity established is 140 000 MWh per month and the different plant sizes can be seen in table 4:

Table 4 – Bio-power production capacity for each plant size *p* [17]–[20].

Bio-power plant, p	Production capacity (MW)
1	1
2	10
3	50
4	100
5	150
6	200

3. Model formulation

The problem assess in this paper is constructed as a mixed integer linear programming and implemented in GAMS®. The general mathematical formulation is based in the model develop by Giarola et al. [12]. In fact, the main model used in this work results from the combination of several models that have been developed during the last 6 years in CAPE-Lab at University of Padua. This model contains a vast level of information that can be consulted in the works of Franceschin et al. [21], Zamboni et al. [15] and Giarola et al. [12]. In this sense, the sets, parameters, variables and most of the equations are not going to be presented in this article but only the equations implemented regarding the new energy supply chain.

The first three modification made are related with an economic function.

$$VarC_t = EPC_t + BPC_t + TCb_t + TCp_t + PPC_t \quad , \quad \forall\ t \qquad (1)$$

Equation (1) reflects the variable costs that are the result from the sum of the main costs involved in the steps of the supply chain in study: ethanol production cost, *EPC*$_{t,}$ biomass production costs, *BPC*$_t$, biomass transport costs, *TCb*$_t$, ethanol transport costs, *TCp*$_t$, and bio-power production costs, *PPC*$_t$.

$$PPC_t = \sum_{k,g}\big(Pppower_{k,g,t} \cdot c_{k,'slope'} + Y_{k,g,t} \cdot c_{k,'intercept'}\big), \ \ \forall\ t \qquad (2)$$

Bio-power production cost, *PPC*$_{t,}$ is represented by the sum of two main contributions, a linear function of the total production rate of the product and a fixed quota depending on the production technology, *k*, adopted.

$$Ptot_{'power',k,g,t} = Pppower_{k,g,t} \qquad \forall\ k,g,t \qquad (3)$$

Equation (3) reveals that all the bio-power produced and sell is only coming from pure bio-power production facilities.

The next equations regard the new constraints in terms of capacity and production

$$Pppower_{k,g,t} \leq Pcap_{max}^{power} \cdot Y_{k,g,t} \qquad \forall\ k,g,t \qquad (4)$$

Equation (4) imposes that the production rate cannot exceed a certain limits, even if it allows for a capacity adjustment according to market demand.

$$Pppower_{k,g,t} \geq Pcap_{min}^{power} \cdot Y_{k,g,t} \qquad \forall\ k,g,t \qquad (5)$$

Equation (5) imposes minimum capacity of a plant regarding to economic feasibility heuristics.

$$Pppower_{k,g,t} \leq \sum_{p} \left(ER\_power_{p} \cdot \lambda_{p,k,g,t} \right) \quad \forall\, k, g, t \tag{6}$$

Equation (6) sets the amount of bio-power produced in each region by multiplying a continuous recursive variable, which has assumed a non-zero value since the moment an investment decision was taken, with the nominal production rate of bioethanol or bio-power for each plant size.

$$Pp_{i,k,g,t} = Cap_{i,k,g,t} \times \xi_{i,k} \qquad \forall\, i, k, g, t \tag{7}$$

Equation (7) defines the bio-power production from biomass *i* through technology *k* in region g at the time t.

$$Pp_{i,k,g,t} = Pppower_{k,g,t} \times \beta e_{i,k}\ , \qquad \forall\, i, k, g, t \tag{8}$$

Equation (8) defines what kind of feedstock is selected for each bio-power technology.

$$\begin{aligned} &\sum_{k} \left(\mathrm{Ptot}_{\text{'ethanol'},k,g,t} + \mathrm{Ptot}_{\text{'power'},k,g,t} \times \theta \right) = \\ &\sum_{l,g'} \left(\mathrm{Qj}_{g,l,g',t} - \mathrm{Qj}_{g',l,g,t} \right) + \mathrm{Dtot}_{g,t}, \qquad \forall\, g,t \end{aligned} \tag{9}$$

In equation (9) is presented the global balance of products for each region *g,* represented by a square.

$$\begin{aligned} &\sum_{k} \left(\mathrm{Ptot}_{\text{'ethanol'},k,g,t} \right) = \\ &\mathrm{Etot}_{g,t} + \sum_{l,gp} \left(\mathrm{Qje}_{g,l,g',t} - \mathrm{Qje}_{g',l,gp,t} \right)\ , \qquad \forall\ i,g,t \end{aligned} \tag{10}$$

In equation (10) is presented the mass balance of ethanol for each region *g,* represented by a square.

$$TPe_{t} = \sum_{k,g} \left(Ptot_{'ethanol',k,g,t} \right)\ , \qquad \forall\ t \tag{11}$$

$$TPe_{t} = \sum_{g} \left(Etot_{g,t} \right)\ , \qquad \forall\ t \tag{12}$$

Equations (11) and (12) define the bioethanol production.

$$TPp_{t} = \sum_{k,g} \left(Ptot_{'power',k,g,t} \cdot \theta \right)\ , \qquad \forall\ t \tag{13}$$

$$TPp_{t} = \sum_{g} \left(Potot_{g,t} \right)\ , \qquad \forall\ t \tag{14}$$

Equations (13) and (14) define the bio-power production.

$$TP_{t} = TPe_{t} + TPp_{t}\ , \qquad \forall\ t \tag{15}$$

In equation (15) the contribution from bio-power and bioethanol are summed to have the total production.

$$Dtot_{g,t} = Etot_{g,t} + Potot_{g,t}\ , \qquad \forall\ g, t \tag{16}$$

In equation (16) the total demand is presented by the sum of bio-power and bioethanol demands.

All these equations are supported by constraints of non-negativity linked with the variables that have physical meaning.

4. Results and discussion

This section presents the results of different scenarios of optimization performed. Six different scenarios where tested considering two factors: price and technology (figure 3).

In terms of price, two approaches are considered: 1) bioethanol and bio-power price with incentives; 2) bioethanol price with incentives and bio-power price without incentives. These two scenarios are presented to simulate a situation where power is sold as a renewable and non-renewable sourced product, respectively.

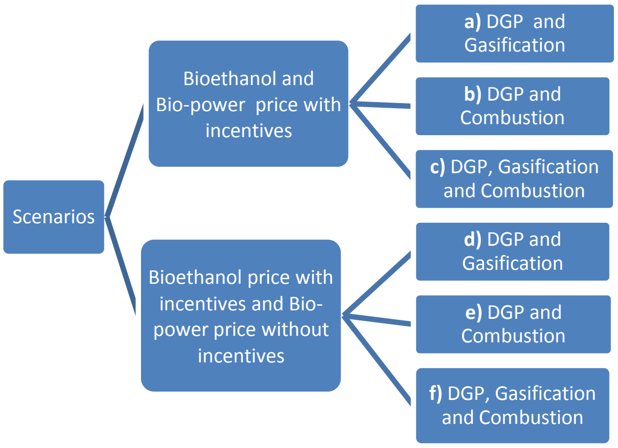

Figure 3 - Scenarios created to assess the profitability of the energy supply chain.

Scenario a)

The results on this scenario show an optimal solution that combines two technologies and includes the implementation of five plants of DGP (k=1) technology that use corn as feedstock and one facility where corn-stover is transformed into bio-power by a gasification process (figure 4a).

The NPV for this supply chain is 370 M€ confirming the profitability of the supply chain. In terms of gross profit bioethanol is the main contributor with a slice of 70.4 % and the share of bio-power is almost inexistent (1.1%).

In terms of costs and analyzing all stages of the supply chain, biomass production and transport accounts 70% of these costs and the cost associated with bio-power production is insignificant comparing to bioethanol production. This may be explained by the fact that only one gasification plant is constructed comparing to the five of DGP.

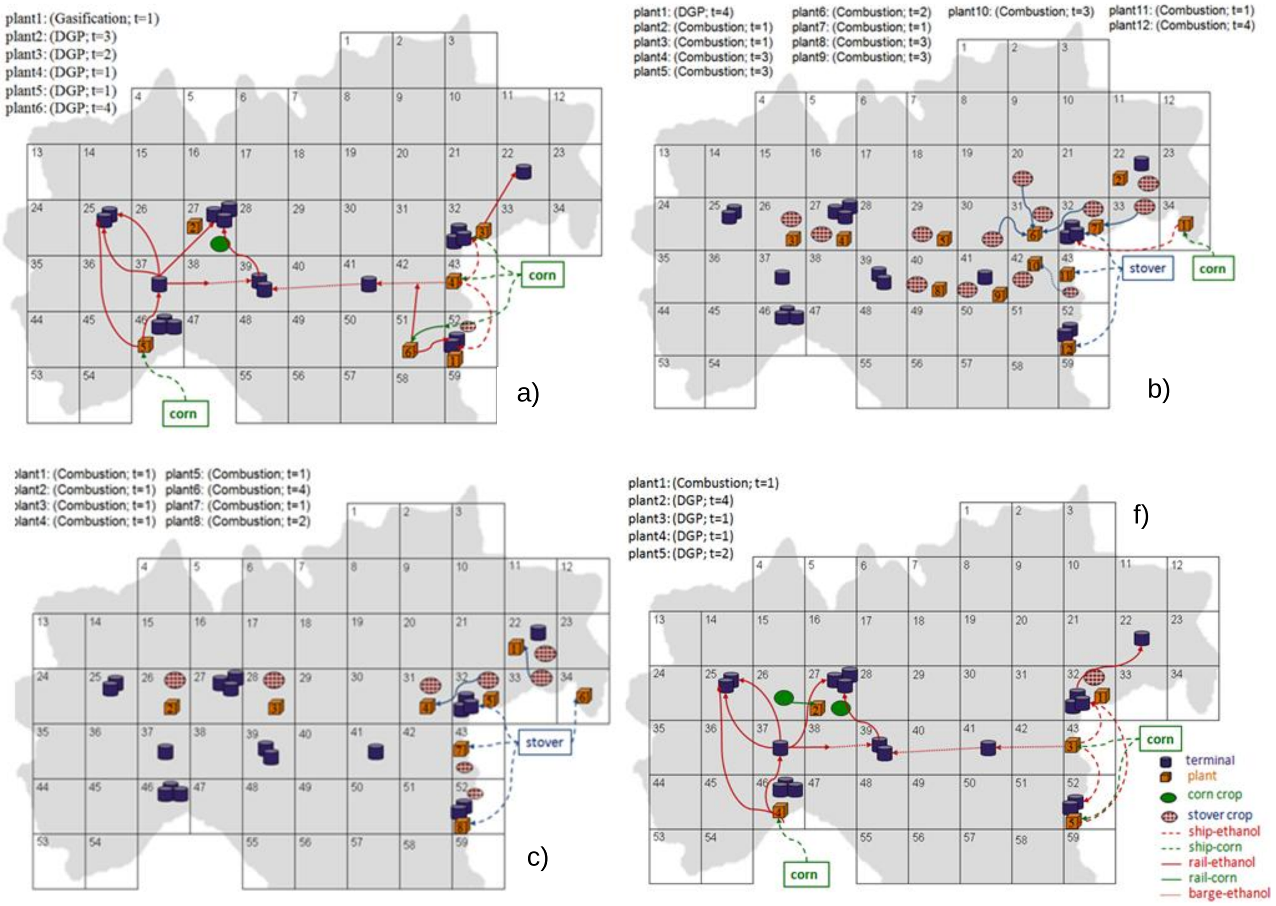

Figure 4 - Results from the optimization performed to scenarios a), b), c) and f) defined in figure3.

Scenario b)

This scenario includes the creation of eleven combustion plants (k=8), technology that use corn-stover as feedstock and that produce bio-power and one DGP plant that uses corn as feedstock and that produces bioethanol (figure 4b).

The NPV to this supply chain is 953 M€ and the principal responsible for the profit is bio-power with 94% of the gross profit.

Regarding the costs distribution, once again, the main contributor to the supply chain costs is the biomass purchase stage. However, with the large number of facilities constructed, the biomass transport cost grows representing 22.6% of all costs. Considering the low quantity of bioethanol produced, the costs associated to its transport (0.1%) are, as expected, low. Considering the number of facilities constructed by each technology, the fact that lower costs are associated with bio-power production (18.8%) comparing to bioethanol production (22.6%) may be explained the higher conversions and lower capital investment (for small plant scales) associated to the gasification process comparing to DGP.

Scenario c)

In this scenario of optimization, that the optimal solution is to construct only bio-power plants (k=8) that use corn-stover as feedstock and combustion as technology (figure 4c).

The NPV to this supply chain structure is 958 M€ which reveal an improvement comparing to the two first scenarios. Results prove that, considering the three technologies, the most profitable way of supplying the demand of energy, in the terminals, is by investing in combustion bio-power plants. This can be linked to two reasons: the production costs in combustion facilities are relatively low comparing to the other technologies and with the fact that the transport costs of bio-power are not considered.

In terms of costs the results reveal reveals that 68.2% of the costs of this energy supply chain are related with the biomass plantation or purchase. The second major contributor to the costs of the supply chain is the biomass transport (28.1%) to the facilities that is carried out by rail, by ship or barge. All production process that accounts capital investment and operational costs, represent 4% of the overall costs. As referred, the bio-power transport has no cost associated.

Regarding the possibility of the governments to slow down their policies in terms of incentives on green energy production, a new group of scenarios is tested. In this sense, the following optimizations are carried out considering the same premises of the scenario a), b) and c) but reducing the price of bio-power from 180 to 66.5 €/MWh.

Scenario d)

In this scenario the optimal solution that suggests the implementation of six plants of DGP (k=1) technology to produce bioethanol, using corn as feedstock. In this scenario, the addition of gasification as a possible technology choice does not affect the results of the supply chain since the optimization results only suggests the implementation of bioethanol by DGP plants. In this sense, the profit of the supply chain is given by the selling of bioethanol and DDGS. The NPV to this scenario is 364 M€.

In terms of costs they can be analyzed considering the different stages of the supply chain. In this scenario biomass production and transport has a weight of 70.4% on the overall costs of the supply chain. Bioethanol production and transport represent 30% of the costs.

Scenario e)

In this case, the reduction of bio-power price drives the model to suggest a completely new optimized structure. In this structure five DGP facilities are built and only one plant uses combustion to produce bio-power as the selected technology.

The NPV for this structure is 369 M€ driven by bioethanol sales.

Regarding the costs, biomass purchase, growth and transport account 68% of the overall costs. The costs related with bioethanol represent 31.8% of all costs and considered the production and the transport to the blending centers. Bio-power's slice of the costs is very small since it does not have transport cost and the production costs are low.

Scenario f)

In this new structure four DGP facilities are built and only one plant uses combustion to produce bio-power as the selected technology.

The NPV is 368M€ revealing the profitability of the supply chain. The model indicates a preference to bioethanol although the introduction of one plant of combustion improves the profitability of the supply chain.

Regarding the costs of the supply chain they can be divided considering the different stages of the supply chain. Biomass purchase, growth and transport account 70.3% of the overall costs. The costs related with bioethanol represent 29.5% of all costs and considered the production and the transport to the blending centers. Bio-power's slice of the costs is very small since it does not have transport cost and the production costs are low.

To accomplish the objective of this work, assess the economical performance of a bio-power and bioethanol supply chain, two groups of scenarios were tested. In the first group, three different production scenarios were analyzed and a value of power's price with incentives was considered. The NPV in €/GJ from these three scenarios are presented in figure 5.

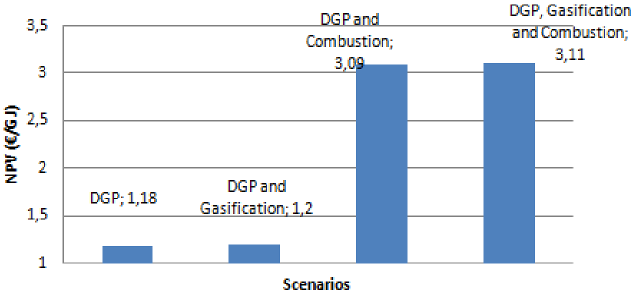

Figure 5 - Economic performance of all supply chain studied with price incentive.

The test performed using DGP and gasification as technologies revealed a NPV of 1.2 €/GJ. In scenario b) only DGP and combustion could be selected as technology. In this case, the new technology implemented made a great impact in terms of the profitability of the supply chain raising the NPV to 3.09 €/GJ revealing a growth of 61.1%. The last optimization scenario of this group accounts DGP, gasification and combustion as technologies that the model can select to produce energy. This scenario shows the best results with a NPV of 3.11 €/GJ. In this case only combustion bio-power plants are built which make this technology the best solution to supply the energy demand in these conditions. From this first group of scenarios, where bio-power and bioethanol prices are both considered to have tax benefits, it is possible to conclude that producing bio-power from combustion is the best solution followed by bioethanol by DGP and bio-power by gasification. The two first solutions are both economic viable by itself, contrasting with gasification that is not profitable. However, since it is an energy supply chain, certain scenarios of optimization chose a technology as preferable over the others but not exclusively. In those cases the combustion is the dominant process.

A second approach on the previous scenarios was taken. This new approach optimizes the model using the same technologies and parameters but change the power price to a lower value regarding the possibility of selling the power without fiscal benefits.

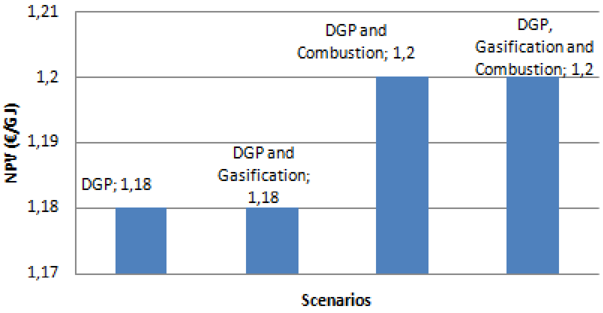

Figure 6 - Economic performance of all supply chain studied without price incentive.

From figure 6 is possible to identify that all optimization scenarios drive the supply chain to approximately the same results. In fact, if the power price is fixed in 66.5 €/MWh the advantage of producing energy by gasification or combustion is not great enough to influence the supply chain significantly. In fact, in this case, all three scenarios of optimization lead the model to suggest the investment in majority bioethanol plants. From these results it can be deducted that, at these conditions, bioethanol obtained by a DGP process is the technology that provides a more profitable supply chain and that the production of bio-power does not significantly influence this situation. By comparing figure 5 and 6 it can be verified that the decrease in bio-power's price implicates a decrease of 1.6%, 61.2% and 61.4% in terms of NPV for each scenario tested. . In fact, if the price gets down to 66.5 €/MWh, the production of bio-power is no longer a viable solution by itself, independently if is considered a combustion or a gasification process. Although the scenario in which bioethanol price is considered without incentives was not performed, taking into account the situation of bioethanol production in Brazil, a viable solution without incentives can be possible. In fact, nowadays, bioethanol produced in Brazil does not get direct subsidies to promote bioethanol production [9].

5. Conclusions

Nowadays, no single alternative such as bioethanol or bio-power will, alone, reach environmental goals due to innumerous factors. However, if the governments keep supporting alternative energies, producing bio-power by a combustion process seems to be the best way to reach those targets. Nevertheless, governments cannot continue to support these alternatives forever and, considering that the incentives will slow down, bioethanol produced by DGP emerge as the probable best solution [22].

6. References

[1] S. Bilgen, "Structure and environmental impact of global energy consumption," *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 890–902, 2014.

[2] F. Manzano-agugliaro, F. G. Montoya, C. Gil, A. Alcayde, J. Gómez, and R. Ba, "Optimization methods applied to renewable and sustainable energy : A review," *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 1753–1766, 2011.

[3] Internacional Energy Agency, "WORLD ENERGY 2013 FACTSHEET," 2013.

[4] M. Brower, D. Green, R. Hinrichs-rahlwes, S. Sawyer, M. Sander, R. Taylor, I. Giner-reichl, S. Teske, H. Lehmann, M. Alers, and D. Hales, "Renewables 2014 - Global Status Report," 2014.

[5] M. Balat, "Production of bioethanol from lignocellulosic materials via the biochemical pathway : A review," *Energy Conversion and Management*, vol. 52, no. 2, pp. 858–875, 2011.

[6] T. Serra and D. Zilberman, "Biofuel-related price transmission literature: A review," *Energy Economics*, vol. 37, pp. 141–151, May 2013.

[7] P. Lamers, C. Hamelinck, M. Junginger, and A. Faaij, "International bioenergy trade—A review of past developments in the liquid biofuel market," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 2655–2676, Aug. 2011.

[8] W. Thompson, J. Whistance, and S. Meyer, "Effects of US biofuel policies on US and world petroleum product markets with consequences for greenhouse gas emissions," *Energy Policy*, vol. 39, no. 9, pp. 5509–5518, Sep. 2011.

[9] G. Sorda, M. Banse, and C. Kemfert, "An overview of biofuel policies across the world," *Energy Policy*, vol. 38, no. 11, pp. 6977–6988, Nov. 2010.

[10] P. Baptista, M. Tomás, and C. Silva, "Plug-in hybrid fuel cell vehicles market penetration scenarios," *International Journal of Hydrogen Energy*, vol. 35, no. 18, pp. 10024–10030, Sep. 2010.

[11] I. Sustainable Enterprises Media, "Clean technica," 2014. [Online]. Available: http://cleantechnica.com/2013/09/30/electric-vehicles-speeding-toward-7-global-sales-2020/.

[12] S. Giarola, A. Zamboni, and F. Bezzo, "Spatially explicit multi-objective optimisation for design and planning of hybrid first and second generation biorefineries," *Computers & Chemical Engineering*, vol. 35, no. 9, pp. 1782–1797, Sep. 2011.

[13] U. S. E. P. Agency, "Biomass Combined Heat and Power Catalog of Technologies," no. September, 2007.

[14] L. Wang, M. a. Hanna, C. L. Weller, and D. D. Jones, "Technical and economical analyses of combined heat and power generation from distillers grains and corn stover in ethanol plants," *Energy Conversion and Management*, vol. 50, no. 7, pp. 1704–1713, Jul. 2009.

[15] A. Zamboni, N. Shah, and F. Bezzo, "Spatially Explicit Static Model for the Strategic Design of Future Bioethanol Production Systems. 1. Cost Minimization," *Energy & Fuels*, vol. 23, no. 10, pp. 5121–5133, Oct. 2009.

[16] E. Comission, "Eurostat." [Online]. Available: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/.

[17] C. Patel, P. Lettieri, S. J. R. Simons, and a. Germanà, “Techno-economic performance analysis of energy production from biomass at different scales in the UK context,” *Chemical Engineering Journal*, vol. 171, no. 3, pp. 986–996, Jul. 2011.

[18] A. V Bridgwater, “The technical and economic feasibility of biomass gasification for power generation,” *Fuel*, vol. 74, no. 5, pp. 631–653, 1995.

[19] T. P. Upadhyay, C. Shahi, M. Leitch, and R. Pulkki, “Economic feasibility of biomass gasification for power generation in three selected communities of northwestern Ontario, Canada,” *Energy Policy*, vol. 44, pp. 235–244, May 2012.

[20] A. Evans, V. Strezov, and T. J. Evans, “Sustainability considerations for electricity generation from biomass,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 5, pp. 1419–1427, Jun. 2010.

[21] G. Franceschin, A. Zamboni, F. Bezzo, and A. Bertucco, “Ethanol from corn: a technical and economical assessment based on different scenarios,” *Chemical Engineering Research and Design*, vol. 86, no. 5, pp. 488–498, May 2008.

[22] C. S. Thomas, “Transportation options in a carbon-constrained world: Hybrids, plug-in hybrids, biofuels, fuel cell electric vehicles, and battery electric vehicles,” *International Journal of Hydrogen Energy*, vol. 34, no. 23, pp. 9279–9296, Dec. 2009.