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Green technologies competition and uncertainty: a Monte Carlo analysis of optimal biofuels supply choices for France

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Abstract

A timely development and diffusion of green technologies is widely recognised as a key element of an effective transition to a low carbon future. This is in particular the case in the transport sector where several low carbon options have been developed as substitute to oil products. However, green technologies do not only compete against conventional ones but also against each over. In this paper we investigate the conditions of such a competition in the biofuel sector. Our methodology uses a long term and technology rich model to describe the cost competiveness of several biofuel generation pathways. Using a Monte Carlo approach we then discuss the long term interaction between first, second, and third generation technologies.

Keywords: biofuel generation technologies, low carbon technologies,

1. Introduction

Biofuels have been fostered at European level to increase renewable energy consumption and mitigation in the transport sector [1]. In 2014, France was the first biofuel consumer of European countries with almost 2.7 Mtep. In France, bioethanol is blended up to 10%vol (on volume basis) in gasoline and biodiesel is blended up to 7%vol. Ethanol is produced by enzymatic fermentation of sugars, such as glucose, fructose, lactose, etc., at ambient temperature and pressure. Two types of feedstocks that require different industrial facilities are commonly used: sugar-rich plants (sugarcane, beet or sweet sorghum) and starch-rich plants (corn, wheat, barley, potato). In 2009, 49% of French fuel ethanol was produced from beet, 30% from wheat and 18% from corn [2].

Biodiesel is produced from fatty acids, mostly by transesterification (98% of French biodiesel consumption) or by co-hydrotreating in conventional refinery process. In 2009, 78% of biodiesel was produced from rapeseed oil, 18% from soybean oil, 8% from palm oil and 4% from sunflower oil [2]; an increasing share of waste cooking oil and

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animal fat has also been used these recent years.

Figure 1 shows the evolution of production capacity and production of ethanol fuel and biodiesel in France since 2003. After a steady growth since 2005, one can notice the production plateau reached in 2010 due to the freezing of French incorporation rate although it should have reached 10% on energy basis by 2015 according to the initial development plan. The subsequent overcapacity caused industrial restructuration in 2014.

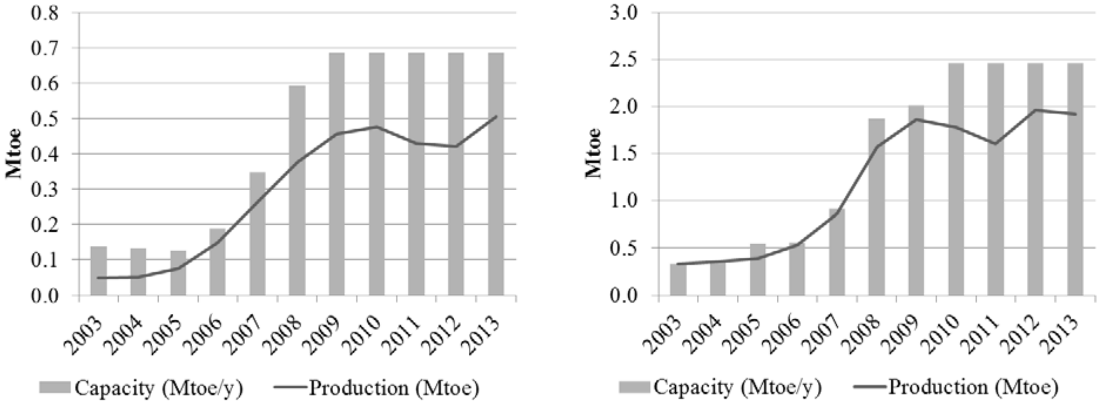

Figure 1: French capacity and production of ethanol fuel (left) and biodiesel (right) [3]

Thus diverse factors, concurrent technical routes, policy push for incorporation target, change in policy support, interact to form a complex policy/technology risk matrix. On the long run biofuels remain parts of the solution towards a low carbon transport system but the environmental and social benefits of traditional biofuels are questioned [4] [5]. However the second and third generation routes that are not mature today create another risk for investors linked to competing innovations. In this paper we consider the interplay of multiple sources of uncertainty to show how competing options interact in time to frame a complex risk context. We address it using a bottom-up optimization model and a Monte Carlo analysis.

2. Competing biofuel production technologies

Many research efforts have been dedicated to advanced biofuel technologies across the world. One usually distinguishes two different generations of advanced processes: second and third generation biofuels. Second generation processes transform lignocellulosic material (wood, leaves, straw…) into biofuel and third generation technologies use microorganisms as ‘synthesis laboratory’.

Among second generation technologies, another distinction is made between thermochemical and biochemical processes. Thermochemical processes consist in heating and pressuring lignocellulosic biomass to break most of chemical bonds to obtain liquid product from solid materials. Two types of thermal decomposition are currently studied: fast pyrolysis and gasification.

In the biofuel sector, biochemical processes have been mostly developed to produce ethanol from lignocellulosic material. The main difficulty is the decomposition of the lignocellulosic matrix to obtain sugars that can be further fermented. Outside the U.S., the process has been brought at industrial scale in Norway by Borregard and in Italy by Beta Renewables.

Third generation technologies, as the name suggests, are far from industrial scale. We have considered two technologies that both produce fatty material whose composition is close to vegetable oil and that can be furthered processed to FAME or HEFA. The first one is a fermentation process where microorganisms digest simple sugars to produce fat, it is call heterotrophic process. The cultivation and fermentation occurs in long glass tubes known as photobioreactors. The second one is an autotrophic process, because it doesn't need an external source of carbon, as microalgae directly transform carbon dioxide and water into fat. Besides photobioreactors, some tests have been performed in open ponds. We performed a literature review of advanced biofuel processes and characteristic values of techno-economic data are displayed in Table 1.

Process	Input (per PJ)		Output (per PJ)		Invest. costs (€2005/(GJ/y))	Fixed O&M costs (€2005/(GJ/y))	Variable O&M costs (€2005/GJ)	Start year
Ethanol fermentation from wood	Wood blend Heat	0.14 $Mt_{25\%}$ 0.42 PJ	Ethanol Electricity Pure CO_2	1 PJ 0.68 GJ 35 kt	46	1.3	1.6	2020
Ethanol fermentation from straw	Straw blend Heat	0.16 $Mt_{25\%}$ 0.42 PJ	Ethanol Electricity Pure CO_2	1 PJ 0.68 GJ 35 kt	51	1.6	0.66	2020
BXTL (Co-gasification)	Wood and straw blend Petcoke Hydrogen Natural gas Electricity Water	0.13 $Mt_{25\%}$ 1.3 PJ 13 TJ 0.13 PJ 0.30 PJ 53×10^3 m^3	Syndiesel Naphtha	1 PJ 7.9 kt	169	0.98	1.2	2020
Pyrolysis + Hydrotreatment for gasoline production	Wood and straw blend Electricity	0.21 $Mt_{25\%}$ 93 TJ	Syngasoline Biochar	1 PJ 19 kt_{DM}	219	7.7	20.6	2020
Pyrolysis + Hydrotreatment for gasoline production (external H_2)	Wood and straw blend Electricity Hydrogen	0.13 $Mt_{25\%}$ 59 TJ 0.28 PJ	Syngasoline Biochar	1 PJ 12 kt_{DM}	86	3.0	9.5	2020
Pyrolysis + Hydrotreatment for diesel production	Wood and straw blend Electricity	0.20 $Mt_{25\%}$ 87 TJ	Syndiesel Biochar	1 PJ 18 kt_{DM}	205	7.3	19.4	2020
Pyrolysis + Hydrotreatment for diesel production (external H_2)	Wood and straw blend Electricity Hydrogen	0.12 $Mt_{25\%}$ 52 TJ 0.27 PJ	Syndiesel Biochar	1 PJ 11 kt_{DM}	80.3	2.8	8.6	2020
Low temperature gasification + FT + HI	Wood and straw blend Natural gas	0.22 $Mt_{25\%}$ 0.43 TJ	Syngasoline Syndiesel Electricity	0.44 PJ 1 PJ 0.15 PJ	192	4.9	4.2	2020
High temperature gasification + FT + HI	Wood and straw blend Natural gas	0.17 $Mt_{25\%}$ 3.8 TJ	Syngasoline Syndiesel Electricity	0.44 PJ 1 PJ 0.1 PJ	190	3.3	3.8	2020
Heterotrophic algae oil production (in photobioreactor)	Sugar Water Fertilizers	0.12 Mt 8.7×10^6 m^3 8 kt	Algae oil	1 PJ	80.4	3.6	3.4	2020
Autotrophic algae oil production in open pond	Water Pure CO_2 Fertilizers	29×10^6 m^3 0.11 Mt 8 kt	Algae oil	1 PJ	223	12.7	18.9	2030
Autotrophic algae oil production in photobioreactor	Water Pure CO_2 Fertilizers	8.7×10^6 m^3 0.11 Mt 8 kt	Algae oil	1 PJ	566	18.9	12.6	2030

Table 1: Techno-economic parameters of advanced biofuel production processes

3. Methodology

3.1. The French bioenergy model

We use a French bioenergy model developed using the TIMES methodology model. It is a technology-rich, linear-programming optimization model. The objective function to minimize is the total discounted cost, i.e. over the entire horizon, with a perfect foresight. It describes the transformation chain from biomass feedstock, logistic and transformation, to final bioenergy demand – heat, electricity and fuel. Figure 2 displays the structure of biofuel part of the model and it shows the variety of possible technological pathways.

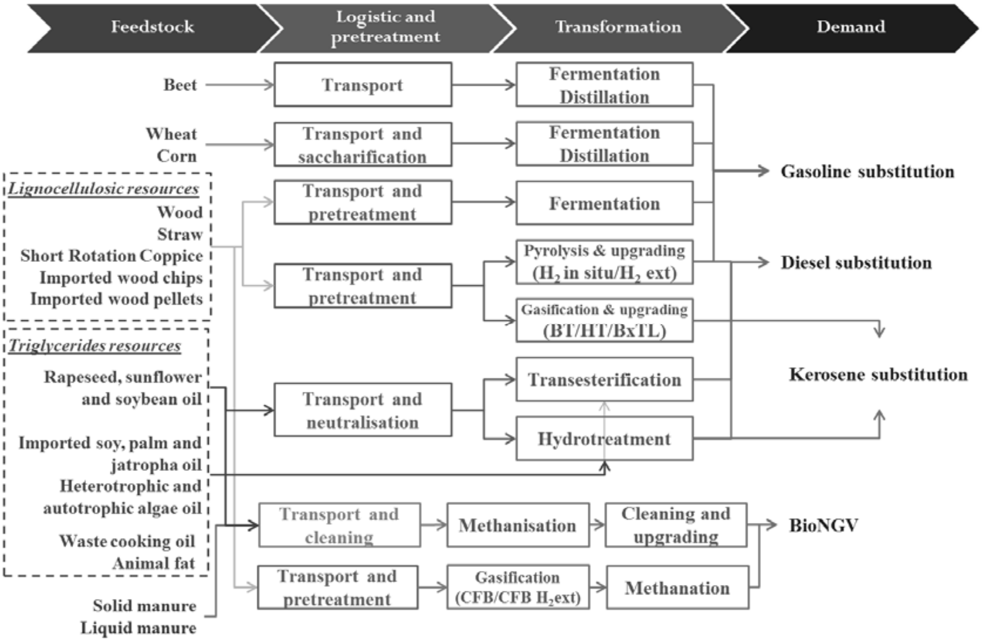

Figure 2: Structure of the biofuel part of the model

3.2. Implementing Monte Carlo analysis in the TIMES framework

Using this technology rich structure and the explicit nature of the different competing routes we question the uncertainty of the future biofuel technologies portfolio in France. The process is represented on Figure 3. First, we generated 1760 sets of parameters which are calculated in accordance with the range of possible values for the different parameters. The output from the TIMES model are stored in a PostgreSQL database and queried with Matlab.

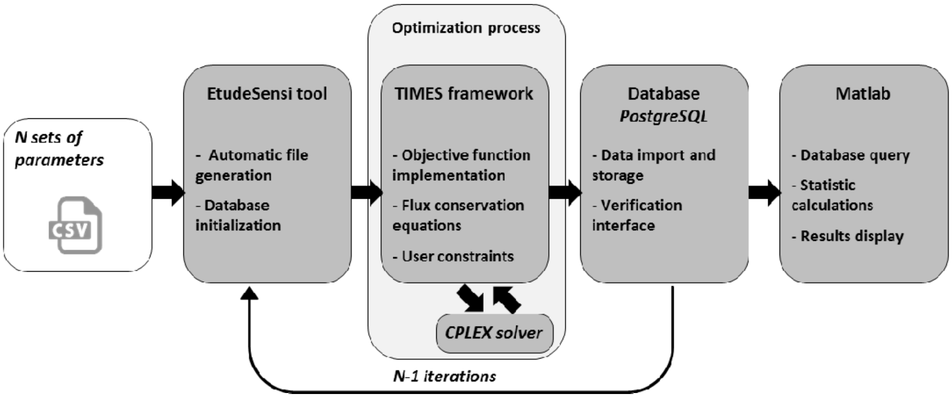

Figure 3: Overview of the tools used to implement Monte Carlo analysis in long term energy planning

To capture a large range of future conditions, four groups of parameters are varying in each scenario: commodity prices, feedstock potential, biofuel technology costs and GHG emissions factors of biofuel processes. Commodity prices are differentiated between: fossil fuel and related commodity prices, agricultural feedstocks, forestry feedstocks, imported biofuel. Feedstock availability includes: agricultural feedstock potential, forestry feedstock, agro-industry by-products and imported feedstock. Technology costs conditions the economic viability of advanced biofuel production process. We consider an uncertainty range on investment, fixed and variable O&M costs of up to 25% of the reference value. Finally uncertainties around GHG emissions factor from the literature are used.

4. Results

4.1. Biogasoline

Without any specific incentives for advanced biofuels, first generation biofuels would be predominant in biogasoline in the mean case as displayed on Figure 1. Second generation biofuels only reduces the growth rate of first generations ones without a real change in paradigm.

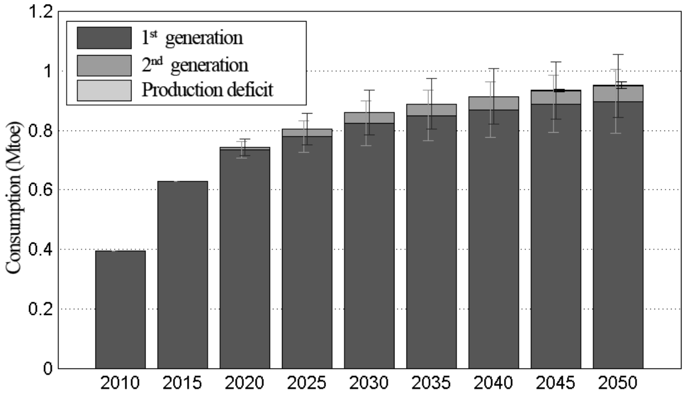

Figure 1: Evolution of biogasoline technological mix, average and standard deviation aggregated by generation

The results also show that there is an important relative variability for second generation biofuel mix as a substitute to gasoline. This higher uncertainty in the long term outlines a potential investment barrier associated to more risky processes to produce lignocellulosic ethanol. The resulting variability also remains significant for first generation producers with a standard deviation of 0.1 Mtoe (0.16 Mt) in 2050. From a feedstock perspective, this corresponds to 70 000 hectares of wheat crop (600 French average-size farms) or 30 000 hectares of beet crop (260 French average-size farms) and 57% of the French largest distillery capacity (owned by Cristanol in Pomacle-Bazancourt).

4.2. Biodiesel and biokerosene

Figure 6 displays the evolution of the biokerosene and biodiesel mix – grouped together since biokerosene can be produced from HEFA and syndiesel through a supplementary hydroisomerisation step – aggregated by generation. The "Other advanced" label corresponds to waste cooking oil and animal fat esters.

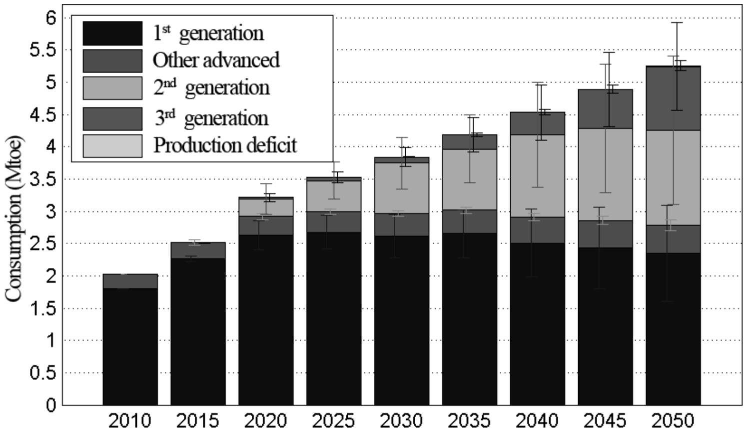

Figure 6: Evolution of biokerosene/biodiesel technological mix, average and standard deviation aggregated by generation

One can notice that first generation gradually loses market share in favor of second and then, third generations, with the reduction of their production costs. Standard deviations are high except for other advanced biofuels, which are the least cost technologies and are consumed as much as their potential. For first generation, the standard deviation in 2050 reaches 0.7 Mtoe which correspond to 32% of the mean output for all runs. This would have a strong impact on the sector: it represents 500 000 hectares of rapeseed crop, the equivalent of 4300 large-scale farms and almost one quarter of current area dedicated to oleaginous crop. While the absolute numbers in Mtoe might seem small, this result highlights the very fragmented nature of the feedstock and the supply chain risk for farmers. From an industrial perspective, three large transesterification plants (250 000 t/y) would be at stake.

4.3. Risk and competition among generation

We now consider the tradeoff between biofuel processes for our set of scenarios. Figure 7 outlines the distribution of first, second and third generation consumption for two periods: 2030 and 2050. These distributions can be interpreted as indicators of the risk for an industrial actor to invest in a given generation considering the potential improvement of competing technologies. The shape of the distribution flattens and widens between 2030 and 2050. This indicates that with the maturity and the multiplication of routes the competition is more intense. This is also true for second generation processes distribution, with a relatively secure market of almost 0.5 Mtoe by 2030 but a much more uncertain prospect by 2050. Risk adverse investors might therefore underinvest or require higher rates of returns or market guarantees from policy makers. As a consequence the full economic potential may not be reached.

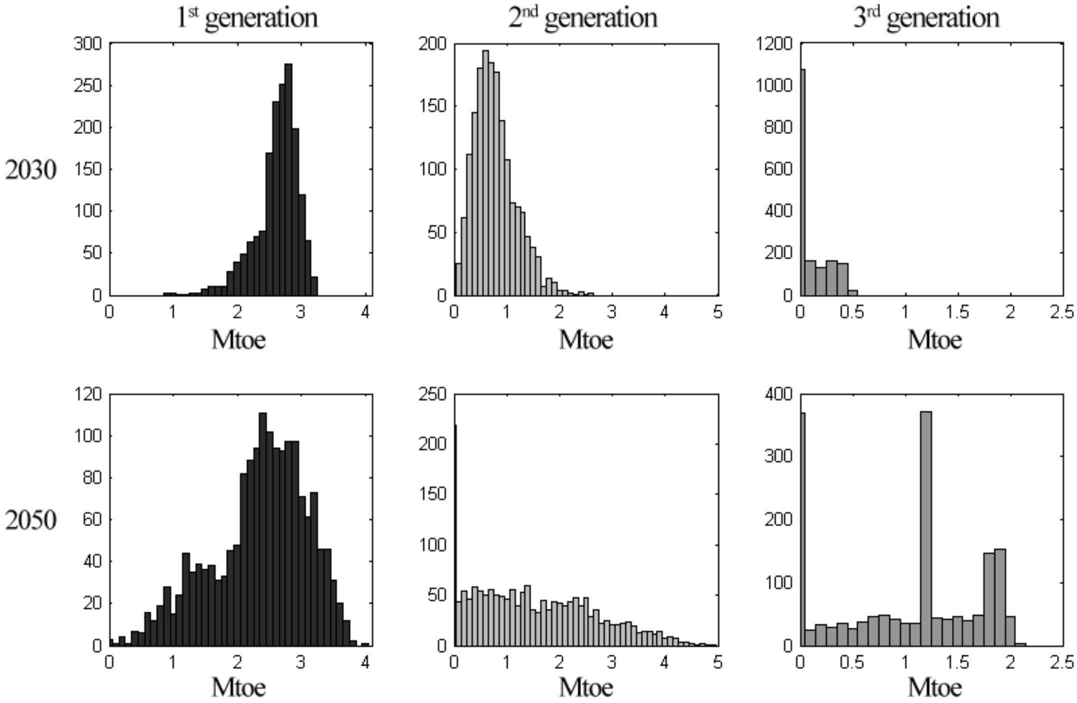

Figure 2: Distribution of consumption by generation of biofuels

5. Conclusion

Several low carbon technologies are proposed to meet ever stringent long term mitigation targets. Their advantages are often determined in comparison to conventional and more polluting technologies. Yet the competition among low carbon technologies could represent a real and underestimated source of risk. In this study we explored the uncertainties in the future biofuel mix for France. In particular we analysed the interaction between first second and third generation technologies. Our results show that the anticipated development of third generation technologies could increase the technological risk associated to second generation. They also show that for ambitious biofuel production target, first generation still play an important role. This is important for decision makers as feedstock suppliers and investors in the medium term could be reluctant to build new facilities at the pace required to move to a low carbon future.

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