Modelling biomass for energy uses: results for France

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MODELING BIOMASS FOR ENERGY USES: RESULTS FOR FRANCE

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Introduction

Future fossil fuel scarcity is a major energy concern. How can we envisage the transition to a world without easy access to cheap fossil fuels? Our transport systems depend on liquid fuels and they are essential in our way of life. So it is important to look at mid-term horizon what can the substitutions to these liquid fuels be.

Biomass use for energy is seen as an attractive solution to provide this continuity. What is feasible in terms of biofuel production in response to a defined demand? What is the technology path to achieve this production? The aim of this study is to assess the potential of biomass for energy uses for France by 2050 and to provide a path for biofuel technologies deployment.

To achieve this objective we have developed a detailed MARKAL/TIMES model for biomass use as energy source in France. This model will give a detailed quantitative inventory of biomass for energy uses. Using this methodology biomass has been studied as part of the European Union's renewable strategy for 2020 in the RES2020 project. For this project we collaborated with other country modelers and used a pan-European TIMES model. Section 1 presents the MARKAL/TIMES methodology and recalls the rationale and biomass results for EU from the work carried on under RES2020 project.

Then section 2 explicates the more detailed biomass assessment tool for France and for 2050 developed in the VALERBIO project. Several improvements have been made. A regional cut-out for the resources is implemented. The byproducts have been included in the model. The demand scenarios include the latest biomass policy views. Section 3 presents some results.

1. Methodology and biomass insights from previous work

1.1 MARKAL/TIMES methodology

To be able to quantify possible evolution of energy systems under different environmental and energy policies prospective energy models are valuable tools. For the current study we use the MARKAL/TIMES [1, 2, 3] model generator. This model is an energy/economy/environmental tool that has been developed by the Energy Technology System Analysis Program (ETSAP) [4, 5]

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under the leadership of the International Energy Agency [6]. It is a demand driven optimization tool that can address regional, national or international region under mid to long term time horizon (from 20 to 100 years). It consists in a mathematical linear program that represents a "Reference Energy System" (RES) that have to satisfy end-use demands over the defined horizon. This horizon is divided in time slices to see the dynamics of investments and activities during these periods. The model minimizes the total discounted system cost. This tool is largely used in more than 70 countries and provides an access to normative results that can be a solid base for policy makers.

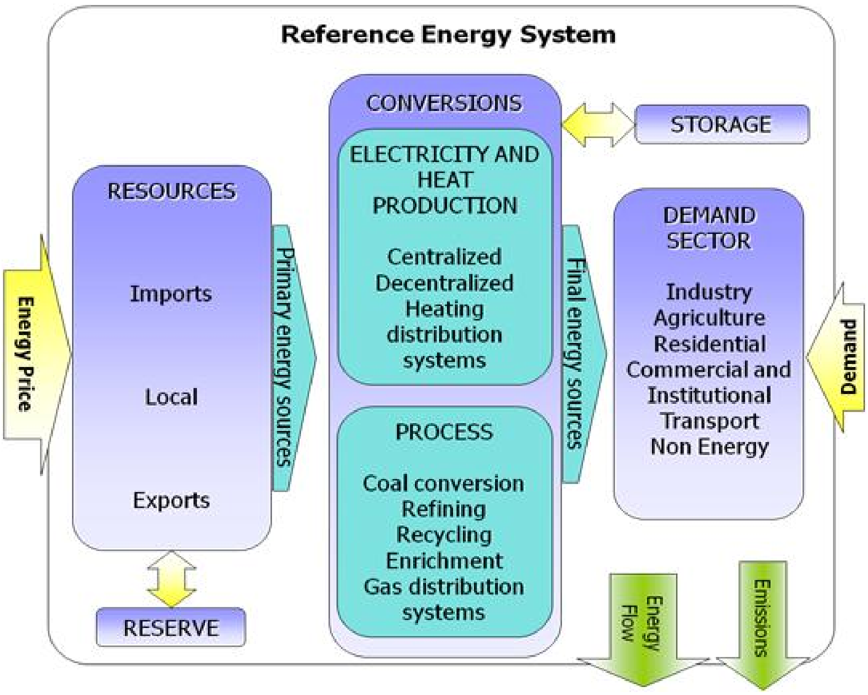

Figure 1 : The general reference energy system

Figure 1 gives a general overview of the Reference Energy System concept. It is an explicit bottom-up approach through a description of individual technologies by explicit input-output relationships. Analyses can then be done via scenarios definition and comparisons. A scenario comports basically four dimensions:

- The end-use demands,
- The potential and prices of materials and energy carriers,
- The appropriate technology database,
- Additional constraints describing policy objectives.

The model is then able to compute the optimal allocation or technology and commodities under the different constraints. The main decision variables are investments levels, activity levels and total installed capacities. For each time period, all the variables can be obtained and regarding the dual of the linear program, all the marginal values can also be interpreted.

1.2 Biomass energy contribution to EU renewable targets and the RES2020 project

MARKAL/TIMES is a methodology for energy model generation and a particular instance of this methodology is the actual energy model. In the research consortium of the RES2020[2] project [7], we studied biomass prospects for 2020 as part of the solution to reach the European targets for renewable energy expressed in the EU climate package (the 20% integration of renewable energy and 20% of CO_2 emission reduction). This EU level approach was implemented in the frame of the Intelligent Energy-Europe program (2006-2009).

A pan-European TIMES model describing a 30 region European energy model (EU-27, Iceland, Norway and Switzerland) was used. The horizon of interest of this project was 2020 and the coverage included all renewable energy sources and the whole EU energy system. Detailed results are accessible in [7, 8, 9, 10, 11].

Type	Industry	Residential and C&S	Agriculture	Transport	Biogas production	Biofuels production	Electricity production
Energy crops							
Oil crops						X	
Starch crops					X	X	
Sugar crops					X	X	
Grassy crops	X	X	X		X	X	X
Woody crops	X	X	X		X	X	X
Waste and residues							
Forestry residues	X	X	X		X	X	X
Agricultural residues	X	X	X		X	X	X
Wood process. residues	X	X	X		X	X	X
Black Liquor	X				X	X	
Municipal waste	X	X					X
Industrial waste	X	X			X		X
End-products							
Biogas	X	X	X	X			X
Biofuels	X		X	X			

Table 1. Biomass routes in the RES2020 project

Biomass description in RES2020 is shown in table 1. It is very detailed for such a large model. To inform the model, data for the primary biomass supply curve (cost and available quantities) at individual country scale were derived from the EU-funded REFUEL project [12]. On the policy side biofuels share of transport and the compliance with the global renewable target are the measures that concern biomass directly. The results show that to meet the EU policy targets, the biomass contribution in the total primary energy supply should increase from 83 Mtoe in 2005 to around 160 Mtoe in 2020 for the various scenarios. The total available biomass potential is a key input. The RES-ref scenario describes a renewable policy case with the initial potential evaluation. The RES-BIO-25% and RES-BIO-10% ones are situations where only 25% and 10% of the biomass is available. Figure 2 shows the results of a sensitivity analysis. Even in the less favorable case the contribution of biomass remains around 140 Mtoe.

[2] Renewable Energy Sources: Monitoring and Evaluation of the RES directives implementation in EU27 and policy recommendations for 2020

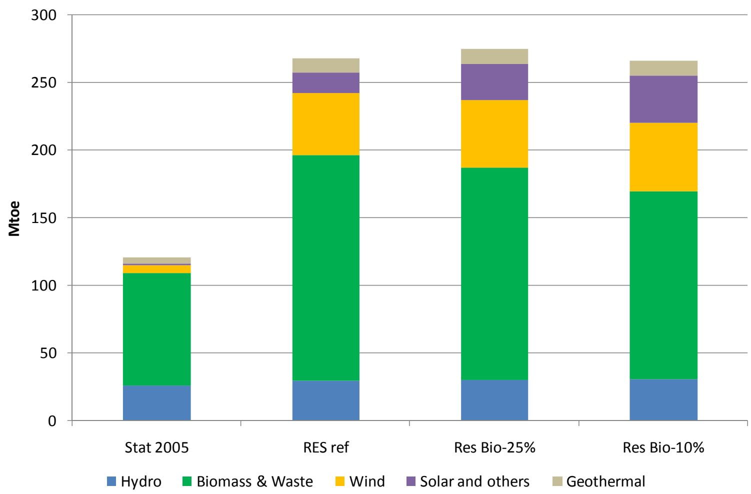

Figure 2 : Renewable energy mix for EU-27. Source; RES2020 project

2. Assessment of biomass for energy uses in France by 2050

The work done in the RES2020 project motivates the role of biomass in reaching European Union's medium term goal for renewable energies. Our central purpose in this section is to present the specific prospective work done in the VALERBIO project for a more detailed assessment of biomass for energy uses in France and for the longer term 2050.

2.1 Description of the VALBIOM-FR model

The VALERBIO project (BIOmass VALorization for enERgy purposes) [13] is a French research project funded by the TUCK Foundation[3]. The project consortium involes the Foundation for Construction Wood and Furnishing (FCBA), the National Institute for Agronomical Research (INRA), the French Institute for Petroleum Studies (IFP) and the Centre for Applied Mathematics of Mines ParisTech. The overall project worked as follow: The FCBA and INRA, as specialists of agriculture and forestry resources, provide the most pertinent regional cut-out for all kind of products for France. All the resources that have been evaluated in this study define potential harvestings that are not in competition with food uses. IFP characterize a set of biofuel production technologies that can appear in France over the modeling horizon. Finally, using our TIMES modeling expertise, we design an enhanced optimization model of the biomass chain that can integrate all these specifications. The coverage is restricted to the biomass chain and the horizon extended to 2050.

[3] The Foundation said TUCK FOUNDATION FOR INTERNATIONAL TRAINING AND RESEARCH IN THE FIELD OF PETROLEUM AND ITS DERIVATIVES, founded in 1992 aims to develop international cooperation and in particular Franco-American in teaching and research in the fields Petroleum, petrochemical, engines, activities related to them, and their effects on the environment (pollution reduction).

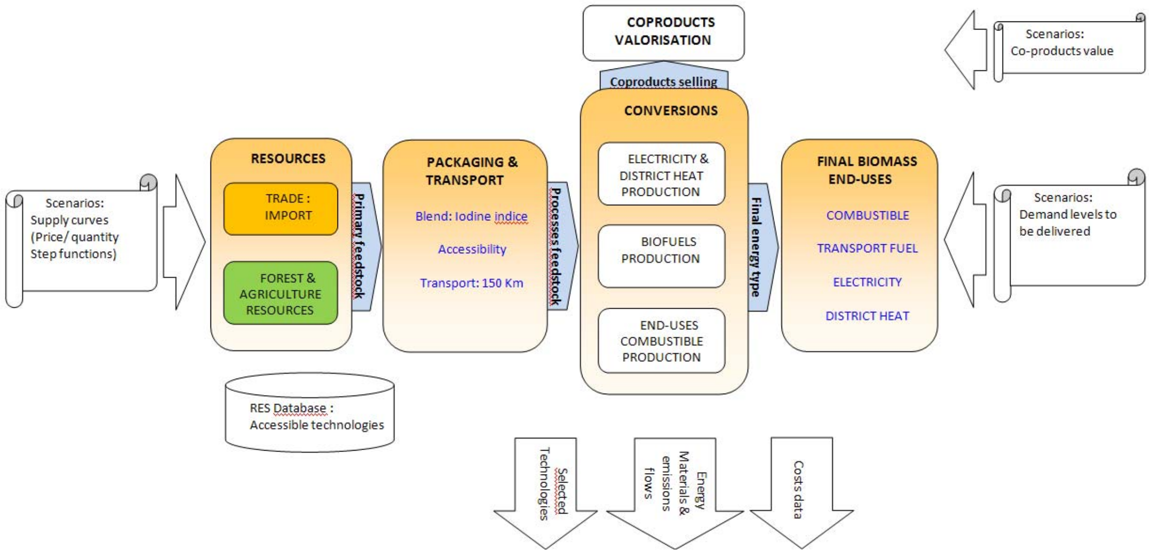

Figure 3 : The reference energy system of our model

Let's now focus on our new reference energy system. The novelty appears in the biomass resource supply steps, the geographical zones (as opposed to a country potential), the explicit description of byproducts and in the way of representing some intermediate stage such as trituration, blending of different oil, and transportation. Blending is important because of the constraints in the quality of the fuel that the engines and regulation require (octane or iodine indices…).

<u>Biomass disaggregation</u>

Here are presented all forms of biomass we have included in our model.

- Agricultural products
  - Grains and the whole plant (grain + straw) are differentiated for :
    - Corn
    - Wheat
    - Rape
    - Triticale
  - Sugar beet
  - Sunflower
  - Miscanthus
  - Soya
  - Switchgrass
  -
- Wood products: by types and by accessibility
  Three types of wood are considered to estimate the potential.
  - Big wood
  - Medium wood
  - Small wood

Four types of accessibilities are considered in order to have a better representation of the regional potential.

- Easy (FA)
- Moderately Difficult (MD)
- Difficult (DI)
- Very difficult (TD)

This distinction in wood quality is very important to be able to have a better analyze of the wood market. Indeed, some of them (like small wood) cannot be employed for some industry uses. And others (like big wood) are not suitable for other energy purpose.

- Short Rotation Coppice
  - Eucalyptus
  - Willow
  - Poplar
  - Locust tree (false acacia)

  These species are not very used in France at the moment. However they can be produced on several kinds of lands (forestry or agricultural fields). So their development can be very important.

Biomass localization

In the present study all the French biomass resources have been cut in several regions. All these regions have their own potential for the products describes above. Figure 4 below describes the cut-out of France for biomass potential in 9 zones. Each region has its own detailed economic description over the time horizon (potential, cost of production, cost of transport and bounds).
The production technologies are not geographically located. Nevertheless, the model includes the different costs for transport for the different products. Transport costs have been estimated for an average distance of 150 km but differentiated by region.

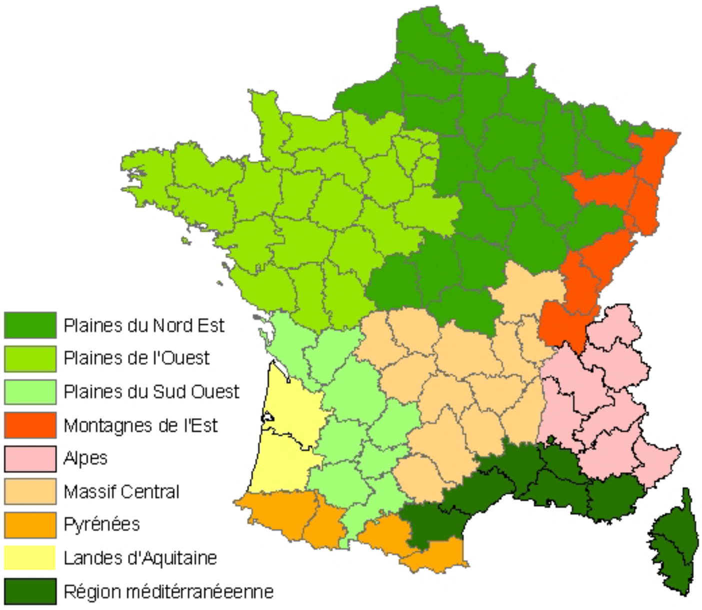

Figure 4 : French biomass resources cut-out

Technologies representation

After transformation, biomass can be used as a liquid fuel as electricity or as heat source. For the transformation into biofuels, three ethanol processes and three biodiesel processes and a Fischer-Tropsch process for synthetic diesel production are modeled:

- Vegetable oil production from grain + blending process
- Ethanol
    - Sugar beet ethanol
    - Cereal ethanol
    - G2 ethanol (second generation)
- Biodiesel
    - The vegetable oil methyl esters (Biodiesel)
    - The hydrogenated vegetable oil (NExBTL)
    - Biomass-to-Liquid (BtL: second generation)

The vegetable oil production is specified separately and a blending process ensures that the mix of vegetable oil products in a biodiesel process satisfies iodine indices requirements. the different energy or non energy by product associated to biofuel processes are also explicitly described: Glycerin, Brewer's spent grain, Press cake, Propane, Naphtha, Carbon dioxide, Vinasses, Electricity. Final the traditional technologies for heat and combined heat and power production, are described as average technologies.

2.2 Scenarios definition: Biomass resource supply curves and bioenergy demands

To perform our analysis, several scenarios have been defined to represent what will be the demand of bioenergy on the long term. They describe alternative levels of resource available for energy use, alternative levels of total demand of final bioenergy, and alternative policy orientation between heat, electricity and biofuels. These scenarios show the effect of some policy drivers on the bio products development.

Biomass resource scenarios

We define three types of scenarios for wood availability, two types for Short Rotation Coppice (SRC) and two types of agricultural products availability and prices.

For wood:

- Business as usual (BaU)
- All for energy: consider that priority is given to energy uses against other industrial uses.
- Dynamic wood industry: wood industry also becomes more dynamic. The resource is less fully allocated to energy.

For agricultural products:

The potentials that have been produced are the potential reachable without any food industry competition. The arbitration between the usage of biomass for food or energy is not endogenously treated in the present study. Agricultural products have experienced high volatility and projecting future prices is delicate. Two levels of prices (high and low) have been considered.

- Business as usual (BaU)
- All for energy: consider that the demand for energy purpose is growing fast, but the food usage for the national market remains important.

For Short Rotation Coppice:

- Mean availability
- Strong availability

We finally made six combinations from the resource availabilities described above:

- **P1**: BaU wood products, BaU agricultural products with low prices and no SRC.
- **P1b**: BaU wood products, BaU agricultural products with high prices and no SRC.
- **P2**: Dynamic wood industry, all for energy agricultural products with high prices, and high availability for SRC.
- **P2b**: Dynamic wood industry, BaU agricultural products with low prices, and high availability for SRC.
- **P3**: All for energy for wood, all for energy for agricultural products with high prices and high availability for SRC
- **P3b**: All for energy for wood, all for energy for agricultural products with high prices and mean availability for SRC

A possibility of imports of wood and bio ethanol is also introduced. This solution is strongly penalized in term of cost (50% more for the imports). This final choice will be interpreted as a lack of local resource. It will show the limit of the French potential to satisfy the demand specified for a given scenario.

<u>End-use bioenergy demands scenarios</u>
A central element for this study is the level of end-use demand for energy produced by biomass products. To produce such scenarios, we base our analysis on the different political constraints for the next decades. Three end use demands have been retained:

  - Bio heat only
  - Bio cogeneration heat
  - Bio electricity by cogeneration
  - Bio fuel

For these three energy carriers, we have defined three scenarios based on two demand level and with the following specificities:

D1: final demand is 20 Mtoe[4] for 2050. This scenario correspond to a pessimistic extension to 2050 of the objective that has been announced in the 10th operational comity for renewable energy development with environmental high quality (ComOp 10) provided in the frame of the French "Grenelle de l'environnement" (environment round table). The original objective has a target of 20 Mtoe for 2020. It has been translated in our scenario to 2050.

D2: final demand is 40 Mtoe for 2050. The ComOp 10 targets are reached in 2020. After this period, we consider a growing demand for bio electricity due to an important penetration of electric vehicles.

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[4] Million Tons of Oil Equivalent

D3: final demand is 40 Mtoe for 2050. The ComOp 10 targets are reached in 2020. After this period, we consider a growing demand for bio jet fuel. It reaches 20% in the transport sector (air and road)

An interesting fact is that the almost doubling of biomass contribution expressed in the RES2020 for Europe as a key element in meeting its renewable target is very consistent with the level in France today and in 2020 for D2 and D3. These three scenarios will provide results that will allow us to determine the limits of the French biomass potential for bio energy and the mix of technologies that have been retained by the optimization process.

3. Results and discussions

We describe in this part some results of our model. We will show for the three scenarios established, the mix of technologies required to meet the demand for biofuel. Then we will show the biomass repartition. On each graph, two different potentials are compared
Key questions of interest are:
- What technical structure is implied by final demands of bioenergy ranging from 20Mtoe to 40Mtoe?

- How is the optimal allocation modified by optimistic or conservative assumptions on the ressources (price and quantities)?

3.1 Scenario 20 Mtoe (D1)

As we can see on the following graph (Figure 4), biofuels are mostly produced from agriculture products. The biodiesel remains the major resource, but cereal ethanol has a growing share of the final mix, and at the end of the period (2050) accounts for 37% of the total production.
The different prices of agricultural resource don’t show big differences in the result. However, we can notice that with low price of agricultural product we have to import a little amount of ethanol instead of produce it with an ethanol G2 technology. This paradox can be explained regarding the investment cost of the ethanol G2 technology. Indeed, with such a low cost of agricultural product, a supplementary amount of production capacity for G2 technology won’t be paid off on the time horizon. With high prices, it will be profitable.

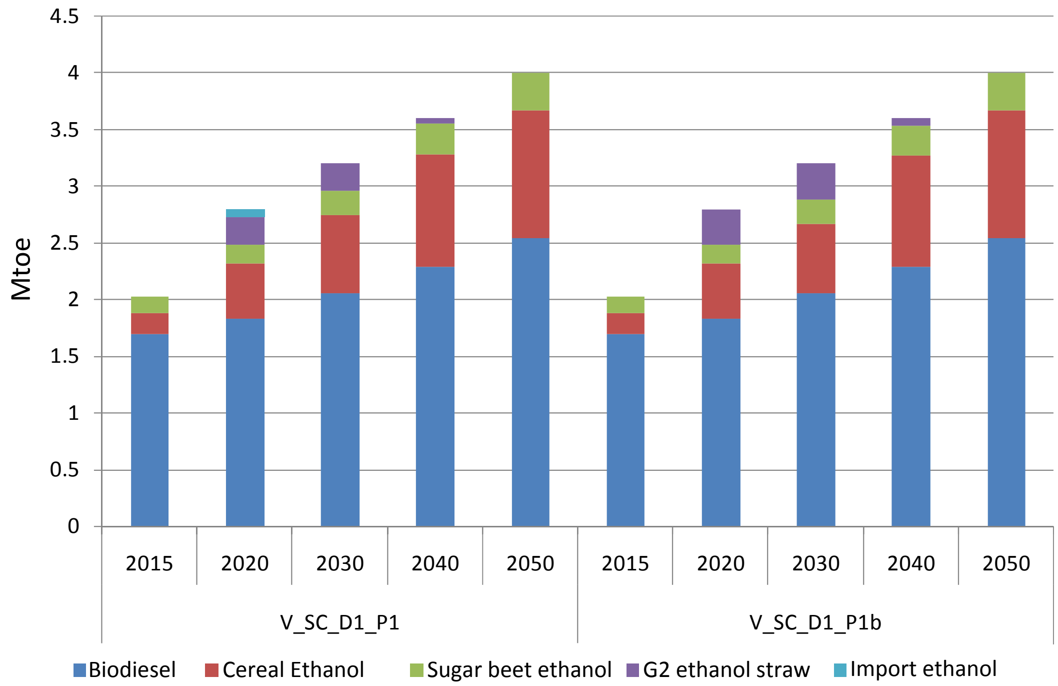

Figure 5 : Conversion technologies repartition for D1 Scenario

The uses of straw have to be analyzed as a whole. Indeed, it represents an important potential and is interesting because of its price. Straw is also pertinent for the non competition with food industry. Regarding the repartition of the use of straw between biofuel and standard energy production (electricity and heat), Figure 6 shows the importance of thermal usages versus biofuel production. The use of straw becomes exclusively dedicated to heat production at the end of the horizon. In the middle of the time horizon its use for biofuel production is economically interesting.

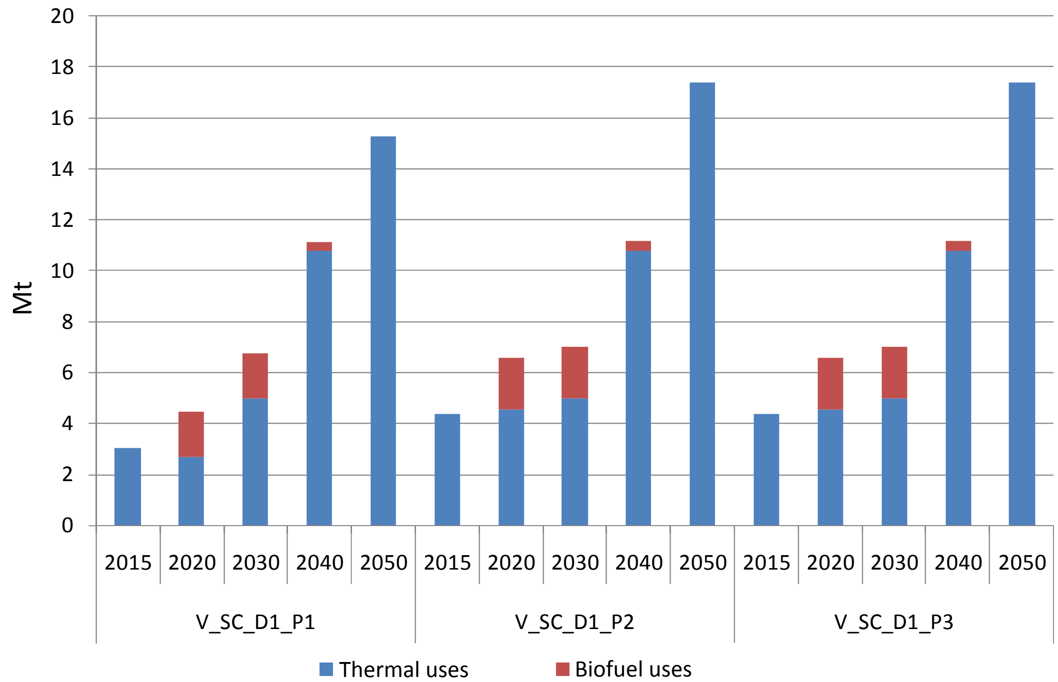

Figure 6 : Resources repartition by usages for D1 scenario

The repartition among agriculture resources is represented in the graph below (Figure 7). We clearly see the increase of the straw used as explained before which represent more than 50% of the total agricultural resources that can be accessible for energy when the potential grows in the last two scenarios. We also notice that wheat, corn, triticale, miscanthus and switchgrass disappear when all the potentials are growing in favor of straw.

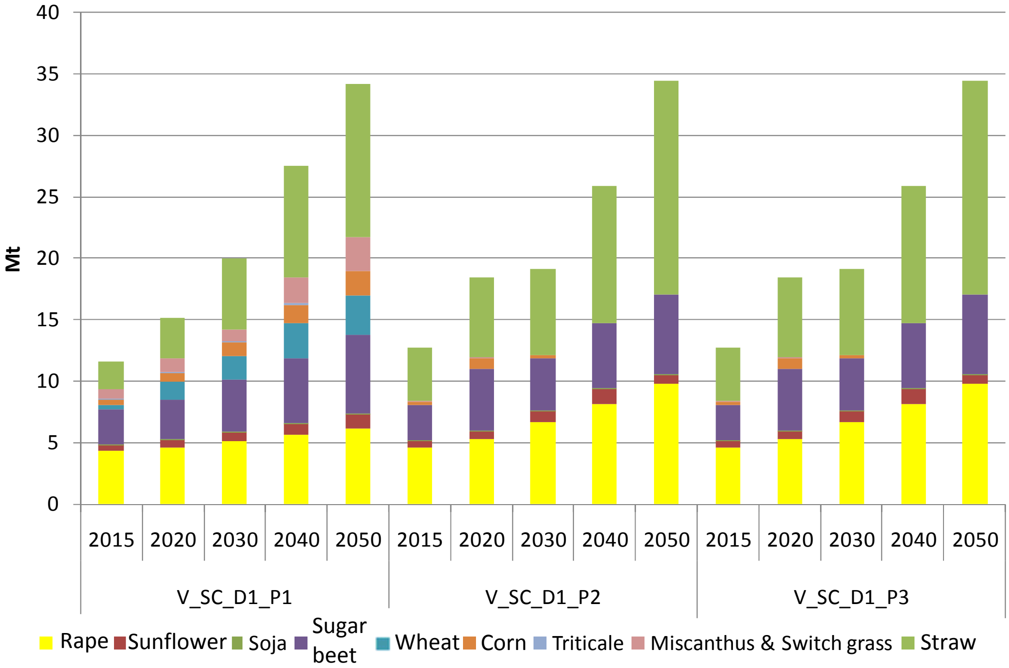

Figure 7 : Agricultural products resources for D1 scenario

The repartition between wood resources and Short Rotation Coppice (when it is available in scenarios P2 and P3) is shown in the following graph (Figure 8). It is clear that SRC availability makes a reduction in the use of standard wood. This fact is even more visible when we look at the scenario “dynamic wood industry” (P2).

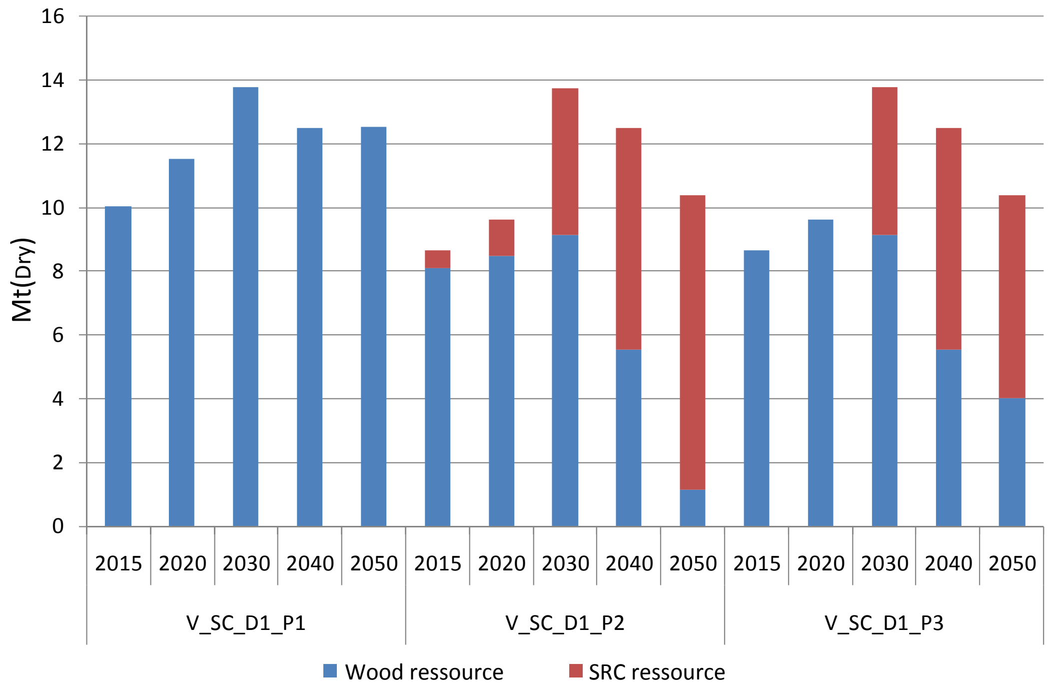

Figure 8 : Wood products resources for D1 scenario

This kind of result shows, for a moderate demand of bio energies (20 Mtoe), the French development of the mix of biofuel technologies and the associated bioresources required. Let's now examine what a more important demand in biofuel implies in a second scenario.

3.2 Scenario 40 Mtoe bio electricity (D2)

For this level of demand, the resources employed are again oriented towards the agricultural products (Figure 9). However, when the resources are limited (P1), the imports of cereals and ethanol are systematic even with a difference in the prices (P1 & P1b). These imports are completed with the apparition of BtL technology production with straw and wood as input. This choice is due to the better energy efficiency of this technology that need less resources to produce the demanded biofuel.

This result shows the limitation of the French potential if the demand is growing. Indeed, the imports have been very constraint with a high price, and even with new technologies, the demand cannot be fulfilled. The potential must then be revised to fulfill such an energy demand level.

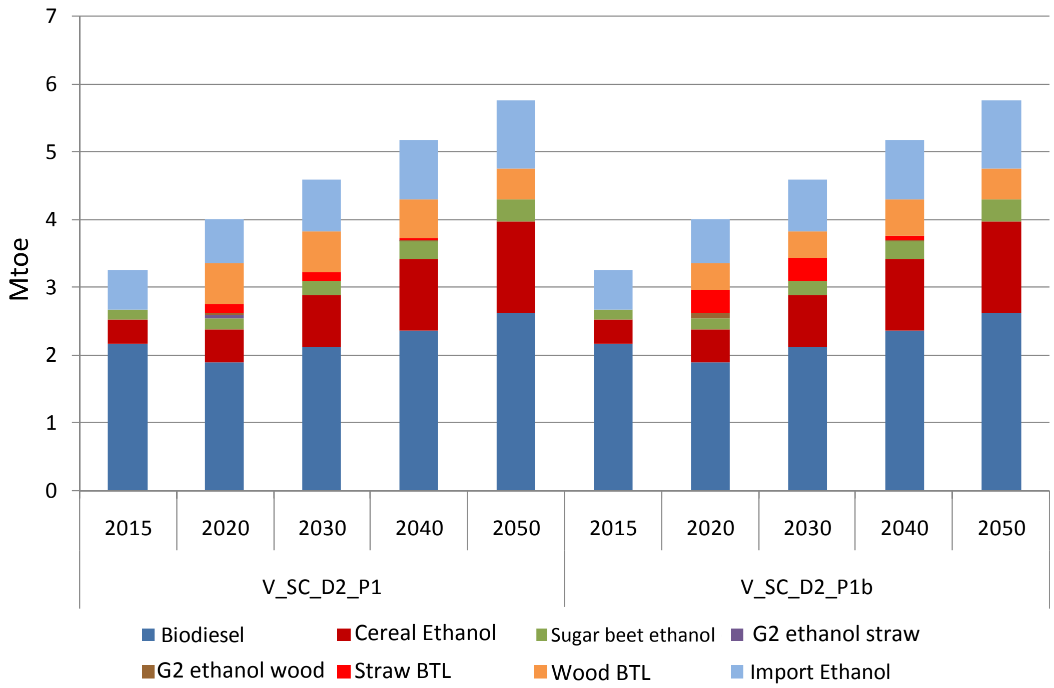

Figure 9 : Conversion technologies repartition for D2 Scenario

For the most important potentials for biomasses (P2 and P3) (Figure 10), the imports and the use of the BTL technology is largely reduced. The G2 ethanol technology is then employed due to his less important production cost. We also notice a certain amount of imports if the prices on agricultural products are higher.

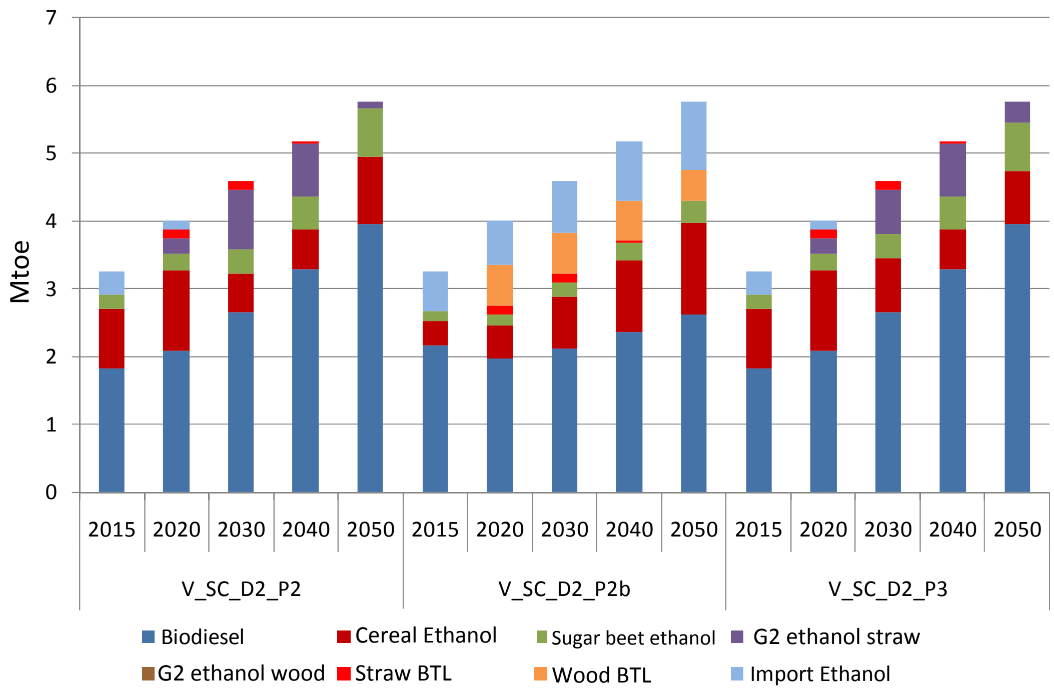

Figure 10 : Conversion technologies repartition for D2 Scenario and P2 & P3 resources

Concerning the agricultural resources employed with this mix of technologies, the following graph (Figure 11) is showing that with such a level of biofuel demand, all the French potential is necessary. The imports also show a lack of this resources when constraints are more severe.

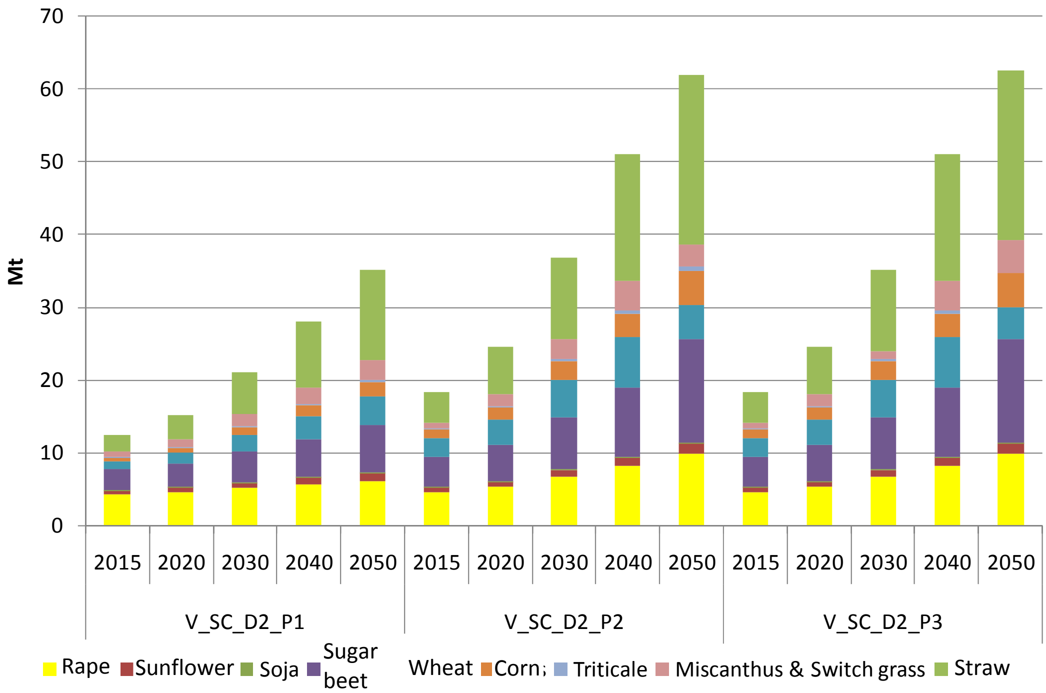

Figure 11 : Agricultural products resources for D2 & D3 scenarios

Following on Figure 12, the wood products evolution's for this 40 Mtoe level of demand. The lack of agricultural products needs a more important use of wood resources.

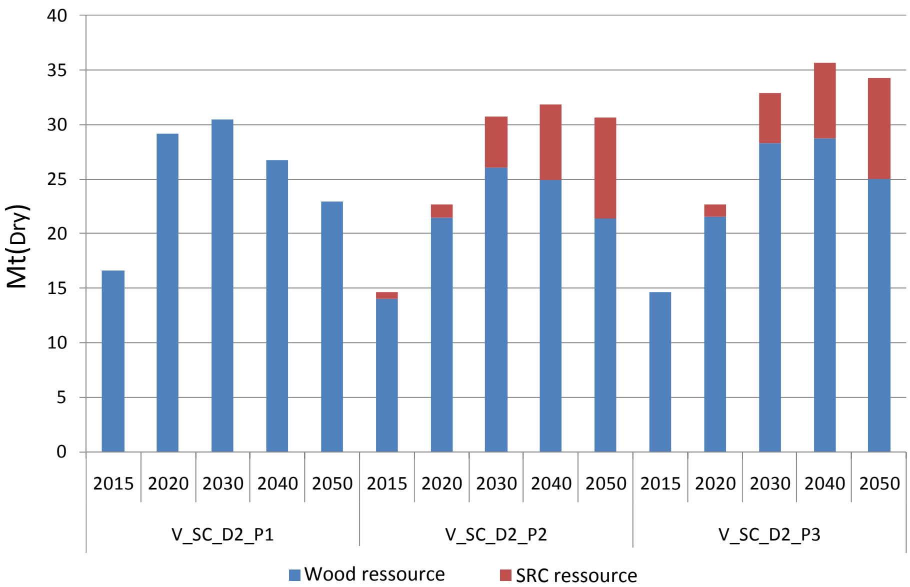

Figure 12 : Wood products resources for D2 & D3 scenarios

These results show the limits of the agricultural resources for a more important biofuel demand. It also shows the importance of the wood resource to fulfill the final demand. Let's see now a variant for this 40 Mtoe final demand of biofuel. It consists in a more important demand centered on biojet.

3.3 Scenario 40 Mtoe biojet(D3)

Due the constraints on the biojet specifications, the BTL conversion process feeded with straw is well suited to provide this biojet (Figure 13, Figure 14). It is the contrary for ethanol that is not well suited for airplane fuel specifications.

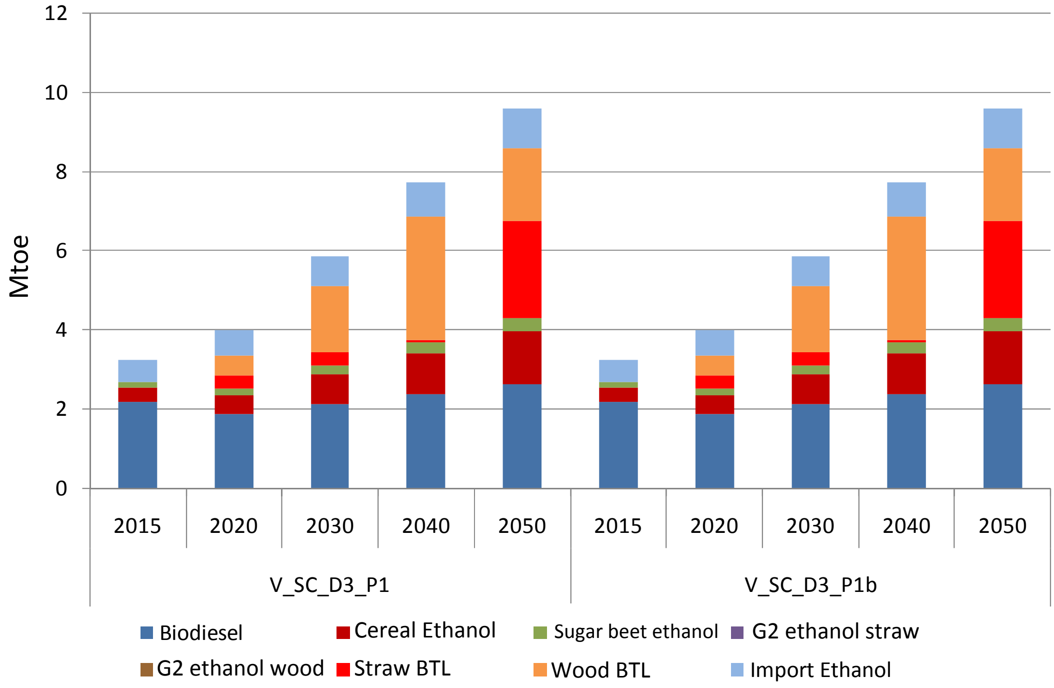

Figure 13 : Conversion technologies repartition for D3 Scenario

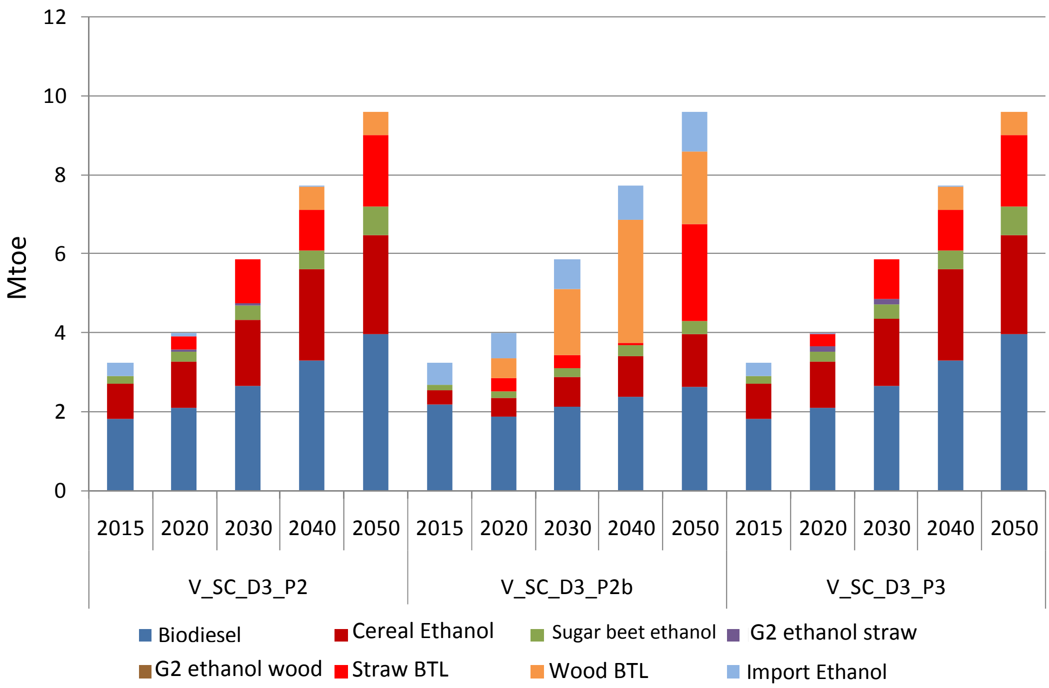

Figure 14 : Conversion technologies repartition for D3 Scenario and P2 & P3 resources

Conclusions

The model discussed in this study to assess the French biomass resources' for energy conversion gave a possible path for the mix of technologies and the related mix of biomass products to fulfill a given scenario. We established three scenarios to evaluate the feasibility of French targets in term of green energy mix. The results obtained with these three scenarios show the limit of the defined potentials for agricultural and wood products. Moreover, despite the high level of import prices, the model didn't choose to install new conversion capacity regarding the level of biomass resources evaluated.

The first objective at 20 Mtoe can be reached. However, 40 Mtoe are too ambitious with the hypotheses we have in our model in term of biomass resources or in term of technologies availability. The technologies employed in our model have shown the possibility of arbitration that imports can play. We also show the role of the second generation biomass conversion processes (BTL and ethanol). Some specifications have to be established to see their advent in a near future.

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