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From raw material to biofuel demand: the AGRAF model

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Abstract: The search for energetic independence, for boosting local economies and for reducing polluting emissions, has supported bioenergy's development and biofuels in particular. Mandatory biofuels incorporation rates have been recently established in several countries, including the European Union, in order to promote the use of renewable energetic resources in spite of several criticisms toward biofuels relating to their impacts on food security, the environment and the conflicts associated with resource allocations. To study existing concerns on the growth, the profitability, the limiting factors biofuels, as well as the impacts of current policies in force, a highly parameterized operational modelling tool (AGRAF) dedicated to the European area has been developed. Based on the coupling of three economic models (AROPAj, OURSEurope and GIRAF), each one representing a key sector of the biofuel production chain (respectively agriculture, refining and biofuel manufacturers), his approach allows to assess different scenarios based on different technical, economic, environmental and political criteria. Furthermore, it helps highlighting the biofuel production potential growth (quantity, nature, location, by products and polluting emissions), related costs (investments, transportation, raw material) and exchanges between the agents. AGRAF incorporates biomass and biofuels importations from outside Europe and takes into account both first and second generation biofuels (involved in the European biofuel policy scheme for 2030). These features help identifying the levers and opportunities for reaching European Union bioenergy's targets over a medium-long term.

***Keywords**:* biofuels; spatial modelling; refinery; agricultural supply.

1 INTRODUCTION

In a context of fossil resources depletion and of global increasing energy demand, biofuels are seen as a viable energy source for the transport sector. This energy transition would also reduce CO_2 emissions from fossil fuels and revitalize the agricultural sector (AIE, 2015, Havlik et al, 2011). In this context, this study aimed at developing a public policy support tool by analysing the economic profitability and identifying the limiting development factors of the European biofuel industry, in line with Carriquiry et al's work (2010). Using aggregated modelling framework to assess the development of biofuel production and blending in the refineries raises several problems concerning land uses and distances between the different processing units. Therefore, a linear programme (LP) chain of models of the entire sector (AGRAF) has been developed, in order to assess the optimal development pathway of the European industry considering a wide range of technical, economic and political scenarios. The desegregated approach that will be presented below, is taking into account the local characteristics at each step of the process: agricultural production, refining industries and biofuel production. The objective of this study is to build a bridge between existing desegregated models (representing both agricultural production and refining industry) at the European level through a modelling "shell". Due to the model's size, several computing techniques have been compared in order to simulate this activity with the minimum computation time considering the detailed representation of the processes.

2 AGRAF COUPLING

2.1 Objectives

The AGRAF model *"from AGriculture to RAFineries"* assesses the impact of Community biofuel policies on the European sector by integrating the different sectoral models of agricultural production, processing and refining, involved in the production of biofuels. The retail sector was not taken into account in this study. Only first and second generation biofuels have been included. Additionally, this model foresights the potential growth of the biofuel sector in Europe and identifies levers and investments needed to achieve EU targets. AGRAF is considered as a weak coupling because independent models interact with each other.

2.2 Coupling process

In AGRAF, the European agricultural supply of raw matter is estimated by the AROPAj model. All or part of this production, as well as raw material imports are then transferred to the GIRAF model. This latter models the industrial transformation of raw matters into biofuels, meeting the refinery demand for biofuels processed by the OURSEurope model. (See Figure 1).

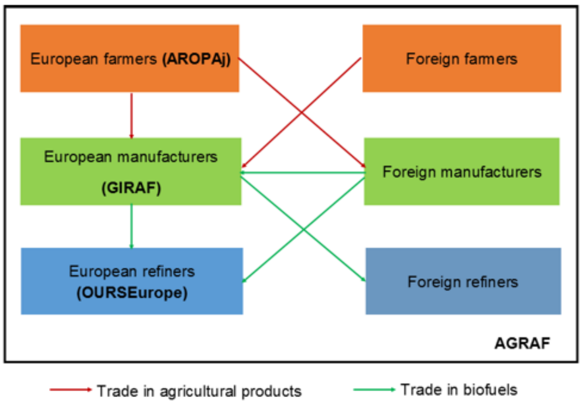

Figure 1: AGRAF's architecture

European refiners are considered here as the unique economic agents involved in biofuel demand. Moreover, all biofuel products are considered to go through refineries as final stage since the blend is processed there. Refiners are seen in AGRAF as the last players in the sector of biofuels for simplification. AROPAj and OURSE have been modified to meet the project's expectations. Indeed, "energy crops" and "by-products" have been introduced into AROPAj, and a European global refining model OURSEurope has been established from the disaggregation of the world wide OURSE model. As for GIRAF, it was specifically developed for this study. The three selected models were georeferenced to bring to light the exchanges between players of the sector. This makes possible the identification of European biofuel production and consumption zones. Therefore the methodological approach used refers to partial equilibrium modelling, considering that the prices of represented products do not affect the other economic goods involved. It takes into account the horizontal (product and actor diversity), the vertical (upstream, downstream) and the geographical dimensions of the problem.
Basically, linear mathematical programming tools have been used to solve this problem.

3 MODELLING COMPONENTS

3.1 AROPAj

3.1.1 Overall AROPAj presentation

AROPAj is a set of mixed integer linear programmes that simulate agricultural agents' choices. Agents are represented by farmers aggregated in farm groups who are maximizing their profits (Jayet et al, 2015). It has been initially designed for analysing the successive reforms of the European Common Agricultural Policy (Galko and Jayet, 2011) and is now used for assessing the relationships between agriculture and the environment (e.g. Humblot et al, 2013). Results can be aggregated at regional, country and EU levels. The model provides results taking into account the diversity of conditions for agricultural production observed across the EU. Even though this model does not consider all kind of farms and agricultural products, the main share of the Utilized Agricultural Land (UAL) is included. However, considering the large scale of the model, it implies some rigidity when defining the parameters, e.g. the number of farms (K) and the UAL per farm group are defined as constant.

Input and output prices (alternatively denoted by p in all the paper) are considered as parameters as it is a supply model, and the underlying optimization programme (A) is summarized as follows:

$$\max_{x,a} \Pi(x,a;p) = \sum_{k=1}^{K} \pi_k(x_k, a_k; p) \quad s.t.\ \{x_k, a_k\} \in A_k$$

The energy use of the optimal raw material supply by the k farm group, a_k^*, competes with other uses (food and feed) exogenously expressed at the GIRAF transformers' level.

3.1.2 Data and model inputs

The model version used in AGRAF includes 1307 farm groups accounting for twenty four EU member States in 2004 (except Malta), by using the Farm Account Data Network (FADN) nomenclature. The database provides holdings accounting data, but also data structures (revenue, expenditures, prices, yields, area allocated to each culture etc.) for a sample of 60 000 farms representing more than 4 million European farmers. Data from FAOSTAT and the IPCC have also been integrated in AROPAj to fill gaps in the FADN regarding technical data on livestock feeds and greenhouse gas (GHG) emissions. Other data were obtained during calibration of the model.

3.1.2 Building and computation

The entire model is available on a Linux server and consists of a sequence of *Cshell* scripts and *Fortran* programs. The heart of the model, represented by the list of parameters, variables, constraints and objective functions is encoded in a Matrix Generator Generator (*MGG*) language. Farm group clustering and econometric estimates are carried out using the *R* software while linear programming in *MGG* is transcribed in *GAMS* (Generalized Algebraic Modelling System) through *Fortran* routines, to be solved (using the CPLEX solver). Back to the construction, the business model is as follows: (i) the FADN sample clustered into virtual farm groups, (ii) estimation of parameters associated with each farm group, (iii) calibration of linear programmes related to farm groups. Each farm group's LP refers to more than 40000 primal and dual variables.

3.1.3 AROPAj's outputs

The endogenous variables optimized by the model are land allocation between the different crops, livestock, inputs, marketed and on-farm products (including raw materials for the energy sector), and environmental indicators (GHG emissions, nitrogen pollutants). One powerful feature of this model is its ability to spatially distribute farm groups through a geolocation module. Among other studies, AGRAF's development required perennial crops and by-products (mainly straws) to be taken into account in the AROPAj model (see Ben Fradj and al, 2016, for energy crop introduction).

3.2 OURSE refining model

3.2.1 General objective of the model

OURSE (Lantz, 2012) is a linear programming model simulating world refinery industry by optimizing the operation of the units and the combination of crude oils and other technical resources needed to meet the demand of oil products at lowest cost. Therefore, the model constraints come from the refinery process (intermediate and finished good balance, refinery fuel balance), quality check, end products demand, resource availability (treatment unit capacity and crude oil supply) as well as pollutant emissions. It is associated with POLES, the European Commission model predicting European energy demand. OURSE is a multi-refinery model, representing nine areas of the world aggregated in a standard refinery. The EU zone has been split in nine refinery sectors represented by over a hundred geo-referenced operators. The European version of OURSE has been named OURSEurope. This is a long run static model to the extent that capacity increases are taken into account. OURSE minimize the global refining cost, according to the specified constraints of the refining industry described earlier and compulsory shares of biofuel in the automotive fuel pools:

$$\min_{x,b} R(x,b;p) = \sum_{z=1}^{Z} r_z(x_z, b_z; p) \quad s.t. \quad x_z \in X_z; b_z \geq f_z(x_z)$$

The optimal biofuel demand by any EU z refiner, b_z^*, meets the transformers' supply, competing with parametrized RoW imports.

3.2.2 Model framework, input data and outputs

OURSEurope considers a crude oil supply based on 5 representative qualities associated with prices and freight costs. The objective cost function refers to feedstock costs and processing costs which have to be minimized according to the following set of constraints: (i) balances of intermediate and final products, (ii) demand equations, (iii) product quality control equations, (iv) capacity constraints, (v) crude oil supply and (vi) pollutant emissions. Foreign trade with the rest of the World can be limited (especially diesel oil imports). The base year is 2005, and the time step for each simulation is 5 years. To summarize, the LP model aims at representing the optimal production which reaches the expected oil products demand according to the feedstock availability, the technical and the environmental constraints of the refineries. Technical data are provided by IFPEN as well as the cost figures. Economic data (oil prices and demand) come from IEA and Eurostat.
The primal and the dual results are obtained from LP optimization. The model primal variables are input quantities (crude oil supply and other feedstock), end products blending, utility consumptions, the size of the units (resulting from investments) and pollutant emissions. The dual values associated to the demand constraints are the shadow costs of the oil products. Furthermore, we can deduct the value associated to each compound through the shadow values of the blending equality constraints.
From the aggregated results over 9 main refining areas, the results are split over 109 identified refineries which were georeferenced (in degree minute second projection WGS84) using Google Earth, i.e. localized in one spot using an R pre-treatment on collected data.
As all the equations are linear, OURSE is a LP model. It contains about 20 000 equations and 100 000 variables. OURSE has been written in GAMS language and it is optimized by using CPLEX solver.

3.2.3 Biofuels blending into OURSEurope

Ethanol and biodiesel being blended with respectively gasoline and diesel, biofuels are also considered in this model as refinery inputs before being incorporated into the finished products. The contribution made to the model is to set up incorporation constraints per regional areas, at the European level and by major type of biofuels (biodiesel and bioethanol).
To implement this biofuel blending, biofuels are introduced in the following constraints: (i) product's blending, (ii) quality control equations, and (iii) lower and upper limits for biofuel blending (according to the energy content). Note that the Road Vapour Pressure of the gasoline grade is a non-linear function of the ethanol share. Thus, the corresponding equation should be linearized using binary variables.

3.3 GIRAF

3.3.1 GIRAF overall presentation

The GIRAF model is a linear programming, georeferenced and clustered model. It represents the European biofuel production sector by taking into account all its identified stakeholders. GIRAF minimizes the overall transformation cost of feedstock in biofuels, considering transport costs between upstream (i.e. farm type groups) and downstream operators (i.e. refiners). Optimisation is performed under technical and economic constraints, particularly regarding feedstock availability and biofuel demand expressed by refiners (OURSE outputs). Therefore, GIRAF is able to estimate the impact of external shocks (public policies, regulations, supply modifications etc.) on the production of biofuels and on the exchanges with the upstream and downstream sector. The results are detailed for each industrial transformed raw material into biofuels. These results can then be aggregated across the region, the country or the European Union. Based on the scenario, programs variables can be enabled (at optimum values) or disabled (fixed to zero). This is particularly the case for investment in new production capacity, only used in long-term scenarios. GIRAF covers the EU-24. For more economic plausibility, only current industrial active plants (t) are taken into account. The associated optimization programme follows:

$$\min_{x,u,v} \sum_{t=1}^{T} d_k(x_t, u_t; a^*, b^*, p) + \sum_k c_{kt} u_{kt} + \sum_k c_{tz} v_{tz} \quad s.t.\ \{x_t, u_t, v_t\} \in W_t;\ \sum_t u_{kt} \leq a_k^*;\ \sum_t v_{tz} \geq b_z^*$$

a^*, b^* respectively refers to EU spatially distributed raw material supply and EU biofuel demand. The vector u_t refers to the set of raw materials produced by (a subset of) K farmers and transformed by the t agent into the biofuel (of two types, i.e. gasoline and diesel substitutes) and vector v delivered to the EU Z refiners. Upstream and downstream transportation costs are denoted by c_{kt} and c_{tz}. Raw material and biofuel imports may be added in the t transformer's programme.

3.3.2 GIRAF data sources and inputs

A large data collection in Europe identified all the processing industries, operational or currently in development and certain features, such as the type of biofuel processed, raw material used, capacity production (t/year), by-products etc., are the characteristics used to define the baseline of GIRAF. The acquisition work was conducted with various institutes, from technical literature (specialized industry websites and newspapers IFQC Biofuels WorldBioplants, BioDzl; journals: F.O. Lichts, etc.) and thanks to expert knowledge. Acquired data is then inputted into GIRAF to, in addition with technical and economic constraints that the industry faces: e.g. processing performance, product nature, geolocation of the production, transport costs, resource availability, raw materials, utilities, and prices.

A survey of economic agents transforming biomass into biofuels, finalised in 2008, has enabled the geo-referencing of the 288 mill locations in Google Earth (degree minute second projection WGS 1984). As with European refineries, a R pre-treatment was used on collected data.

3.3.3 GIRAF's organisation

This model allows manufacturers to make the best use of available resources (raw materials, production capacity) and to optimize their production according to the demand for biofuels refiners (location, nature and quantity, defined by OURSEurope), availability of raw materials (location, type, quantity, defined by AROPAj) their investment capacity. The exchanges are represented at three levels of stakeholders: primary producers (farmers), processors of these raw materials into biofuels (industrials) and biofuels consumers (refiners). The bilateral trade optimization is carried out by the transformation industries because they are both connected to downstream and upstream sectors. Therefore, we considered that all the transport costs are supported by the biofuel producers. This assumption makes easier the trade optimization which is therefore carried out in one GIRAF simulation.

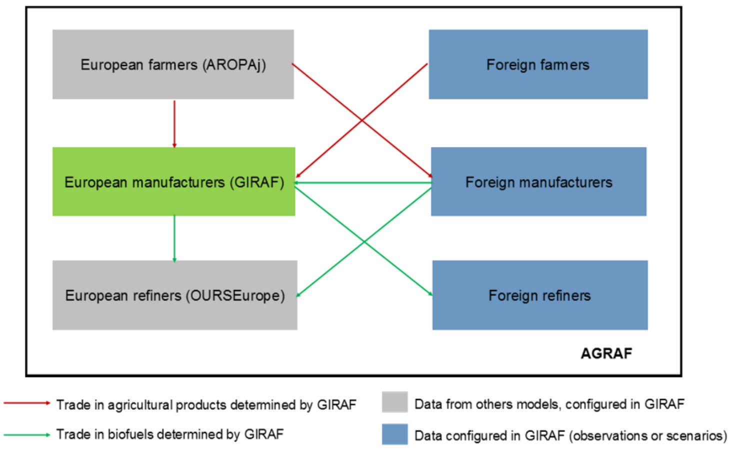

Figure 2: Representation of trades in GIRAF.

Biofuel production is not homogeneous in Europe as there are several types and several processes to produce them. . Three major industrial categories were distinguished: chemists, Agro-Food Industries (crushers, oil refiners, ester and ethanol producers) and refiners (ETBE and second generation). We have modelled individual and common constraints between producers. The optimization is then globally carried out.

GIRAF includes trades with foreign agents (i.e. with non-EU agents). Intra Europe exchanges (between EU farmers, manufacturers and refiners) are considered as

variables in the model whereas all trades concerning foreign operators are estimated and used as parameters.
The balance constraints linked to the exchanges between farmers, industries and European and foreign refiners, ensure that the quantities sold were effectively purchased and what was produced was effectively used. Technical functions of production are defined for each process.
Other constraints define supply costs (raw materials, utilities and other inputs), investment costs based on the discount rate, the amount and the nature of the investment (type method, lifetime, etc.) and operating costs, especially labour. In order to reduce the computation time, investments are defined with real variables and an upper bound (depending on the scenario) rather than with integer variables.

3.3.4 Computation

The model is available on the same Linux server than AROPAj. The linear program is written in Gams and the solver CPLEX is used. The primal model variables are the input quantities and the production capacities (integer variables). The parameters are the input along with product prices, taxes or subsidies, technical coefficients, investments and operating costs, demand for biofuels, input availability and agent location. This model has about 154,000 equations and 2 million variables.

3.3.5 GIRAF's outputs

GIRAF provides the production of various types of biofuels and marginal costs associated with constraints that each European industry represented faces. GIRAF also defines the quantity, nature and location of each purchase of raw materials from farmers and sales to each biofuel refiners. GIRAF also determines the nature and the amount of investment spent in new units if the script allows it. In addition, GHG emissions can also be computed.

4 AGRAF COMPUTING PROCESS

4.1 Basic algorithm

The way AGRAF models actor's operations impacts the way the different modelling components operate. Considering how difficult it is to manage a complex economic modelling tool in a general or partial equilibrium perspective, upstream (farmers) and downstream actors (refiners) have been set up to make their own choice independently. In the same way, AROPAj's farm groups maximize their profits independently from each other. In the same time, the 9 refiner zones defined in OURSEurope minimize their costs independently from each other. As a second step, intermediate actors (biofuel producers) minimize their production costs at the global level (in addition to upstream and downstream transportation costs). In a nutshell, GIRAF computes both quantities of raw materials purchased from different farm groups and quantities of biofuels sold to different refining units.

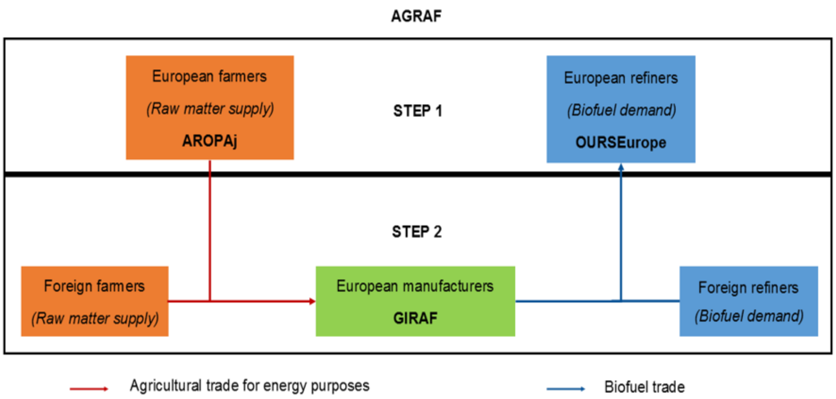

Figure 3: The two major steps of the computational process.

The only restriction that has been made at this stage refers to the exchange limitations between agricultural and industrial workers based on their geographical proximity (i.e: 200km around). However, no restrictions have been put in place concerning trades between refiners and manufacturers.
In this approach, all prices are considered as parameters, as well as

exchange limitations due to products having competing uses (food and feed on the agricultural demand side and biofuel importation on the oil substitute supply side). This 2-step process is illustrated in Figure 3.

4.2 Computations

For a given scenario (e.g. prices, policies etc.), AROPAj generates the European production of agricultural commodities. The latter agricultural supply available for biofuel production is distributed over geographic space via the AROPAj "spatialization" module. On the other side of the processing chain, OURSEurope generates the European strain of biofuel demand by refining units. Then, these different demands, raw material supplies and foreign trade opportunities are geographically transmitted to GIRAF.
Practically, the coupling is launched on a Linux OS 20-core server, using a CShell command which controls the three models and manages data and result's transfers from one model to the other. An elementary complete simulation requires significant computation time which is possibly reduced when GAMS steps are repeatedly performed in some iterative simulations (e.g. when changing the blending rates of biofuels in the final fuel demand). The table below delivers computation times when the server is free of other computations, in a preliminary run and in iterative calculations.

Steps	Initial run computation time	Iterative calculation
AROPAj / EU (FORTRAN, GAMS)	10	8
AROPAj results spatialized and categorized (R)	10	10
OURSEurope (GAMS)	50	2
GIRAF (GAMS)	8	2

Table 1: Computation times (minutes)

4.3 Implementation of resolution

Iterative AGRAF simulations highlight the potential development of the European biofuel industry and its related costs. The results point out the nonlinear evolution of the global cost due to the feedstock availability. We have performed a sensitivity analysis (see Figure 4) on both bioethanol and biodiesel share, from 0% to 36%.

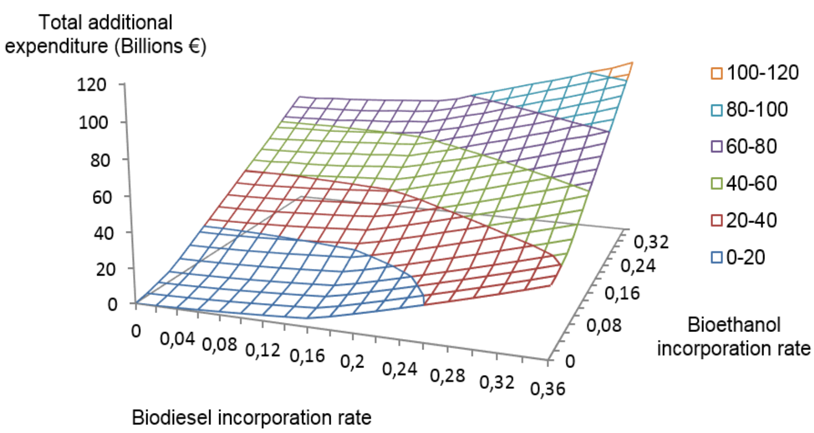

Figure 4: Total additional cost compared to a 0% biofuel incorporation rate scenario

The results revealed that the processing cost of the biofuel industry (modelled by GIRAF) strongly increase when the overall biofuel incorporation rate is greater than 10%. From 0% to 10%, the total cost increases by 3% whereas it reaches 12% for raw material transformers. From 10% to 20%, the respective increases are 7% and 20%.Therefore, the biggest economic effort while developing the EU biofuels industry would be carried on by the transformation sector. First because of the biomass availability (in addition of transport costs related) and because capacity investment required. Because LP refining models allow several compounds blending to reach the oil demand (Tehrani et al., 2008), a particular attention is paid to the result's robustness according to the biofuel blending shares.

5 CONCLUSION

Fitting into the current energy and environmental framework, this work aims to study the growth potential of the European biofuel industry and thus to assess the features of both domestic supply and production and the trades associated with the rest of the world. This is done considering the policy framework in force and taking into account economic and environmental constraints. In order to avoid the constraints associated with an integrated model representing the entire industry, AGRAF is based on a weak coupling between AROPAj, OURSEurope and GIRAF to obtain a static, spatial and highly parameterized modeling. The methodology used is essentially based on data collected during Melissa Clodic's PhD on a vertical (upstream/downstream), but also horizontal (product diversity) and geographic dimension of the industrial chain. Indeed, AGRAF analyses, at short and medium-long run, the impacts of political decisions such as the implementation of a carbon tax or an obligation of incorporation of biofuels on land use, agricultural production, on agent's profit, on product trade in Europe and outside, on greenhouse gases emissions and on investments in new industrial production capacities. Additionally, assuming future profitability of biofuels, it is possible to determine the optimal development of biofuels from an economic, technical and environmental point of view.

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