Logistics optimization of a biomass supply chain

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Summary

The French project GAYA is a demonstration project at pilot scale for modelling optimised biomass supply with technical, economic, environmental and societal aspects specific to gaseous biofuels obtained by thermochemical production. Faced by the need to secure biomass supplies, a major challenge lies in establishing economically optimised logistic chains. The optimisation can be realised by the use of intermodal transportation systems (road, rail, and river) and the corresponding supply platforms performing pre-treatment.

The method requires the building of structured and consistent databases including information on the location of resource, costs of different logistic services and platform scenarios (grouping, drying, pre-processing). Two methodologies are compared:

- Multi Dimensional Scaling (MDS)
- Linear programming

This approach allows optimum geographical positioning of the supply chain (port, train station, road transportation) and the calculation of the economic performances. The linear programming method can find with certainty the optimum solution based on the input data but it is time-consuming. The MDS-methodology proved to be faster for a similar output hence allowing to quickly test the impact of the parameters.

The results point out that the use of intermodal transportation systems and their corresponding pre-treatments is non-generalisable to all supply chain channels. Under current cost conditions, none of the analysed transportation systems is profitable, thus the largest gains can be achieved by reducing the supply radius. In future, if road costs increase by 40%, rail transportation could be a suitable option for resources located farther than 200 km. If we take the carbon footprint into account the river transportation will prove to be the most interesting alternative.

Introduction

This study is part of the research project GAYA that aims to develop and deploy on industrial pilot scale the production of 2nd generation biomethane. The production of the industrial site will be around 20 MW biomethane (approximately 120 000 dry tons of biomass) A key task is the design of the optimal logistic system for biomass supply. The key assumptions in this study relate to the annual consumption (200 000 dry tons) and the supply radius (about 250 km around the plant). In the baseline scenario, all biomass is transported by trucks from the forest site to the plant.

Alternative scenarios considered are:

- Crushing and/or drying on the forest site.
- Creating platforms to aggregate the biomass including the possibility of pre-treatments that will then allow different types of transport systems.
- Reducing the supply radius.

Material and methods

Hypothesis tested

Forest biomass is harvested in two forms: logs and chips. Based upon previous studies it is defined that both have a moisture content directly after logging of approximately 50%. In the baseline scenario, this biomass is transported directly from the forest to the plant. Several alternatives are tested:

- Natural drying of wood in the forest in order to carry less water.
- Chipping logs on the forest site and afterwards transportation of the chips (fresh or after drying)
- Grouping of the forest biomass on supply platforms and choosing an alternative transportation system :
    - Without transformation of biomass
    - Chipping logs and air dried chips
    - Chipping logs and drying in sheds
    - Chipping logs and kiln drying
    - Transformation of logs and chips into pellets

Three transportation systems are used:

- Road transportation: it is considered that the infrastructure can be adapted to the various needs. So its location can be defined and calculated to minimize the transport costs.
- Rail transportation: existing infrastructure has to be used, therefore the platform must be located near an existing station (252 stations in the study area)
- River transportation: it involves the same constraints as rail transportation, five independent ports exist in the study area plus one at the plant site. Two out of the six ports are located more than 100 km from the plant and are attractive for long-distance water transportation.

Data needed

The objectives of this study requires numerous data:

1. The quantity and the localisation of biomass resources available for new uses (resources that are not already exploited). The resources are estimated at the community level (6655 communities). Figure 1 shows a map of the study area
2. Geographical information: road, rail and river networks to compute transport distances between :
    - The resources and the plant,
    - The resources and the supply platforms,
    - The supply platforms to the plant.
3. Costs related to:
    - Handling
    - Transportation of the various forms of biomass for each mode of transport (road, rail, river) and the travelled distance.
    - Storage and pre-treatment of the biomass (drying, transformation of logs to chips or pellets)

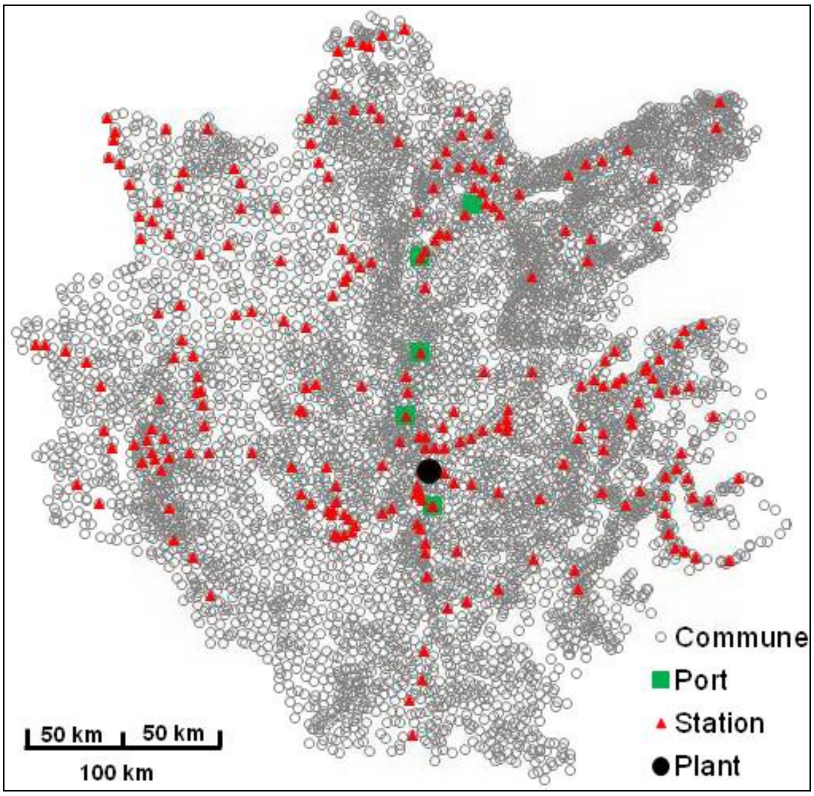

Figure 1: Localisation of plant, port, stations and communities with resource.

Statistical methods

The originality of this study is lies in the choice of economically interesting locations for the supply platforms. A supply platform of economic interest must be in an area where the resource is important and geographically concentrated. Indeed collecting wood in forest requires specifics trucks with low capacities and thus creates high transportation costs. It is therefore optimal to minimize the travelled distance by these specific trucks and the supply platforms.

Two analysis methodologies are tested to position supply platforms:

1. **Multidimensional Scaling (MDS):** it is used to group units by integrating similarities and differences.
   Four steps are carried out within this methodology:
   - Step 1: Principal Component Analysis (PCA) on the distances matrix between all communities and they are weighted by quantities of biomass in each community.
   - Step 2: Ascending Hierarchical Classification on the PCA axes (Ward method)
   - Step 3: All communities are assigned to a group; calculation of the cost of transporting biomass for each group :
     - From the forest directly to the plant
     - From the forest to a supply platform and then from the supply platform to the plant by adding handling, storage and pre-treatment costs
   - Step 4: Identification of best supply platforms for the plant.

2. **Mixed Integer linear Programming (MIP)**: it's a method to achieve the best outcome (lowest costs) in a numerical mathematical model. All costs (transportation, handling,

storage, pre-treatments) are included in the model. The optimisation program provides the best solution with the lowest costs.

The major difference between these two methodologies is their processing time: about a few minutes for the first methodology (MDS) in comparison to several hours for the second (MIP). However, the second methodology can find the optimum solution on the scenarios evaluated in our study (and on harder instances, it would always provide a gap to the best possible solution), whereas the first methodology identifies good and sometimes near-optimal solutions quickly and can be seen as a heuristic. In particular, MDS can be used to quickly test the impact of some parameters. So the two methods are complementary to each other.

Results

The results of the two methodologies are consistent.

Baseline scenario

In the baseline scenario, the cost of transportation for the total amount of biomass (200 000 dry tons) is 36 euros per dry ton. This cost varies depending on the real distance between the forests and the plant as shown in table 1.

	Biomass in the area		**Cost (€/dry ton)**
	Dry tons	**%**	
< 50 km	12 000	6 %	22,0
50 – 100 km	32 000	16 %	28,5
100 – 250 km	156 000	78 %	38,5
Total	200 000		36,0

Table 1: cost of transportation from forest to plant depending on their distances

Scenario without platform

The cost of chipping logs is high and cannot be compensated by lower transportation costs of chips. One option to reduce some of the costs is drying the chips in open air in the forest where they are harvest and produced (cost of drying considered null). The costs would then be 34.5 euros per dry ton instead of 36 for the baseline scenario. Still the gain is low because chips represent only 15% of the supply chain for the plant.

Scenario with supply platforms

The passage through the platforms causes additional costs. The tested scenarios show that these costs cannot be compensated by gains on transportation costs between platforms and the plant. The results are valid for the current costs of transportation and only if assessment of a supply chain is based on the cost criteria.

In our study, river transportation is not a real alternative as the ports are closely located to the plant. For rail transportation extra costs compared to the baseline scenario is about 8% in the best case. The most favourable alternative for train transportation is given, when the forest and the station are located more than 250km away from the plant. It means that if the costs of road transportation increase, the rail transportation may become economically attractive. Thus, if the costs of road transportation increase by 40%, about 10 000 dry tons could be transported by rail, when they are located farthest from the plant as shown on figure 2. This may also be the case for environmental factors.

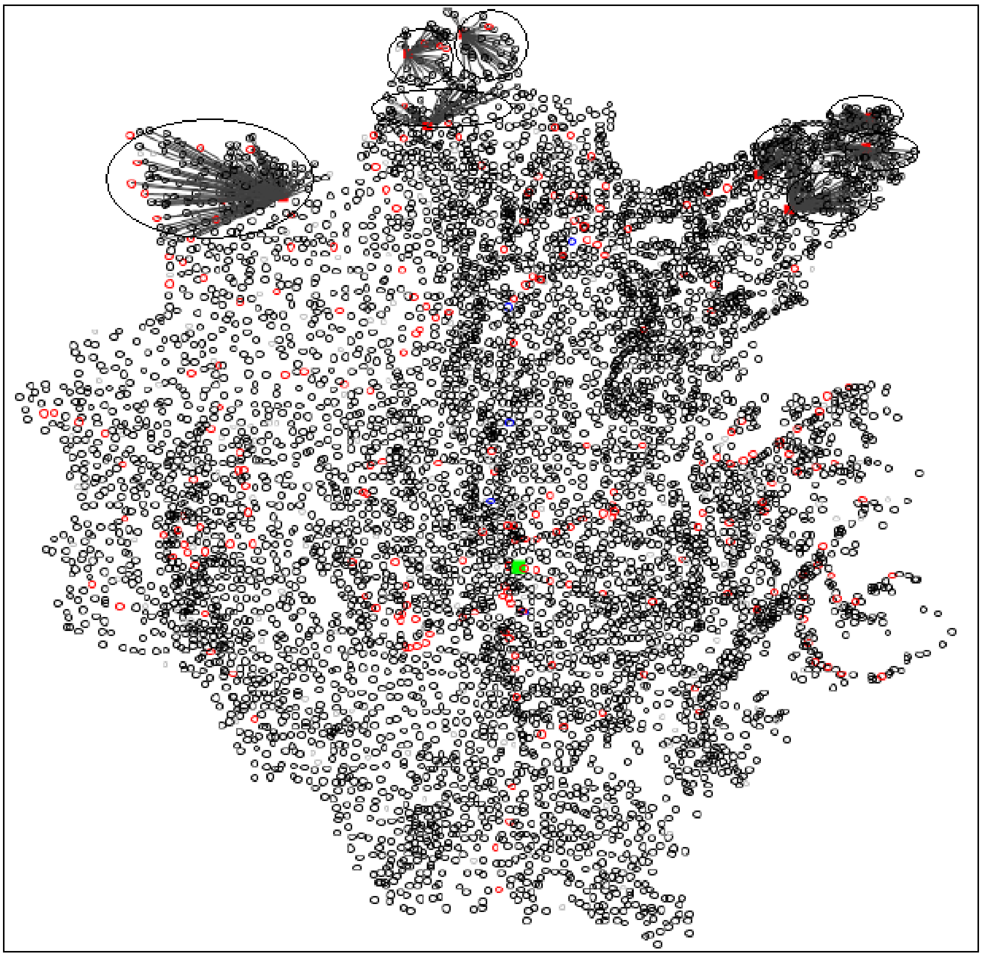

Figure 2: Interesting station in case of an increase in road transportation by 40%

Reduction of the supply radius

As the results of the baseline scenario show, the costs are highly dependent on the travelled distance. So, if possible, the supply radius should be shortened.

In the study area, the quantity of wood available for new uses (WANU) is quantified in each community. This wood can be logged and by definition will not be used by other traditional industries.

Therefore the volume of WANU is fixed for the entire study area and evaluated in practice to 10.7 millions dry tons.

The biomass supply for the plant is around 0.2 million dry tons. In the previous calculations the capture rate is fixed at 2% of the total volume for each community. It can easily be imagined to vary the capture rate by increasing it in areas close to the plant.

Two approaches are tested:

1. Keeping the total area of supply but varying the capture rate of biomass
2. Fixing a maximum biomass capture rate and limiting the distribution area.

For each approach, several maximum capture rates are tested. Table 2 shows the hypothesis tested in the first approach. For example an increased maximum capture rate of 8% of WANU shows that 80% of the biomass is located less than 100 km away from the plant in comparison to only 22% when a capture rate is fixed at 1,8%.

In the second approach, the maximum capture rates tested are 2%, 3%, 4% and 5%. Figure 3 shows the supply radius for a maximum rate of 5%.

	Rate in each radius				Part of total biomass in each radius			
Max rate →	**1,8**	**4**	**6**	**8**	**1.8**	**4**	**6**	**8**
< 50km	1.8	4	6	8	6	13	19	26
50-100 km	1.8	2	4	6.3	16	17	34	54
>100km	1.8	1.7	1.1	0.5	79	70	47	20

Table 2: Hypothesis tested in fixed area approach

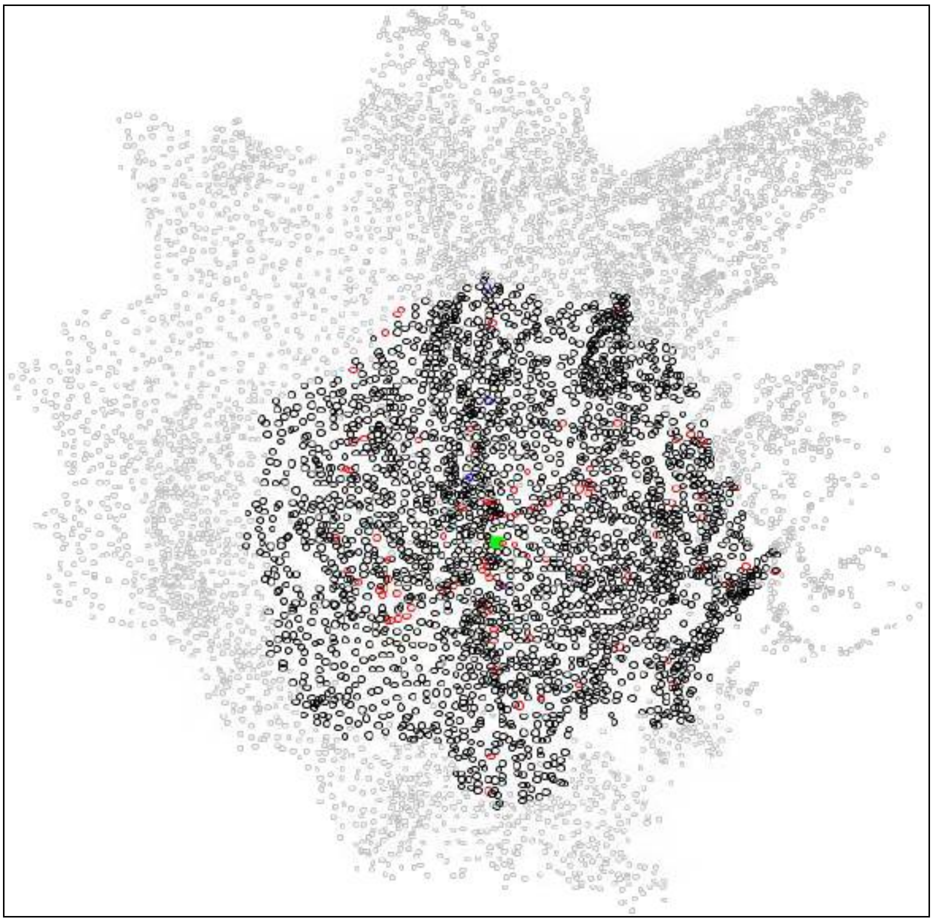

Figure 3: Supply radius with a maximum capture rate of 5%

By increasing the capture rate at a limit of 8%, it is possible to reduce 20% of logistic costs as shown in figure 4. This result is of course obvious: smaller is the supply radius and lower is the transportation cost. But the increase in capture rate can increase purchase price of biomass either because the demand if higher (market law), either because harvesting costs for this additional biomass are higher. Knowing the gain on the transportation cost, it is possible to know what additional cost can be supported on the purchase price of biomass in area close to the plant.

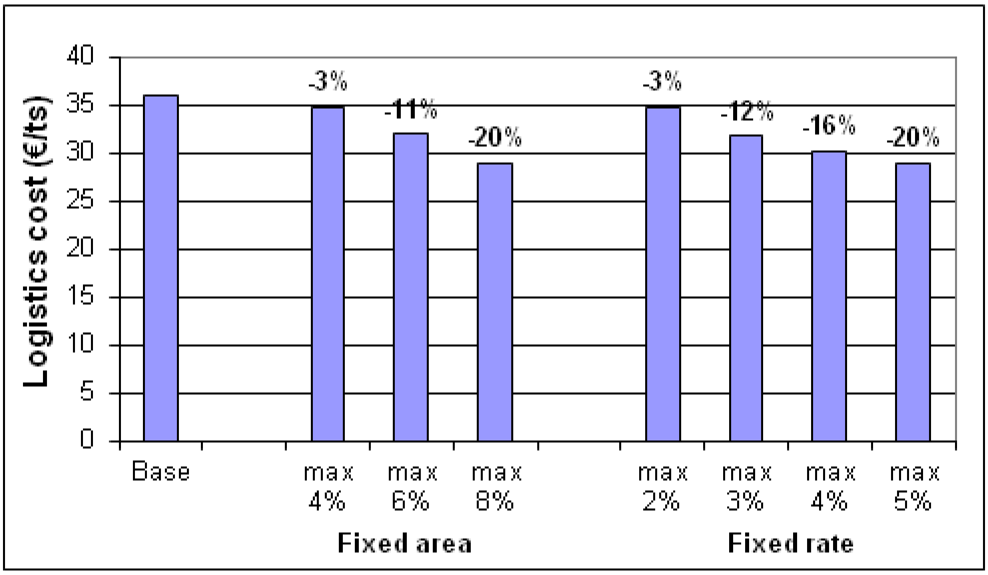

Figure 4: logistics cost with various capture rates.

Discussion

The results show the passage through a supply platform causes additional costs that cannot be compensated only by the reduction of transportation costs. In this study, it is assumed that the processing costs at the plants are constants regardless of the biomass. In practice, they may depend on the type of biomass (fresh logs or dry chips for example). These additional costs must be compared to the gain on transportation costs plus on processing costs. In this case, the results would certainly be different.

Only the available wood for new uses is considered at the moment and taking all available wood into account would likely change the spatial distribution of biomass and thus the conclusions. Indeed, some supply platforms could probably receive larger volumes and thus the management costs of the supply platforms could be lower.

The results of such a study are highly dependent on assumptions. The methodology developed under the GAYA project can easily be transposed to other case studies.

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