Delivery of sustainable supply of non-food biomass to support a
"resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

D3.4 + D3.6: Cover report
Results logistical case studies

16 December 2016




About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies, and roadmaps that will be informed by a "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

Project coordinator

FNR Fachagentur Nachwachsende Rohstoffe e.V.

Scientific coordinator

Imperial College London

Project partners

About this document

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Editor	E. Annevelink
Authors	E. Annevelink, B. Gabrielle, M. Carozzi, D. García Galindo, S. Espatolero, M. Izquierdo, K. Väätäinen, P. Anttila, I. Staritsky, B. Vanmeulebrouk, B. Elbersen & S. Leduc
Quality reviewer	R. van Ree

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Executive summary

A case based approach was followed, where optimal logistical concepts (conceptual designs) were matched with the specific regional situation. This was done in three logistical case studies that were performed:

1. Small-scale power production with straw and Miscanthus in the Burgundy region (France);
2. Large-scale power production with straw and with residual woody biomass in the Aragon region (Spain);
3. Advanced wood logistics in the Province of Central Finland.

Data on biomass availability and demand and quality specifications of the conversion technology have been used in combination with data on logistical components and concepts. These advanced regional case studies can be seen as an example for other regions in the EU-27. This cover report is closely connected to three D3.4 + 3.6 Annex reports that describe the three individual regional case studies in much more detail:

- Annex 1. Burgundy (France) (Annevelink et al., 2016b);
- Annex 2. Aragón (Spain) (García Galindo et al., 2016) and;
- Annex 3. Province of Central Finland (Väätäinen et al., 2016).

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1. Introduction

1.1 Aim of the logistical case studies

The logistical cases studies in WP3 follow the practical stepwise approach for the design and implementation of optimal sustainable biomass delivery chains that was described in D3.5 (Annevelink et al., 2016a). This logistical stepwise approach was used as a basis for the development of a set of assessment tools within WP4. A case based approach was followed, where optimal logistical concepts (conceptual designs) were matched with the specific regional situation. This was done in three logistical case studies that were performed in cooperation with WP9 'Regional adaptation & application, user integration, testing, validation and implementation planning'. The chosen advanced regional case studies are:

4. Small-scale power production with straw and Miscanthus in the Burgundy region (France);
5. Large-scale power production with straw and with residual woody biomass in the Aragon region (Spain);
6. Advanced wood logistics in the Province of Central Finland.

Data on biomass availability (WP1) and demand and quality specifications of the conversion technology (WP2) have been used in combination with data on logistical components and concepts (WP3) to provide guidelines for the case study partners in WP9 to construct relevant regional cases. These advanced regional case studies can be seen as an example for other regions in the EU-27.

This cover report is closely connected to three D3.4 + 3.6 Annex reports that describe the three individual regional case studies in much more detail:

- Annex 1. Burgundy (France) (Annevelink et al., 2016b);
- Annex 2. Aragón (Spain) (García Galindo et al., 2016) and;
- Annex 3. Province of Central Finland (Väätäinen et al., 2016).

1.2 Content of report

In Chapter 2 the used assessment methods are briefly described. Chapter 3 gives a general characterization of the three regional cases studies. Then a summary of the main results of these three case studies is compiled in Chapter 4. Finally the main conclusions and recommendations are repeated.

2. Assessment methods for logistical case studies

2.1 Introduction

Various logistical assessment methods have already been described in Deliverable D3.2 'Logistical concepts' (Annevelink et al., 2015). From these, the following methods have been chosen and further developed for further assessments in the logistical case studies for the S2Biom project:

- BeWhere for the European & national level;
- LocaGIStics for the Burgundy and Aragón case study at the regional level;
- Witness simulation model Truck Transport Logistics for the Finnish case.

2.2 BeWhere and LocaGIStics

BeWhere and LocaGIStics are closely interlinked so that LocaGIStics can further refine and detail the outcomes of the BeWhere model. Furthermore, the BeWhere model can use the outcome of the LocaGIStics model to modify their calculations if needed. The relationship between BeWhere and LocaGIStics in the S2Biom project is given in Figure 1.

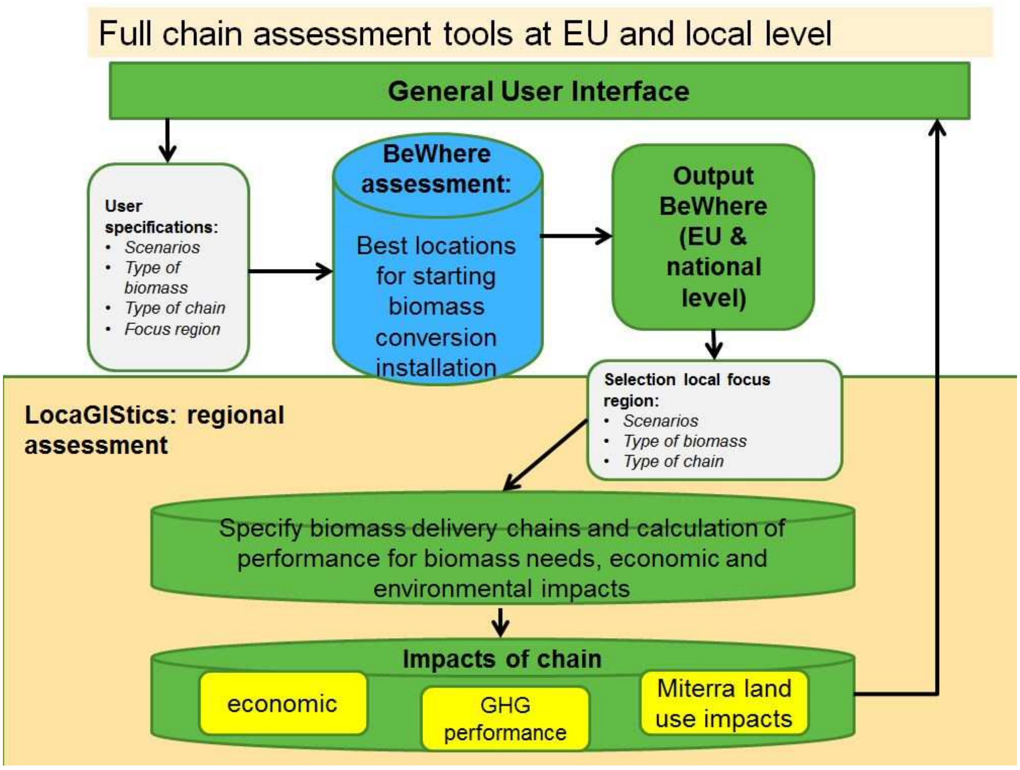

Figure 1. Relation between BeWhere and LocaGIStics.

These two assessment tools are described in further detail in D3.5 ‘Formalized stepwise approach for implementing logistical concepts using BeWhere and LocaGIStics’. So please consult deliverable D3.5 to better understand these tools.

2.3 Witness simulation model: Truck Transport Logistics

The *Truck Transport Logistics* simulation model was developed especially for the Finnish case study and is described in further detail in D3.4+D3.6 Annex 3 (Väätäinen et al., 2016). It was compiled in Witness simulation software and combined with an Excel-spreadsheet environment (Figure 2). A combination of these two tools enabled us to study the transport logistics of timber trucks from roadside storages to end-use facilities. Simulation runs are conducted in Witness, whereas the Excel-spreadsheet file controls simulation scenario parameters and combines time and performance data from Witness to cost accounting carried out in Excel workbook.

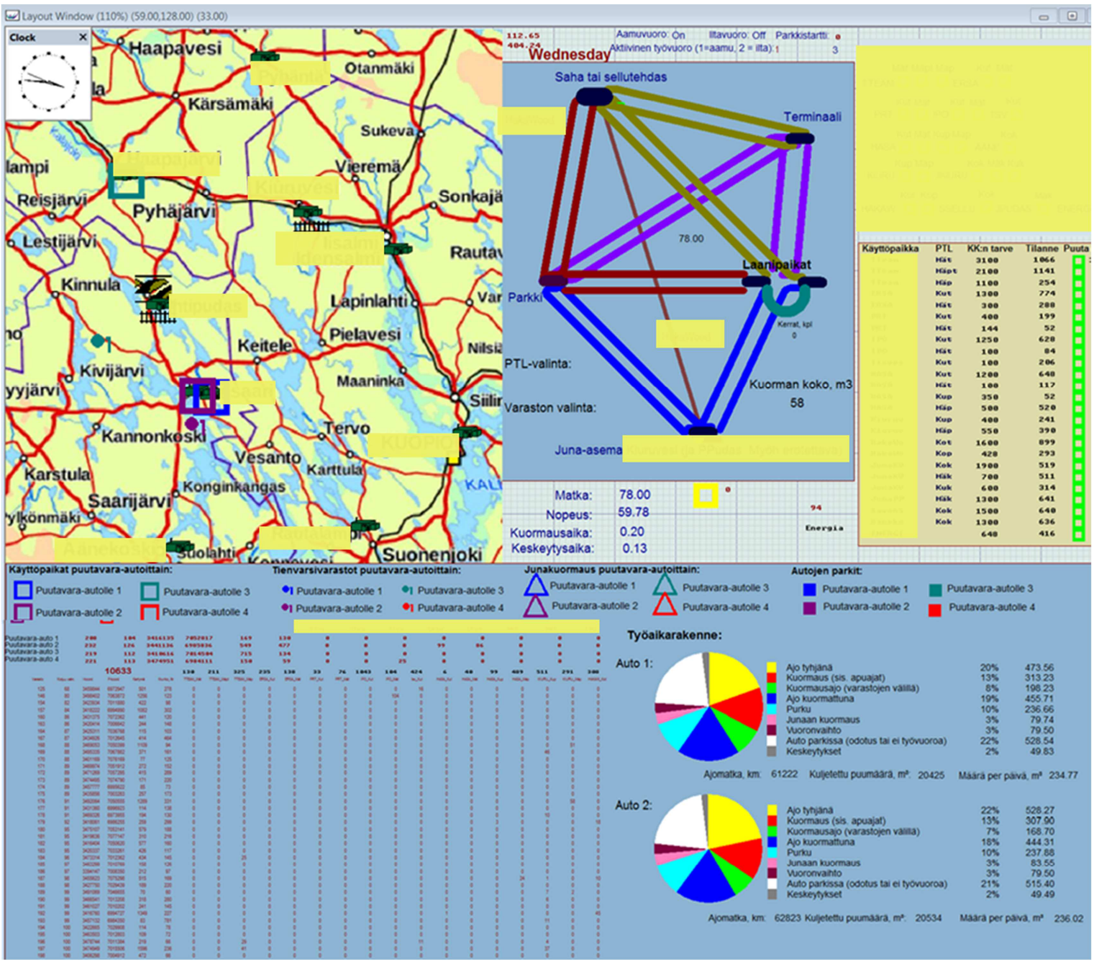

Figure 2. **A screenshot from the Truck Transport Logistics -simulation model in Witness® simulation software.**

3. General characteristics of the case studies

3.1 General characteristics of case 1 - Burgundy (France)

The case that was described originally in the LogistEC project (Gabrielle et al., 2015) focuses on the biomass crop Miscanthus. The case is about the small scale local production of Miscanthus pellets and the logistics are pretty simple: feedstock Miscanthus - harvesting as bales or chips - bales stored at the farm - and then transported to the pellet plant - where they are chipped and pelletized. The case in the LogistEC project does not include the further use of the pellets (yet) e.g. in a bioenergy power plant or in other applications. So it is only about producing intermediate products (pellets). Miscanthus pellets or chips may also be used for other purposes like animal bedding. Another application could be directly (without the pelletizing step) transporting the bales to a power plant with boilers that can burn bales directly.

So the focus of the Burgundy case study within S2Biom is on Miscanthus and also on straw. For these types of feedstock the BeWhere model will tell us where there is a possibility to locate the (new) biomass conversion factory specifying the type of technology and size (in this case small scale combustion power plants). The case for BeWhere is to determine best solutions for satisfying the energy demand in Bourgogne in terms of cost and GHG efficiency based on overall energy (electricity demand) and local biomass availability in different scenarios. In order to make this assessment in BeWhere there is a need for detailed biomass potentials and electricity and heat demand.

LocaGIStics will then take the information on the size and type of technology and assess how the organisation of the biomass delivery chain should look like in terms of logistical concepts, specifying e.g. alternative user defined locations for a conversion plant, and for intermediate storage and pre-treatment alternatives given different types and amounts of Burgundy biomass use, etc.

3.2 General characteristics of case 2 - Aragón (Spain)

The case study Aragón has been developed in close cooperation with Forestalia Group. In 2016, Forestalia started the promotion of the Monzón, Zuera and Erla power plants. These facilities are located in the Region of Aragón and they are the main target of the case study here presented. They were scoped to be fed only by means of energy crops wood, but Forestalia Group is also interested in exploring the potential role of other biomass resources. For the present case, the fuel mix targeted consists of 70% energy crops and 30% agriculture residues. The aim of the case study consists of the definition of the area of supplying nearby the plants and the determination of the biomass cost at the plant gate for each feedstock and for every supply chain concept.

Within this case study, CIRCE and WUR-FBR have made use of LocaGIStics for determining the feedstock potential and the supply cost of biomass at plant gate considering the three power plants together and separately. In first place, available potential of different agricultural residues has been obtained in order to select main feedstock options. Finally, the case study has been focused on two main biomass: straw and stalk from annual crops (winter cereals, summer cereals, sunflower) and wood from olive, fruit and vineyard plantations removal, both above ground and underground biomass. Then, for each feedstock option, different supply chains have been defined:

- Herbaceous agricultural residues
    - Case 1.1: Straw and stalk from annual crops (Figure 3).

- Wood from olive, fruit and vineyard plantations removal
    - Case 2.1: Underground biomass (UGB): small plantations, removal and transport to collection point done by farmer.
    - Case 2.2: Aboveground biomass (AGB) and UGB: small and medium plantations in areas with relevant density of permanent crops; removal in charge of Forestalia Group.
    - Case 2.3: AGB and UGB separated: large plantations, removal in charge of Forestalia Group. Biomass obtained separately to avoid mixing.

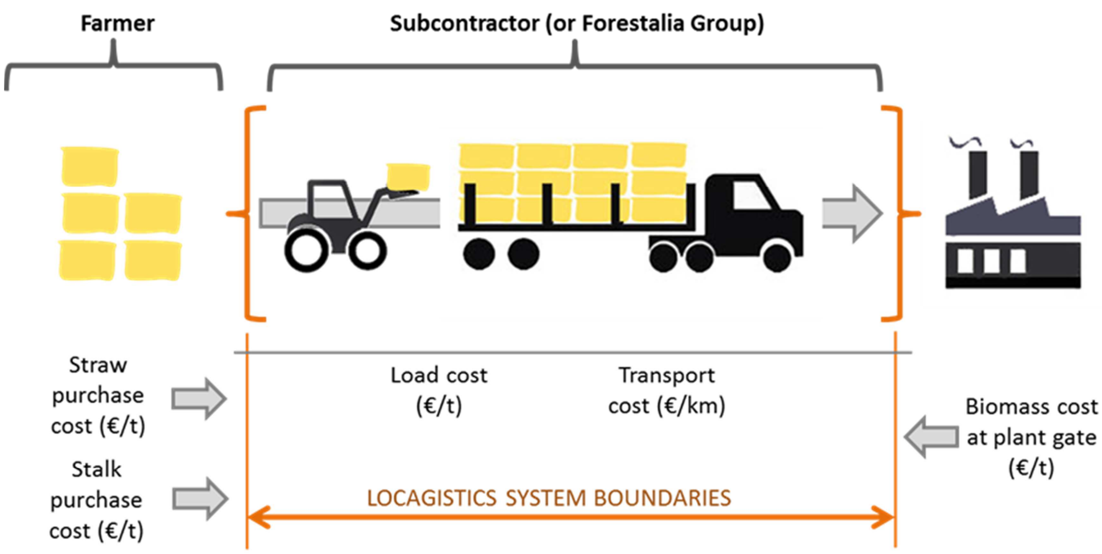

Figure 3. **Example of the description of a chain in the Aragón study for Case 1.1.**

3.3 General characteristics of case 3 - Province of Central Finland

In the Finnish case study, saw logs, pulp wood and de-limbed energy wood stems were transported to end-use facilities. In total, 25 different timber assortments were included in the supply chain of this case. Currently, each timber assortment is transported as single-assortment loads to the end-use facility. Due to the small volume of individual assortments in a roadside storage, the timber trucks often have to collect timber from several roadside storages to obtain a full load. This kind of driving between piles at different roadside storages and setup times at these piles are relatively time consuming elements in the whole transport cycle. Therefore, a scenario with a multi-assortment load option was introduced to the case study. The multi-assortment load opportunity is only available for timber assortments, which are all transported to a same end-use facility.

In the Finnish case study, the Witness simulation model included four trucks operating in Central Finland and supplying timber to 12 end-use facilities being eight saw mills, two pulp mills and two train loading terminals. A simulation run covered a period of one year. Each scenario was simulated by five stochastic repetitions and the average values of these five repetitions were used for calculating the result data of a certain scenario. Two simulation scenario sets were simulated in Finnish case study. The business as usual scenario corresponded to timber transports with the single-assortment load method, whereas the multi-assortment scenario included the multi-assortment load transports. Each simulation scenario was repeated five times and the averages of the five repetitions were used for comparing scenario results.

4. Main results

4.1 Case 1 - Burgundy (France)

BeWhere results

When it comes to optimizing the number of plants for the whole region, where the only constraints are the biomass availability and the heat demand, the final solution looks like as presented in Figure 4. The plants are mainly located where the heat demand is the highest (Figure 4, right). The technology chosen remains the same for all plants as well which is a grate boiler for CHP, with a capacity of 10 MW_{th}.

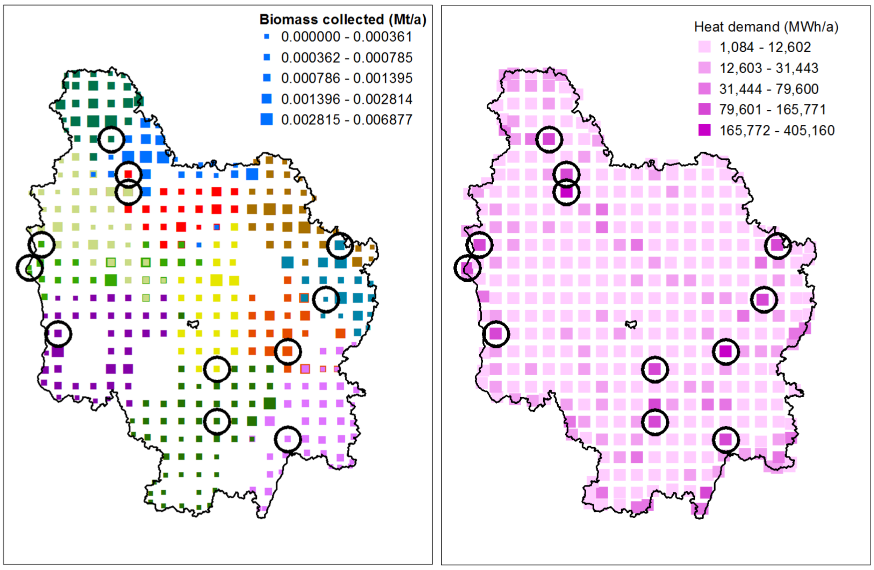

Figure 4. **Location of the production plants on top of their respective collection points (left) and the heat demand (right). A same color of the biomass location means that the biomass is collected to the same plant which usually is located within the corresponding colored area.**

As can be noticed the location of the feedstock collected is no longer within a circle around the plant, but some optimal distribution around the plant balancing transport cost, availability and collection cost. This means that heat demand has a greater impact on the location of the plant than the biomass, which is collected within distances ranging from 70 to 158 km. The model allows some flexibility in the production and may not operate at full capacity, explaining the differences in power and heat generation (see Table 1).

Table 1. Overview of the bioenergy plant locations, biomass collection and energy carrier generation.

No	Longitude deg	Latitude deg	Max collection distance (km)	Straw (kt/a)	Miscanthus (kt/a)	Power (TJ/a)	Heat (TJ/a)
1	3.59	47.78	146	17	13	128	306
2	4.87	47.03	121	13	17	128	306
3	4.35	46.92	146	12	18	128	306
4	2.90	47.35	143	6	15	89	214
5	2.97	47.47	158	11	18	126	302
6	5.13	47.31	70	18	12	128	306
7	5.20	47.58	114	20	10	128	306
8	3.15	47.03	109	14	14	122	293
9	3.42	48.04	79	18	12	128	306
10	4.91	46.58	103	16	14	128	306
11	4.38	46.65	108	10	17	115	276
12	3.58	47.86	108	16	14	128	306

LocaGIStics results

The LocaGIStics tool was used to further detail the biomass value chain of one of these possible locations. Five variants were calculated for one specific power plant location:

1. Power plant & no biomass yard; only straw;
2. Power plant & no biomass yard; straw & Miscanthus;
3. Power plant & one biomass yard; straw & Miscanthus;
4. Power plant & two biomass yards; straw & Miscanthus;
5. Power plant & two biomass yards; only straw.

Table 2. Main results of the five variants.

Variant no.	Financial profit (€)	Energy profit (GJ)	Net GHG avoided (ton CO_2-eq)
1	1,863,492	356,738	35,208
2	3,173,480	377,106	37,285
3	2,939,348	377,532	37,337
4	3,008,029	385,318	38,107
5	1,553,969	359,421	35,477

The exact calculation results were of less importance in the Burgundy case than the testing process during the development of the new LocaGIStics tool. However, some results are shown here to give an impression of the effects of the choices in the different variants. The results of the five variants are summarized for financial profit, energy profit and net GHG avoided in Table 2. As an example the results of Variant 2 are described below. More results are given in the Annex 1 report (Annevelink et al., 2016b).

Variant 2 – Power plant & no biomass yard; straw (33%) and Miscanthus (100%)

Characteristics variant 2 - Again 33% of the overall straw production, but now also 100% of the grown Miscanthus is available as feedstock. Again there is no intermediate collection point (biomass yard), so all raw biomass is transported by truck straight to the site of the power plant. Therefore, the biomass is only loaded and unloaded once in this variant. At the site of the power plant the raw biomass is first stored in open air during an average of 4.5 months, then pelletized, and then the pellets are again stored under a cover for an average of 4.5 Months. Before the pellets can be fed to the power plant they need to be grinded. The demand of the power plant is 30,000 t dm per year.

Results variant 2 – The main results are shown in Table 3. The map with the collection area of the Miscanthus is shown in Figure 5. The demand of the power plant is completely met. The maximum collection distance is 17.5 km which is 15 km lower than the collection distance in variant 1. Variant 2 has a smaller supply area, because more biomass (Miscanthus) is now available at a closer distance. The transport amount is 298,544 ton.km which is about 2.4 times smaller than the 709,961 ton.km in variant 1 due to the smaller collection area. The purchase costs of variant 2 are much lower than in variant 1 because more than 2/3 of the sourced biomass is now Miscanthus with a much lower price (8.82 €/t dm). The storage costs are again relatively low 60,815 € compared to the variants 3 until 5, because there is only open air storage. The transport costs are relatively low compared to variant 1, because of the smaller collection area in variant 2. Loading and unloading cost the same as in variant 1, but lower than in variant 3-5, because they only occur once in variant 1 and 2. The pre-treatment costs are more or less the same for all variants. The variable conversion costs are more or less the same for all variants and the fixed conversion costs are exactly the same for all variants. The revenues in variant 2 with both straw and Miscanthus are higher than in the variants 1 and 5 with only straw. This is caused by the higher energy content of Miscanthus (HHV 18.5 GJ/t dm) compared to straw (HHV 17 GJ/t dm). So more electricity and heat can be sold if the 30,000 t dm only consists of more Miscanthus and less straw. The overall financial profit of variant 2 is the best of the five, because of the relatively lower costs and higher revenues.

Remarks - The size of the collection circle can also be influenced by placing intermediate collection points in the middle of densely occupied biomass areas. To see this effect one intermediate collection point was included in Variant 3.

Table 3. Main results Variant 2.

Variable	Straw	Miscanthus	Total
Logistics			
Maximum collection distance (km)	17.5	17.5	17.5
Collected biomass (ton dm)	8,782	21,321	30,103
Transport amount (ton·km)	86,847	211,697	298,544
Costs			
Purchase costs (€)	395,186	188,051	583,237
Storage costs (€)	17,783	43,175	60,958
Transport costs (€)	10,644	25,945	36,588
Loading/Unloading costs (€)	11,416	27,717	39,134
Pre-treatment costs (€)	816,592	1,982,545	2,799,137
Variable conversion costs (€)	263,457	639,630	903,087
Fixed conversion costs (€)	-	-	625,000
		Total	5,047,141
Revenues			
Electricity (€)	-	-	7,198,985
Heat (€)	-	-	1,021,635
		Total	8,220,621
Profit			
Financial profit (€)	-	-	3,173,480
Energy profit (GJ)	-	-	377,106
Net GHG avoided (ton CO_2-eq)	-	-	37,285

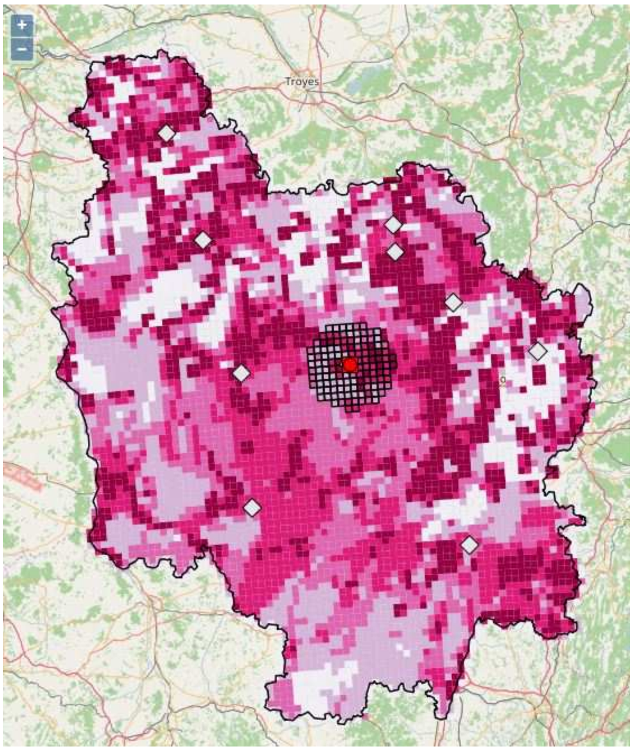

Figure 5. Map Miscanthus for Variant 2.

4.2 Case 2 - Aragon (Spain)

Based on the supply chains, some scenarios were analyzed by LocaGIStics for the two feedstock options in terms of the number of power plants and their sites, the biomass availability, the total demand per plant and the presence of collection points.

Case 1.1 results show the amount of herbaceous biomass is enough to cover the annual needs of the three power plants in any case. Competition problems appear between Erla (Figure 6) and Zuera power plants and consequently, biomass collecting distances are higher than for Monzón power plant supply. Regarding the final price at gate, Monzón power plant always shows the minimum value, between 43-44 €/t dm. Although Erla and Zuera have a similar fuel price at gate considering 100% biomass availability, in the case of Erla power plant, this price yields a remarkable increase when just a 50% of biomass is available. When the power plants are analyzed individually, the results are different since competition between plants does not take place. The Monzón power plant seems to be the one with lower distances but when just 25% of biomass is available, the collection distance increases above the other two power plants.

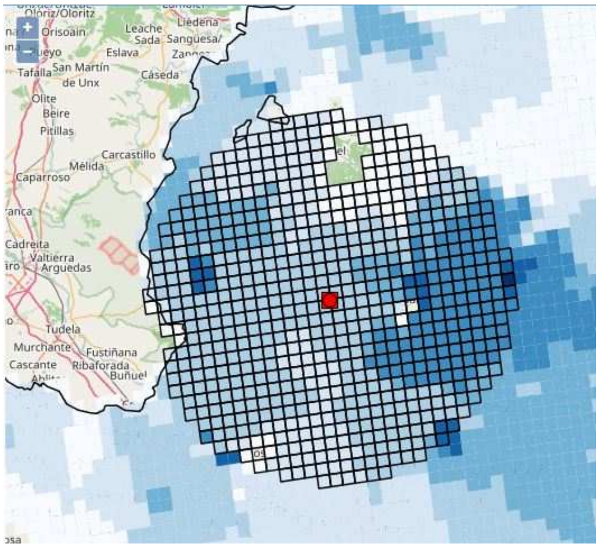

Figure 6. Example of the sourcing of straw from winter cereals for the Erla power plant in a single plant calculation (scenario 002).

Regarding wood plantations removal option, there is not enough biomass close to the different sites in order to cover the whole demand of the power plants (not even one of them). Two of the supply chain concepts proposed (Case 2.1 and Case 2.2) have a purchase cost higher than the price at gate limitation considered by Forestalia Group (57 €/t dm), so it is obvious than both chains are not feasible with this price at gate limitation. The Case 2.3 supply chain is the most promising one. Prices are below the Forestalia limitation for all the power plants. Comparing now the three locations, Monzón suffers lower competition effects than Erla and Zuera and it shows the lowest price at gate.

In order to complete the analysis, the Zuera power plant was studied alone for obtaining the variation of the results regarding the availability percentage from 100% to 25%. To this context, availability has not significant influence on price at gate (€/t). However, biomass collected amount is reduced from 60,000 t (100%) to 24,600 t (25%) and maximum distance is also increases from 82 to 130 km.

4.3 Case 3 - Province of Central Finland

The multi-assortment method decreased the time consumption particularly for driving between piles (see Figure 7). The number of rides between piles was 1,152 times in the single-assortment load method, whereas in the multi-assortment load method driving between piles was 794 times. This is a 31% decrease. On the other hand the off-shift time increased in the multi-assortment load method mainly because of roadside storages was finished earlier during June before the holiday month (July) in the multi-assortment load method.

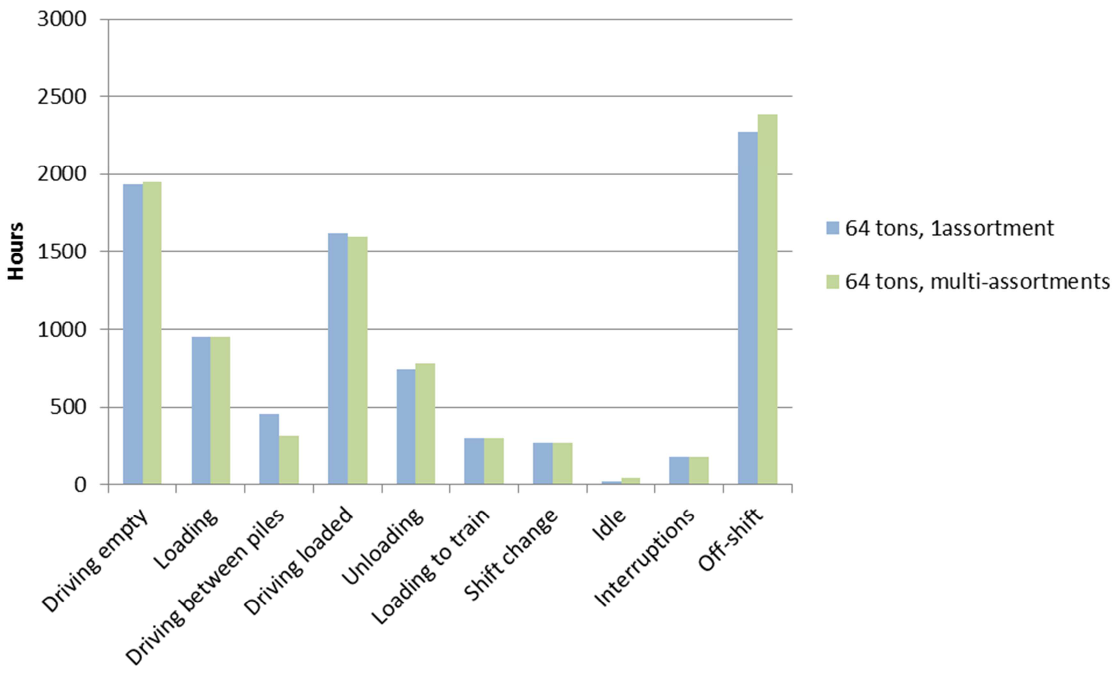

Figure 7. Time element distribution and time durations for studied scenarios. One year simulation experiments.

The multi-assortment load method was on average 3.3% cheaper than the single assortment load method (Figure 8). In addition, the driving performance - presented as solid-m³ of timber per 100 kilometers - was 4.0% higher with the multi-assortment load method.

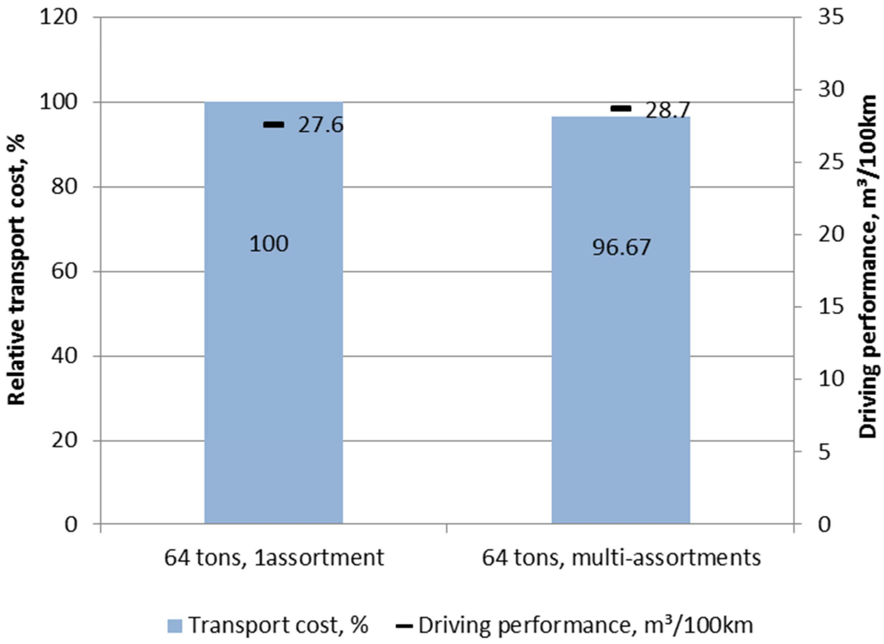

Figure 8. **Relative transport costs and driving performance in the scenario comparisons. A cost level of 100% was set for the single-assortment load method.**

5. Conclusions and recommendations

5.1 Conclusions

Burgundy

The BeWhere model has been applied for the case study of Burgundy in order to identify the optimal locations of bioenergy production plants. The locations of the plants were highly driven by the location and amount of the demand of heat. The collection points of the biomass are very well concentrated around the production plants.

LocaGIStics was used as a quality check of the feedstock collection, capacity and therefore the validity of the chosen location. Several logistical concepts have been tested with LocaGIStics in the Burgundy case. These are: i) mixing different biomass types (straw as a biomass residue and Miscanthus as an energy crop), ii) applying pretreatment technology (pelletizing) to densify the material in order to lower the transportation costs and increase handling properties, iii) switching between different types of transport means (truck and walking floor vehicle) and iv) direct delivery to a power plant versus putting an intermediate collection point in the value chain.

Because the case was used to develop LocaGIStics, less value should be given to the exact results of the five variants that are described in this report. However, these variants are perfect examples of what effects can be achieved if the set-up of a lignocellulosic biomass value chain is changed, even if that change is only slightly. So the case was used successfully to build a first version of the LocaGIStics tool. However, many improvements are still possible and could be achieved in future project cases.

Aragón

After analyzing the results, it seems clear that in terms of biomass availability and supply chains definitions, the Forestalia Group should focus on straw and stalk as main feedstock option. Case 1.1 is technical and economically reliable and there is enough biomass for fulfilling the three power plant fuel requirements.

Regarding wood plantation removal, supply chains Case 2.1 and Case 2.2 are not profitable. So, a solution could be that the collection points where farmers dump their residues ask for a fee to the farmers or increase the service price. Pretreatment operations at the power plant with static equipment could reduce costs in comparison to mobile units (e.g., primary crusher could be moved to the fields and then the shredded material to be transported directly to the power plant, where static screening and chipping machines would treat the material). Case 2.3 is by far the most suitable. It is based on large fields, and therefore, the best conditions are available.

LocaGIStics has been successfully adapted to Forestalia Group requirements in order to run all the supply chains and scenarios proposed. It can be perfectly used to obtain the cost of biomass at plant gate (€/t) considering only the purchase cost and the logistic chain costs, without taking into account the power plant characteristics and IRR and NPV calculations.

Province of central Finland

The Witness simulation model *Truck Transport Logistics* has proved to express well the behavior of truck transports of timber. The model could be used for supporting decisions on enhancing the transport operations. Compared with the other logistical assessment methods in S2Biom, i.e., BeWhere and LocaGIStics, *Truck Transport Logistics* is the most detailed one. This means that it can simulate the operation of real logistical chains and even the interactions between logistical components and stochasticity can be taken into account. The downside of this ability is that very detailed input data, which not always is available, is needed. The model also needs to be tailored to the operating environment which requires expertise.

The multi-assortment load method that was studied in the Finish case offers a nearly 4% improvement potential for the transport economy compared to the prevailing single-assortment load method. Small assortment piles at roadsides cause difficulties in efficient timber transport due to driving between piles and the need of loading many small piles for filling the entire load space. The multi-assortment load method decreases drastically the number of rides between piles and, therefore, improves performance of the fleet.

5.2 Recommendations

Burgundy

The BeWhere model is a tool useful for policy planning, because it indicates what technology should be used in which region providing a specific energy or emission target. The results of the model need further analysis from a LocaGIStics model that will conduct a very detailed analysis of the economic feasibility of setting up a new production plant in a particular region. For good energy planning for biomass based industries, both models are very much complementary and useful.

Now the Burgundy case was primarily used for developing the new LocaGIStics model. The variants that were presented in this report were especially aimed at creating different circumstances for the model to be tested. The LocaGIStics model was shown to potential users (agricultural advisors and the manager of BP), and they confirmed that the tool was relevant to address the design and optimization of their value-chains. However, for a 'real' logistical assessment further research will need to be performed. The LocaGIStics model can still be further improved to make it more flexible so that it can deal with a variety of different biomass value chain set-ups.

Aragón

The use of collection points would improve the management of the straw and stalk supply chain. Transport cost would be slightly higher but the supply security would be higher too and in addition, pretreatment costs could be reduced.

The work done has revealed that the initial strategy for biomass procurement of Forestalia Group can be improved. This has been specially evident in the case of biomass procurement from the wood residues of vineyards, fruit and olive trees plantation removals. So the wood plantation removal supply chains must be rethought. Case 2.1 and Case 2.2 supply concepts are not profitable in any case. Just Case 2.3. shows good results but this supply chain can only be applied in large fields and not enough biomass can be collected. For instance, as it was stated in previous section, all the cases would be improved if the only machinery mobilized to field was the primary shredder and then transport material to the plant where a static screening and chipping was performed.

As recommendations, some actions have been proposed in order to improve the tool LocaGIStics. For instance, road distance method for transport costs calculation should be improved in order to obtain more accurate results. In addition, we have pointed out that when several power plants are included in the analysis, some potential competition limitations appear and final results and figures might depend on the resolution order of each plant.

Province of central Finland

Research topics for the future in timber transports by road with the Witness simulation model would be to study the effect of bigger roadside storage sizes, smaller number of timber assortments, including terminals and including high capacity trucks for long distance transports. In addition, the influence of bigger trucks for transporting timber from roadside storages to mills could be tested with the Witness simulation model.

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