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: Annex 2
Results logistical case studies
Aragon

22 November 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

Scientific coordinator

Project partners

About this document

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Editor	E. Annevelink
Authors	D. García Galindo, S. Espatolero, M. Izquierdo, I. Staritsky, B. Vanmeulebrouk & E. Annevelink
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Executive summary

The following report includes the analysis and results of the case study Aragón. It 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

- Wood from olive, fruit and vineyard plantations removal
    - Case 2.1: UGB: small plantations, removal and transport to collection point done by farmer.
    - Case 2.2: 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.

Based on these 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 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.

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.

Some conclusions and recommendations have been proposed after results analysis. For instance, 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. Regarding wood 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 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.

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1. Introduction

The case study Aragon has been developed in close cooperation with Forestalia Group. The Forestalia Group was established in 2011 in Zaragoza (Aragón, Spain) and it is focused on wind energy and energy crops. Currently, it owns energy crops in Spain, France and Italy, it is building the largest pellets facility in Spain and it promotes biomass power plants all around the country. In 2016, Forestalia Group started the promotion of five new power plants in Spain: Monzón (Huesca): 49,5 MW, Zuera (Zaragoza): 49,5 MW, Erla (Zaragoza): 49.5 MW, Cubillos del Sil (León): 49.5 MW, La Vega Requena (Valencia): 15 MW and Lebrija (Sevilla): 9.98 MW. The Monzón, Zuera and Erla power plants are located in the Region of Aragón and they are the main target of the case study here presented.

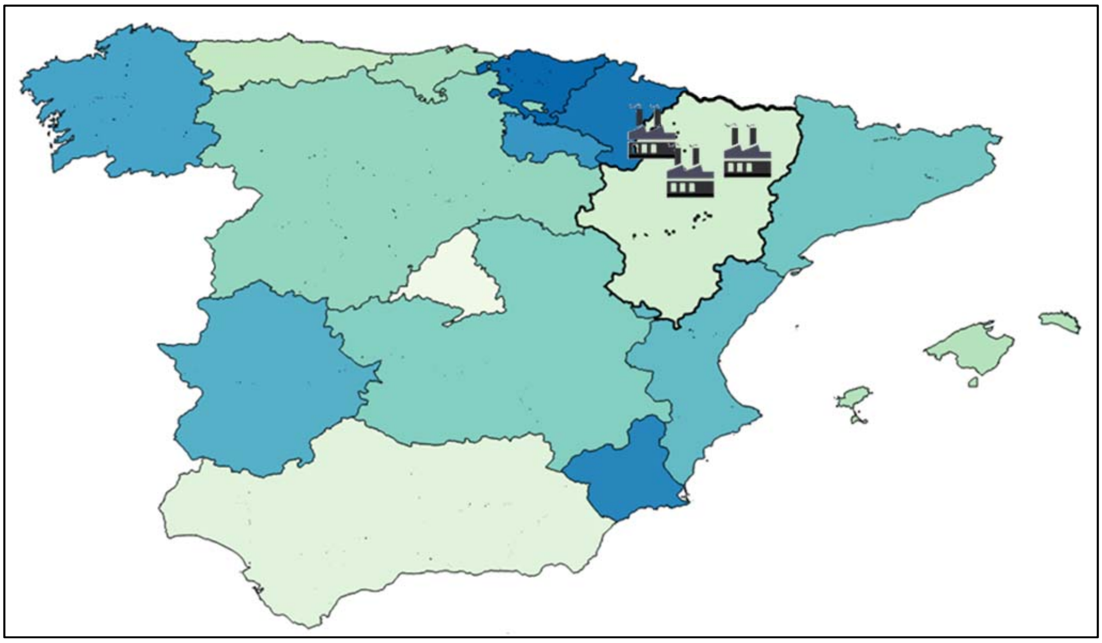


Figure 1. Forestalia Group biomass power plants location (Aragón, Spain).

The three power plants are going to be identical in power. 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. Forestalia Group would control the expansion of energy crops for the future procurement of the power plants, but, is also studying the availability of the different biomass types close to their facilities in order to complete the total fuel needs of the plants.

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, then two types of agricultural residues have been selected and finally, four different supply chains have been implemented and analyzed with LocaGIStics.

1.1 Aim of logistical case studies

The aim of the case study consists of the determination of the biomass cost at the plant gate for each feedstock and for every supply chain concept. In this particular case, Forestalia Group has already defined the conversion technology for their power plants (circulating fluidized bed boilers), thus the target of the logistical study is the calculation of the fuel price and the definition of the area of supplying nearby the plants.

1.2 Content of report

This report includes a brief introduction of the context and scope of the case study. Then, within section 3, can be found a description of the location and the biomass potential in the site close to the power plants in the region of Aragón. In addition, the supply chains are defined for the different feedstock options. The type of data requirements and the actual data used for the case study are presented in section 4 and section 5, respectively. Finally, the results are including in section 6. For each scenario, the main results table and the collection areas for every power plant are established and here presented. In section 7, some conclusions and recommendations are proposed.

2. Assessment methods for logistical case studies

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

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

BeWhere and LocaGIStics have been closely interlinked so that LocaGIStics can further refine and detail the outcomes of the BeWhere model and 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 2. These tools are described in further detail in D3.5 'Formalized stepwise approach for implementing logistical concepts (using BeWhere and LocaGIStics) so please consult that deliverable to understand the tools. The Witness simulation model was not used for the Burgundy case.

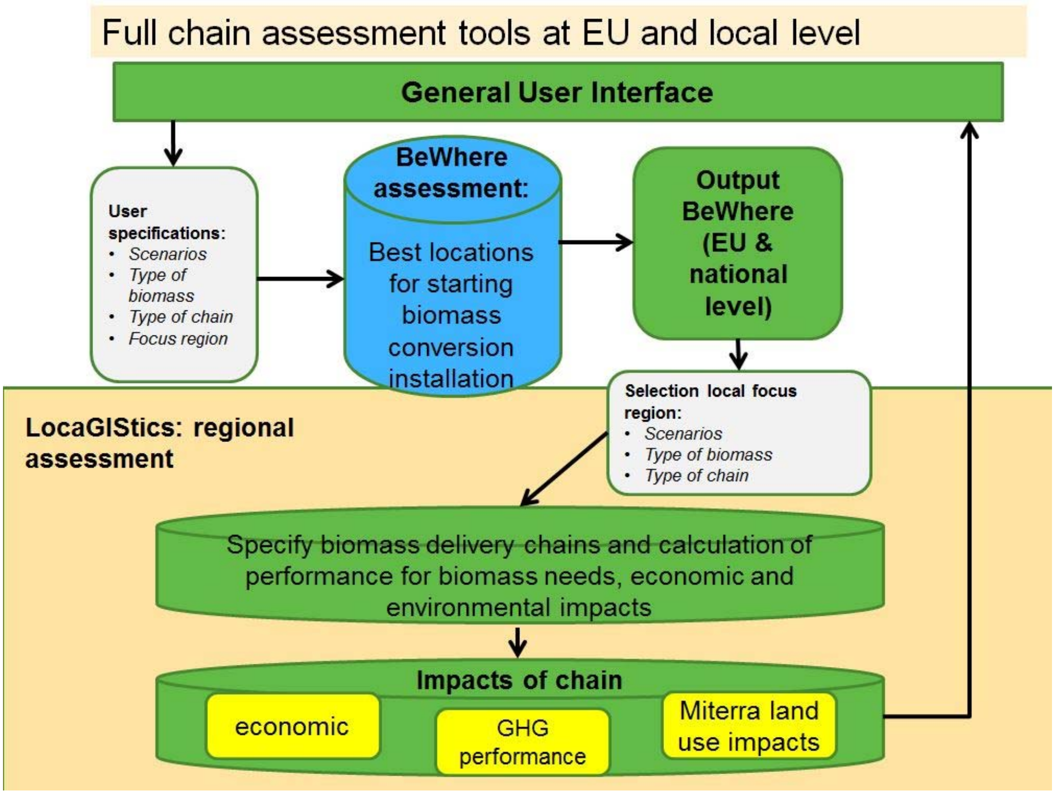


Figure 2. Relation between BeWhere and LocaGIStics.

3. Set-up of the case study

3.1 Introduction

Forestalia Group is promoting three new biomass power plants in Aragon region. The electrical power output of these facilities is 49.5 MWe each one. The fuel fed into the boiler is a mix of 70% energy crops and 30% agricultural residues. The objective of this case study consists of determining the biomass availability of the agricultural residues and the optimum logistic supply chain. For this purpose, the tool LocaGIStics has been used in order to obtain the biomass cost supply at plant gate.

3.2 The region

The area of interest for the case study covers Aragon region (see Figure 1). The total area is about 47,719 km^2. In a very first approach for the accounting of the biomass potential, a 50 km radius around the location of the three power plants was defined. Specific datasets available from CIRCE projects were utilized. Once the area of interest was set, the surfaces corresponding to the different crops were quantified in every spatial unit's NUTS-5 (see Figure 3).

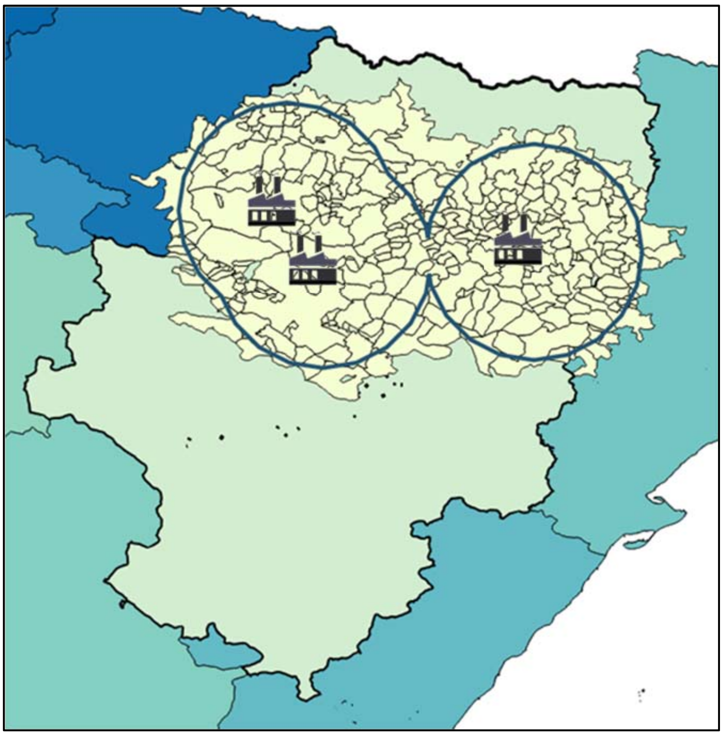


Figure 3. Area of interest for preliminary biomass potential quantification

Then, the different agricultural crops have been ranked and some of them have been chosen according to their presence in the zone of interest, their available potential and the residues characteristics (see Table 1 and Table 2). The total potential refers to the total agricultural residues produced per year (theoretical potential) and the available potential refers to the biomass without any other competitive use and therefore, it can be totally used as energy biomass (technical and competitiveness constraints have been accounted, though economic restrictions have not been applied). So, it is not fully comparable with the datasets produced at EU level in S2Biom WP1, where theoretical, technical, base and user defined potentials are being utilized. It must be noted that for the present work the specific databases for Aragón are being utilized, instead of the generic NUTs3 datasets produced by S2Biom for the whole Europe.

Table 1. Area and biomass potential (wet basis, straw and stalk: 10% humidity, 20% humidity prunings).

GROUP	CROP	AREA (ha)	TOTAL POTENTIAL (t/year)	AVAILABLE POTENTIAL (t/year)	GROUP AVAILABLE POTENTIAL (t/year)
Winter cereals (straw and stalk)	Barley	317,058	884,592	176,918	287,386
	Wheat	188,218	530,775	106,155	
	Oat	9,160	18,870	3,774	
	Rye	1,731	2,692	538	
Summer cereals (straw and stalk)	Maize	74,990	301,460	211,022	211,307
	Sorghum	952	1,428	286	
Dry fruit (prunings)	Almond	21,089	27,416	24,674	24,674
Stone fruit (prunings)	Peach	17,199	38,285	34,456	37,184
	Cherry	1,048	1,515	1,364	
	Apricot	627	962	866	
	Plum	360	553	497	
Seed fruit (prunings)	Pear	12,243	45,054	40,549	53,097
	Apple	4,552	13,943	12,548	
Olive (prunings)	Olive oil	16,676	20,862	16,689	16,689
Vineyard (prunings)	Grape	11,215	23,866	21,479	21,479

GROUP	CROP	AREA (ha)	TOTAL POTENTIAL (t/year)	AVAILABLE POTENTIAL (t/year)	GROUP AVAILABLE POTENTIAL (t/year)
Industrial (straw and stalk)	Sunflower	8,430	13,404	9,383	10,337
	Rapeseed	1,273	1,910	955	

Table 2. **Area and biomass potential. Wood from fruit, vineyard and almond plantations removal (above ground and underground biomass).**

ABOVE GROUND BIOMASS		AREA (ha)	TOTAL POTENTIAL (t/year)	AVAILABLE POTENTIAL (t/year)	GROUP AVAILABLE POTENTIAL (t/year)
Wood	Fruit	36,029	36,029	25,220	40,778
	Vineyard	11,215	5,608	4,486	
	Almond	21,089	15,817	11,072	
UNDER GROUND BIOMASS					
Wood	Fruit	36,029	25,220	25,220	41,305
	Vineyard	11,215	4,486	4,486	
	Almond	21,089	11,599	11,599	

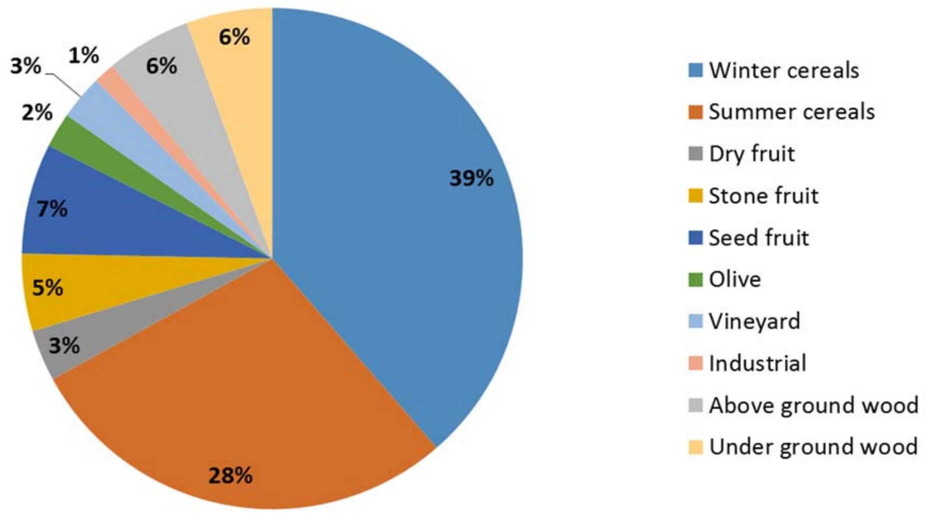


Figure 4. Percentage distribution agrarian residues close to power plants sites

Considering the availability of the different agricultural residues located close to the power plants sites, Forestalia Group and Circe decided to focus the case study on two main feedstock options (Figure 4):

- Straw and stalk from annual crops (winter cereals, summer cereals, sunflower)
- Wood from olive, fruit and vineyard plantations removal, both above ground and underground biomass.

Even though pruning wood could also represent a relevant source of energy, it was discussed that the logistics depend too much on each farmer's willingness. The business model chosen for the exploitation of pruning wood may vary from farmer to farmer, even if all of them supply biomass to a single facility (the EuroPruning project (Deliverable report D5.1) has described this situation for several large facilities consuming pruning wood from hundreds of farmers). Therefore, it was considered that a generic modelling that describes a single type of farmer would not be representative.

Taking into account these two options (cereal straw and stalks, and wood from olive, vineyards and fruit plantation removals), more than 80% of agrarian residues are being considered by Forestalia Group. Straw and corn stalks amount to more than 500,000 tonnes of available biomass (energy use) per year and wood from olive, fruit and vineyard plantations removal represents almost 100,000 tons per year.

3.3 Biomass value chains

For each feedstock option, different supply chains have been defined as follows:

- Option 1: Herbaceous agricultural residues
    - Case 1.1: straw and stalk from annual crops delivered just in time from the original storage sites, to the power plants

- Option 2: Wood from olive, fruit and vineyard plantations removal, considering either the utilization of local collection points, or direct delivery from the fields, whenever the conditions allow it. The biomass in Aragón to be collected by one of the three alternative schemes:
    - Case 2.1: underground biomass (UGB): small plantations, removal and transport to collection point done by farmer.
    - Case 2.2: above ground biomass (AGB) and underground biomass (UGB): small plantations and medium plantations in areas with some relevant density of permanent crops; service for restoring field (up-root trees and restore soil) and for wood recovery to be carried by Forestalia Group.

- Case 2.3: above ground biomass (AGB) and underground biomass (UGB) separated: large plantations, removal in charge of Forestalia Group, who would offer the service to remove plantations and restore the field. Biomass obtained separately to avoid mixing the aboveground part (free from stones) from the underground biomass (including substantial amounts of soil and stones)

These value chains have been discussed among Forestalia Group and CIRCE as the preliminary value chains to be implemented for the future procurement of straw, stalks and woody residues from fruit, grape and olive plantations removed. The operations for the biomass supply could be executed either by third parties (existing biomass suppliers, new entrepreneurs), or be partially covered by Forestalia Group. This shows that a variety of opportunities for business could be created to cover the biomass demand of Forestalia plants.

In respect the cases of the value chains for the wood obtained from olive, fruit and vineyard plantations removal, it is worth mentioning that they are complementary value chains models to cover the supply of the plantation removal wood from the whole Aragon territory. In other words, three alternative supply schemes have been initially considered as the best solutions to gather the maximum wood residues from the heterogeneous reality of the vineyards, olive grove and fruit plantations in the region.

As initial approach, the logistics for case 2.1, 2,2 and 2.3 consider the use of a mobile equipment (mounted on trucks) performing next operations: shredder (primary biomass comminution), screening system, and chipper (secondary comminution).

The main requisites determining the biomass that can be collected by each supply scheme is shown in Table 3.

Table 3. **Specific requirements to determine if the biomass from vineyards, olive groves and fruit plantations is collected through Case 2.1, case 2.2 or case 2.3 value chains.**

Case	Requirement	Part of the available potential covered
2.3	Parcels of more than 2 ha: allow a 1 day operation of the mobile Density of vineyards, olive groves and fruit plantations: a minimum of 800 ha in a radius of 10 km. Assuming rotation every 20 years, 40 ha/yr are being uprooted in the nearness, ensuring that the mobile equipment can work in the area for more than 1 week (>1200 t).	Biomass produced in areas densely populated by permanent crops, and where large fields are usual. Access to fields allow mobilising the whole mobile equipment. It represents the biomass with less constraints in terms of logistics.

2.2	Parcels of more than 0.25 ha: allows the gathering of sufficient material to complete a trip with a large agrarian trailer or a dumper (50 m^3 of capacity). Density of vineyards, olive groves and fruit plantations: a minimum of 400 ha in a radius of 10 km. Assuming rotation every 20 years, 20 ha/yr are being uprooted in the nearness, ensuring that the mobile equipment can work in the area for more tha1 week (> 600 t)	Biomass produced in areas well populated by permanent crops, even though parcel size is smaller than 2 ha. It represents intermediate interesting areas, where concentration still may allow that a company specialises in retrieving the wood residues.
2.1	Not accomplishing requirements for 2.2 or 2.3 cases	Remaining potential, meaning the biomass in dispersed fields, small fields. It is assumed that farmer will produce some firewood out of the aerial part, and the roots will be loaded on their trailers and deposited in local collection points in the nearness.

3.3.1. Case 1.1: straw and stalk from annual crops

In this supply chain concept, the farmers, cooperatives or local biomass suppliers are in charge of collecting and storing the herbaceous residues. They behave as suppliers, and it is assumed they organize themselves locally in the most adequate way. Then, Forestalia takes care of the further biomass collection. It sends a platform truck, loads the bales on field with a telehandler or tractor and finally, transports the biomass directly to the power plant (without intermediate collecting points, just in time). Figure 5 sums up the supply chain and it sets the logistical concept boundaries in order to define the final input data and output results.

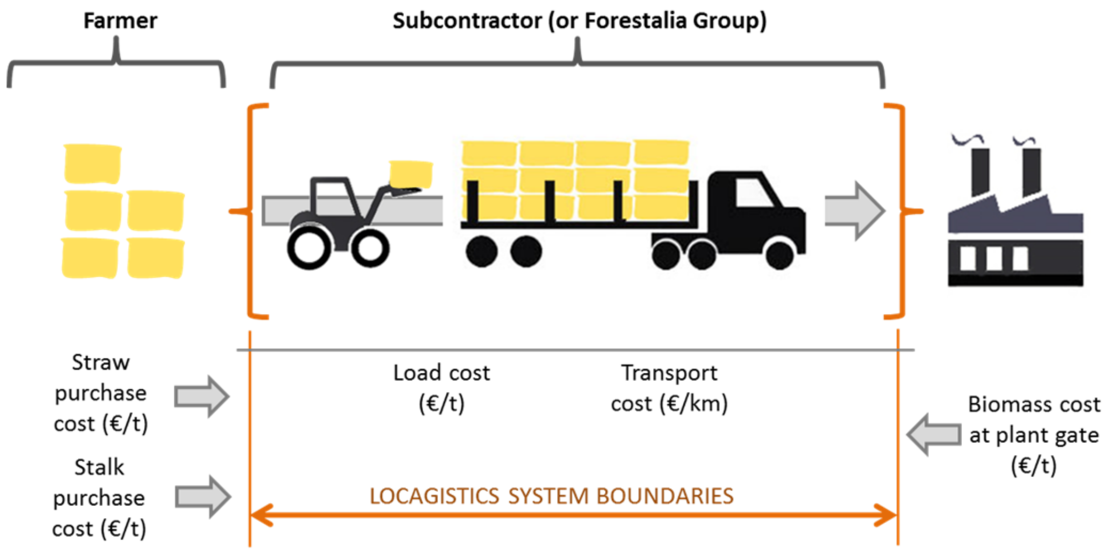


Figure 5. Case 1.1: supply chain for straw and stalk from annual crops.

3.3.2. Case 2.1: UGB from small plantations, removal and transport to collection point by farmer

This case considers small parcels, of 0.25 ha or less, or other fields even of larger size, but in areas where the permanent crops are not predominant. In such cases the biomass produced per field is not expected to be more than 5 t, which is insufficient to make economic the mobilization of heavy machinery mounted on truck like primary shredders or forestry chippers.

The farmer cooperative or field owner is in charge of cleaning their own plantations. This case assumes that the farmer is interested in the firewood. It assumes that farmer will have to burn the roots in piles. So we consider here that farmers will keep AGB for firewood, hence it is not available. The case proposes that Forestalia Group offers a local collection point (kind of an authorized area for dumping the UGB, that is the roots). The collecting point would be the property of Forestalia Group or a local biomass supplier.

Then, when a collecting point accumulates sufficient biomass to work for at least for one week, Forestalia Group would send a mobile unit consisting of a primary crusher, a screening system, and chipper. Biomass produced would be loaded to a large capacity truck, a walking floor truck, and Forestalia would then transport the biomass directly to the power plant. We are going to consider that the biomass acquisition cost is 0 €/t as starting point (the owners of the plantations are not asked for a fee to dispose the roots in the local collection point).
It must be noted that here the "roadside" site is considered the local collection points. From there on the transporting costs of treatment, load, transport and download, have to be added.

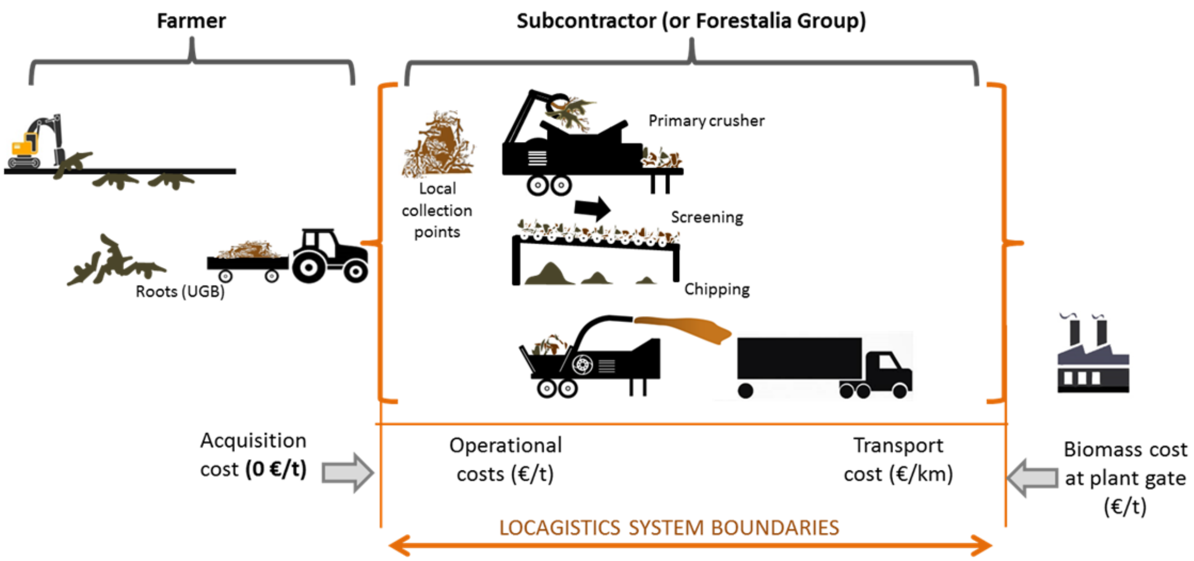


Figure 6. **Case 2.1: supply chain for UGB from small plantations, remove and transport to collection point by farmer**

Figure 6 sums up the supply chain and it sets the logistical concept boundaries in order to define the final input data and output results. In this case, biomass processing costs have been implemented per ton, by considering an equivalent cost as an external service company would ask for carrying out the service.

3.3.3. Case 2.2: AGB and UGB from small plantations, removal and transport to collection point by Forestalia Group

In this case it is considered that parcels are larger than 0.25 ha, smaller than 2 ha, but having a density in 5 km radius of at least 400 ha (see details in table 3). In other words, that we ensure there are sufficient fields of a minimum size of 0.25 ha in the area of 5 km, to make appealing for a company to start organizing a new procurement. Assuming an average of plantation removal of 20 years period, it ensures 20 ha to be removed per year. Assuming net wood (AGB+UGB) of 40 t/ha (fresh matter), a total of 800 t/yr could be collected, which ensures that a collection point could maintain sufficient wood (every year) to operate there for a whole week, and then to displace the mobile equipment to another collection point in a nearby area (e.g. 5 to 10km in distance, depending the zone). In such case Forestalia Group or a local subcontractor could invest in a mobile unit including primary shredder, grinder and a chipper.

In this case it was considered that due to the size of the fields, many of them may not allow the mobilization of heavy machinery and the circulation of large walking floor trucks. Therefore, it is assumed that the best option is to uproot the whole tree and load it on dumper trucks or agricultural trailers to transport it to local the collection point in the area.

Forestalia Group in this case is in charge of providing the service of uprooting the whole tree, withdrawing the wood from the field, and restoring soil conditions. We consider here that both AGB and UGB are going to be collected. The primary transport to the local collection points would be done with 40 m^3 agricultural trailers towed by tractor.

There Forestalia Group processes the biomass (primary crusher, screening and chipping) and would load a walking floor truck and to transport the biomass directly to the power plant. In this case, we are going to consider a balance between how much does the service cost and how much would a farmer pays to get the service done. That gives us an initial value of acquisition cost as starting point. The calculation is presented in detail within the following section.

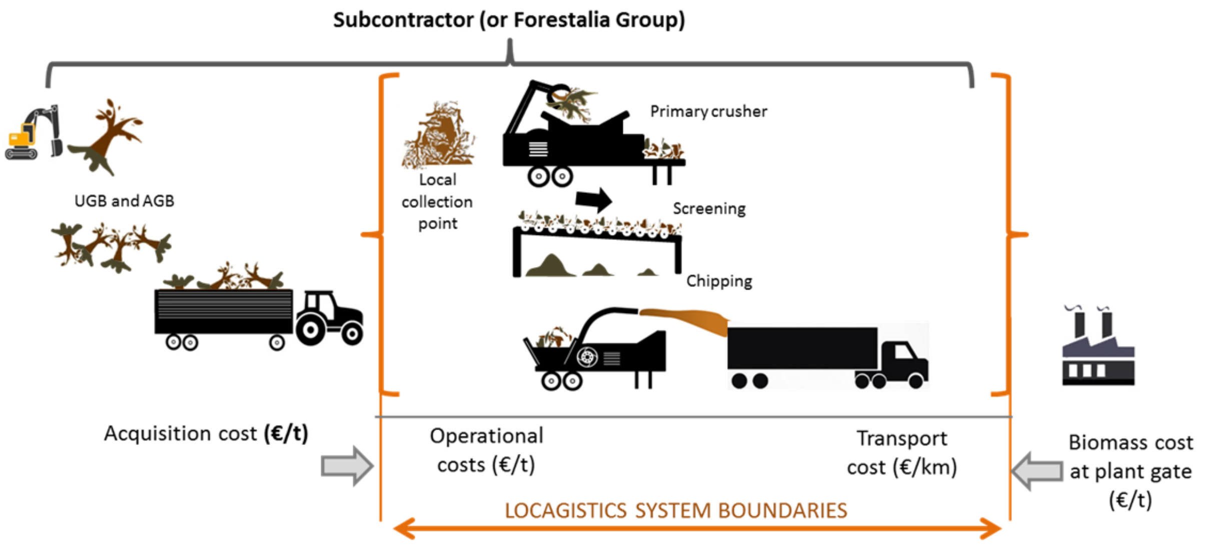


Figure 7. Case 2.2: supply chain for AGB and UGB from small plantations, remove and transport to collection point by Forestalia Group.

3.3.4. Case 2.3: AGB and UGB from large plantations, separate removal by Forestalia Group

In this case the target fields are those which size is larger than 2 ha, and sufficient density of crops in the area, with at least 800 ha in 10 km radius (as explained in Table 3). In this case the idea is that large fields allow to work for one day per field (at least 80 t/field). And the density of permanent crops in the area ensures that the mobile units can easily go to another field to continue their work day after day.

In this case either a subcontractor or Forestalia Group is in charge of collecting the biomass. They do the service of restoring the field to be ready for starting a new crop. In this case the work is carried out in two stages, in order to obtain separately the wood from the AGB (clean, without soil and stones) and from the UGB (not clean, requiring some treatment before being chipped). All biomass is obtained, but AGB and UGB are treated separately. Figure 8 shows the case regarding AGB. In this case, wood is clean and thus, just a chipping is needed (no need of primary shredding and screening). This chipping is carried out in the field and then a walking floor truck is loaded and it transports the biomass directly to the plant (without intermediate collecting points, just in time).

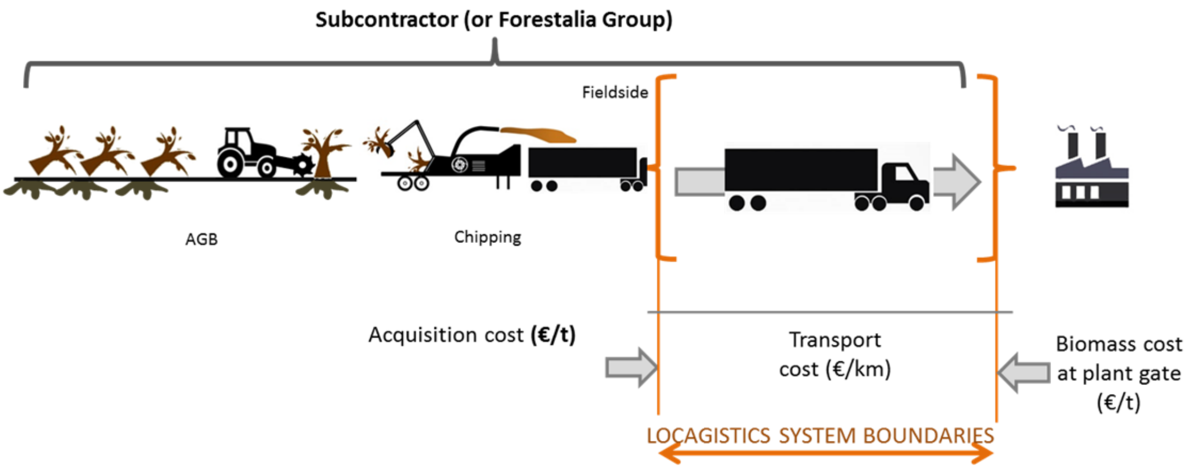


Figure 8. Case 2.3: supply chain for AGB from large plantations, removed by Forestalia Group.

Figure 9 shows the case regarding UGB. In this case, wood is not clean so, Forestalia Group processes the biomass in three stages: primary crusher, screening and chipping. Operations are carried out at field side and biomass loaded in a walking floor truck and to be transported directly to the plant (without intermediate collecting points, just in time).

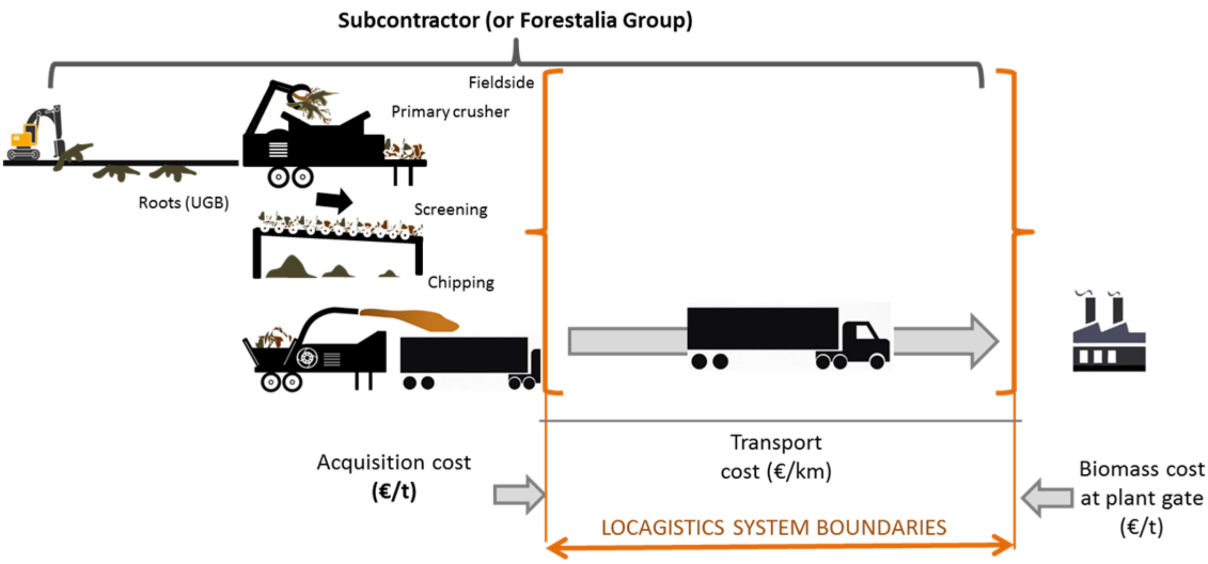


Figure 9. Case 2.3: supply chain for UGB from large plantations, removed by Forestalia Group.

Again, an acquisition cost must be calculated considering the balance between the service price (price paid by the farmer to receive the service) and all the operational costs. This acquisition value is included in following sections and it is the same for both subcases.

4. Type of data requirements for the case studies

4.1 Introduction

The type of data that are needed to run the model depends on the definition of the logistical supply chain and its limits. In Case Study Aragon, no conversion technologies have been considered since Forestalia Group has already defined their facilities (49 MWe CFB units). Therefore, the limits of the model run in LocaGIStics are the following:

- Main input data: biomass cost at the roadside landing. This parameter depends on the feedstock option and the case analysis. In some cases, it is easy to define and the value is given by the market prices in the region. However, in other cases, this cost has been obtained taken into account biomass processing before entering LocaGIStics model.
- Main output result: final biomass cost after logistical chain at the plant gate. This value is of special interest for Forestalia Group since they need to know the final cost of fuel in an accurate way in order to obtain the revenues of the different power plants.

The rest of the data required to complete the case study are presented in the following sections.

4.2 LocaGIStics

The LocaGIStics model needs the data that are described in Table 4 and 5.

Table 4. Description of the set-up of the biomass value chain.

Category	Attribute description (unit)
Biomass value chain	General description of the set-up of the biomass value chain, including variants and specific questions (e.g. intermediate collection points included or not) that could be addressed by the LocaGIStics tool in the case study (text)
	Number of biomass yards (number)
	Coordinates of possible locations for intermediate collection points (plus map-projection)
	Number of conversion plants (number)
	Coordinates of possible locations for conversion plants (plus map-projection)
	Locations where conversion plants or intermediate collection points should not be placed (e.g. Natura 2000 regions)

Table 5. Required data for LocaGIStics.

Category	Attribute description (unit)
Biomass characteristics	Biomass type(s) available (name)
	Bulk density per biomass type (kg dm/m^3)
	Higher heating value per biomass type (GJ/ton dm)
	Moisture content at roadside per biomass type (kg moisture/ kg total)
Biomass availability	Amount of biomass available per source location/grid cell (ton dm/year) (this should be as detailed as possible, e.g. Nuts4 or Nuts5 or even at parcel level, please add GIS file (shapefile) with locations)
	Description of form/shape (name) e.g. bales or chips
	Costs at roadside per biomass type (€/ton dm)
	Energy used for biomass production (GJ/ton dm)
	GHG emission used for biomass production (ton CO_2-eq/ton dm)
Storage	Type of storage per specific location (name)
	Capacity per storage type per location (m^3)
	Costs per storage type per location (€/m^3.month)
	Energy used per storage type per location (MJ/ m^3.month)
	GHG emission per storage type (ton CO_2-eq/ton dm)
Logistics	Type of available transport means for each part of the chain (name)
	Detailed road/rail network (could be taken from open street maps)
	Maximum volume capacity per transport type (m^3)
	Maximum weight capacity per transport type (ton)
	Costs variable per transport type (€/km)
	Costs fixed per transport type (€/load)
	Energy used per transport type (MJ/km)
	GHG emission per transport type (ton CO_2-eq/ton dm)
Handling	Type of available handling equipment per specific location (name) e.g. for loading and unloading
	Costs handling equipment per type (€/m^3)
	Energy used per handling equipment type (MJ/m^3)
	GHG emission per handling equipment type (ton CO_2-eq/ton dm)
Pre-treatment	Type of pre-treatment needed per specific location (name)
	Description of output form/shape (name) e.g. chips, pellets
	Costs of pre-treatment per type (€/m^3)
	Energy input of pre-treatment per type (MJ/m^3)
	GHG emission per pre-treatment type (ton CO_2-eq/ton dm)
Conversion	Technology type per conversion plant (name)
	Net energy returns electricity (usable GJ/GJ input *100%)
	Net energy returns heat (usable GJ/GJ input *100%)
	Capacity input (ton dm/year or ton dm/month)
	Working hours (hours/month)
	Costs conversion plant fixed (€/year)

	Costs conversion variable (€/ton dm input)
	Energy use for conversion (GJ/m^3)
	Emissions CO_2 (mg/Nm^3)
	Emissions NO_x (mg/Nm^3)
	Emissions SO_2 (mg/Nm^3)
Revenues	Price electricity (€/GJ)
	Price heat (€/GJ)
	Price other type(s) of (intermediate) products (€/ton)

5. Actual data used for case study

5.1 Aragón tailored biomass assessment

Herbaceous biomass residues

The biomass assessment for herbaceous biomass residues bases on the previous work carried out by CIRCE in the framework of the ACVCOCO project (CIRCE, 2008). It utilizes a series of ratios (t/ha) that are applied to the area gown by NUTs5 (municipality level). Ratios can be consulted at Royo et. al 2009. The NUTs5 data refers to 2011 data published by Caja Duero, 2012. The theoretical biomass has been transformed into available biomass by multiplying the theoretical by a coefficient of reduction representing the current competitiveness, as obtained by CIRCE from previous projects. Reductions to be applied to the theoretical potentials were: 80% for winter cereal straw, 40% for rice straw, and 30% for sunflower and maize stalks. These coefficients indicate that cereal straw is being already object of use, especially as cattle feedstock, bedding, and some industrial uses, like the biomass power plant of Sangüesa (in Navarra, northwestern neighboring region). It also shows how the residues of sunflower and maize are not being utilized currently in the region.

Data at municipal level was transformed by WUR-FBR into a grid dataset of 2.5x2.5km size as input data for Locagistics.

Woody residues from vineyard, olive grove and fruit plantation removals

In respect the data from permanent crops, the data by municipality was insufficient. In order to know the biomass handled by the complementary value chains of case 2.1, 2.2 and 2.3, it was necessary to know the parcel size, and the density of cropped land in radius of 5 km and 10 km (requisites explained in Table 3).

It was crucial for such purpose to obtain the SIGPAC data from Aragón, the inventory of agrarian parcels provided by the Ministry of Agriculture (Agricultural Plots Geographical Information System). The data was obtained from, provided by municipality, and required a total of 364 downloads. Data was obtained from the official Aragón spatial data infrastructure system: http://idearagon.aragon.es

Data contained all the agricultural and forestry parcels. Parcels coded as permanent crops were selected and merged into a sole file with QGIS 2.14.0-Essen software. The merged file contained more than 300,000 parcels. The biomass for each parcel was calculated on the base of its area and a production ratio of aerial and underground biomass (internal CIRCE data). The availability was considered 90% for all permanent crops (10% reduction coefficient applied to the theoretical potential).

The criteria for splitting the available potential into the potentials to be mobilized through the value chains of Case 2.1, 2. 2 and 2.3 was applied following the indications of Table 3. It required QGIS operations of parcel selection by size and density in an area through neighborhood statistics plugging (LecoS - Landscape Ecology Statistics 1.9). The results were three different complementary shapefiles as next:

- Case 2.1: containing 201,022 parcels, adding a total of 9714 t/yr of dry matter biomass
- Case 2.2: containing 91,613 parcels adding a total of 54,022 t/yr of dry matter
- Case 2.3: containing 9,093 parcels adding a total of 34,612 t/yr of dry matter

As observed the case 2.1 for small parcels provides the lower amount of biomass, exemplifying the difficulty to establish a logistics value chain from obtaining this biomass. This is coherent with the sense of Case 2.1, where it is assumed that establishing a logistic chain from fields is unfeasible, and the biomass procurement bases on the fact that farmers may find interesting to dispose their rootstocks into a local collection point instead of performing the burning in the open air.

As observed case 2.2 involves more than 91,000 parcels able to provide 54,022 t/yr of dry matter, and 2.3, provides up to 34,612 t/yr of dry matter from barely 9,000 parcels. Logistics are therefore more favorable from Case 2.1 (most difficult) to case 2.3 (more advantageous).

Data from the three shapefiles was transformed by WUR-FBR into a grid dataset of 2.5x2.5km size as input data for Locagistics.

5.2 General data

Below are included the tables containing the main general data for the cases 1, 2.1, 2.2 and 2.3.

Table 6. Case 1.1: straw and stalk from annual crops.

Category	Attribute description (unit)
Biomass characteristics	Straw and stalk from annual crops (maize, sunflower, winter cereals)
	Bulk density: 400 kg dm/m^3
	Higher heating value: 15-20 GJ/ton dm
	Moisture content at roadside: 0.15 kg moisture/ kg total
Biomass availability	Amount of biomass required: 120,000 t/year
	Description of form/shape: bales
	Costs at roadside: 38.82 €/ton dm
Storage	No storage

Logistics	Type of available transport: platform truck
	Detailed road/rail network (could be taken from open street maps)
	Maximum volume capacity per transport type: 80 m^3
	Maximum weight capacity per transport type: 26.6 ton
	Costs variable per transport type: 2.128 €/km
Handling	Type of available handling equipment: manitou machine / tractor
	Loading cost: 0.564 €/m^3
	Unloading cost: 0.564 €/m^3
Pre-treatment	No pre-treatment
Output cost	Maximum cost at gate: 47.06 €/ton dm

Table 7. Case 2.1: wood plantations removal UGB: small plantations, removal and transport to collection point done by farmer.

Category	**Attribute description (unit)**
Biomass characteristics	Wood plantations removal (UGB)
	Bulk density: 250 kg dm/m^3
	Higher heating value: 15-20 GJ/ton dm
	Moisture content at roadside: 0.30 kg moisture/ kg total
Biomass availability	Amount of biomass required: 120,000 Mt/year
	Description of form/shape: roots
	Costs at roadside(*): 0.0 €/ton dm
Storage	Type of storage: pile
	Costs per storage type: 0.5 €/t
Logistics	Type of available transport: walking floor truck
	Detailed road/rail network (could be taken from open street maps)
	Maximum volume capacity per transport type: 90 m^3
	Maximum weight capacity per transport type: 22.5 ton
	Costs variable per transport type: 1.5 €/km
Handling	Type of available handling equipment:
	Loading cost: 1.0 €/t fm
	Unloading cost: 0.5 €/t fm
Pre-treatment	Primary crusher cost: 15.0 €/t
	Screening cost: 11.0 €/t
	Chipping cost: 11.5 €/t
Output cost	Maximum cost at gate: 40 €/t fm (30% moisture content)

(*) Cost at roadside is referred to the start of the supply change, i.e. the local collection points (see figure 5 in section 3.3.2)

Table 8. Case 2.2: wood plantations removal AGB and UGB: small plantations, removal in charge of Forestalia Group.

Category	Attribute description (unit)
Biomass characteristics	Wood plantations removal (AGB and UGB)
	Bulk density: 250 kg dm/m^3
	Higher heating value: 15-20 GJ/ton dm
	Moisture content at roadside: 0.40 kg moisture/ kg total
Biomass availability	Amount of biomass required: 120,000 Mt/year
	Description of form/shape: roots and tree
	Costs at roadside(*): 13.3 €/ton dm
Storage	Type of storage: pile
	Costs per storage type: 0.5 €/t
Logistics	Type of available transport: walking floor truck
	Detailed road/rail network (could be taken from open street maps)
	Maximum volume capacity per transport type: 90 m^3
	Maximum weight capacity per transport type: 22.5 ton
	Costs variable per transport type: 1.5 €/km
Handling	Type of available handling equipment:
	Loading cost: 1.0 €/t fm
	Unloading cost: 0.5 €/t fm
Pre-treatment	Primary crusher cost: 15.0 €/t
	Screening cost: 11.0 €/t
	Chipping cost: 11.5 €/t
Output cost	Maximum cost at gate: 40 €/t fm (30% moisture content)

(*) Cost at roadside is referred to the start of the supply change, i.e. the local collection points (see figure 6 in section 3.3.3)

Table 9. Case 2.3: wood plantations removal AGB and UGB separated: large plantations, removal in charge of Forestalia Group.

Category	Attribute description (unit)
Biomass characteristics	Wood plantations removal (AGB and UGB)
	Bulk density: 250 kg dm/m^3
	Higher heating value: 15-20 GJ/ton dm
	Moisture content at roadside: 0.50 kg moisture/ kg total
Biomass availability	Amount of biomass required: 120000 Mt/year
	Description of form/shape: roots and tree
	Costs at roadside(*): 45.8 €/ton dm
Storage	No storage
Logistics	Type of available transport: walking floor truck
	Detailed road/rail network (could be taken from open street maps)

	Maximum volume capacity per transport type: 90 m^3
	Maximum weight capacity per transport type: 22.5 ton
	Costs variable per transport type: 1.5 €/km
Handling	Type of available handling equipment:
	Loading cost: 0.0 €/t fm
	Unloading cost: 0.5 €/t fm
Pre-treatment	No pre-treatment
Output cost	Maximum cost at gate: 40 €/t fm (30% moisture content)

(*) Cost at roadside is referred to the start of the supply change, i.e. fieldside (see figures 7 and 8 in section 3.3.4)

5.3 Costs Case 1

Case 1 considers roadside cost is the purchase price of the biomass (38.82 €/ton dm). Costs of loading and transport have to be added. No further costs involved till the delivery. Therefore, the costs at gate are simply estimated as sum of both items.

5.4 Costs Case 2.1

Case 2.1 considers roadside cost is 0 €/ton dm, as it is figured that farmers will transport the rootstocks with their own means to the local collection point. Therefore no costs associated to purchase. However the material consisting of roots with substantial amounts of soil and stones, needs of gathering, shredding, screening and chipping. Operations are carried out with mobile units displaced to the collection points when sufficient biomass is accumulated, allowing an operation during a whole week Transport costs have to be added to the treatment costs. As well as the renting of the soil of the parcel.

5.5 Costs Case 2.2

In this case the farmer opts for contracting a service to carry out the plantation removal. A subcontractor will take care of the service, consisting in restoring the plantation to be ready to start the growth of a new crop cycle. The farmer will pay for the service and the contractor will take care of handling the biomass, and produce biomass to be delivered to Forestalia Group plants.

In this case it has been estimated and operational cost of 300 €/ha to perform the tree up-rooting, which is the price to be covered by the payment for the service.

Biomass at roadside is considered the biomass placed at the local collection points, consisting of whole trees with roots. Therefore the acquiring costs include the extra costs of gathering, loading and performing a local transport from the field to the local collection point, equivalent to 13.3 €/ton dm. Costs of shredding, screening and chipping, storage site and transport have to be added when operating locagistics.

5.6 Costs Case 2.3

In fields larger than 2.5 ha it is assumed it is possible to access with large trucks, and the conditions are given to mobilize multiple mechanized means for collecting the residual wood.

In this case it has been estimated that the farmer will pay for the service an equivalent sum as in Case 2.2, 300 €/ha (service is the same, though the handling and treatment of the biomass is different).

Biomass at roadside is considered the biomass loaded on truck at field side. It must be understood that here trees are felled, then chipped directly into walking floor trucks. Afterwards the rootstocks are withdrawn with an excavator, and then the shredding, screening and chipping performed (load directly into walking floor truck. The costs of the aboveground and underground biomass treatments are the averaged to obtain the average costs at roadside, 55.0 €/t dm. So, in this case the roadside biomass already includes the whole treatments, and only the transport costs have to be added.

6. Results case study

6.1 Introduction

Based on the previously defined supply chains (in Chapter 3), some scenarios were analyzed by LocaGIStics for the two feedstock options. Table 10 collects the scenarios matrix in terms of the number of power plants and their sites and the biomass availability.

Table 10. Scenarios matrix.

Biomass feedstock	Scenario	Demand per plant	Power plant	Availability
Herbaceous biomass	S001	120 kt fm	Zuera, Erla, Monzón	100%
	S002	120 kt fm	Erla	100%
	S003	120 kt fm	Zuera	100%
	S004	120 kt fm	Monzón	100%
	S005	120 kt fm	Zuera, Erla, Monzón	50%
	S006	120 kt fm	Erla	50%
	S007	120 kt fm	Zuera	50%
	S008	120 kt fm	Monzón	50%
	S009	120 kt fm	Erla	25%
	S010	120 kt fm	Zuera	25%
	S011	120 kt fm	Monzón	25%
Woody biomass	S012	60 kt fm	Zuera, Erla, Monzón	100%
	S013	20 kt fm	Zuera, Erla, Monzón	100%
	S014	60 kt fm	Zuera	100%
	S015	60 kt fm	Zuera	50%
	S016	60 kt fm	Zuera	25%

6.2 Results of different scenarios for herbaceous biomass

Scenario SC001

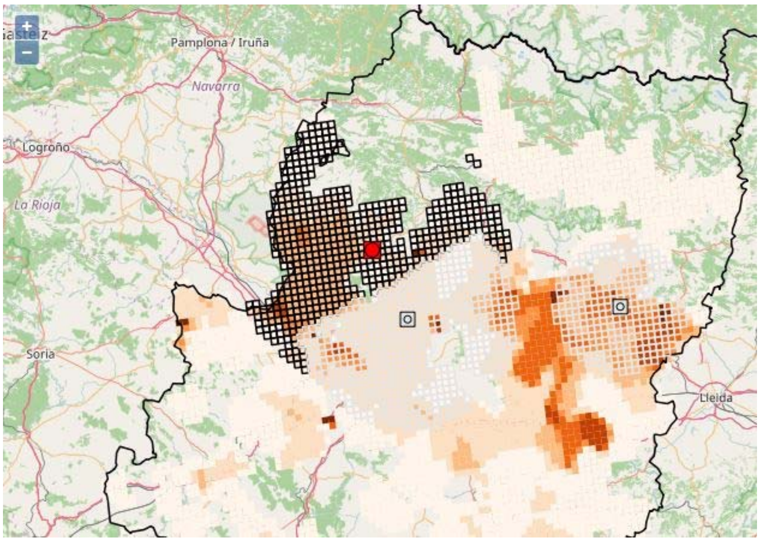
This scenario includes the three power plants (Table 11). Straw and stalk feedstock option is analyzed considering the 100% of biomass availability and no intermediate collection points. The complete demand of the three power plants (103,200 t dm) is met. The map shows only the grid cells that really delivered biomass. The power plants Erla (West) and Zuera (Centre) have competition problems concerning biomass that is situated in between them. This leads to 'strange' collection circles. Furthermore, Erla also touches the western border of the Aragon region. The collection circle of Monzón (East) does not touch the collection circle of Zuera (Centre), so there is no competition for biomass. Distances vary a lot for the three power plants. The same ratio between the biomass types applies more or less for all three power plants. The Monzón power plant is situated much better in the center of the available biomass, because the same amount of biomass can be collected with much less ton.km. Since the purchase costs of each biomass type at road side is the same, differences in costs only reflect differences in amounts of biomass collected. Since the price limit was set at 47.06 €/t dm (which equals 40 €/t fresh) all three supply chains fulfil the plans of Forestalia Group.

Table 11. Scenario SC001. Main results table.

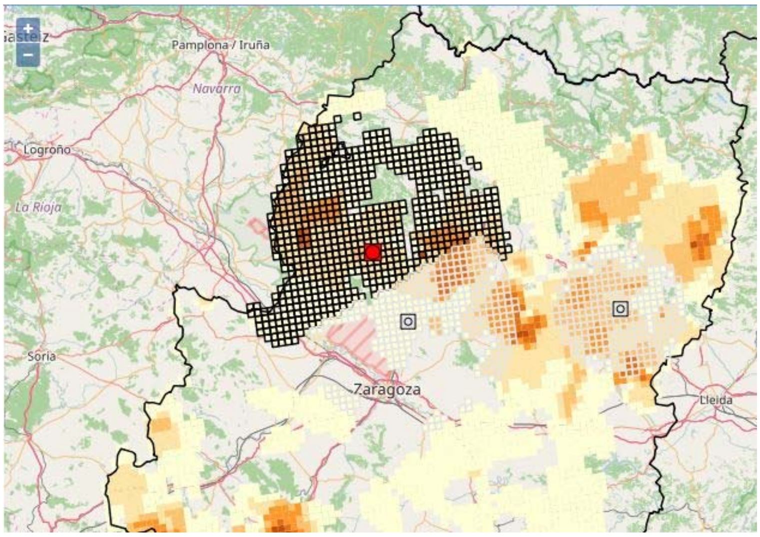
	Erla	Zuera	Monzón
Maximum collection distance (km)	52.5	42.5	25.0
Total collected biomass (ton dm)	103,220	103,250	103,509
Maize	50,946	60,180	76,877
Winter cereals	48,328	39,765	23,954
Sunflower	3,946	3,305	2,678
Total transport amount (ton·km)	3,397,967	3,426,014	1,928,233
Maize	1,587,637	2,062,315	1,408,048
Winter cereals	1,690,654	1,249,300	469,346
Sunflower	119,676	114,399	50,839
Purchase costs (€)	4,007,004	4,008,177	4,018,212
Transport costs (€)	271,837	274,081	154,259
Loading/Unloading costs (€)	291,081	291,166	291,895
Extra costs supply chain (€/t dm)	5.45	5.47	4.31
Price at gate (€/t dm)	**44.27**	**44.29**	**43.13**

Map sourcing Erla

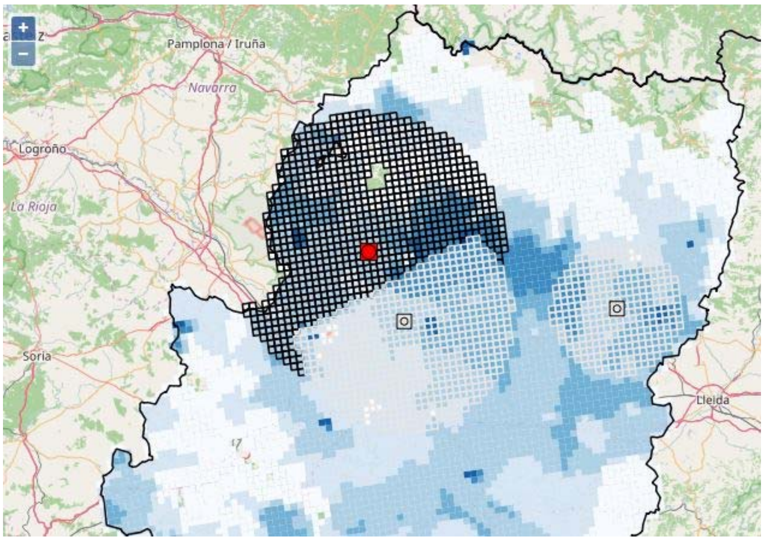
Biomass type: maize



Biomass type: sunflower

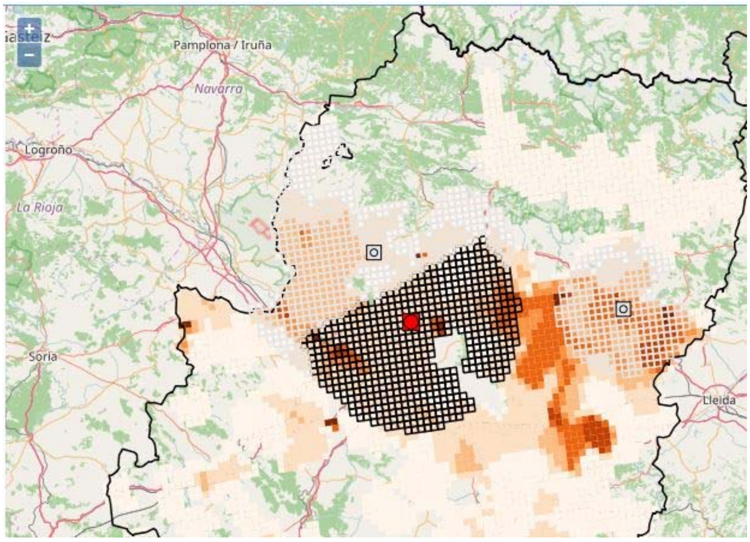


Biomass type: winter cereals

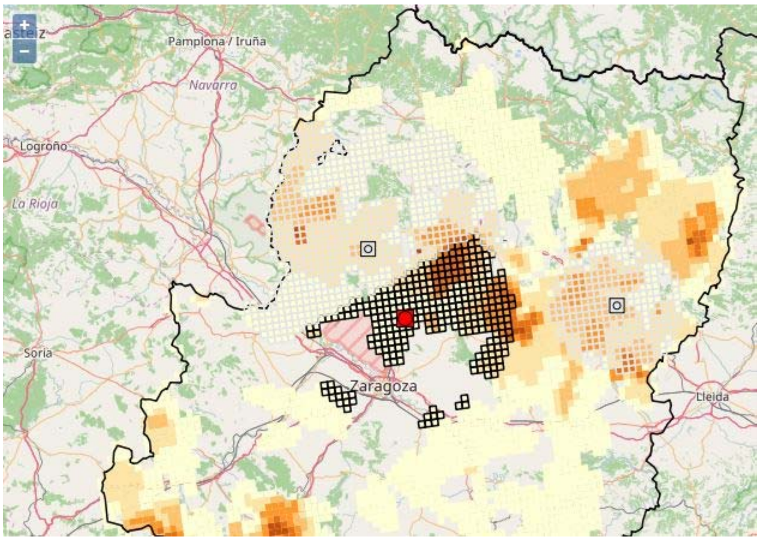


Map sourcing Zuera

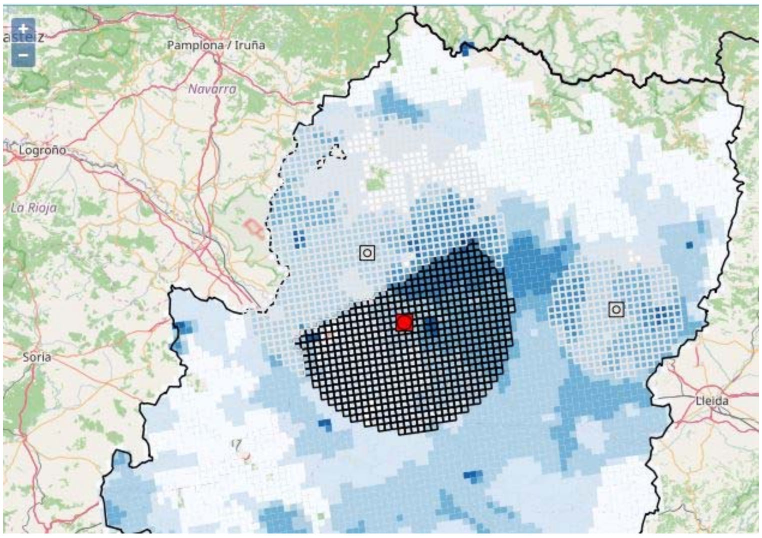
Biomass type: maize



Biomass type: sunflower

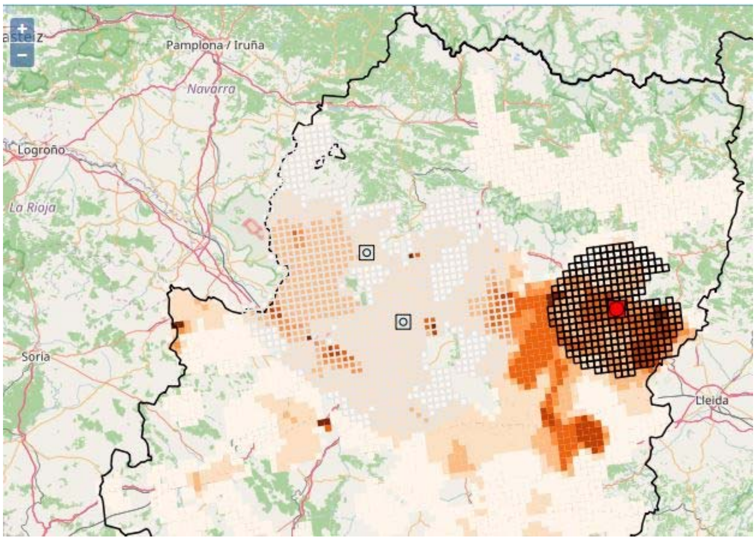


Biomass type: winter cereals

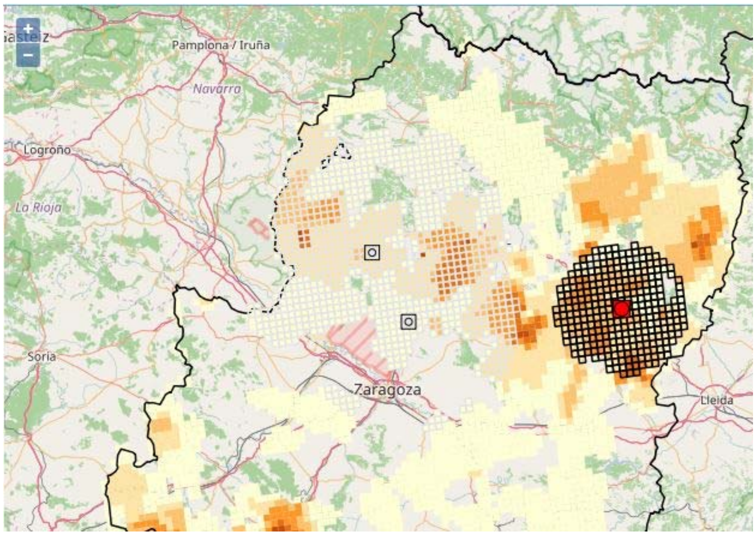


Map sourcing Monzón

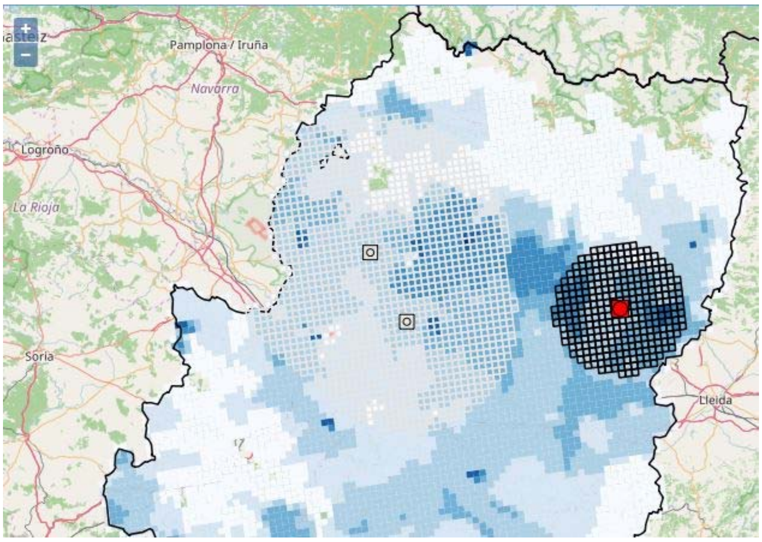
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC002

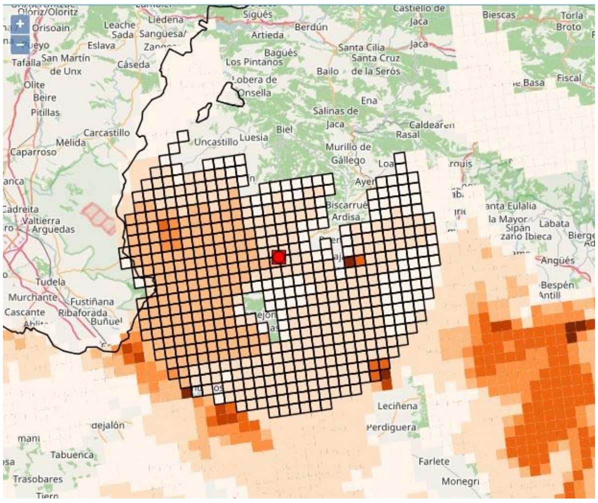
This scenario includes only the Erla power plant (Table 12). Straw and stalk feedstock option is analyzed considering the 100% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met, and it is even over supplied (109,639). This is because of the algorithm always takes the complete content of the (final) chosen grid cells. Erla PP has now almost round collection circles and almost no border problems anymore. The maximum collection distance for winter cereals is now 37.5 km, which is lower than the one needed with the three power plants competing each other. The total transport costs are 4.47% less than in SC001 and the final extra costs for the logistical chain are 0.265 €/t dm lower comparing with the three power plants scenario.

Table 12. Scenario SC002. Main results table.

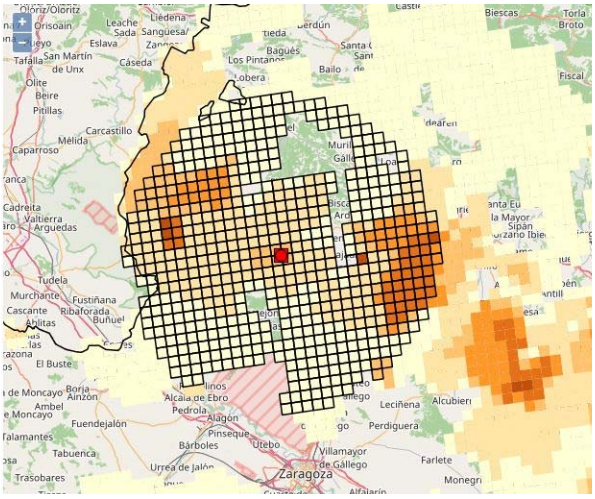
	Erla
Maximum collection distance (km)	37.5
Total collected biomass (ton dm)	109,639
Maize	57,875
Winter cereals	46,825
Sunflower	4,939
Total transport amount (ton·km)	3,246,197
Maize	1,717,896
Winter cereals	1,380,969
Sunflower	147,332
Purchase costs (€)	4,256,190
Transport costs (€)	259,696
Loading/Unloading costs (€)	309,182
Extra costs supply chain (€/t dm)	5.19
Price at gate (€/t dm)	**44.01**

Map sourcing Erla

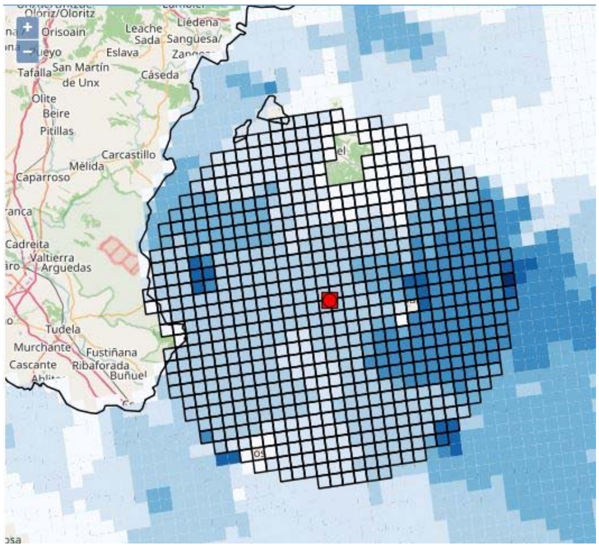
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC003

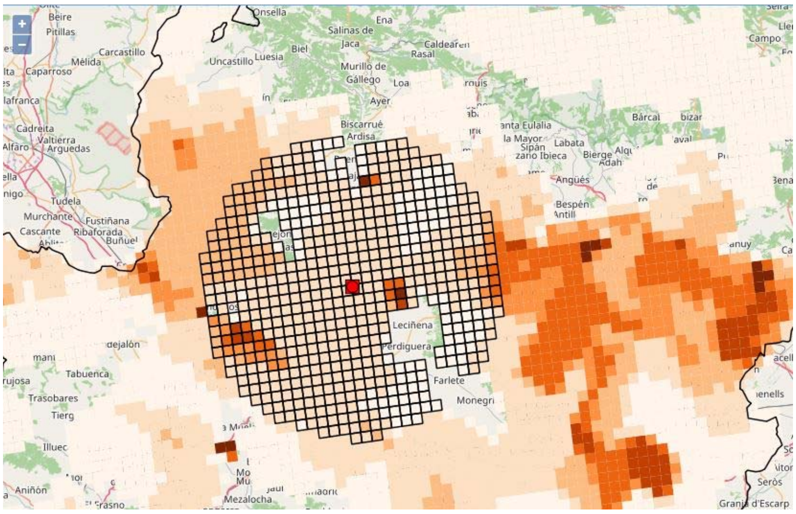
This scenario includes only the Zuera power plant (Table 13). Straw and stalk feedstock option is analyzed considering the 100% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. Without competition, the collection circle is not strangely shaped anymore, but almost round. The maximum collection distance for winter cereals is now 35 km, which is lower than the one needed with the three power plants competing each other. The total transport costs are 9.56% less than in SC001 and the final extra costs for the logistical chain are 0.253 €/t dm lower comparing with the three power plants scenario.

Table 13. Scenario SC003. Main results table.

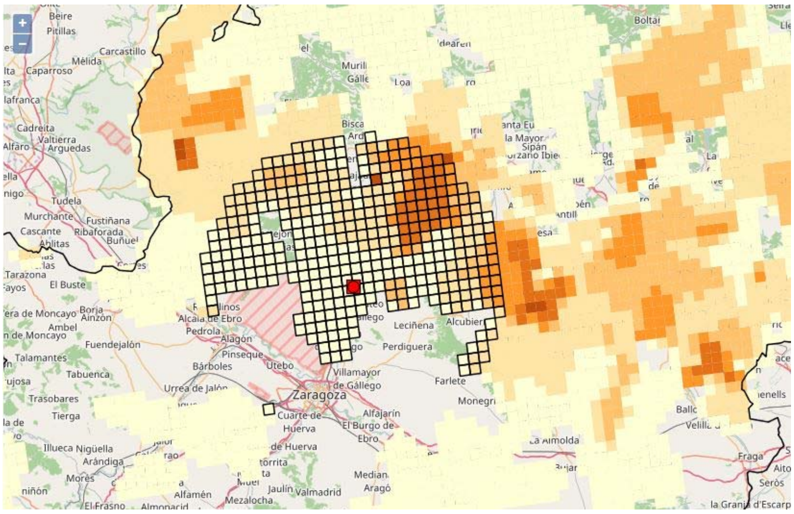
	Zuera
Maximum collection distance (km)	35.0
Total collected biomass (ton dm)	103,229
Maize	55,513
Winter cereals	44,105
Sunflower	3,611
Total transport amount (ton·km)	3,098,387
Maize	1,713,463
Winter cereals	1,270,944
Sunflower	113,980
Purchase costs (€)	4,007,371
Transport costs (€)	247,871
Loading/Unloading costs (€)	291,107
Extra costs supply chain (€/t dm)	5.22
Price at gate (€/t dm)	**44.04**

Map sourcing Zuera

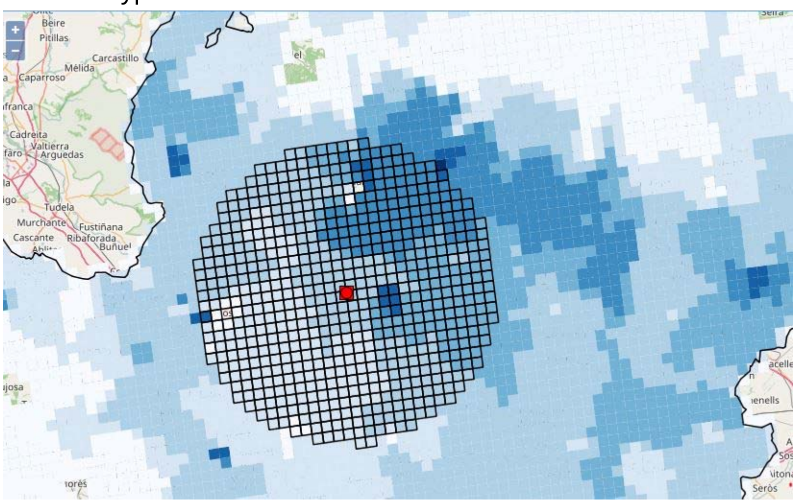
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC004

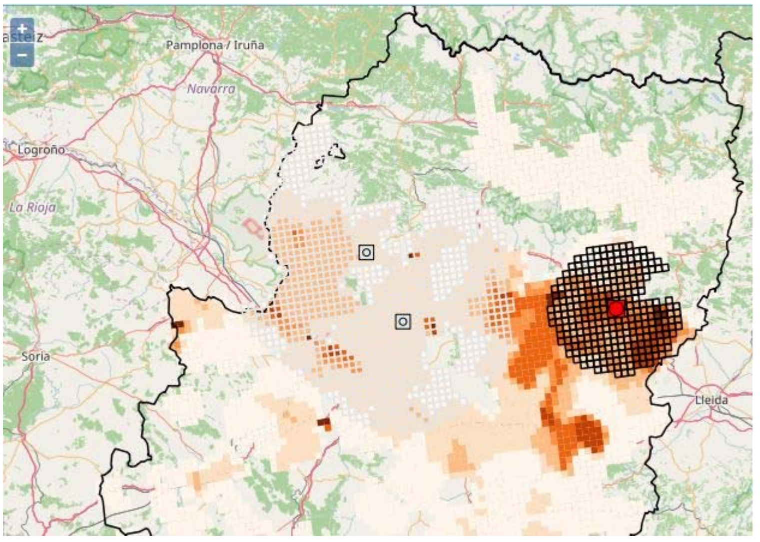
This scenario includes only the Monzón power plant (Table 14). Straw and stalk feedstock option is analyzed considering the 100% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. Since no interaction between Monzón PP and the other two power plants happens, results are the ones presented in previous run, SC001.

Table 14. Scenario SC004. Main results table.

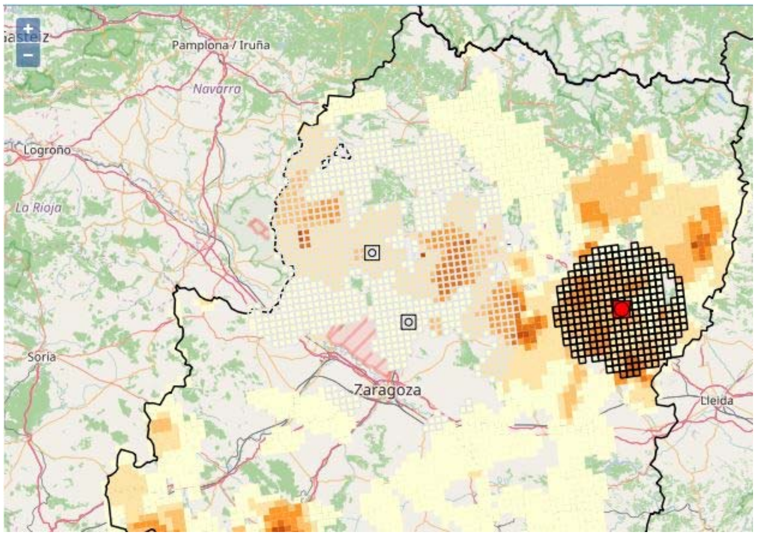
	Monzón
Maximum collection distance (km)	25.0
Total collected biomass (ton dm)	103,509
Maize	76,877
Winter cereals	23,954
Sunflower	2,678
Total transport amount (ton·km)	1,928,233
Maize	1,408,048
Winter cereals	469,346
Sunflower	50,839
Purchase costs (€)	4,018,212
Transport costs (€)	154,259
Loading/Unloading costs (€)	291,895
Extra costs supply chain (€/t dm)	4.31
Price at gate (€/t dm)	**43.13**

Map sourcing Monzón

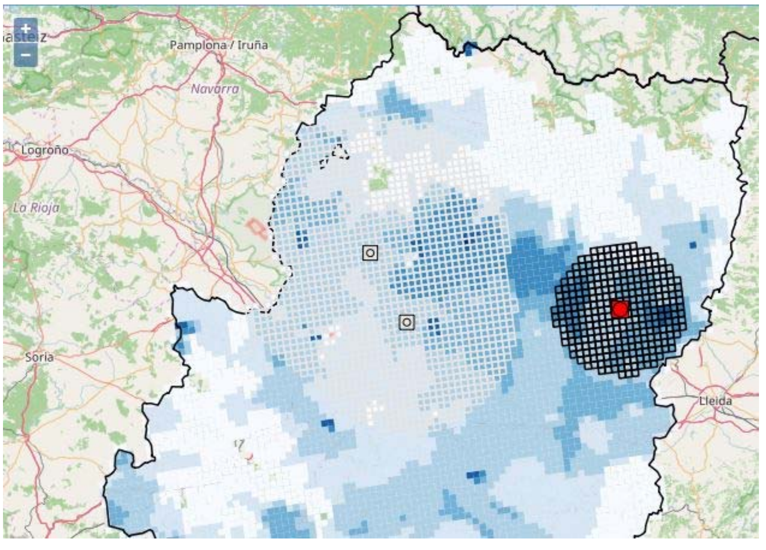
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC005

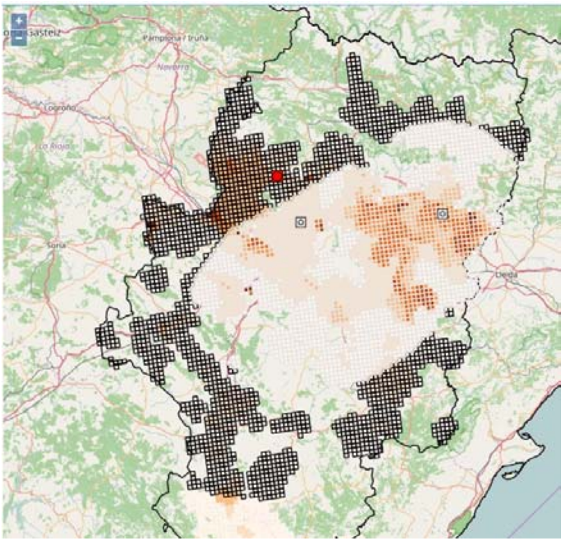
This scenario includes the three power plants (Table 15). Straw and stalk feedstock option is analyzed considering the 50% of biomass availability and no intermediate collection points. The complete demand of the three power plants (103,200 t dm) is met. The collection circles of the three power plants are now much larger and sometimes strangely shaped. Now there is a competition between all of the three power plants, so also between Zuera (Centre) and Monzón (East). Especially Erla has to make a lot of effort to collect biomass even around the areas of Zuera and Monzón. It virtually collects everything around them. This is partly caused by the search algorithm in LocaGIStics that arranges the decisions which power plant goes first (probably Monzón). Therefore in this case the analysis of the separate power plants will give a better idea of the actual collection circle per power plant. In this scenario not always the same ratio applies between the biomass types for the three power plants. We see now a dramatic increase of the total transport amount for all three power plants due to less available biomass (only 50%), competition and border effects. Since the price limit was set at 47.06 €/t dm (which equals 40 €/t fresh) the supply chain of Erla will not fulfil the plans of Forestalia Group. However, Zuera and Monzón will fulfil the price limit.

Table 15. Scenario SC005. Main results table.

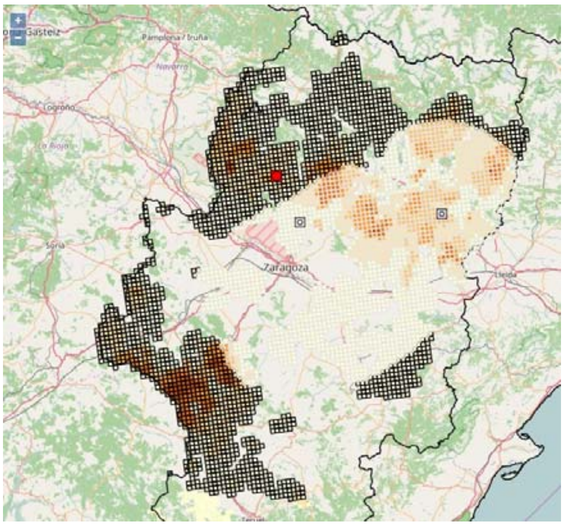
	Erla	Zuera	Monzón
Maximum collection distance (km)	185.0	97.5	52.5
Total collected biomass (ton dm)	103,211	103,201	103,349
Maize	35,944	54,605	71,862
Winter cereals	60,374	46,229	27,990
Sunflower	6,893	2,367	3,497
Total transport amount (ton·km)	9,573,194	5,507,259	3,180,806
Maize	2,358,138	2,737,416	2,148,568
Winter cereals	6,417,811	2,667,052	912,303
Sunflower	797,245	102,791	119,935
Purchase costs (€)	4,006,681	4,006,261	4,012,056
Transport costs (€)	765,856	218,993	254,465
Loading/Unloading costs (€)	291,057	291,027	291,448
Extra costs supply chain (€/t dm)	10.24	7.09	5.28
Price at gate (€/t dm)	**49.06**	**45.91**	**44.10**

Map sourcing Erla

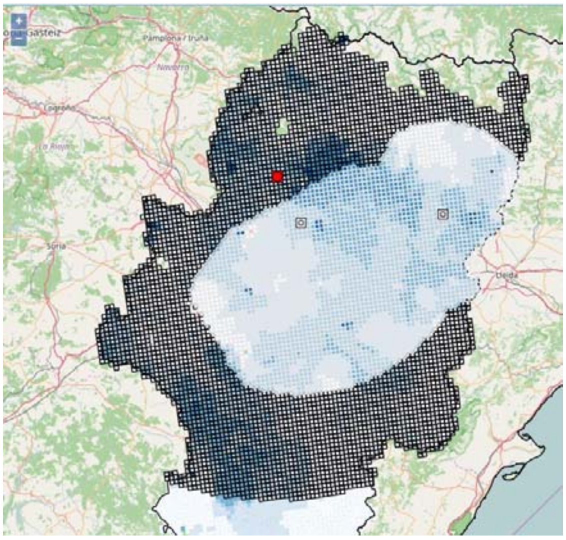
Biomass type: maize



Biomass type: sunflower

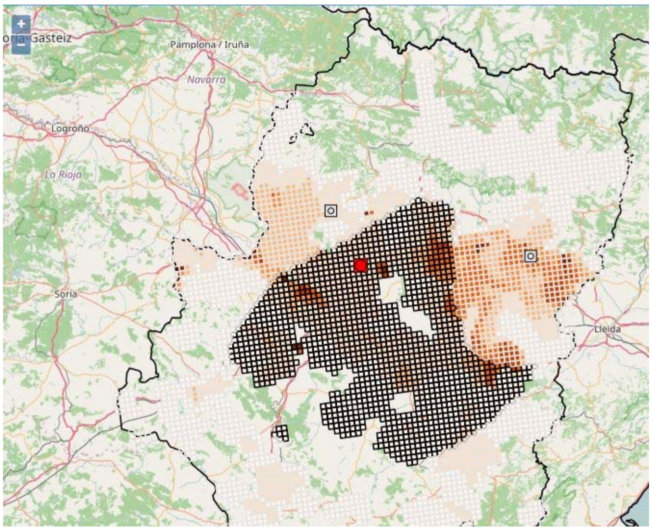


Biomass type: winter cereals

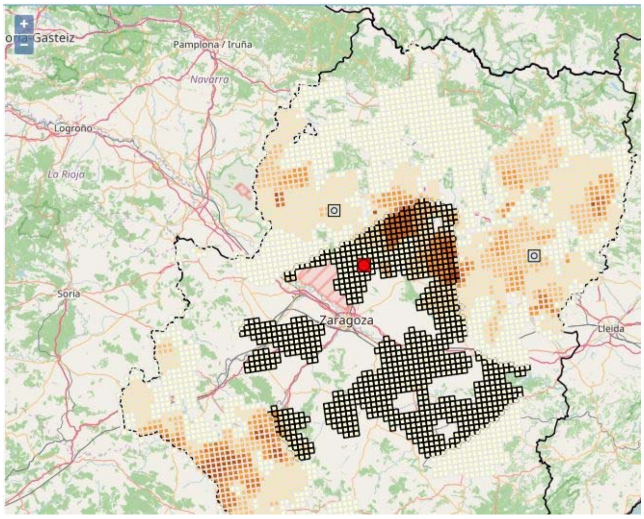


Map sourcing Zuera

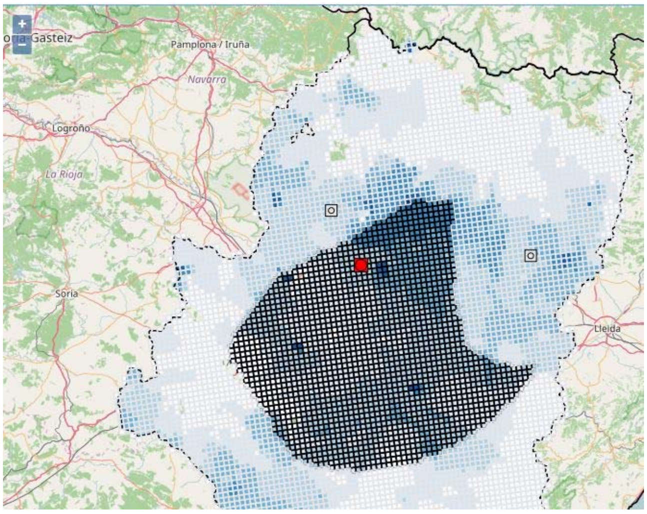
Biomass type: maize



Biomass type: sunflower

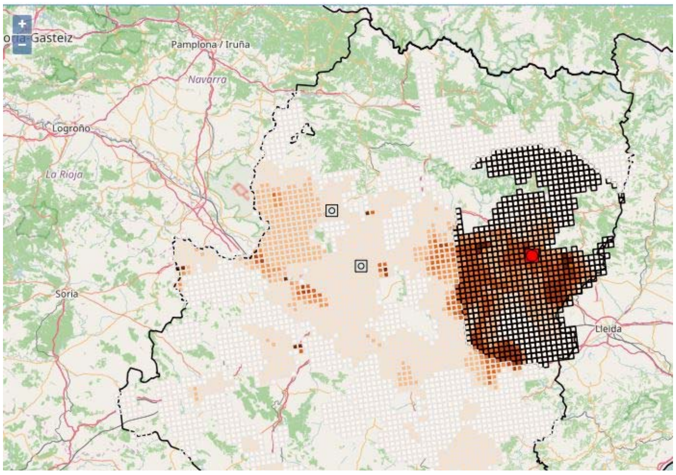


Biomass type: winter cereals

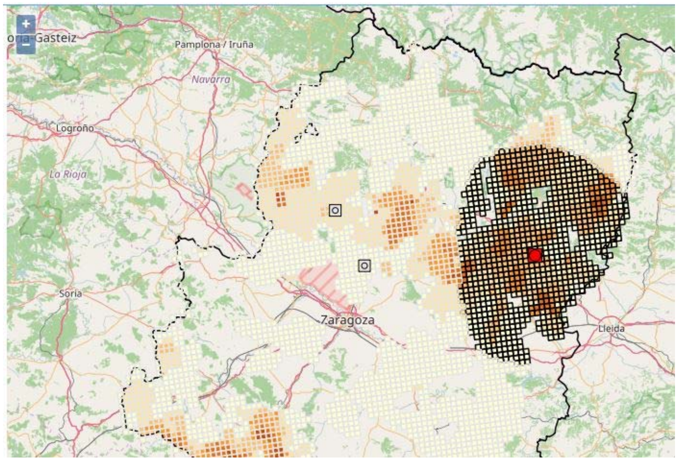


Map sourcing Monzón

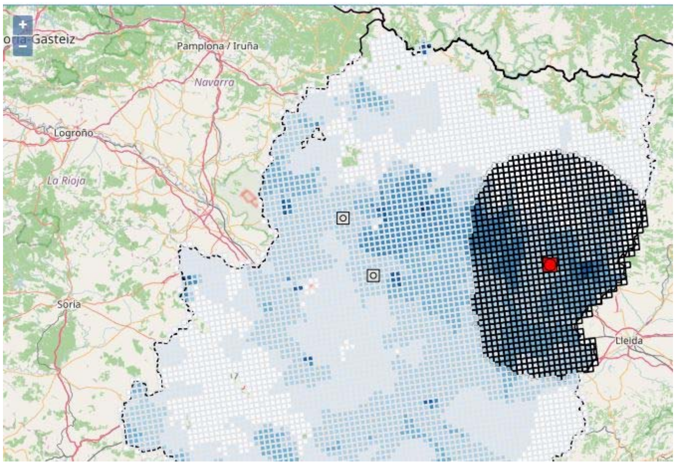
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC006

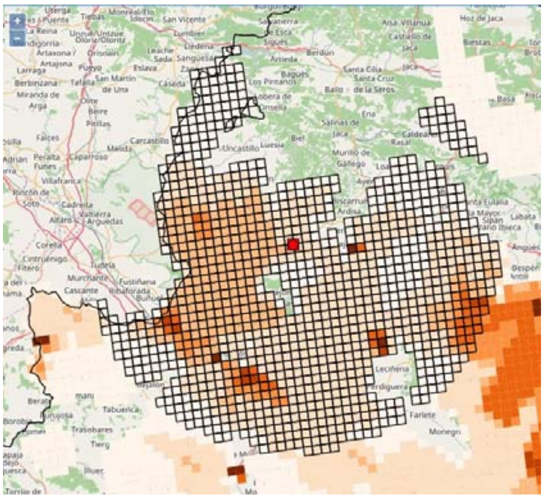
This scenario only includes the Erla power plant (Table 16). Straw and stalk feedstock option is analyzed considering the 50% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. Now the collection areas are again more circle shaped. However, Erla is also experiencing 'border problems' in the West, which causes the circle to be larger than necessary. The maximum collection distance for winter cereals is now 60 km, which is three times lower than the one needed with the three power plants competing each other. The total transport costs are 31.2% more than in SC002 (Erla, 100% availability). However, the final extra costs for the logistical chain are 4.12 €/t dm lower comparing with the three power plants scenario, SC005, 50% availability.

Table 16. Scenario SC006. Main results table.

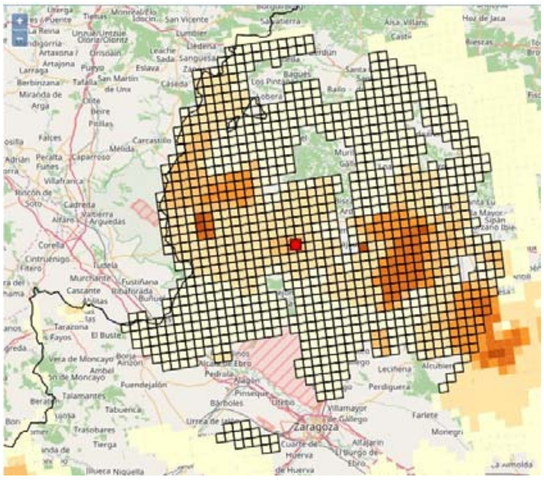
	Erla
Maximum collection distance (km)	60.0
Total collected biomass (ton dm)	103,208
Maize	53,710
Winter cereals	45,936
Sunflower	3,562
Total transport amount (ton·km)	4,260,631
Maize	2,188,505
Winter cereals	1,936,778
Sunflower	135,348
Purchase costs (€)	4,006,542
Transport costs (€)	340,850
Loading/Unloading costs (€)	291,047
Extra costs supply chain (€/t dm)	6.12
Price at gate (€/t dm)	**44.94**

Map sourcing Erla

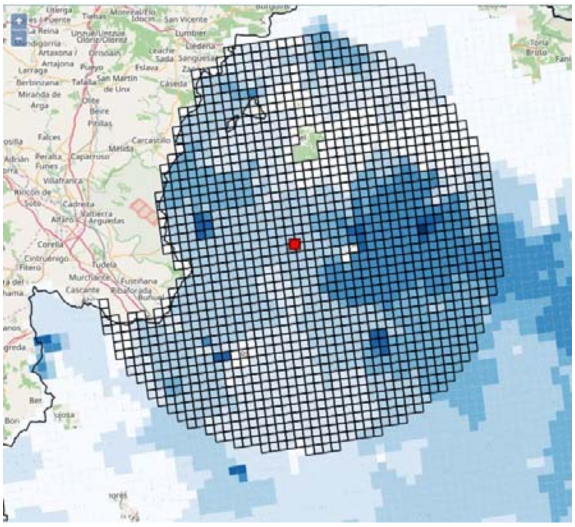
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC007

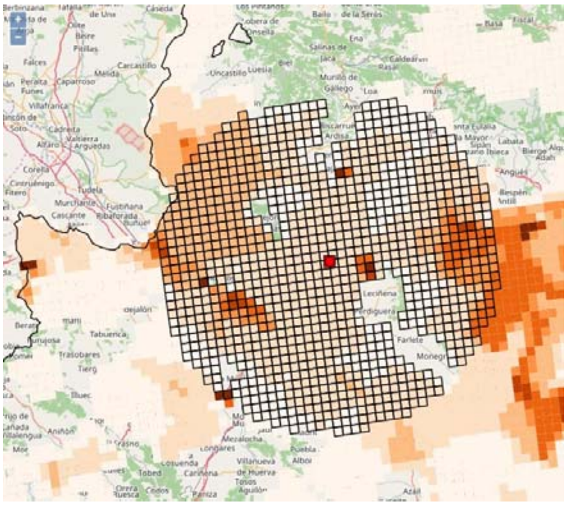
This scenario includes only the Zuera power plant (Table 17). Straw and stalk feedstock option is analyzed considering the 50% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. Now the collection areas are again more circle shaped. The maximum collection distance for winter cereals is now 47.5 km, which is two times lower than the one needed with the three power plants competing each other. The total transport costs are 37.5% more than in SC003 (Zuera, 100% availability). However, the final extra costs for the logistical chain are 1 €/t dm lower comparing with the three power plants scenario, SC005, 50% availability.

Table 17. Scenario SC007. Main results table.

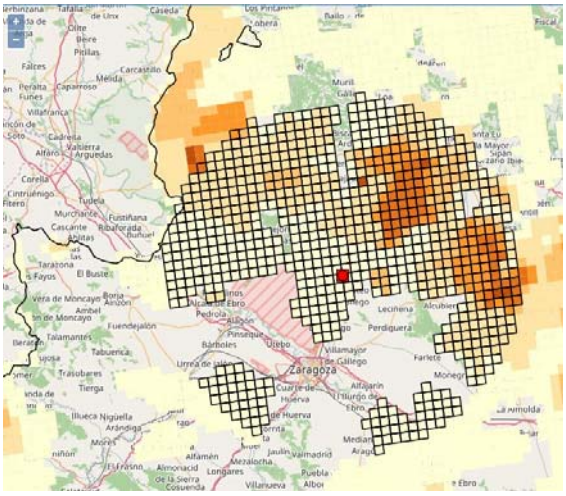
	Zuera
Maximum collection distance (km)	47.5
Total collected biomass (ton dm)	103,212
Maize	59,001
Winter cereals	40,850
Sunflower	3,361
Total transport amount (ton·km)	4,100,135
Maize	2,403,471
Winter cereals	1,563,174
Sunflower	133,490
Purchase costs (€)	4,006,699
Transport costs (€)	328,011
Loading/Unloading costs (€)	291,058
Extra costs supply chain (€/t dm)	6.00
Price at gate (€/t dm)	**44.82**

Map sourcing Zuera

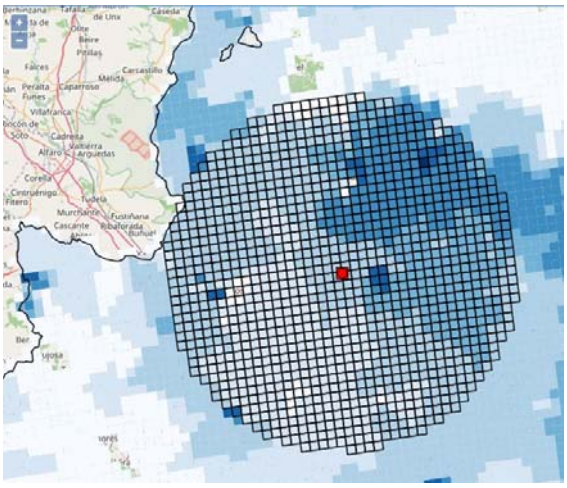
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC008

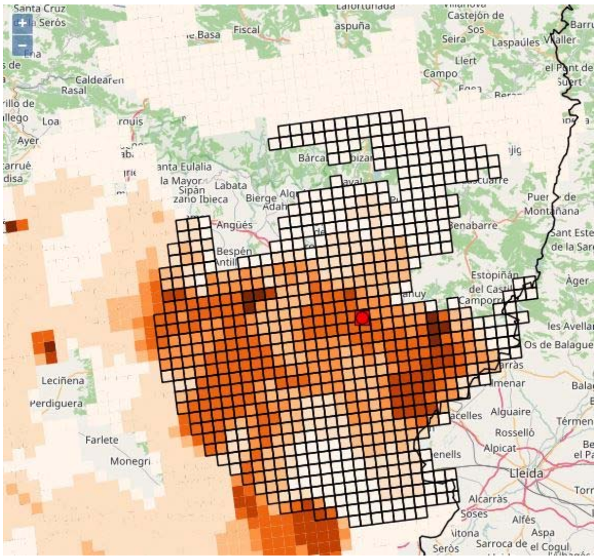
This scenario includes only the Monzón power plant (Table 18). Straw and stalk feedstock option is analyzed considering the 50% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. The collection circle is not completely round anymore like it was in SC004. Now also Monzón has to deal with border effects at the East. The maximum collection distance for winter cereals is now 45 km, which is almost two times higher than the one needed with the single Monzón 100% availability case. The total transport costs are 60.3% more than in SC004 (Monzón, 100% availability).

Table 18. Scenario SC008. Main results table.

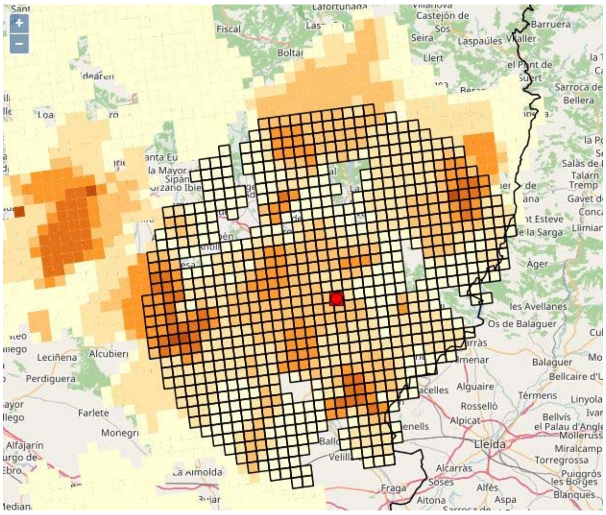
	Monzón
Maximum collection distance (km)	45
Total collected biomass (ton dm)	103,258
Maize	71,136
Winter cereals	28,289
Sunflower	3,833
Total transport amount (ton·km)	3,090,076
Maize	2,045,722
Winter cereals	911,546
Sunflower	132,808
Purchase costs (€)	4,008,473
Transport costs (€)	247,206
Loading/Unloading costs (€)	291,187
Extra costs supply chain (€/t dm)	5.21
Price at gate (€/t dm)	**44.03**

Map sourcing Monzón

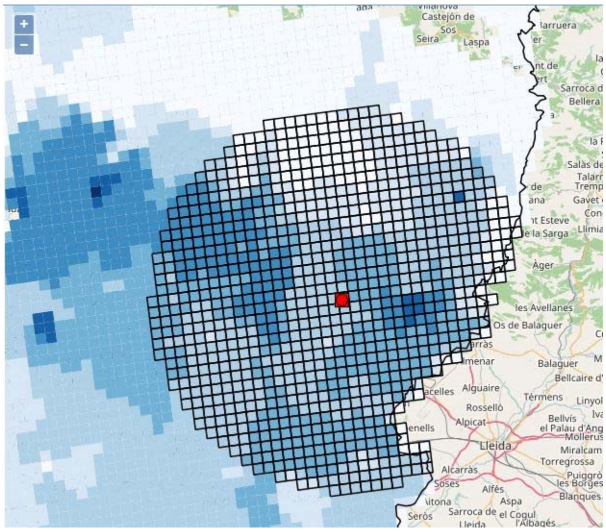
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC009

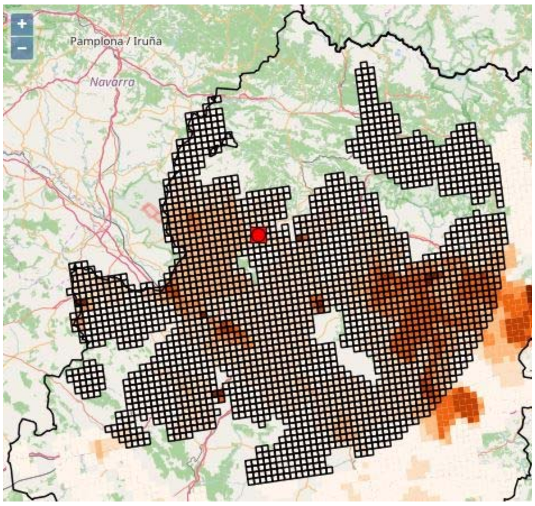
This scenario includes only the Erla power plant (Table 19). Straw and stalk feedstock option is analyzed considering the 25% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. The collection area is much larger now and more like half a circle because of the border effects in the West. The maximum collection distance for winter cereals is now 100 km, which is almost three times higher than the one needed with the single Erla 100% availability case. The total transport costs are 114% higher than in SC002 (Erla, 100% availability).

Table 19. Scenario SC009. Main results table.

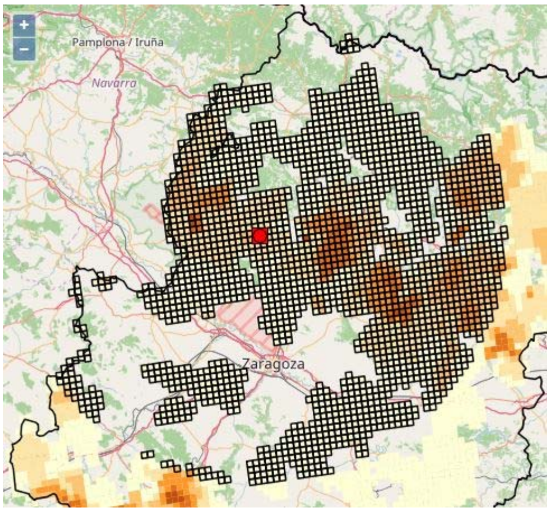
	Erla
Maximum collection distance (km)	100
Total collected biomass (ton dm)	103,201
Maize	58,956
Winter cereals	41,141
Sunflower	3,104
Total transport amount (ton·km)	6,935,829
Maize	4,099,337
Winter cereals	2,644,176
Sunflower	192,316
Purchase costs (€)	4,006,252
Transport costs (€)	544,866
Loading/Unloading costs (€)	291,026
Extra costs supply chain (€/t dm)	8.20
Price at gate (€/t dm)	**47.02**

Map sourcing Erla

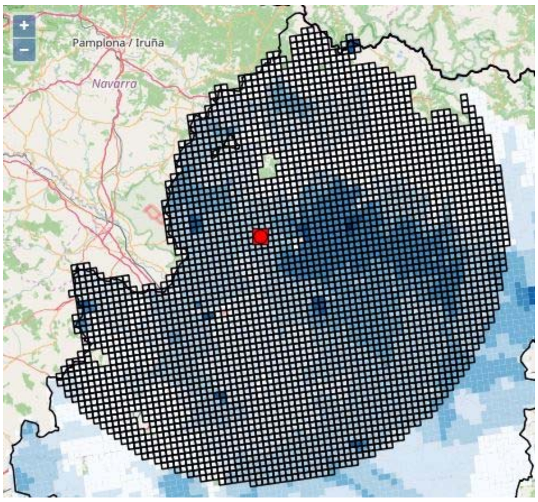
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC010

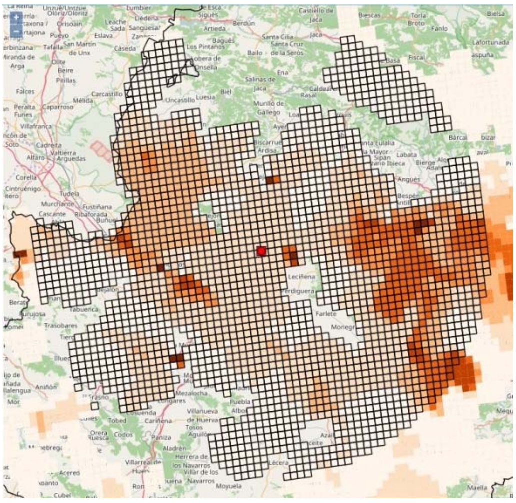
This scenario includes only the Zuera power plant (Table 20). Straw and stalk feedstock option is analyzed considering the 25% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. The collection areas are still more or less circle shaped. However, some border effects can be seen on the North-West side of the area. The maximum collection distance for winter cereals is now 80 km, which is 2.3 times higher than the one needed with the single Zuera 100% availability case. The total transport costs are 90% higher than in SC003 (Zuera, 100% availability).

Table 20. Scenario SC010. Main results table.

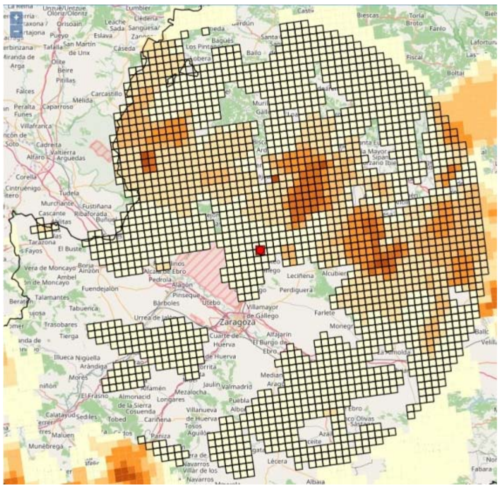
	Zuera
Maximum collection distance (km)	80
Total collected biomass (ton dm)	103,238
Maize	59,715
Winter cereals	40,675
Sunflower	2,848
Total transport amount (ton·km)	5,894,354
Maize	3,442,407
Winter cereals	2,297,866
Sunflower	154,081
Purchase costs (€)	4,007,714
Transport costs (€)	471,548
Loading/Unloading costs (€)	291,132
Extra costs supply chain (€/t dm)	7.39
Price at gate (€/t dm)	**46.21**

Map sourcing Zuera

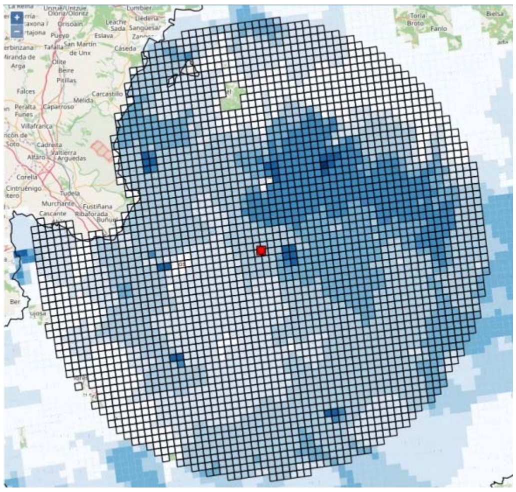
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



Scenario SC011

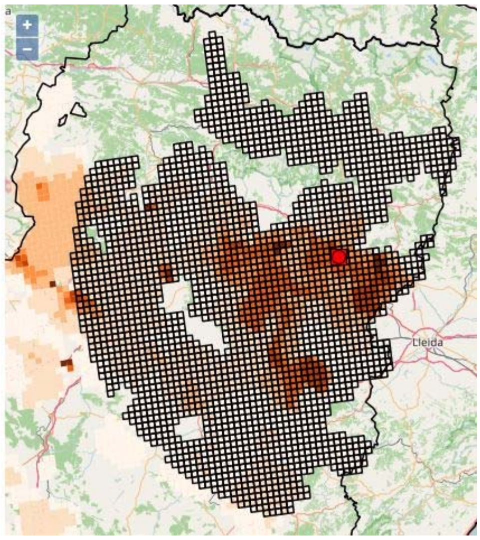
This scenario includes only the Monzón power plant (Table 21). Straw and stalk feedstock option is analyzed considering the 25% of biomass availability and no intermediate collection points. The complete demand of the power plant (103,200 t dm) is met. The collection circle is not completely round anymore. Now also Monzón has to deal with severe border effects at the East, which make the collection circle more half-round. The maximum collection distance for winter cereals is now 107.5 km, which is 4.3 times higher than the one needed with the single Monzón 100% availability case. The total transport costs are 208% higher than in SC004 (Monzón, 100% availability).

Table 21. Scenario SC011. Main results table.

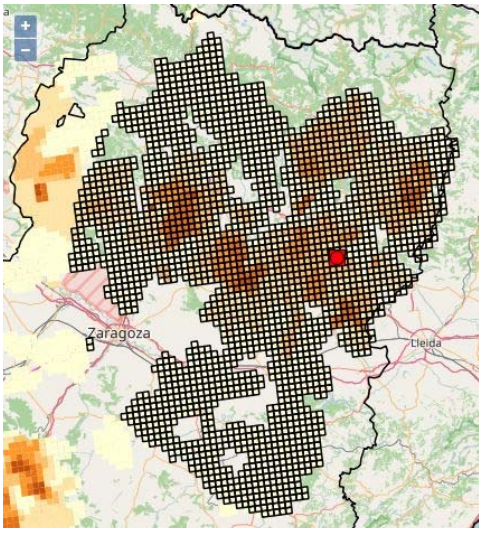
	Monzón
Maximum collection distance (km)	107.5
Total collected biomass (ton dm)	103,205
Maize	59,463
Winter cereals	40,293
Sunflower	3,449
Total transport amount (ton·km)	5,948,696
Maize	3,032,023
Winter cereals	2,730,857
Sunflower	185,816
Purchase costs (€)	4,006,400
Transport costs (€)	475,896
Loading/Unloading costs (€)	291,037
Extra costs supply chain (€/t dm)	7.43
Price at gate (€/t dm)	**46.25**

Map sourcing Monzón

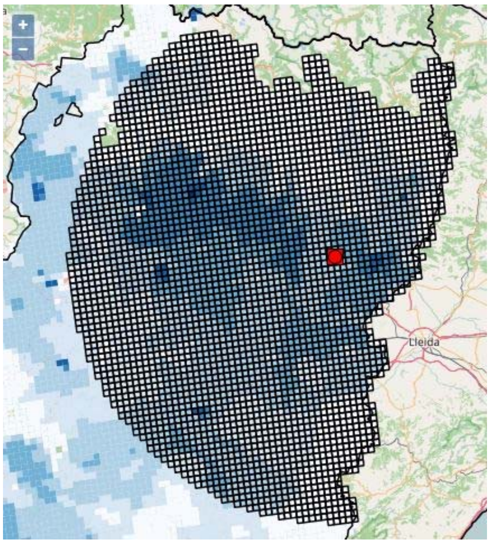
Biomass type: maize



Biomass type: sunflower



Biomass type: winter cereals



6.3 Results of different scenarios for woody biomass

Scenario SC012

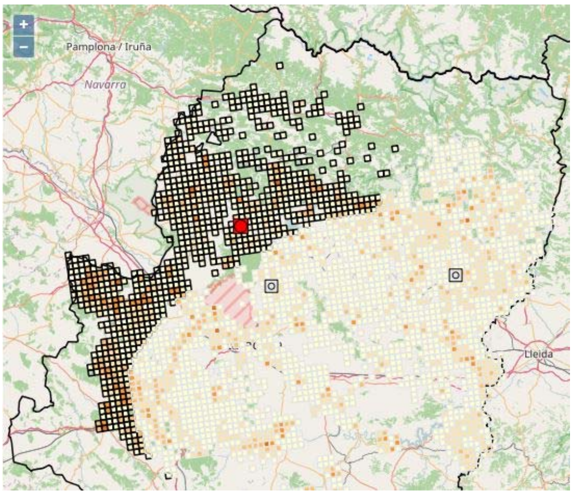
This scenario includes the three power plants (Table 22). Wood feedstock from plantations removal option is analyzed considering the 100% of biomass availability and an initial demand of 60,000 t per plant. The complete demand of each power plant cannot be met due to the limited amount of biomass and the competition of the plants. The collection areas are no circles, but shapes that reflect the competition between the three power plants and border effects. Comparing the three supply chains and the total biomass collected, it can be concluded that all the biomass available is collected for this case. Since the price limit was set at 57.14 €/t dm (which equals 40 €/t fresh matter 30% moisture content) the supply chain Case 2.3. is the only one that fulfil the plans of Forestalia Group regarding the price limit.

Table 22. Scenario SC012. Main results table.

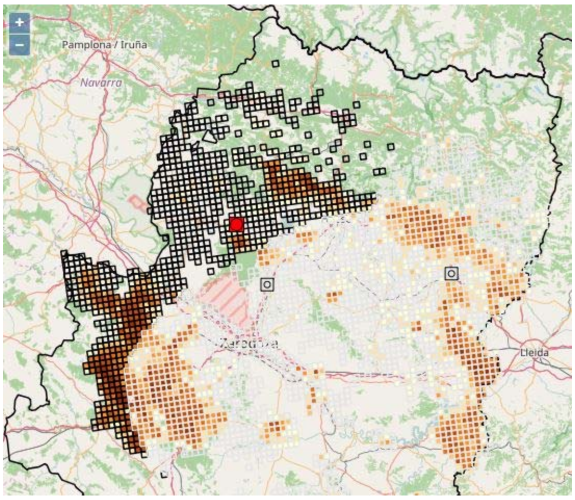
	Erla	Zuera	Monzón
Maximum collection distance (km)	92.5	112.5	90.0
Total collected biomass (ton dm)	22,158	35,674	40,644
Case 2.1. supply chain	2,867	3,615	3,259
Case 2.2. supply chain	14,856	19,754	19,513
Case 2.3. supply chain	4,436	12,305	17,871
Total transport amount (ton·km)	2,499,651	3,999,803	2,952,737
Case 2.1. supply chain	229,786	302,893	172,096
Case 2.2. supply chain	1,744,090	2,132,069	1,362,004
Case 2.3. supply chain	526,375	1,564,841	1,418,637
Costs for Case 2.1. supply chain			
Purchase cost (€/ t dm)	67.08		
Transport cost (€/t dm)	6.22	6.52	4.11
Price at gate (€/t dm)	**73.30**	**73.60**	**71.19**
Costs for Case 2.2. supply chain			
Purchase cost (€/t dm)	80.42		
Transport cost (€/t dm)	7.83	7.20	4.65
Price at gate (€/t dm)	**88.25**	**87.62**	**85.04**
Costs for Case 2.3. supply chain			
Purchase cost (€/t dm)	46.67		
Transport cost (€/t dm)	6.59	7.07	4.41
Price at gate (€/t dm)	**53.26**	**53.73**	**51.07**

Map sourcing Erla

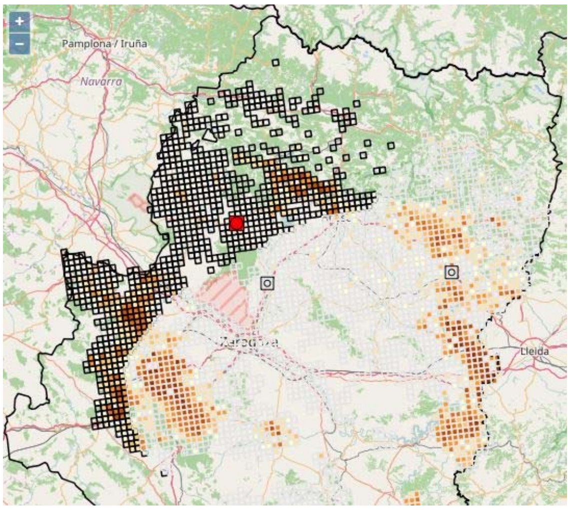
Case 2.1. supply chain



Case 2.2. supply chain

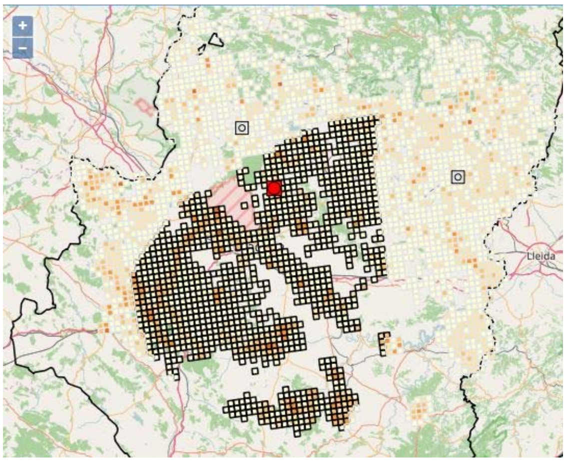


Case 2.3. supply chain

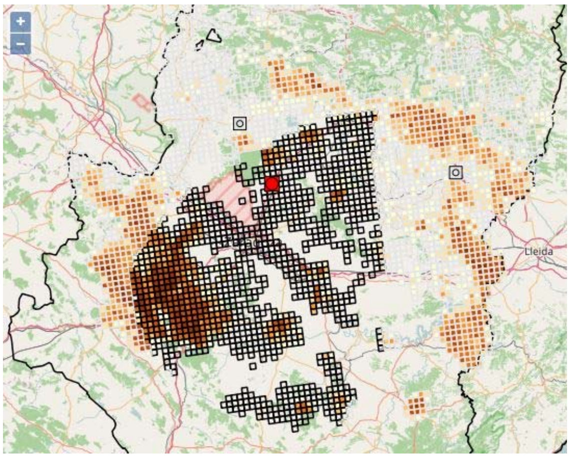


Map sourcing Zuera

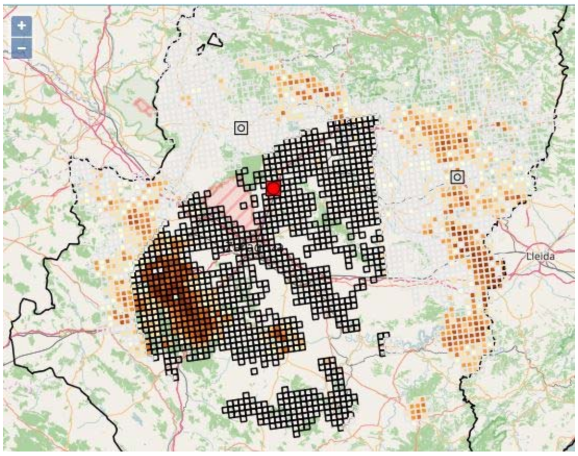
Case 2.1. supply chain



Case 2.2. supply chain

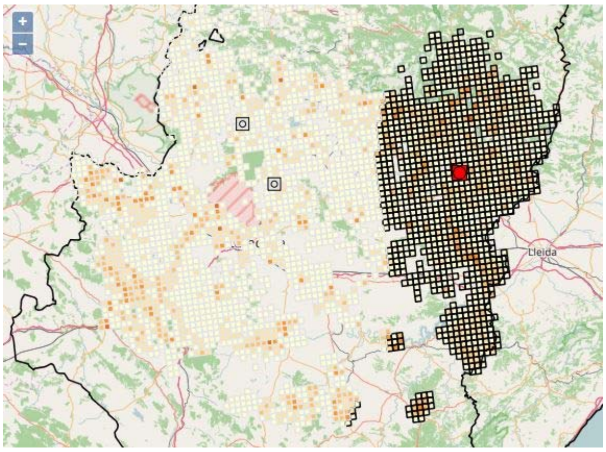


Case 2.3. supply chain

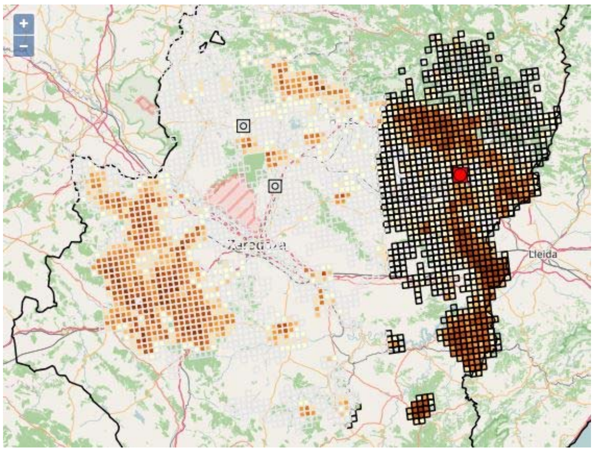


Map sourcing Monzón

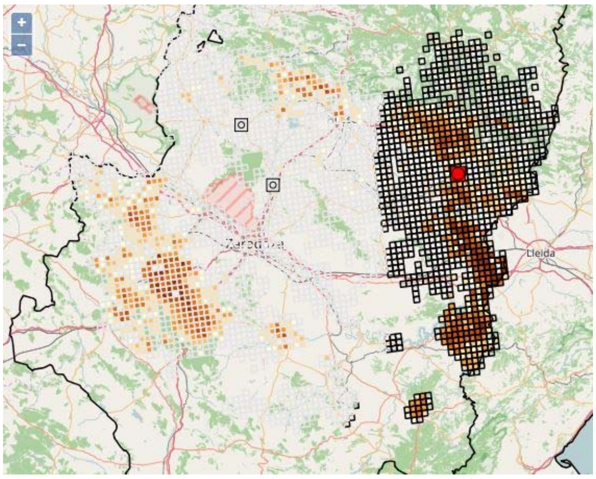
Case 2.1. supply chain



Case 2.2. supply chain



Case 2.3. supply chain



Scenario SC013

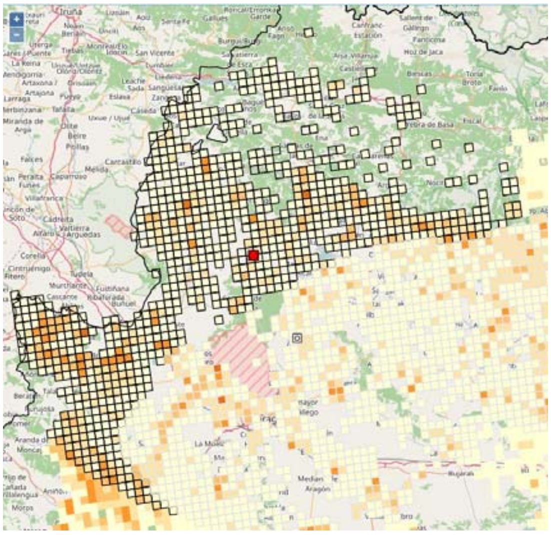
This scenario includes the three power plants (Table 23) Wood feedstock from plantations removal option is analyzed considering the 100% of biomass availability and an initial demand of 20,000 t per plant. Now the complete demand of each power plant can be met. The collection areas are still no circles for Erla and Zuera, but shapes that reflect the competition between the two power plants and border effects. For Monzon the shape is almost a circle with only some border effects in the East. Since the price limit was set at 57.14 €/t dm (which equals 40 €/t fresh matter 30% moisture content) the supply chain Case 2.3. is the only one that fulfil the plans of Forestalia Group regarding the price limit.

Table 23. Scenario SC013. Main results table.

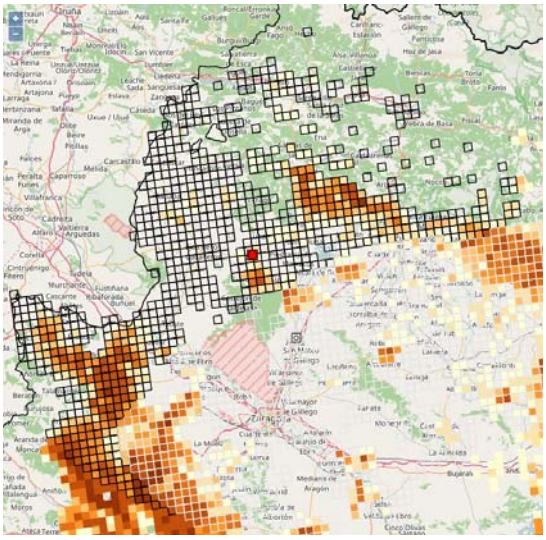
	Erla	Zuera	Monzón
Maximum collection distance (km)	85.0	67.5	35.0
Total collected biomass (ton dm)	20,088	20,087	20,094
Case 2.1. supply chain	2,676	2,092	1,833
Case 2.2. supply chain	12,369	9,396	9,907
Case 2.3. supply chain	5,043	8,607	8,347
Total transport amount (ton·km)	2,077,544	2,016,698	821,581
Case 2.1. supply chain	192,824	116,964	58,634
Case 2.2. supply chain	1,290,719	855,290	380,531
Case 2.3. supply chain	594,001	1,044,444	382,416
Costs for Case 2.1. supply chain			
Purchase cost (€/ t dm)	67.08		
Transport cost (€/t dm)	5.60	4.35	2.48
Price at gate (€/t dm)	**72.68**	**71.43**	**69.57**
Costs for Case 2.2. supply chain			
Purchase cost (€/t dm)	80.42		
Transport cost (€/t dm)	6.96	6.07	2.56
Price at gate (€/t dm)	**87.38**	**86.49**	**82.98**
Costs for Case 2.3. supply chain			
Purchase cost (€/t dm)	46.67		
Transport cost (€/t dm)	6.54	6.74	2.54
Price at gate (€/t dm)	**53.21**	**53.41**	**49.21**

Map sourcing Erla

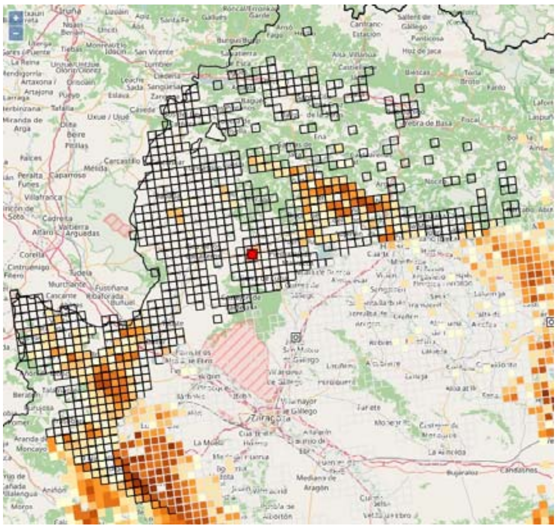
Case 2.1. supply chain



Case 2.2. supply chain

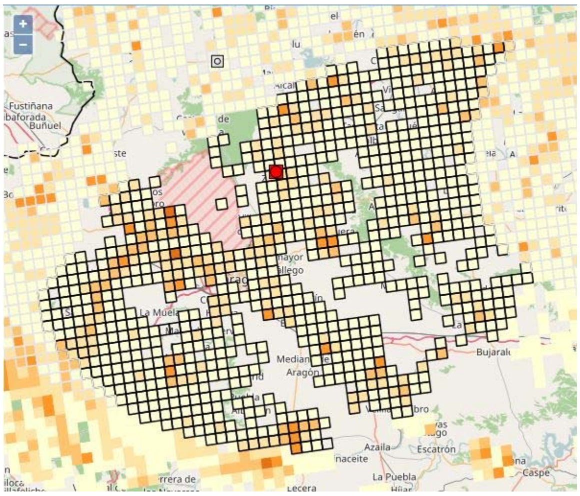


Case 2.3. supply chain

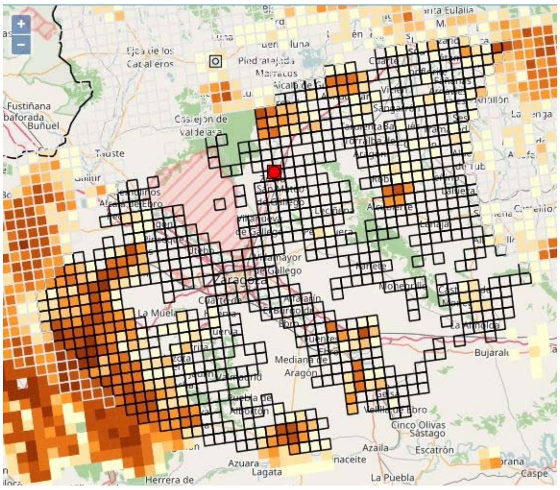


Map sourcing Zuera

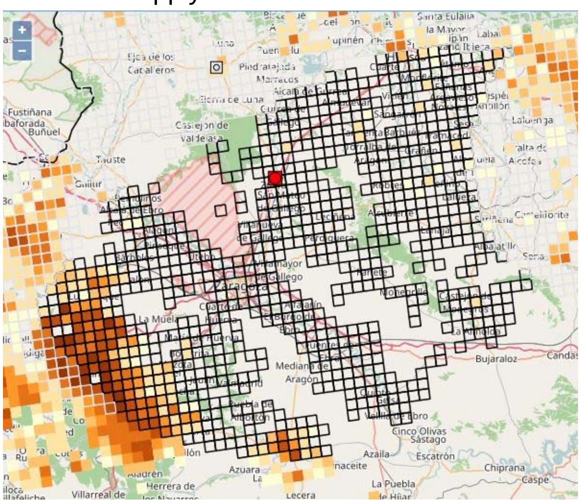
Case 2.1. supply chain



Case 2.2. supply chain

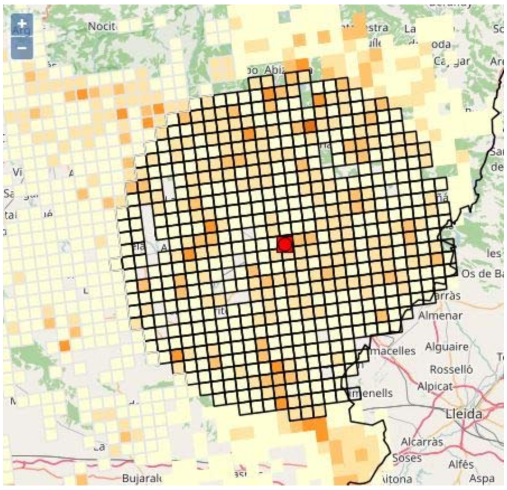


Case 2.3. supply chain

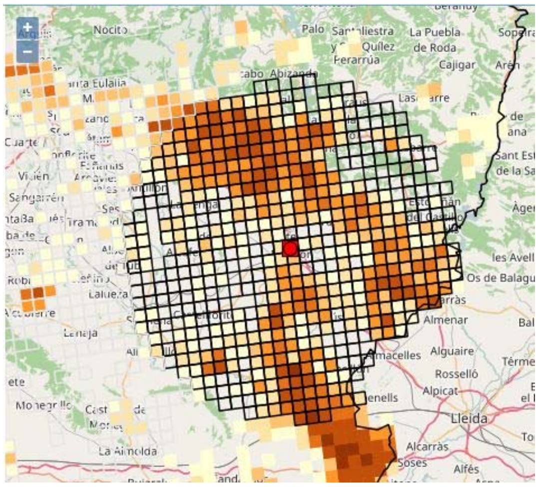


Map sourcing Monzón

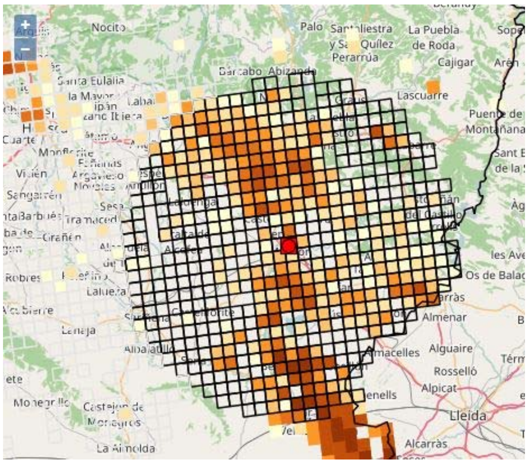
Case 2.1. supply chain



Case 2.2. supply chain



Case 2.3. supply chain



Scenario SC014

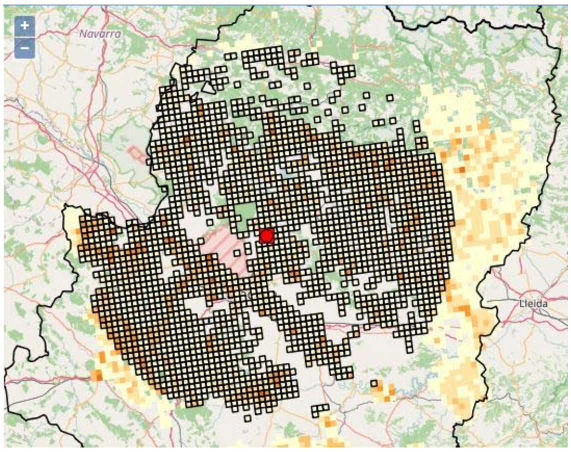
This scenario includes only Zuera power plant (Table 24). Wood feedstock from plantations removal option is analyzed considering the 100% of biomass availability and an initial demand of 60,000 t per plant. The complete demand can now be met due to there is no competition between plants. Regarding the scenario SC012 with the three power plants, it is difficult to compare Zuera power plant numbers since biomass collected is very different in both situations, 60,011 ton instead 36,674 ton. The collection areas are almost circles, just some border effects in the western region. Since the price limit was set at 57.14 €/t dm (which equals 40 €/t fresh matter 30% moisture content) the supply chain Case 2.3. is the only one that fulfil the plans of Forestalia Group regarding the price limit.

Table 24. Scenario SC014. Main results table.

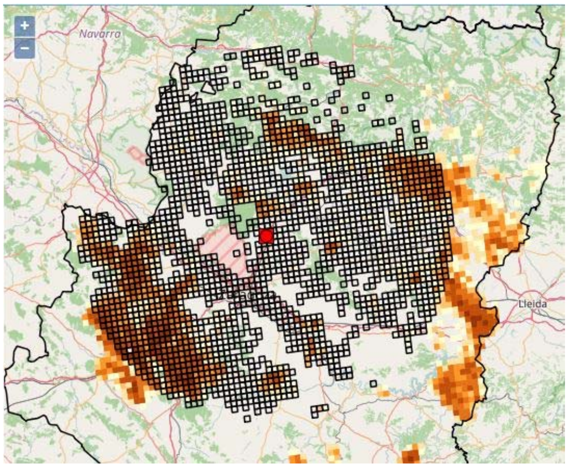
	Zuera
Maximum collection distance (km)	82.5
Total collected biomass (ton dm)	60,011
Case 2.1. supply chain	6,359
Case 2.2. supply chain	34,934
Case 2.3. supply chain	18,719
Total transport amount (ton·km)	6,684,970
Case 2.1. supply chain	504,436
Case 2.2. supply chain	3,786,837
Case 2.3. supply chain	2,393,697
Costs for Case 2.1. supply chain	
Purchase cost (€/ t dm)	67.08
Transport cost (€/t dm)	6.17
Price at gate (€/t dm)	**73.25**
Costs for Case 2.2. supply chain	
Purchase cost (€/t dm)	80.42
Transport cost (€/t dm)	7.23
Price at gate (€/t dm)	**87.65**
Costs for Case 2.3. supply chain	
Purchase cost (€/t dm)	46.67
Transport cost (€/t dm)	7.11
Price at gate (€/t dm)	**53.77**

Map sourcing Zuera

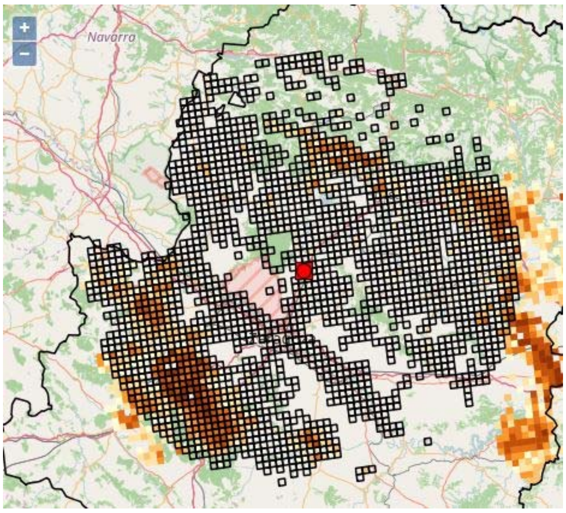
Case 2.1. supply chain



Case 2.2. supply chain



Case 2.3. supply chain



Scenario SC015

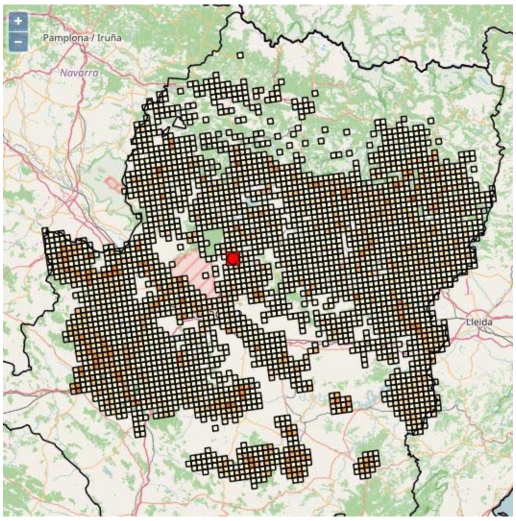
This scenario includes only Zuera power plant (Table 25). Wood feedstock from plantations removal option is analyzed considering the 50% of biomass availability and an initial demand of 60,000 t per plant. The complete demand cannot be met because of the limited availability condition. The collection areas are not circles, and distances are now significantly increased. Since the price limit was set at 57.14 €/t dm (which equals 40 €/t fresh matter 30% moisture content) the supply chain Case 2.3. is the only one that fulfil the plans of Forestalia Group regarding the price limit.

Table 25. Scenario SC015. Main results table.

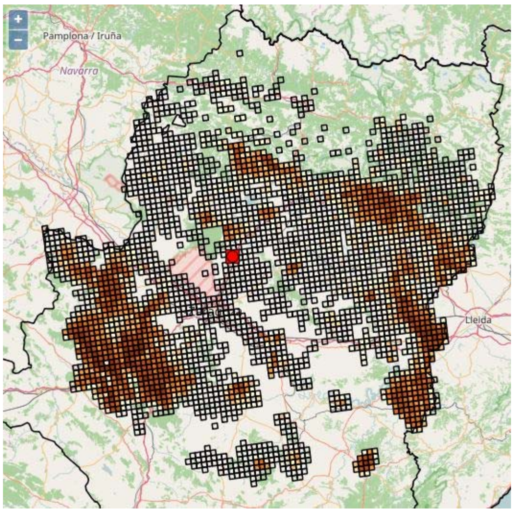
	Zuera
Maximum collection distance (km)	130.0
Total collected biomass (ton dm)	49,238
Case 2.1. supply chain	4,870
Case 2.2. supply chain	27,061
Case 2.3. supply chain	17,306
Total transport amount (ton·km)	6,704,944
Case 2.1. supply chain	485,867
Case 2.2. supply chain	3,456,606
Case 2.3. supply chain	2,762,471
Costs for Case 2.1. supply chain	
Purchase cost (€/ t dm)	67.08
Transport cost (€/t dm)	7.76
Price at gate (€/t dm)	**74.84**
Costs for Case 2.2. supply chain	
Purchase cost (€/t dm)	80.42
Transport cost (€/t dm)	8.52
Price at gate (€/t dm)	**88.94**
Costs for Case 2.3. supply chain	
Purchase cost (€/t dm)	46.67
Transport cost (€/t dm)	8.87
Price at gate (€/t dm)	**55.53**

Map sourcing Zuera

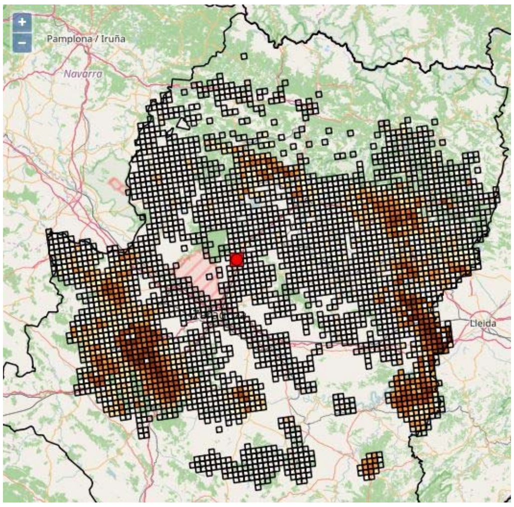
Case 2.1. supply chain



Case 2.2. supply chain



Case 2.3. supply chain



Scenario SC016

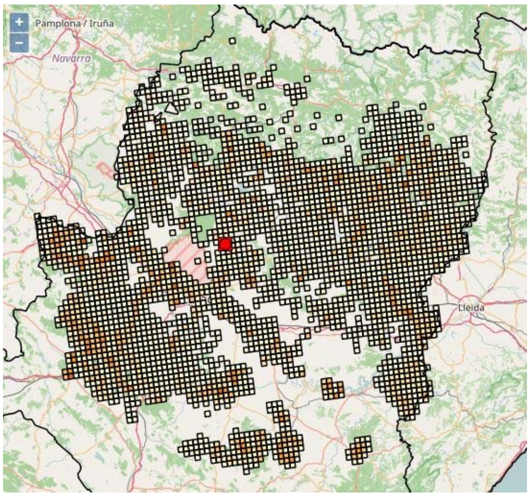
This scenario includes only Zuera power plant (Table 26). Wood feedstock from plantations removal option is analyzed considering the 25% of biomass availability and an initial demand of 60,000 t per plant. The complete demand cannot be met because of the availability condition. The collection areas are not circles, but distances are the same than in previous scenario with 50% availability. Since the price limit was set at 57.14 €/t dm (which equals 40 €/t fresh matter 30% moisture content) the supply chain Case 2.3. is the only one that fulfil the plans of Forestalia Group regarding the price limit.

Table 26. Scenario SC016. Main results table.

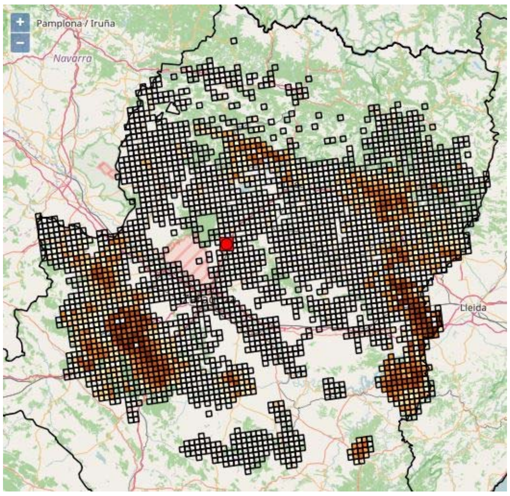
	Zuera
Maximum collection distance (km)	130.0
Total collected biomass (ton dm)	24,619
Case 2.1. supply chain	2,435
Case 2.2. supply chain	13,531
Case 2.3. supply chain	8,653
Total transport amount (ton·km)	3,352,472
Case 2.1. supply chain	242,934
Case 2.2. supply chain	1,728,303
Case 2.3. supply chain	1,381,235
Costs for Case 2.1. supply chain	
Purchase cost (€/ t dm)	67.08
Transport cost (€/t dm)	7.76
Price at gate (€/t dm)	**74.84**
Costs for Case 2.2. supply chain	
Purchase cost (€/t dm)	80.42
Transport cost (€/t dm)	8.52
Price at gate (€/t dm)	**88.94**
Costs for Case 2.3. supply chain	
Purchase cost (€/t dm)	46.67
Transport cost (€/t dm)	8.87
Price at gate (€/t dm)	**55.53**

Map sourcing Zuera

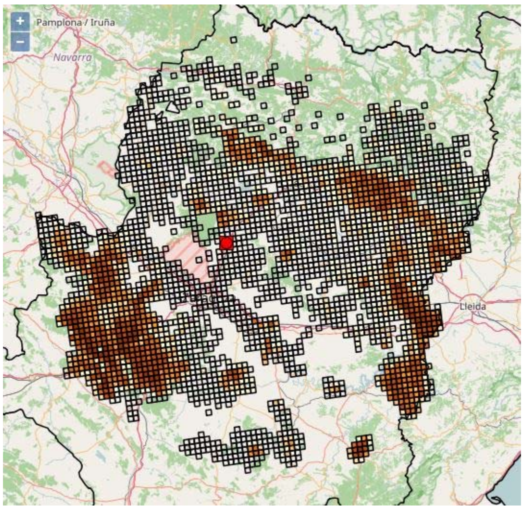
Case 2.1. supply chain



Case 2.2. supply chain



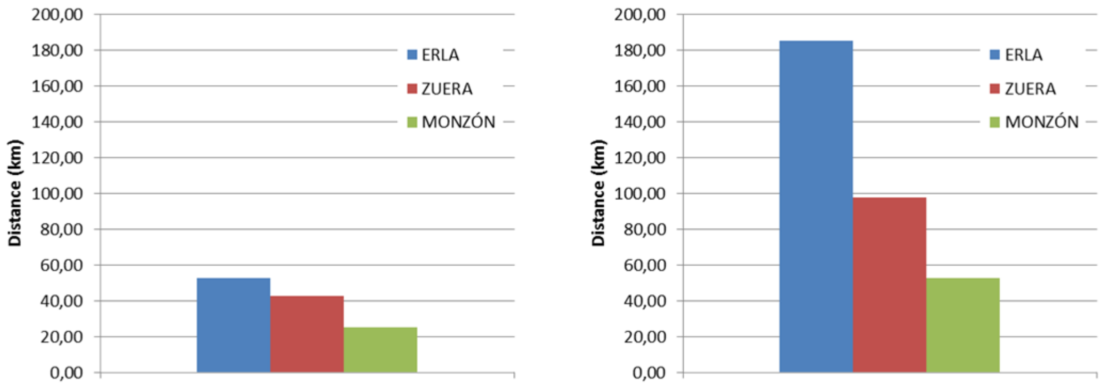
Case 2.3. supply chain



6.4 Discussion

Herbaceous biomass

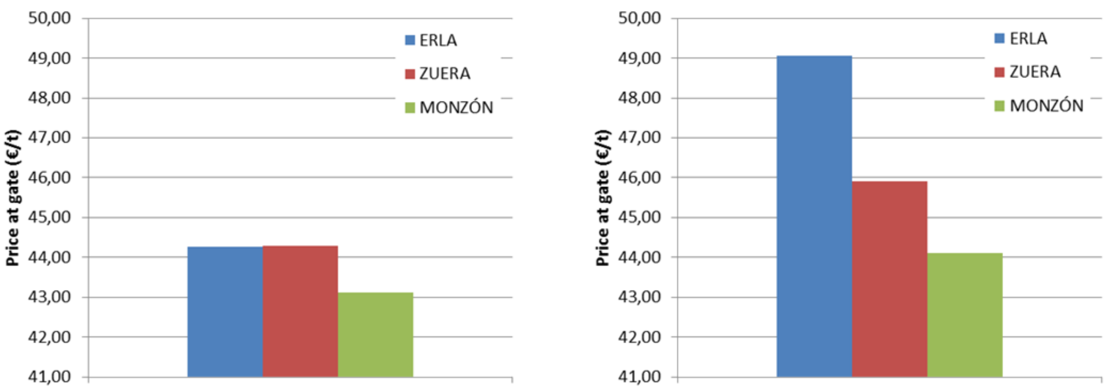
The amount of herbaceous biomass is enough to cover the annual needs of the three power plants in any case. Competition problems appear between Erla and Zuera power plants and consequently, biomass collecting distances are higher than for Monzón power plant supply. When only 50% of biomass is considered as available, Monzón is also affected by competition problems but in a minor way.



(a) (b)

Figure 10. **Maximum collection distance for the three power plants competition scenarios: (a) 100% biomass availability, (b) 50% biomass availability.**

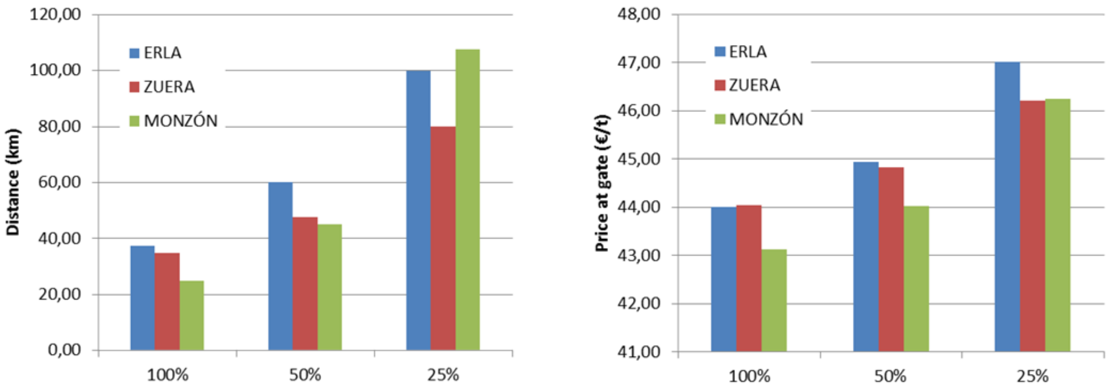
Regarding the final price at gate, Monzón power plant always shows the minimum value. Although Erla and Zuera have a similar fuel price at gate considering 100% biomass availability, in the case of Erla power plant, this price yields a remarkable increase when just a 50% of biomass is available (see Figure 11b).



(a) (b)

Figure 11. **Price at gate for the three power plants competition scenarios: (a) 100% biomass availability, (b) 50% biomass availability.**

When the power plants are analyzed individually, the results are different since competition between plants does not take place. Figure 12 shows the variation of the maximum collection distance with the percentage of biomass availability for each power plant. 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.

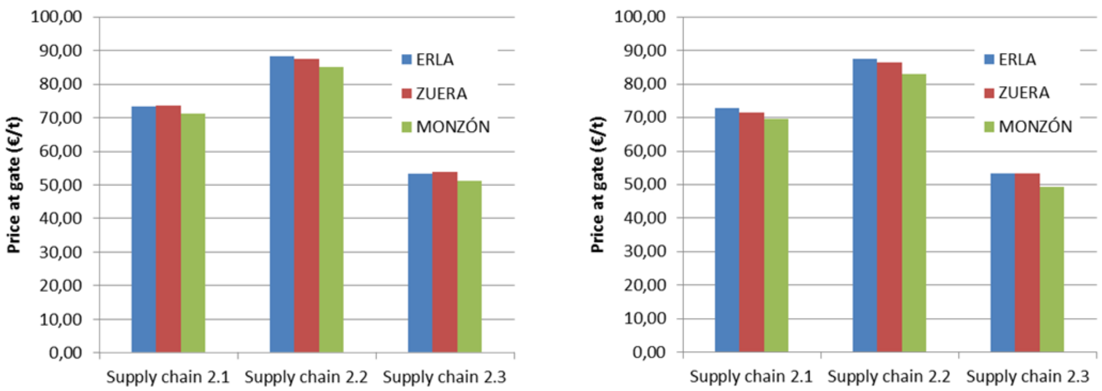


(a) (b)

Figure 12. Evolution with the biomass availability of the results of the single power plants scenarios: (a) maximum collection distance (km), (b) price at gate (€/t).

Wood plantations removal

As we stated in the previous biomass potential analysis (see Table 2), there is not enough wood from plantations removal close to the different sites in order to cover the whole demand of the power plants (not even one of them). Therefore, two kind of scenarios were proposed regarding the maximum demand per plant, 60,000 t and 20,000 t.



(a) (b)

Figure 13. Price at gate of the different supply chains for the three power plant scenarios: (a) 60,000 t demand limitation, (b) 20,000 t demand limitation.

Regarding the three supply chain concepts, Case 2.1 and Case 2.2 chains 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. Nevertheless, some conclusions can be drawn from these results as we introduce in the next section (7. Conclusions and recommendations). The Case 2.3 supply chain is the most promising one. Prices are below the Forestalia Group limitation for all the power plants. Comparing now the three locations, Monzón suffers lower competition effects than Erla and Zuera, especially when the demand per plant is reduced. In this case just minor border effects appear. That is the main reason for the lower price at gate for Monzón power plant.

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%.

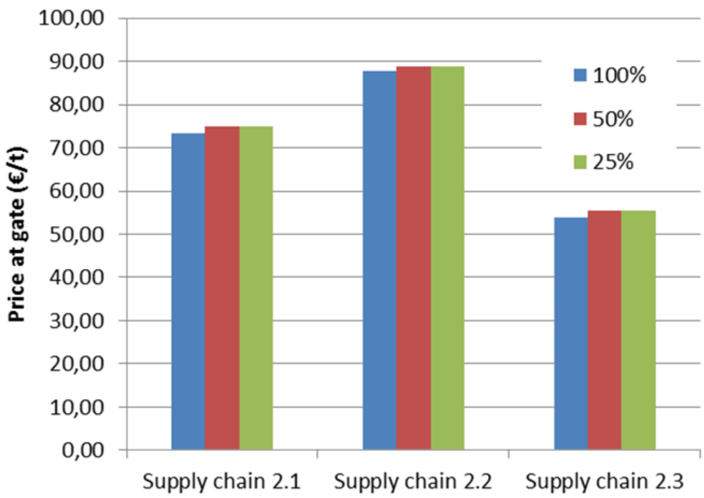


Figure 14. Variation with the percentage of biomass availability of the price at gate for Zuera power plant.

Figure 14 shows that 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.

7. Conclusions and recommendations

7.1 Conclusions

Wood plantation removal

- Supply chain Case 2.1 is not profitable. So, a solution could be that the collection points where farmers dump their residues ask for a fee to the farmers just in order to compensate the costs. The initial scenario considered that they dump the residues for free. It should be explored how much they would be willing to pay to be able to dump their residues at the collection point. However, it also would require a storage site with more controlled conditions, and so, a potential increase of costs in this collection points. Pretreatment operations at the power plant with static equipment reduce costs in comparison to mobile units. The alternative to the initial logistic proposal explored by Forestalia Group could be, for instance, that the primary crusher could be moved to the fields (mounted on a truck), and then the shredded material to be transported directly to the power plant, where static screening and chipping machines would treat the material. Although transport costs would be slightly higher, the pretreatment costs would be reduced.
- Case 2.2 is the worst case in terms of economics. However, could be more attractive increasing the price asked to the farmers to receive the service that Forestalia Group is giving to the farmer (currently, calculations are made with a low price, 300 €/ha. This could potentially rise to 500 €/ha. Improvements in the logistic chain could be like those explained for case 2.1: use of a primary shredder at field side and transport to the plant where a static screening and chipping is performed.
- Case 2.3 is by far the most suitable. It is based on large fields, and therefore, the best conditions are available. It also could be improved in terms of costs if the only machinery mobilized to field is the primary shredder.
- The supply chains for wood plantation removal are complementary because their application depends on the size of the fields. Consequently, despite of the fact that Case 2.3 is the most promising one, it could not be used for wood plantation removal in other different sites and fields.
- It could be argued if building intermediate treatment centers (ITCs) could be useful. Each one could treat 10 to 20 thousand t/yr, and include a screening system and a chipper. It would be the base for the mobile unit (primary shredder and tractor with shear or shovel). The pretreatment costs would be similar to those proposed above as an improvement to the initial system of mobile units. However, it would allow better organization in the territory and better control of the biomass flow. The general costs would rise as the creation

of several centers would cause larger costs than a sole centralized facility next by the power plant.

Straw

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

7.2 Recommendations

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.

After analyze the results, it seems clear that in terms of biomass availability and supply chains definitions, 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.

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.

Regarding the logistic tool, 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.

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.

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