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Market Uptake Support for Intermediate Bioenergy Carriers

WP4: Optimisation tools

Deliverable 4.2.
## Software and tools for selected case studies

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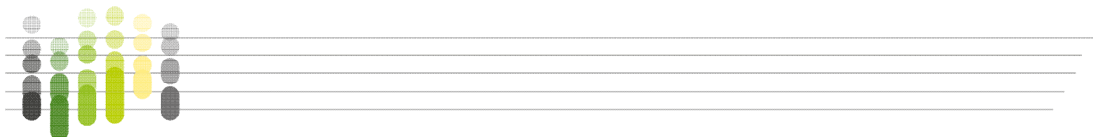
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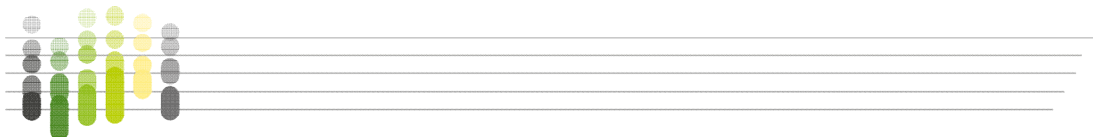
EXECUTIVE SUMMARY

MUSIC project aims to facilitate further market uptake of three types of intermediate bioenergy carriers (IBC), namely pyrolysis oil, torrefied biomass and microbial oil, by developing feedstock mobilization strategies, improving logistics and developing of IBC trade centers. Core project actions are the development of regional feedstock mobilization strategies and tools for mobilizing biomass and optimizing size and location of trade centers, which will end up in optimized, cost-effective solutions for logistics along the entire IBC value chain in specific, industry-driven advanced and strategic case studies in the four target regions of the project: Greece, Italy, Sweden/Finland and International.

The present Deliverable 'D4.2: Software and tools for selected case studies' comprises the models developed for local use in the various case study regions, in order to assess regional biomass flows and facilitate regional biomass trade. GIS system coverage varied from region to region based on the respective maturity of the bioenergy market. The models will be applied in the various case studies of the project.

The Deliverable also contains an optimisation model that aims to determine the optimal time planning for biomass procurement and the maximum torrefaction unit capacity in a cost-effective way.

More specifically:

- ### Greek Case-Study / MUSIC-MyGIS model

The MUSIC-MyGIS model has been developed in the frame of the MUSIC project to calculate the logistics of the Greek Case Study Region. It is a GIS application that contains cartographic backgrounds, administrative layers, road network, storage and selling points, land use maps and data bases with data on crop types, yields and energy potentials, biomass forms and transport means. Data are used in algorithms, so that the interested party can calculate not only the final cost, but also the costs of the intermediate phases, until the final delivery to the end user.

The aim of the application is to allow the user to select the fields where the biomass will be collected, storage points where it will be stored as solid biomass or as torrefied biomass, and selling points and calculate the involved transportation costs in the entire biomass supply chain.

Logistics are processed in two stages. In the first stage the biomass is transferred from the fields to the storage point (torrefaction unit) and in the second stage the torrefied biomass is transferred to the end user (selling point), which can be a biomass heat and/or power plant or an individual consumer. Alternatively, in the absence of a torrefaction unit, solid biomass will be stored in the storage point and transported as such to the end user. For each of the above stages the transport cost is calculated and added to determine the final cost. The allocation of costs for each stage of the process will help each involved user or stakeholder to see the costs of the stage he is interested in separately. Total routes, distances, and times are calculated, along with total costs, costs per ton and per MJ.
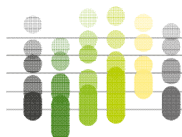
- ### Italian Case-Study / INFER-NRG model

The INFER-NRG model has been developed within MUSIC to get insights about the potential biomass availability and costs in the Italian Case Study regions. INFER-NRG combines a set of crop simulation models with a logistic model under a GIS framework, with the scope of providing optimized solutions and information support for the upstream, supply side of a techno-economic analysis for the feasibility study of an IBC production plant.

Core of the model is the geographical database, which contains all the input information needed by both crop model and logistic model to correctly operate, such as the ones regarding Climate, Soil, Administrative layers, Land Use, Crop productivity and phenology, Cultivation techniques (rotations, fertilizations etc.) and Road networks.

All these data are applied on a spatial grid to be used in several crop simulation models, to forecast the expected yields of ligno-cellulosic residues such as olive and grapevine pruning, herbaceous residues and finally dedicated energy crops, cultivated on marginal lands, such as *Arundo donax*. The simulation has a 30-years' time horizon and several possible scenarios are considered, based on climate forecast and crop rotations.

Objective of the logistics model is to assess the most effective way to bring the biomass from each production cell to the final transformation site, optimizing the process in terms of overall costs and year-round availability. Several interviews with expert and companies have been conducted, in order to gain insights and data related to the most common practices and related costs.

All the outputs are made available by the model at single cell level; then, they could be aggregated, e.g. to describe the average monthly biomass availability of a certain area to be used as raw material input for an IBC plant.

- ### The Swedish Case-Study

The first model -from the forest to the pyrolysis facility- to be applied in the Swedish case study is based on information on the annual projected forest biomass potentials from final fellings and thinnings of five assortments (branches, stumps, bark, pulpwood and saw logs) from several woody species, including also ecological restrictions. The distance from the collection points to the nearest receiving point within the region, either facility (heating plant, biorefinery, pulp mill or sawmill) or terminal, was estimated based on the Swedish road network by using the Network Analyst module in ArcGIS10.
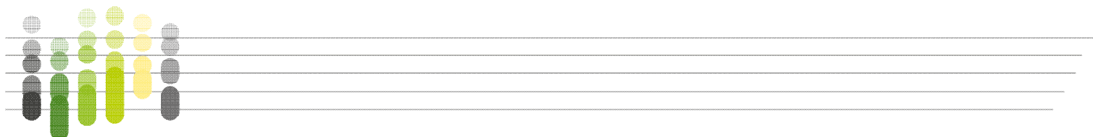
In the second model - from sawmills to a pyrolysis facility that is located at a sawmill- all 28 sawmills in the region were georeferenced and sawdust availability for use in a pyrolysis reactor was assessed. For the purpose of the analysis one sawmill was selected as host of the pyrolysis reactor. Using the Network Analyst module in ArcGIS10 (Closest facility function), sawdust was transported via the existing road network to the pyrolysis reactor. When the total demand of 80,000 tons of sawdust was reached, no more transports happened. The same procedure was applied for four sawmills (Sikfors, Kåge, Bygdsiljum and Sävar) that were assumed to serve as hosts for the pyrolysis reactor and the relevant costs curves were assessed.
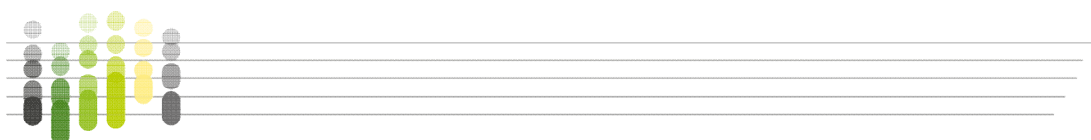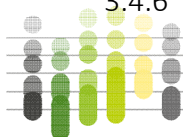
● The Optimisation tool

A biomass supply optimization model, based on non-linear programming, is used to determine the optimal time planning for biomass procurement and the maximum torrefaction unit capacity. The overarching goal is the cost minimization, taking into account seasonal biomass availability issues, biomass seasonal cost, storage options and cost, logistics, end-users demand, torrefaction unit operational parameters, capital expenditures (CAPEX), operational expenditures (OPEX) and biomass properties.

The model is developed for a stand-alone biomass torrefaction unit and accounts for biomass procurement, storage, and utilization under variable conditions.
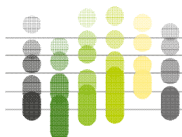
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1 Introduction

The challenges that climate change brings to our lives requires the ability to predict the responses of crops to environment and management. Geographic information systems (GIS), climatic models and crop simulation models are complementary tools that are increasingly used for such predictive analyses. The role of these systems and models in predicting future situations centres around extrapolation; for GIS, extrapolation from the past based on correlation in a very loose sense plays an important role. For crop models, extrapolation based on how known processes respond to factors of interest (i.e. simulation) is a key factor; GIS and crop models can be integrated, providing predictions that combine the spatial perspective of GIS with the stronger representation of temporal processes of simulation models (Hodson et al., 2010).

The increase in the world population, combined with the need to operate production processes in a more ecological and sustainable way, leads us to reconsider the use of biomass produced by the agricultural sector in marginal areas. At the same time, biomass residues could play an important role for the production of energy.

The European Commission (EC) places its trust in the private sector as a key financier of the green transition. The European funds will lay the foundations for sustainable investments, facilitating the identification of sustainable investment opportunities and integrating climate risks into the financial system. This offers opportunities, especially for large renewable energies corporations, since the bureaucratic efforts to receive grants are substantial and might scare off small- and medium-sized companies (Streetz, 2020).

The enhancement of biomass for energy purposes is important from several points of view: the promotion of renewable sources, the diversification of energy sources, the reduction of greenhouse gas emissions and the sustainable use of local resources.

Moreover, the choice of allocating this natural resource to energy conversion constitutes an additional development opportunity for local communities, limiting depopulation and guaranteeing that function of monitoring the territory which is fundamental for the purposes of a correct / sustainable management and territorial protection.

The MUSIC project aims to facilitate further market uptake of three types of intermediate bioenergy carriers (IBC), namely pyrolysis oil, torrefied biomass and microbial oil, by developing feedstock mobilization strategies, improving logistics and developing of IBC trade centers. Core project actions are the development of regional feedstock mobilization strategies and tools for mobilizing biomass and optimizing size and location of trade centers, which will end up in optimized, cost-effective solutions for logistics along the entire IBC value chain in specific, industry-driven advanced and strategic case studies in the three target regions of the project: Greece, Italy, Sweden/Finland.

The scope of MUSIC case studies is diversified, and so are the models.

- In the **Greek Case Study,** the logistics and feasibility of a torrefied biomass value chain will be investigated. Biomass will be agricultural residues. A big challenge in these case studies will be to mobilise the biomass against acceptable costs.
  - o In the *advanced case study*, supply to a 30 MW$_{th}$ district heating pant (the Amyntaion district heating plant of DETEPA) that is being implemented at this
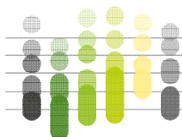
moment is investigated. DETEPA plans to replace the lignite coal gradually by biomass. Torrefied biomass would minimise additional plant investment and facilitate logistics and storage.

   o In the *strategic case study* large-scale implementation at multiple regional (district) heating plants and relevant (cement, quick lime or magnesite) industries in the region will be investigated.

- In the **Italian Case Study**, the advanced and strategic case studies are quite different:

   o The *advanced case* study involves investigating a value chain concerning the production of charcoal/pyrogas of regional biomass for use in the Arcelor Mittal steel mill in Taranto (Puglia, South of Italy). The approach is to develop a network of biomass suppliers to several carbonisation units of ca. 35,000 tonne/year capacity. After carbonisation, transport to the steel mill is foreseen. Feedstocks to be considered include agricultural residue, olive pruning, olive oil production residues and potentially wood derived from infected olive trees.

   o The *strategic case study* will research the logistics and feasibility of a microbial oil (MO) value chain for large scale use at the ENI existing biorefineries in Porto Marghera (Veneto) and Gela (Sicily). Lignocellulosic residues are to be converted to sugars using the PROESA^{TM} technology. This conversion step has been demonstrated already in the ENI cellulose ethanol plant in Cresentino (Italy). The sugars can subsequently be converted to lipids by oleaginous yeasts. These lipids can then be used to as feedstock in the existing biorefineries of ENI. The microbial oil production step has not been demonstrated yet.

- In the **Swedish Case Study** the aim is to investigate the logistics and feasibility of a long-distance value chain starting with pyrolysis oil production at various sites in Sweden and Finland and ending with pyrolysis oil upgrading to advanced marine biofuels at a site in the Netherlands. Logistic challenges include transport to ports in Sweden and Finland, followed by transport per ship to the Netherlands, where the pyrolysis oil can be upgraded to marine biofuels.

   o The *advanced case study* will be conducted with the minimum amount of pyrolysis oil needed for the upgrading plant, namely 72,000 tonne pyrolysis oil per year.

   o The *strategic case study* with quantities of ca. 2 to 3 times as much will also be investigated.

The aim of this deliverable is to develop existing GIS systems and tools that can be applied in the above targeted case studies. This work belongs to 'Task 4.2 Software and tools for the selected case studies', which aims to apply and build on earlier developed GIS systems in the targeted case study regions (NW Greece; Puglia, Sicily and Venice regions in Italy; parts of Sweden and Finland).

2 The Greek case study – MUSIC MyGIS

2.1   Objective of the work

The application covers the prefecture of Florina, where the strategic and advanced case-studies are conducted (Figure 2-1).

Figure 2-1: Location of the Greek CS

The aim of the application is to allow the user to select the fields where the biomass will be collected, the storage points where it will be stored as solid biomass or as torrefied biomass, and the selling points, and to calculate the involved transportation costs in the entire biomass supply chain.

2.2   Methodology

Logistics are processed in two stages. In the first stage the biomass is transferred from the fields to the storage point (torrefaction unit) and in the second stage the torrefied biomass is transferred to the end user (selling point), which can be a biomass heat and/or power plant or an individual consumer. Alternatively, in the absence of a torrefaction unit, solid biomass will be stored in the storage point and transported as such to the end user.

For each of the two stages the transport cost is calculated and added to determine the final cost.
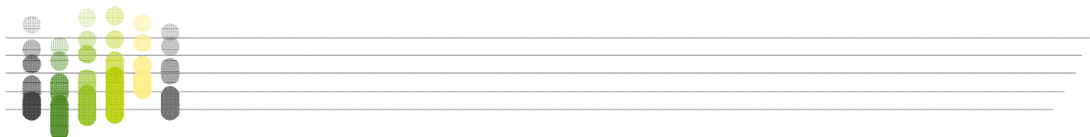
The structure of the application consists of cartographic backgrounds (Chapter 2.3.1.1), administrative layers (Chapter 2.3.1.2), road network (Chapter 2.3.1.3), storage and selling points (chapter 2.3.1.4), land use (Chapter 2.3.1.5), data bases with data on crop types, yields and energy potentials (chapter 2.3.1.6), biomass forms (Chapter 2.3.1.7) and transport means (Chapter 2.3.1.8), the MyGIS platform (Chapter 2.3.2) and user interface scenarios (Chapter 2.3.3). Data are used in algorithms, so that the interested party can calculate not only the final cost, but also the costs of the intermediate phases, until the final delivery to the end user.

2.3 Geographical Database creation

2.3.1 Data retrieval

2.3.1.1 Cartographic backgrounds

Various cartographic backgrounds, such as Google Maps and roads, terrain, Greek cadastre maps etc. are used to visualise specific observations regarding the relief, distances, villages, area names, etc. (Figure 2-2, Figure 2-3).
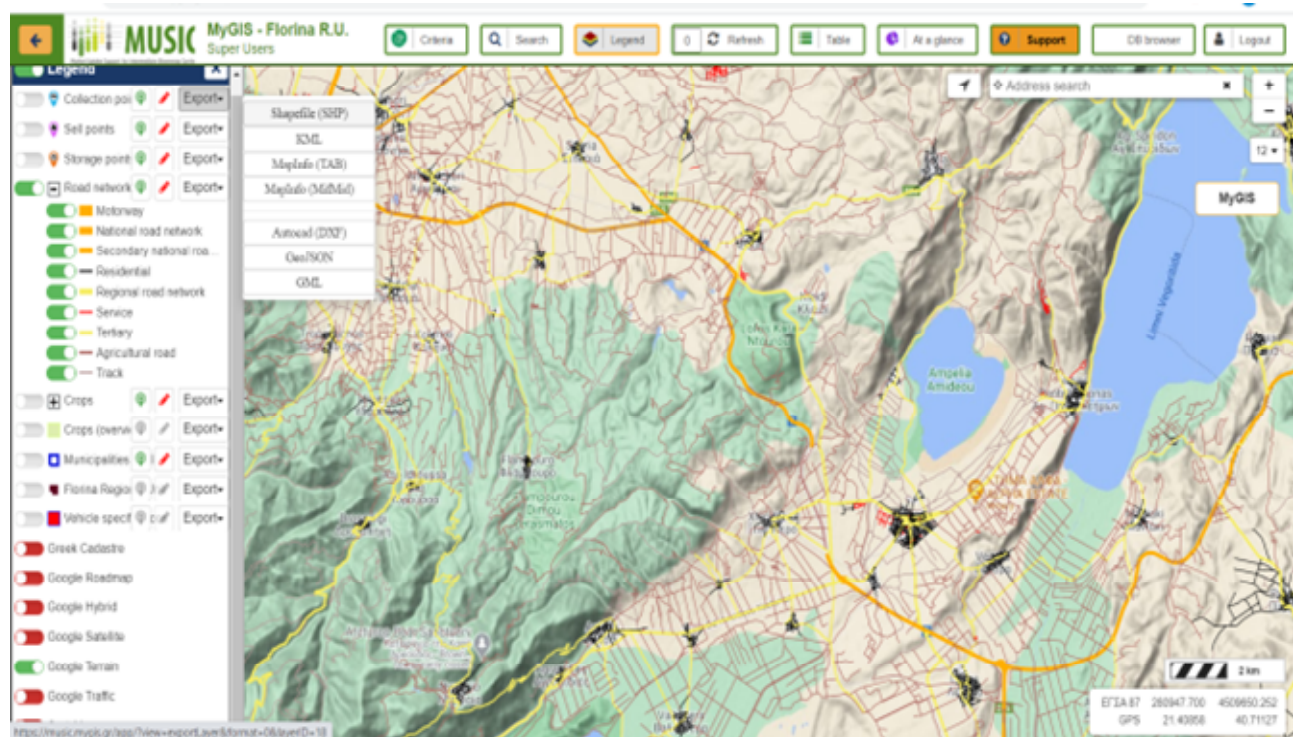
Figure 2-2: Google Terrain as cartographic background
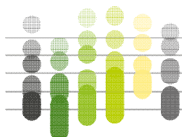
Figure 2-3: Greek cadastre

2.3.1.2   Administrative layers

The application is focused on the Regional Unit of Florina located in the Prefecture of West Macedonia in North Greece. Within the regional unit (NUTS3 level - Nomenclature of Territorial Unit for Statistics), three municipalities (LAU1 – Local Administrative Unit) are studied, namely the municipality of Florina, the municipality of Prespes and the municipality of Amyntaio (Figure 2-4).

Figure 2-4: Administrative layers

2.3.1.3 Road network

OpenStreetMap is used to depict the road network, through which the routes and consequently the transport times of solid biomass / torrefied biomass are calculated from the collection points to the storage points and from the storage points to the selling points (Table 2-1).

Table 2-1: Analysis of 'road_network' interface

Variable	Type	Comments
id	integer	
Wkb_geometry	geometry	
Osm_id	bigint	Barcode (OpenStreetMap)
Tag_id	bigint	Road network category code (OpenStreetMap)
Type_gr	character varying	Road network category (in Greek)
Type_en	character varying	Road network category (in English)
name	text	Road name
oneway	text	One-way direction (yes/no)
maxspeed	double precision	Max transport speed

The road network includes motorways, primary and secondary national road network, residential and regional network, agricultural roads and trucks (Figure 2-5). For each category the maximum speed of tractors and the presence of one-way roads are taken into account (Figure 2-6).

2.3.1.4 Storage- selling points

The storage points are essentially the warehouses where the biomass will be stored after collection from the fields (Figure 2-7). The torrefaction units are also considered as 'storage points' in this application, in the sense that solid biomass is transported there, converted to torrefied material and stored as such until there is a demand from the end users. The solid or torrefied biomass will then be transported to the selling point.
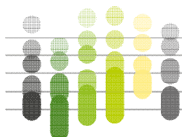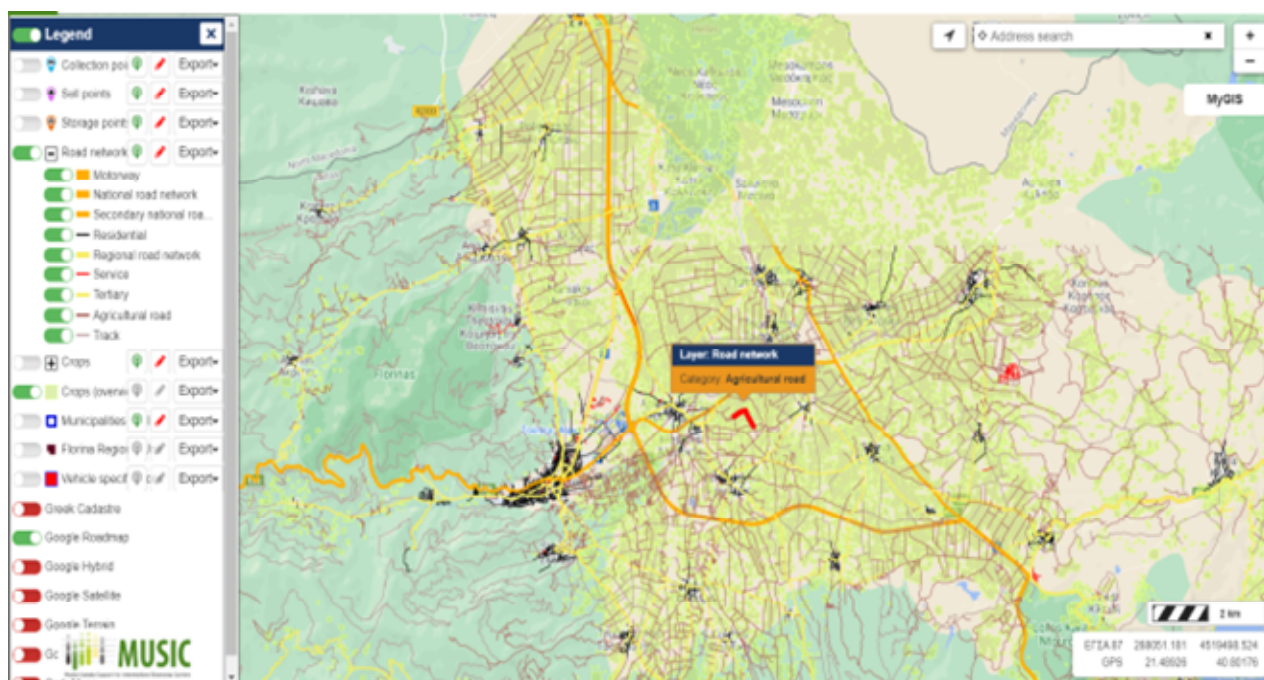
Figure 2-5: Google roadmap
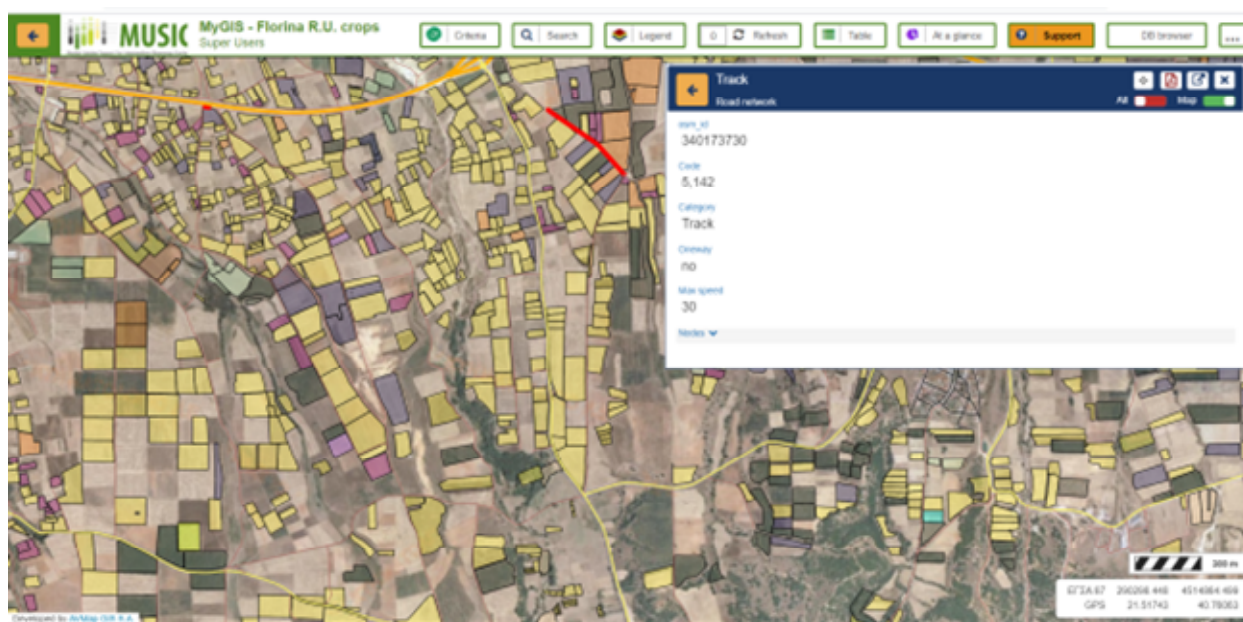
Figure 2-6: Road network identification

The selling points are the final recipients to whom the user wishes to transport the solid or torrefied biomass (Figure 2-7). The user enters the demand for biomass (solid biomass or torrefied) and some additional data (location and name of the point of sale). Based on the demand, the amount of biomass that should be collected from the fields is calculated.

Table 2-2 is used to insert the user's storage points into the application and Table 2-3 is used to enter the selling points. For each collection and storage point information on its name, location and coordinates are shown (Figure 2-8).
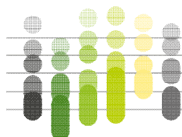
Table 2-2: Analysis of 'storage_points' interface

Variable	Type	Comments
id	integer	
Wkb_geometry	geometry	
Name_gr	character varying	Name of storage point (in Greek)
Location_gr	character varying	Location of storage point (in Greek)
Name_en	character varying	Name of storage point (in English)
Location_en	character varying	Location of storage point (in English)
UserID	bigint	User ID making the recording

Table 2-3: Analysis of 'sell_points' interface

Variable	Type	Comments
id	integer	
Wkb_geometry	geometry	
Name_gr	character varying	Name of selling point (in Greek)
Location_gr	character varying	Location of selling point (in Greek)
Name_en	character varying	Name of selling point (in English)
Location en	character varying	Location of selling point (in English)
UserID	bigint	User ID making the recording

Figure 2-7: Storage and selling points
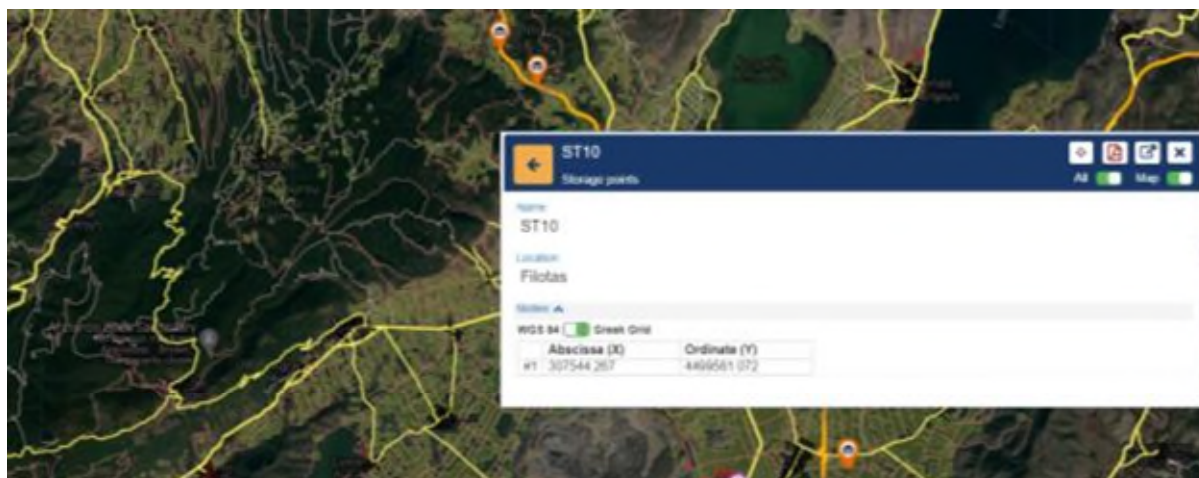
Figure 2-8: Storage point identification

2.3.1.5   Land use

In order to assess biomass types of the studied area and biomass availabilities, maps from the Greek Payment and Control Agency for Guidance and Guarantee Community Aid (OPEKEPE) are used, which accurately describe the boundaries of the fields and the type of the crops grown in them (Figure 2-9). OPEKEPE is the Greek Payment Authority of Common Agricultural Policy (CAP) Aid Schemes, a private legal entity supervised by the Ministry of Rural Development and Food. Its main task is the control and payment of beneficiaries, according to European and national legislation. Beneficiaries are mainly farmers and farmers' associations, export companies, investors of the agricultural sector, manufacturing enterprises, etc. (https://www.opekepe.gr/en/).

Figure 2-9: Land uses
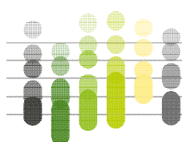
2.3.1.6   Crops

According to the national statistics and the OPEKEPE data, the crops grown in the case study area are mainly maize, wheat and other cereals, and fruit trees. Table 2-4 includes data on the cultivation area and annual solid and torrefied biomass.

Fields are shown in the map in the form of polygons (Figure 2-10). Each polygon corresponds to an agricultural holding, for which information on its size and biomass productivity is shown (Figure 2-11).

Table 2-4: Analysis of 'crops' interface

Variable	Type	Comments
id	integer	
Wkb_geometry	geometry	
cropcode	character varying	Code of each crop
crop_gr	character varying	Name of crop (in Greek)
crop_en	character varying	Name of crop (in English)
Emvadon_str	numeric	Size of field (in 0.1 ha)
Biomass_annual	numeric	Annual biomass production(tons)
Char_annual	numeric	Annual torrefied biomass production (tons)

Figure 2-10: Agricultural holdings and selection of crops
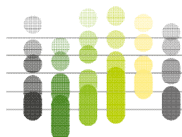
Figure 2-11: Agricultural holdings and biomass production

A database is used where all the data concerning the crops and estimated solid biomass and torrefied biomass yields and energy content etc. are stored. Data are used in algorithms, so that the interested party can calculate not only the final cost, but also the costs of the intermediate phases, until the final delivery to the end user.

For the annual biomass calculation for each field, the area of each field (expressed in stremma, which equals to 0.1 ha) is multiplied with biomass production efficiency factors (tons of biomass/0.1ha/year) for biomass 'as received', for each biomass type. Assumptions of the biomass production efficiency factors were based on own experience and information from local stakeholders. Production efficiency factors for the torrefied biomass from each biomass type are also defined based on presentations offered in the MUSIC project [Wild. M., 2020; Torr-Coal Group, 2020]. Calorific values of the solid biomass and torrefied biomass are defined for each biomass type, based on own data and literature data.

Availability of biomass near the district heating plant is significant, including mainly corn stalks and cobs, and tree pruning, still not exploited due to challenging logistics.

Table 2-5 contains crop data that refer to the efficiency factors on the basis of which the amount of solid biomass and torrefied biomass produced by each plot per year is calculated (calculated by multiplying the area by the corresponding efficiency factor for each type of crop). The table does not contain geographic information and is used in the application algorithm.

Table 2-5: Analysis of 'factors' interface

Variable	Type	Comments
id	integer	
cropcode	character varying	Code of each crop
Biomass_cal_value	double precision	Biomass calorific value (kJ/kg)
Biomass_annual_ef	double precision	Annual biomass production (t/0.1 ha/year)
crop_gr	character varying	Name of crop (in Greek)
crop_en	character varying	Name of crop (in English)
Char_cal_value	double precision	Calorific value of torrefied biomass (KJ/Kg)
Char_annual_ef	double precision	Annual torrefied biomass production (tons/0.1 ha/year)

2.3.1.7   Biomass form

Collected biomass will be transported and stored in the form of round/rectangular bales, chips, whereas torrefied material will be in the form of pellets or powder (Table 2-6). The size of chipped biomass is considered as 1 cm^3 to facilitate calculations (see below in chapter 2.4.2)

Table 2-6: Solid and torrefied biomass forms

form_en	form_gr	size	bulk_density	userID	code	id
Big bags (biomass)	Μεγάλοι σάκοι (βιομάζα)	0.729	0.35		b2	1
Round bales (biomass)	Στρογγυλά δεμάτια (βιομάζα)	0.0754	0.4		a2	2
Rectangular bales (biomass)	Ορθογώνια δεμάτια (βιομάζα)	0.072	0.278		a1	3
Chips (biomass)	Θρύμματα (βιομάζα)	1	0.35		b1	4
Pellets (charcoal)	Πέλλετ (εξανθράκωμα)	1	0.65		c2	6
Powder (charcoal)	Τρίμματα (εξανθράκωμα)	1	0.27		c1	5

Table 2-7 includes bulk density and volume figures for various forms of solid and torrefied biomass (big bags, round/rectangular bales, chips, pellets, powder). These data are used to calculate the maximum load that a vehicle can carry and therefore to calculate the routes. This table does not contain geographic information and is used in the application algorithm.
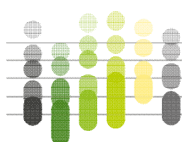
Table 2-7 Analysis of 'biomass_char_form' interface

Variable	Type	Comments
id	integer	
form_en	character varying	Biomass type (in English)
form_gr	character varying	Biomass type (in Greek)
size	double precision	Volume (m^3)
bulk_density	double precision	Bulk density (t/ m^3)
UserID	bigint	User ID making the recording

2.3.1.8   Transportation vehicles

Transportation vehicles transport the biomass from the fields to the storage point or torrefaction plant and from there to the final end user. Three types of vehicles are considered, based on the local conditions (a Ford Ranger, a Scania R164L480 and a tractor with trailer) (Figure 2-12)).

Each vehicle type affects the final cost in a major way, since the following factors are taken into consideration (Figure 2-13).

   - Capacity (volume)

   - Maximum payload (weight)

   - Biomass packaging type (e.g. big bags, rectangular bales, etc.)

   - Transportation cost (Fuel/oil consumption and costs, service costs, etc.)

   - Time and cost to load/unload

Table 2-8 includes the characteristics of the vehicles used to transport the solid biomass or torrefied biomass. This table does not contain geographic information and is used in the application algorithm.

Figure 2-12: Transportation vehicles

Left panel (Tractor with trailer):

Vehicle specifications   is not a geographic layer

Can carry Charcoal - Powder
YES

Maximum payload (tn) Charcoal - Pellets
5.20

Vehicle name
Tractor with trailer

Capacity (m3)
8

Average speed (km/hr)
40

Work cost (€/hr)
5.00

Load/unload time (hrs)
0.50

Fuel cost (€/l)
1.30

Fuel consumption (l/km)
0.20

Payback €/year (vehicle)
6,500

Payback €/year (trailer)
700

Year expenses (€)
0

Service cost (€/km)
0.03

Can carry Biomass - Rectangular bale
YES

Can carry Biomass - Bulk
YES

Can carry Biomass - Round bale
YES

Can carry Biomass - Big bags
YES

Vehicle type
tractor

userID
0

Maximum payload (tn)
8.00

Maximum payload (tn) Biomass - Rectangular bales
2.22

Maximum payload (tn) Biomass - Round bales
3.20

Maximum payload (tn) Biomass - Bulk
2.80

Maximum payload (tn) Biomass - Big bags
2.55

Maximum payload (tn)
8.00

Maximum payload (tn) Biomass - Rectangular bales
2.22

Maximum payload (tn) Biomass - Round bales
3.20

Maximum payload (tn) Biomass - Bulk
2.80

Maximum payload (tn) Biomass - Big bags
2.55

Maximum payload (tn) Charcoal - Powder
2.16

Right panel (Scania R164L480):

Vehicle specifications   is not a geographic layer

Can carry Charcoal - Powder
YES

Maximum payload (tn) Charcoal - Pellets
13.00

Vehicle name
Scania R164L480

Capacity (m3)
20

Average speed (km/hr)
65

Work cost (€/hr)
15.00

Load/unload time (hrs)
2.00

Fuel cost (€/l)
1.20

Fuel consumption (l/km)
0.15

Payback €/year (vehicle)
0

Payback €/year (trailer)
5500

Year expenses (€)
1000

Service cost (€/km)
0.09

Can carry Biomass - Rectangular bale
YES

Can carry Biomass - Bulk
YES

Can carry Biomass - Round bale
YES

Can carry Biomass - Big bags
YES

Vehicle type
Truck

userID
0

Maximum payload (tn)
20.00

Maximum payload (tn) Biomass - Rectangular bales
5.54

Maximum payload (tn) Biomass - Round bales
7.99

Maximum payload (tn) Biomass - Bulk
7.00

Maximum payload (tn) Biomass - Big bags
6.89

Maximum payload (tn) Charcoal - Powder
5.40

Figure 2-13: Truck characteristics

Table 2-8: Analysis of 'biomass_char_form' interface

Variable	Type	Comments
id	integer	
vehicle_name	character varying	Vehicle name
capacity	double precision	Vehicle capacity m^3)
avg_speed	double precision	Average speed (km)
work_cost	double precision	Cost of work (€/hour)
load_unload_time	double precision	Loading / unloading time (hours)
fuel_cost	double precision	Fuel cost (€/litre)
fuel	double precision	Fuel (litre/km)
payback_year_vehicle	double precision	Payback €/year for the vehicles
payback_year_trailer	double precision	Payback €/year for the trailers
year_expenses	double precision	Annual costs (€/year)
service_cost	double precision	Service costs (€/km)
can_carry_a1	character varying	Capability to transfer a1) rectangular bales of solid biomass
can_carry_a2	character varying	Capability to transfer a2) round bales of solid biomass
can_carry_b1	character varying	Capability to transfer b1) chipped solid biomass
can_carry_b2	character varying	Capability to transfer b2) big bags of solid biomass
can_carry_c1	character varying	Capability to transfer c1) torrefied biomass in powder form
can_carry_c2	character varying	Capability to transfer c2) torrefied biomass in pellets
vehicle_type	character varying	Vehicle type
max_payload	numeric	Maximum payload (tons)
payload_a1	numeric	Maximum payload (tons) for rectangular bales of solid biomass
payload_a2	numeric(5,2)	Maximum payload (tons) for round bales of solid biomass
payload_b1	numeric	Maximum payload (tons) for chipped solid biomass
payload_b2	numeric	Maximum payload (tons) for big bags of solid biomass
payload_c1	numeric	Maximum payload (tons) for torrefied biomass in powder form
payload_c2	numeric	Maximum payload (tons) for torrefied biomass in pellets
userID	bigint	User ID making the recording
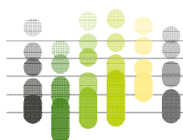
2.3.2 The MUSIC MyGIS platform

The MygGIS platform is software developed by AVMaps so as to give the user basic geographical features and information, like pan/zoom, coordination of the mouse cursor, link to database, map legend creation etc. (Figure 2-14).
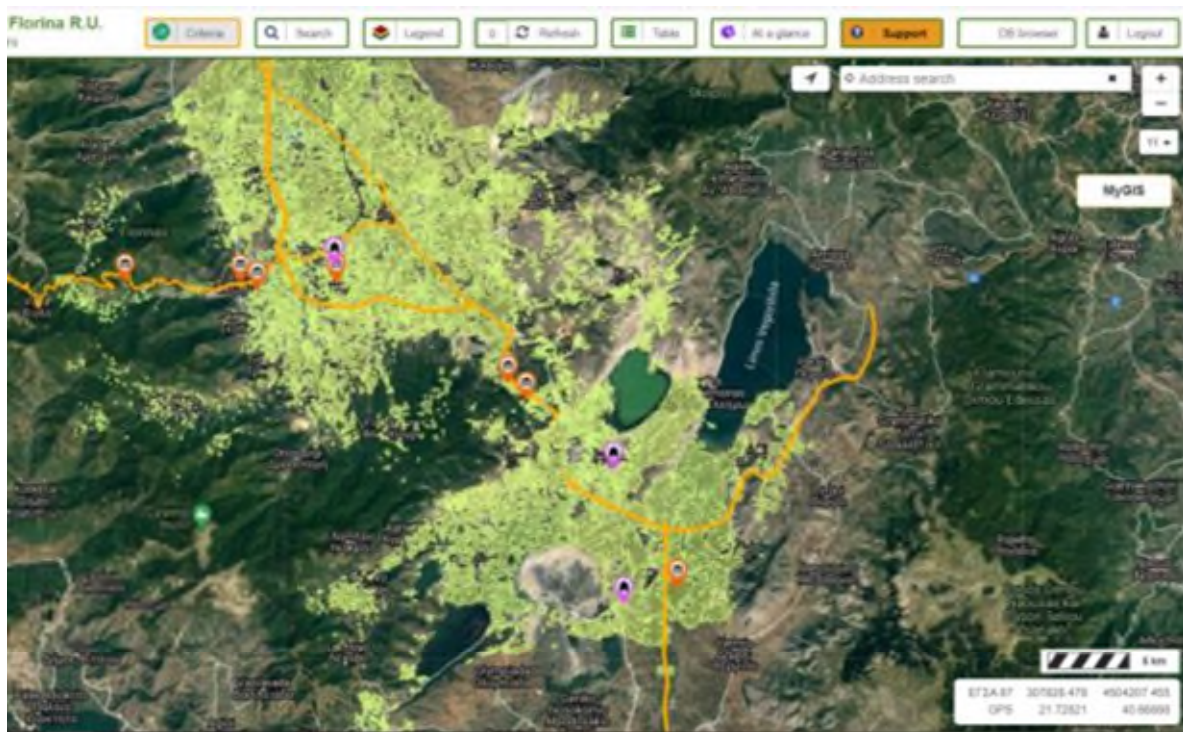
Figure 2-14: MUSIC MyGIS platform

2.3.3 User interface scenarios

Crucial element of the user interface is the scenarios that are usually created by drop-down menus in which the user can enter data, describing the scenario he is interested in (Figure 2-15).

2.4 Model functionality

The application user must either use the predefined points or digitize himself some points on the map, which will depict the concentration points and /or torrefaction units (storage points) and the final purchaser (selling points) (Figure 2-16).

Figure 2-16: Storage points (in orange) and selling points (in purple)

Figure 2-15: User interface scenarios

The user selects the required parameters step-by step. The required parameters are:

- Selling point, the final destination of the biomass (client). Each point specifies a required biomass and/or torrefied material quantity by the end user.
- Transportation vehicle, which will transport the biomass (or torrefied material) from the storage point to the selling point. In case of torrefied material, the packaging types are limited to bulk material or pellets.
- At the selection screen, the maximum payloads in tons per packaging type are displayed. In order of appearance, these are: Rectangular bales, Round bales, Chips, Big bags. If the user clicks on the vehicle's picture, the full vehicle tab is displayed (Figure 2-13).
- Storage point (or Torrefaction Unit), which is the collection point of all biomass before it is transported to the client. Next to the name, the distance from the chosen selling point is displayed, which is updated dynamically when selections are changed.
- Collection vehicle, which will transport the biomass from the collection points (fields) to the storage point. It has similar functionality as the transportation vehicle. The collection points are located on the road network, one for each field in the area. The user may add if he wants new collection points.
- Finally, there is the option to determine (a) specific producer (s), but it is not yet available, due to the lack of data.
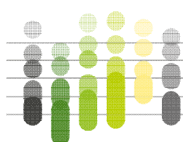
2.4.1 Model algorithm and assumptions

The shortest path algorithm used was Dijkstra's algorithm. It is one of the most commonly used algorithms to find the optimal path.

The model assumes:

- Biomass demand is expressed in annual tones at the selling point.
- The storage point has sufficient capacity to store the required biomass.
- The calculation is done for the optimal packaging type per vehicle chosen.
- 22 working days in a month.
- 2 work shifts of 8 hours each per vehicle

2.4.2 Calculations

For the annual biomass calculation for each field, the area (in stremma, which equals to 0.1 ha or 1,000 m^2) of each field is multiplied with a biomass efficiency factor (tons of biomass/stremma/year). The factors which were used for solid biomass are:

2.4.2.1   Biomass form

In the biomass form table, the size for the biomass from chips is considered as 1 cubic meter for easiest calculations.

2.4.2.2   Vehicle specifications

The maximum payload for each biomass form is calculated as follows:

Number of items: X1 = Capacity of the vehicle / size of the biomass type (integer quotient)

Max available volume: X2 = X1* size of the biomass type

Max payload = X2 * bulk density of the biomass type

Example 1 – Biomass from Round Bales (a2), and Track ID 2 (Scania):

Number of items: X1 = 20 m^3 / 0.0754 m^3 = 265 items

Max available volume: X2 = 265 items * 0.0754 m^3= 19,981 m^3

Max payload = 19,981*0.4 (tons/ m^3) = 7.99 tons

Example 2 – Biomass form chips (b1), and Track ID 2 (Scania):

Number of items X1 = 20 / 1 = 20 (*)

Max available volume X2 = 20*1 = 20 m^3

Max payload = 20 * 0.35 (tons/ m^3) = 7 tons

If the max payload of a biomass form that is calculated above is greater than the vehicle max payload, then the vehicle max payload is inserted.

For the biomass from chips, the whole vehicle capacity is considered for the maximum payload calculation. For this reason the size of chips, pellets and powder is considered as 1).
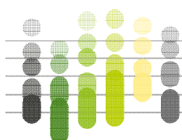
2.4.2.3   Route average speed

The route average speed depends on the various road types that the vehicle passes.

There is a maximum speed for each road type. For the maximum speed calculation, the speed limit was multiplied with a 0.8 factor. We have chosen to multiply the speed limit with the 0.8 factor based on empirical observation. The trucks rarely or never exceed the road speed limits. On the contrary, as the speed limits are set for passenger cars, the trucks especially when loaded, move slower, especially on uphill/downhill more than 3% slope, sharp turns and wet surface. Usually, this reduction is about 50% of the road maximum speed. In addition, the speed limits that are signed on the roads (and also set on Google Maps) are referred to passenger cars, while speed limit for trucks heavier than 3.5 tons are slower by 12.5% by the law (Hellenic Ministry of Transportation and Communications and Eugenidou Foundation, 1999).

Thus, when the biomass transport routes are calculated, the individual speed values are aggregated and divided by the total number of routes. The result is the average speed which is inserted if it is lower than the vehicle max speed, and if it is higher, then the vehicle max speed is inserted. Then, the total distance is divided by the average speed and the result is the total time. For example, there are 5 points (A, B, C, D, E) and the road sections AB (max speed 50 km/h), BC (30 km/h), CD (30 km/h) and DE (50 km/h). The average speed is (50+30+30+50)/4=40 km/h. If the total distance is 10 km, then the total time is 10/40=0.25 hours.

2.4.3 Result Calculations

Variables and calculation formulas are presented in Table 2-9.

Table 2-9: Variables and calculation formulas

Variable	Calculation formula	Notes
Storage routes	Biomass demand / max payload	Max payload calculation (see 3.4.4)
Selling routes	Biomass demand / max payload	
Storage distance (km)	Storage distance in kilometres * STORAGE_ROUTES	Distance is calculated by GIS
Sell Distance (km)	Sell distance in kilometres * SELL_ROUTES	
Storage Transport Time (hours)	STORAGE_KILOMETERS / MIN (average route speed, collection vehicle max speed)	MIN = minimum The average route speed is calculated by GIS
Sell transport time (hours)	SELL_KILOMETERS / MIN (average route speed, sell vehicle max speed)	

Total storage time (hours)	(Load_unload_time * STORAGE_ROUTES) + STORAGE_TRANSPORT_TIME	
Total sell time (hours)	(Load_unload_time * SELL_ROUTES) + SELL_TRANSPORT_TIME	
Storage fixed cost (€ / hour)	(year_expenses+payback_year_vehicle +payback_year_trailer) / 1000	The 1000 value is the annual vehicle operation man-hours
Storage work cost (€ / hour)	2 * work_cost	2 shifts - The fields refer to the collection vehicle
Storage fuel cost (€ / km)	fuel_cost*fuel	The fields refer to the collection vehicle
Storage service cost (€ / Km)	service_cost	The fields refer to the collection vehicle
Sell fixed cost (€ / hour)	(year_expenses+payback_year_vehicle +payback_year_trailer) / 1000	The 1000 value is the annual vehicle operation man-hours
Sell working cost (€ / hour)	2 * work_cost	The fields refer to the sell vehicle
Sell fuel cost (€ / km)	fuel_cost*fuel	The fields refer to the sell vehicle
Sell service cost (€ / km)	service_cost	The fields refer to the sell vehicle
Final cost (€)	(STORAGE_FIXED_COST * TOTAL_STORAGE_TIME) + (STORAGE_WORK_COST * TOTAL_STORAGE_TIME) + (STORAGE_FUEL_COST * STORAGE_DISTANCE) + (STORAGE_SERVICE_COST * STORAGE_DISTANCE) + (SELL_FIXED_COST * TOTAL_SELL_TIME) + (SELL_WORK_COST * TOTAL_SELL_TIME) + (SELL_FUEL_COST * SELL_DISTANCE) + (SELL_SERVICE_COST * SELL_DISTANCE) +	If there are multiple storage points, route costs are added to each one.
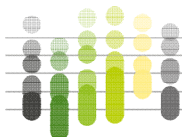
2.5   Music Platform

2.5.1 Application environment

When the registered users log in to their account they are directed to the following landing page Figure 2-17. In this screen the user can choose the language to use when creating scenarios. The application concerns the region of Florina (NUTS 3 level).

Figure 2-17: First page

2.5.2 Toolboxes

The operations of the application are the following (Figure 2-18).

- The user can load an earlier-saved scenario. Scenarios are saved per user.
- The user can add an additional collection point, visible only to the user
- The user can add an additional storage point, visible only to him/her
- The user can add an additional selling point, visible only to him/her.
- The button "Go" is activated after all mandatory criteria have been filled in. Pressing the button executes the calculation to find best fields to collect biomass as well as to calculate the associated cost.
- The button "Reset" is activated after at least one criterion is selected. Pressing it resets the application.
- The user can save his/her choices (scenario with a friendly name after pushing the relevant button.

Figure 2-18: Toolboxes (a)
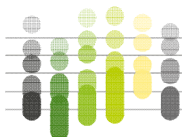
Then the user can choose (Figure 2-19):

- Quantity of biomass/torrefied material (t)
- Feedstock type (biomass or torrefied material)
- A selling point (it is the client where the biomass is sold). Every point has associated information regarding the required biomass quantity.
- A vehicle type which will transport the selected quantity from the storage point to the selling point.
- A storage point where all the biomass will be collected before it is transferred to the final destination. More than one storage points can be selected.
- A vehicle type which will transport the biomass from the collection point to the storage point.
- One or more crops with the corresponding quantities from each crop.
- Optionally, the user can choose a particular producer.

On the map, the user-defined selling and storage points are displayed. Any selling/storage point that the administrators have chosen to share are also displayed. If there is no selling/storage points available, or the user wishes to add one, the user can do so by pressing the "New storage point" or "New selling point" buttons on the top right corner of the screen. When the user clicks on one of the above, the model asks the user to point the cursor to the desired location (Figure 2-20).

Figure 2-19: Tool boxes (b)
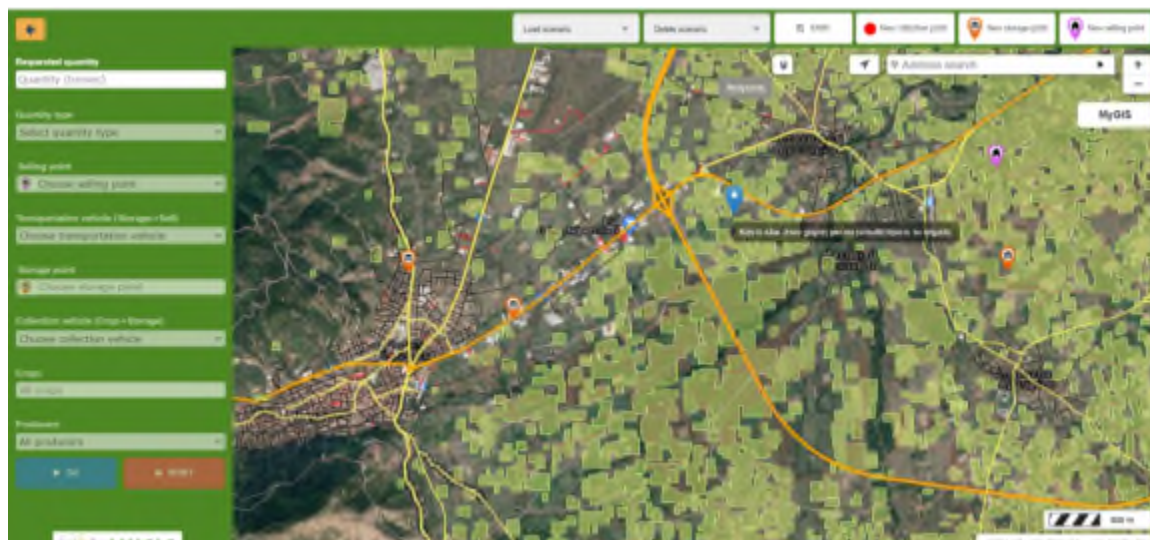
Figure 2-20: Add new storage point

In Figure 2-21 is presented how the user inserts the data for the new point. Then follows the procedure already described in section 2.4 Model functionality. Transportation routes are shown in Figure 2-22.
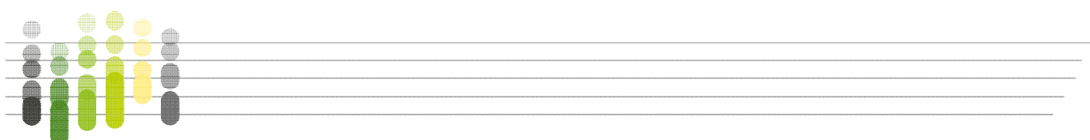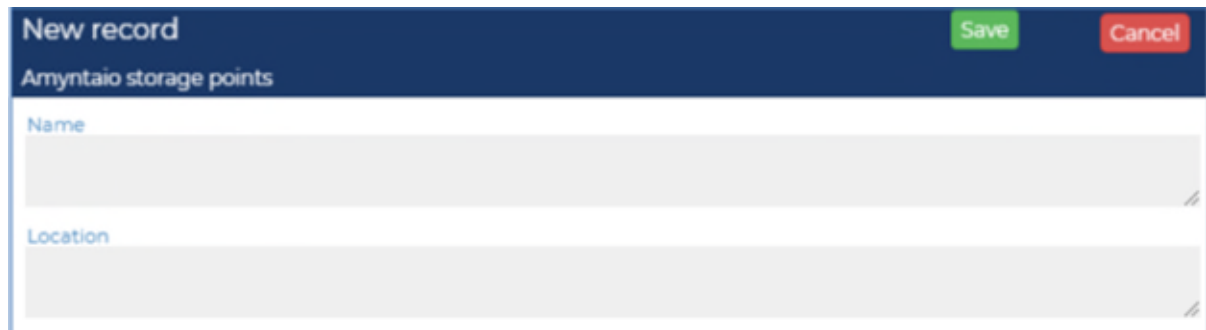
Figure 2-21: New record

Figure 2-22: Transportation route

2.5.3 Final results

Depending on the user's scenarios on the biomass demand for certain or all available agricultural residues, the type of biomass (solid and/or torrefied), the selected means of transportation that is appropriate for the biomass type and form (bales, chips, pellets, big bags) and its payload capacity, as well as the locations of the fields, storage/torrefaction units and end users, the model calculates the number of routes required and the total distance that has to be covered.

Thereafter transportation times are calculated including distance-base times and loading-uploading times depending on the number of routes. Fixed costs, labour costs, fuel costs and service costs are also calculated (in €/h and €/t).
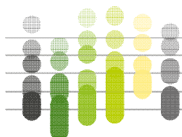
The total cost for each stage of the process (transportation from the fields to the storage/torrefaction unit and transportation for the storage/torrefaction unit to the end user) is finally calculated per ton and energy of the biomass transported. The allocation of costs for each stage of the process will help each involved user or stakeholder to see the costs of the stage he is interested in separately.

Finally, total routes, distances, and times are calculated, along with total costs, costs per ton and per MJ.

Final results are shown in Table 2-10.

Table 2-10: Final results

Individual costs for the two stages: (Field->Storage Point / Storage Point ->Selling Point)	Total Cost
Type of the vehicle selected	Collection-storage trips
Transport method	Collection-Storage total (km)
Total quantity (t)	Storage - Sell trips (km)
Routes	Storage Sell total (km)
Total distance (km)	Total routes
Distance based-time (hours)	Total distance (km)
Transport time (hours)	Total time (hours)
Fixed cost (€/h)	Total cost (€)
Work cost (€/h)	Grand total per ton (€)
Fuel cost (€/h)	Grand total per MJ (€)
Service cost (€/h)	
Fixed cost (€/t)	
Work cost (€/t)	
Fuel cost (€/t)	
Service cost (€/t)	
Energy content (MJ)	
Cost (€)	
Cost per ton (€/t)	
Cost per MJ (€/MJ)	
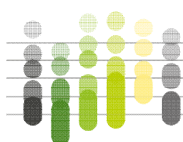
3 The Italian Case-Study

3.1 Objective of the work

The work studied three areas in Italy related to MUSIC case studies: two areas centred on the sites of Porto Maghera (Northern Italy, Veneto Region) and Gela (Southern Italy, Sicily Region) for the strategic case study and one area centred on the site of Taranto (Southern Italy, Apulia Region) for the advanced case study, as illustrated in Figure 3-1.
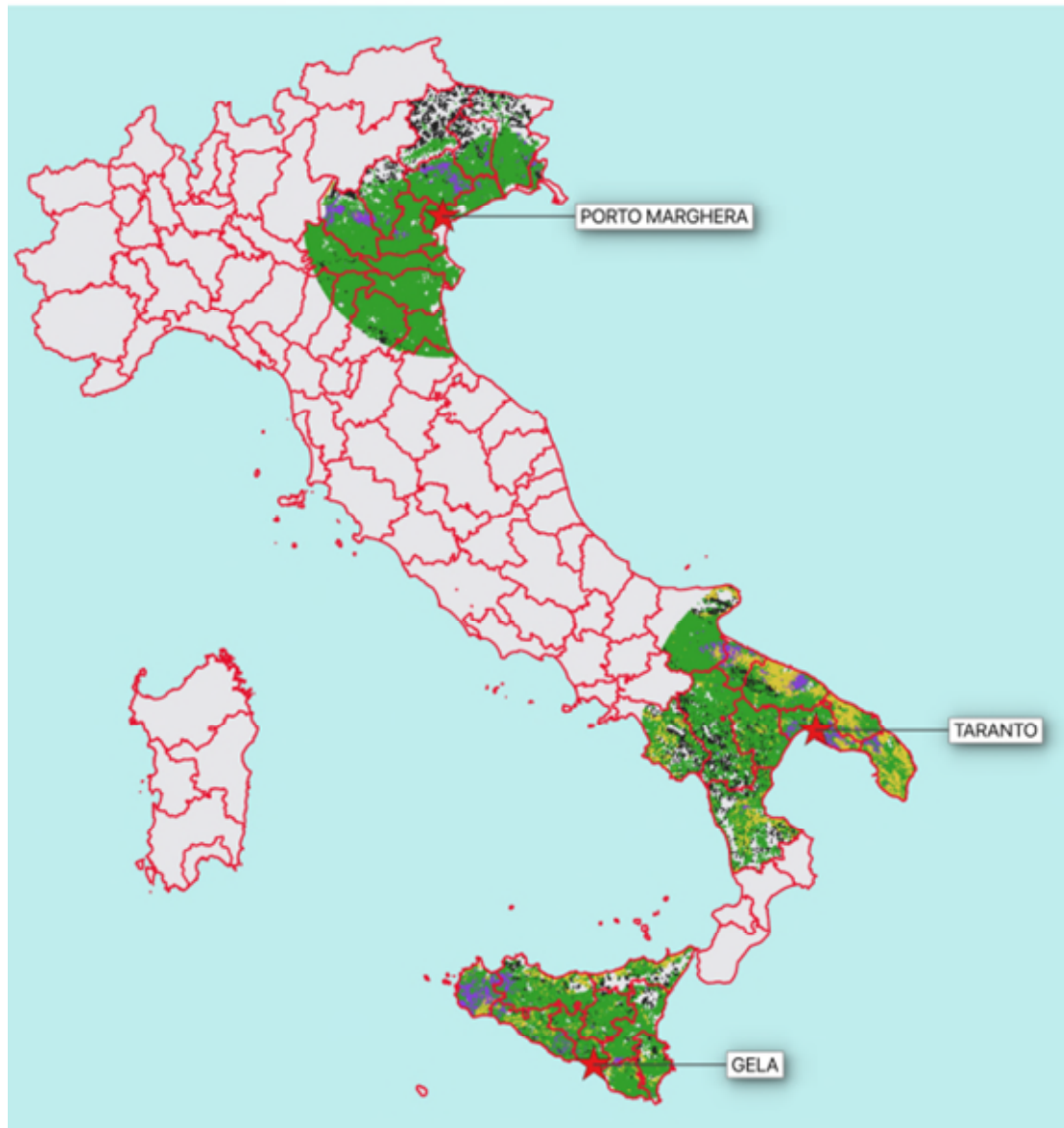
Figure 3-1: Map of the three Italian case studies.

In the figure, green indicates arable land, purple indicates vineyards, dark yellow refers to olive groves and in dark grey marginal land is shown.
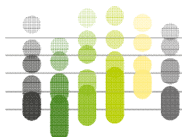
3.2   Methodology

In order to get insights about the potential biomass availability for the three geographical regions, we implemented the INFER-NRG model, which combines crop simulation models and a logistic model.
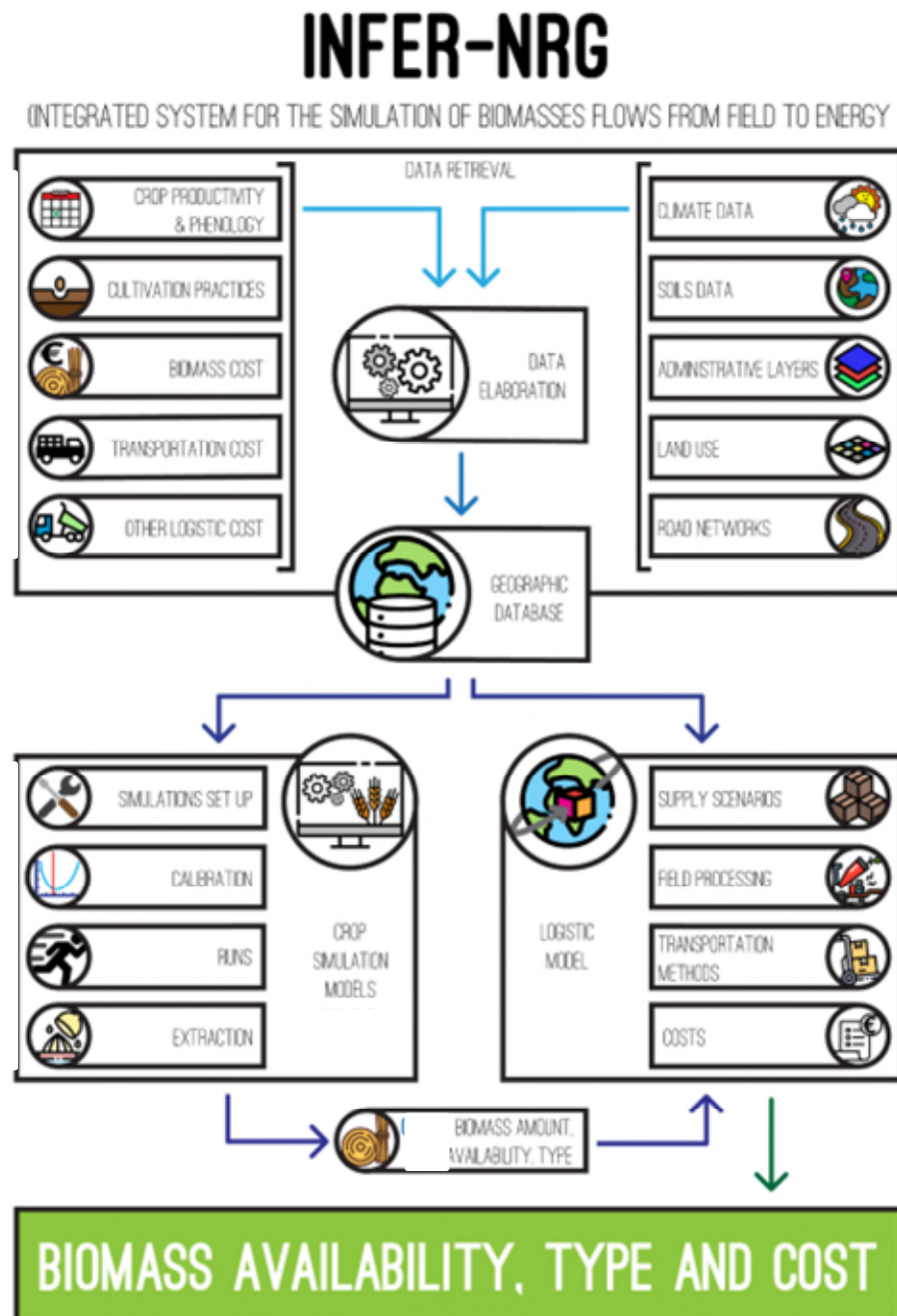
Figure 3-2: Workflow of INFER-NRG model.

In the first phase we structured and filled a geographic database (Chapter 3.3). This required several spatial data to be collected (Chapter 3.3.1) and elaborated (Chapter 3.3.2), in order to feed both models. Then we used part of the gathered data as input for the crop growth simulation models (Chapter 3.4), which were set up (Chapter 3.4.4), calibrated in order to faithfully reproduce the real-world dynamics and results (Chapter 3.4.5) and finally run for the
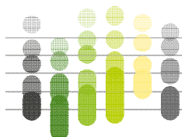
chosen crops, rotations and climate scenarios (Chapter 3.4.6). The results of the simulations were then processed in order to feed the logistic model (Chapter 3.4.7).

Both data from the geographic database and processed results extracted from the crop models simulations were used in the logistic model (Chapter 3.5): first the supply scenarios were structured in order to assess the required amounts to sustain continuously the main site (Chapter 3.5.1), then the method of in-field biomass pre-processing were defined (Chapter 3.5.2), as well as the transportation methods (Chapter 3.5.3). Finally, the different components of the biomass costs entering the transformation site were determined (Chapter 3.5.4).

The results produced by the INFER-NRG model were finally analysed in order to assess the biomass availability and costs at territorial level for the case studies (Chapter 3.6).

The INFER-NRG model workflow described above is summarised in Figure 3-2.

3.3   Geographical Database creation

Since all the information is spatial, the database contains all the input information needed by crop models and the logistic model to correctly operate, as well as their outputs.

3.3.1 Data retrieval

For the three areas (multiple NUTS2[1] areas) the following types of data were used: Climate, Soil, Administrative layers, Land Use, Crop productivity and phenology, Cultivation techniques (rotations, fertilizations etc.), Road networks, Average biomass costs, Transportation costs, other logistic costs (i.e.: chipping (if needed) and loading/unloading of the feedstocks/materials).   Administrative layers were taken from Regional official websites: Ramsar areas, Regional protected areas and SIC-ZPS layers (SIC: sites of community interest, ZPS: Special protected areas).

We found information about crop productivity and phenology of the selected regions by integrating bibliographic research[2] and interviews to local experts; from the latter source we acquired the data relating to the most typical crops and rotations, as well as data on fertilizer (kind and application) and specific average harvest date for each crop.

We have validated the harvest data of the different crops with data from ISTAT website (Italian National Institute of Statistics) that every year provides provincial data on the distribution and production of all agricultural crops.

The average costs of biomass were obtained from weekly bulletins of local chambers of commerce (Source: Weekly wholesale price list Borsa Merci Bologna)[3], while as regards the cost of wood chips, where market prices were not available, we estimated the overall cost by the supplier farm in order to have the in-field biomass cost.

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[1]   As from EC Regulations 1059/2003 accessible at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02003R1059-20191113

[2] https://www.regione.puglia.it/web/agricoltura/-/disciplinare-di-produzione-integrata-2020

[3] https://www.agerborsamerci.it/listino/listino.html
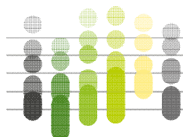
3.3.1.1   Climate

With the increase of mathematical knowledge and the unprecedented level of computing capacity offered by current technologies, climate models are increasingly used for a variety of purposes, from the study of dynamics of the weather and climate system to projections of future climate. In this case study, historical, current and future daily climate data of temperature (minimum and maximum), precipitation and solar radiation were used to feed the crop growth simulation models. When approaching a future case study, such as the present ones, it is important to define the climate scenarios in which the exercise will take place.

For the present study we decided to use two simple scenarios widely used in strategic studies and assessments (Masia et al.2018, Minambiente 2020), the so-called "RCP45" and "RCP85". RCPs (Representative Concentration Pathways) are not fully integrated scenarios with socioeconomic, emissions and climate projections. Instead, they are consistent sets of projections, based on greenhouse gas concentration (not emissions) trajectory, with the basic components of radiative forcing used to feed subsequent climate modeling. They have been adopted by the Intergovernmental Panel on Climate Change (IPCC) for its Assessment Reports. In particular, "RCP45" refers to a specific experiment in which a "representative concentration pathway" (RCP) has been specified which leads to an approximate radiative forcing of 4.5 W m^{-2}, while RCP85 will lead to 8.5 W m^{-2}. RCP 4.5 is described by the IPCC as an intermediate scenario, while in RCP 8.5 emissions continue to rise throughout the 21st century. RCP8.5 is therefore taken as the basis for worst-case climate change scenarios. The use of these scenarios allows depicting the case in which the crop production could be lower due to adverse climate conditions, being thus the worst-case scenario (RCP85) in terms of biomass availability, and another case in which the production level could be considered not a limiting factor (RCP45).

The climate data for this study were taken from the results of the numerical model ALADIN (Herrmann et al., 2011), Aire Limitée Adaptation dynamique Développement InterNational It is a Regional Climate Model (RCM) limited to a specific area (the Mediterranean Basin), with the main advantage that, thanks to the lower numerical cost of simulations with respect to global climate model at the same resolution, it allows climate representation at very fine scale. Due to the high spatial resolution and the specific geographical coverage of the model, in this study we used the output of the ALADIN RCM version 5.2 of the Météo France Institute (CNRM) driven by the CNRM-CM5 (Voldoire et al., 2012), hereafter CNRM-ALADIN. However, it should be mentioned that, exactly as it happens when you finally decide to buy a new TV, in 2020, when the case study simulations were already at an advanced stage, the newer version 6 of CNRM-ALADIN was released.

Table 3-1: CNRM-ALADIN 5.2 scenarios sheet

	Historical	RCP45	RCP85
Geographical Coverage	Mediterranean Basin		
Data Resolution	12km x 12km		
period	1950-2005	2006-2100	2006-2100
CO2 (ppm)	360	650	993
Radiative Forcing	Observed data	4.5 W m^{-2}	8.5 W m^{-2}

3.3.1.2   Soils

Crop growth simulation models need soil information in order to properly simulate the soil water dynamics, the nutrient cycle, the root activities etc. In the present study, depending on the crop model, we needed information about soil texture (clay, sand and silt), bulk density, field capacity and wilting points, which are the most important parameters affecting crop growth and productivity in crop simulation models. The soils data for the case studies were obtained by the multilayered European Soil Hydraulic Database (EU SoilHydroGrids ver1.0, Tóth et al. 2017) and SOILGRIDS database (SoilGrids250m version 2.0, Hengl et al. 2017).

3.3.1.3   Administrative layers

Since in Italy most of statistical information are on provincial basis, including those related to agriculture, an administrative layer was needed in order to carry out the study. To do so, we included in our GIS the NUTS3 shapefile provided by the Italian National Institute of Statistics (ISTAT). Furthermore, since in Italy there are 2636 sites within the Natura 2000 network (as under the Habitats Directive 92/43/CEE), in which the cultivation could be subject to more strict regulations, we included these areas in the study as well.

The classification includes the Zone di Protezione Speciale, ZPS (Special Protection Area, SPA), the Siti di Interesse Comunitario, SIC (Site of Community Importance, SCI) and the Zone Speciali di Conservazione, ZSC (Special Area of Conservation, SAC). Sites under the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat (RAMSAR) and those under the Official List of Protected Natural Areas (EUAP) of Italian Environmental Ministry were included in the study.

3.3.1.4   Land use

In order to assess the biomass availability, we decided to take into account the land use of the territories surrounding the main transformation sites. To do that, we gathered the information needed from the CORINE Land Cover 2018 (Copernicus 2018). The CORINE Land Cover (CLC) inventory was initiated in 1985 (reference year 1990). It consists of 44 land use classes, with a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The Eionet network National Reference Centres Land Cover (NRC/LC) is producing the national CLC databases, which are coordinated and integrated by the European Environmental Agency. CLC is mainly produced by visual interpretation of high-resolution satellite imagery, while in a few countries semi-automatic solutions are applied. The resolution of CORINE is 250 * 250 meters. For the present study, only a few land use classes were used, as in the Table 3-2.
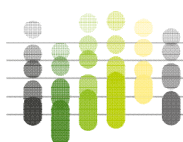
Table 3-2: CORINE Land Cover classes used in the study

Code	Class	Crop/Rotations
2	Agricultural areas	
2.1	Arable land	
2.1.1	Non-irrigated arable land	BAU, Energy, Livestock
2.2	Permanent crops	
2.2.1	Vineyards	Grapevine
2.2.2	Fruit trees and berry plantations	-
2.2.3	Olive groves	Olive Tree
2.4	Heterogeneous agricultural areas	
2.4.1	Annual crops associated with permanent crops	BAU, Energy, Livestock
2.4.2	Complex cultivation patterns	BAU, Energy, Livestock
2.4.3	Land principally occupied by agriculture, with significant areas of natural vegetation	BAU, Energy, Livestock
3	Forest and semi-natural areas	
3.2	Shrub and/or herbaceous vegetation associations	
3.2.1	Natural grasslands	*Arundo donax*
3.2.2	Moors and heathland	*Arundo donax*
3.2.4	Transitional woodland-shrub	*Arundo donax*

Note: the crop/rotations column indicates whether the CLC is related to a single crop or to a rotation, and in case the rotations are listed (Business As Usual – BAU, Energy production oriented and Animal feeding oriented – Livestock)

3.3.1.5   *Crop productivity and phenology*

From the statistical data (ISTAT 2018) and from the interviews it emerged that olive trees, vines and cereals are respectively the most common trees and food crops in the related areas; the cultivation of *Arundo donax*, still in the phase of gradual introduction, is an excellent solution for the enhancement of marginal areas, with a significant production of biomass (Biocolt project 2010).

While the harvesting of cereals and consequent crop residues is concentrated in summer, pruning and therefore the production of wood biomass takes place in winter; the variations in sowing and budding of the various crops are strictly linked to the geographical distribution of the project areas.

The biomass production data from the pruning of the vineyards were derived from the grape harvest data, applying the Ravaz Index which links the fruit production data with the biomass. The data of wood production from the pruning of the olive trees were obtained from scientific publications (Progetto Faesi, 2012) concerning the use of the biomass produced for energy
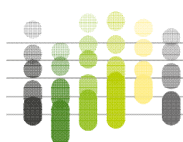
purposes; the same method was used to estimate the production of crop residues from cereal crops, taking into account the provincial average productions.

3.3.1.6   Cultivation practices

The use of specific fertilizers or the adoption of certain rotations is data linked to the territory and the local agricultural market. The presence or absence of farms determines to varying degrees the adoption of a specific rotation for zootechnical purposes; often the use of a chemical or organic fertilizer is affected by the availability on the market and the price recognized at harvesting the product.

For this reason, the data relating to rotations and fertilizers used were acquired through interviews with sector technicians. Table 3-3 provides an overall picture of the common rotations used in different areas in North and South Italy; the rotations are different for the type of crop often not climatically suitable for some areas (e.g. tomato in Lombardy) and are affected by a greater spread of farms in northern Italy.

3.3.1.7   Road networks

In order to assess the logistics of the biomass, from each production site to the (final) transformation site(s), we obtained the road network graph layer of Italy made by ANAS (Azienda Nazionale Autonoma delle Strade, National Autonomous Roads Corporation) from the website of the Government of Italy (MIT, 2020). The graph includes information about the type of road (e.g. highway, motorway). Furthermore, an account was open at OpenRouteService (https://openrouteservice.org) in order to get the relevant transport information (e.g. path, time of travel and distance) for each production site.

3.3.1.8   Biomass costs

The costs of the biomass of the different crops were deduced using different methodologies; where there was a quotation on the biomass market, it was decided to consider the purchase price. This is the case of hay bales which are generally purchased for zootechnical purposes; in the case of grapevine, as there is no commercial quotation, it was decided to construct the cost bottom-up from the expenses incurred by the seller.

Finally, as far as the olive tree pruning is concerned, we considered the price of wood chips on the market, assuming the sure presence of a chipper on the farm; in relation to this hypothesis, from market surveys we have found that the purchase of a chipper is a sustainable cost for the farmer, as a consequence of the creation of a source of income that does not exist today and is considered as a cost for the management of crops.

Regarding tree crops, in order to enhance the value of the crop residues, the company must purchase a chipper (average cost of a small company chipper equal to around 2000 €) and consider that in the sale price of the biomass it must include the technical times for the collection of pruning or trunks, chipping time, tool depreciation and loading times; we don't include the pruning operation in the biomass costs, because the company still has to do this expense regardless of the sale of residues.
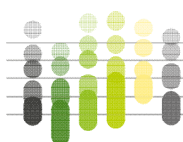
Table 3-3: Rotation and crops for the studied regions

Prod. Scen. / Years	1	1	3	4	5	6	7
Lombardy (Lombardia)							
BAU	Rice	Rice	Maize	Soybean	Rice		
Livestock	Maize	Soybean	Barley	Pea	Alfalfa	Alfalfa	Alfalfa
Energy	Triticale	Sorghum	Barley	Maize			
Friuli Venezia Giulia (FVG)							
BAU	Maize	Soybean	Maize	Barley	Soybean		
Livestock	Wheat	Alfalfa	Alfalfa	Alfalfa	Maize	Wheat	Sorghum
Energy	Rapeseed	Triticale	Maize	Sorghum	Sunflower	Soybean	Maize
Emilia-Romagna (ER)							
BAU	Maize	Soybean	Sorghum	Sunflower	Wheat		
Livestock	Wheat	Alfalfa	Alfalfa	Alfalfa	Maize	Sorghum	Barley
Energy	Sunflower	Triticale	Maize	Soybean	Rapeseed	Sorghum	Triticale
Apulia (Puglia), Basilicata, Calabria, Campania							
BAU	Wheat	Tomato	Rapeseed				
Livestock	Wheat	Wheat	Alfalfa	Alfalfa	Alfalfa	Chickpea	
Sicily (Sicilia)							
BAU	Rice	Rice	Maize	Soybean	Rice		
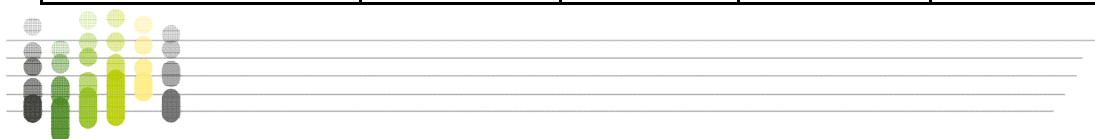
Livestock	Maize	Soybean	Barley	Pea	Alfalfa	Alfalfa	Alfalfa
Energy	Triticale	Sorghum	Barley	Maize			
Veneto							
BAU	Maize	Soybean	Sorghum	Rapeseed	Maize		
Livestock	Barley	Alfalfa	Alfalfa	Alfalfa	Wheat	Soybean	Maize
Energy	Sunflower	Triticale	Rapeseed	Maize	Soybean	Triticale	Sorghum
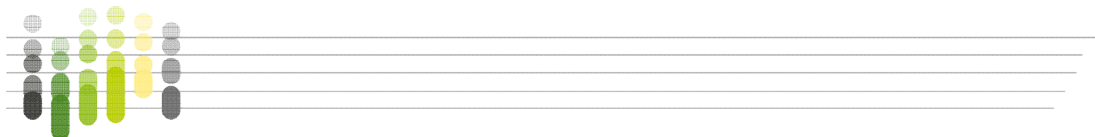
In order to validate the costs of wood chips, in addition to market prices, a bibliographic search was conducted on publications concerning the economic aspect of the use of crop residues from tree plants (Agres Project 2016).

As regards the cost of the biomass of the arundo we have considered the agronomic costs for the cultivation of the *Arundo donax*, which being a perennial crop, in addition to the costs of the first plant, provides only annual fertilization interventions. Table 3-4 summarizes the information.

Table 3-4: Biomass costs sum in euro per ton

	Grapevine	Olive trees	Arundo donax	Wheat bales
Fresh biomass price (market quotation)	50 €/t	50 €/t	34[4] €/t	62 €/t

3.3.1.9   Transportation costs

Transport costs were taken from regional price lists of trade associations, as well as interviews with local contractors. The transport price lists are expressed in Euro per hour and based on the type of means used; as a result of the research activity, we defined a cost of 50 €/hr for the truck considered in the model.

3.3.1.10 Other logistic costs

It is necessary to distinguish production costs and biomass loading and unloading costs based on the type of crop from which the biomass is obtained; the simplest case is crop residues from herbaceous crops, which are packed in bales (either round or squared) at the time of harvest. We decided to exclude round bales because of the higher costs (loading/unloading and transport) with respect to squared ones. Loading costs are limited and therefore are generally included by the transport companies in the offered prices. We did not consider the contractor's waiting times for biomass loading/unloading because on average they are estimated to be less than one hour. Specific interviews with contractors in the sector on the times and any additional costs validated this hypothesis.

All the considerations made above are summarized in Figure 3-3 below.

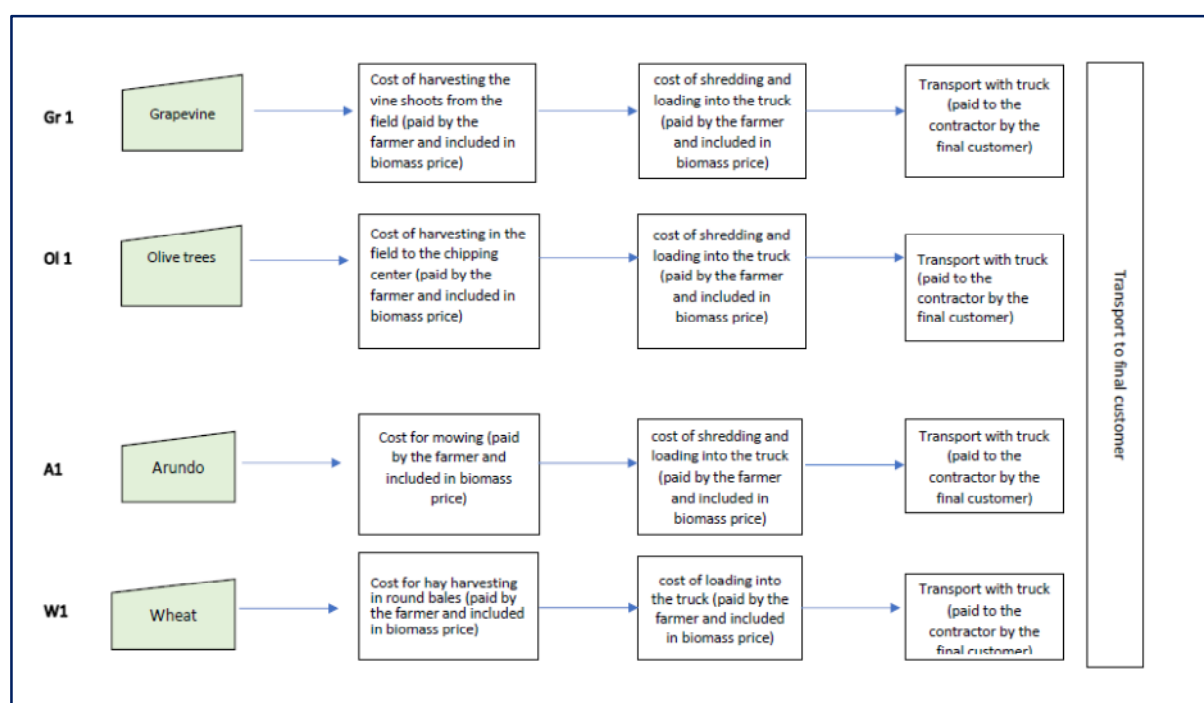[4] Based on the estimated cost of production (Candolo, 2006)

Figure 3-3: Biomass cost components based on crops

3.3.2 Data elaboration

3.3.2.1   Areas and cells definition

Three circles with a 150km radius were drawn with the three main transformation sites placed in the centre, in order to define the initial, main study areas.

For all the case study regions, it was decided, in order to simplify the data retrieval and to avoid unnecessary work, to exclude the territories belonging to other countries (such as Croatia, Austria, Slovenia, Malta) that were included in the initial circles. Furthermore, initially included NUTS3 (Italian provinces) with low presence of agricultural land, poorly connected to the main sites or with little area included, were excluded from the study as well, namely: for Porto Marghera case study Trentino-Alto Adige Region NUTS3 provinces (Trento and Bolzano), Brescia and Cremona provinces (Lombardy Region); for the Taranto case study Avellino province (Campania Region), Crotone and Catanzaro provinces (Calabria Region); for the Gela case study Reggio Calabria province (Calabria Region).

Since it was not possible to obtain the exact shape of all the farms on the territories, the considered areas were gridded with cells 1km x 1km (hereinafter referred to as *singlecells*) in order to have detailed information about logistics. During the work, each *singlecell* was associated with geographical information (centroid coordinates, elevation), administrative information (province, region, municipality, Natura 2000 site, EUAP, RAMSAR), soil information (for each horizon: texture, depth, bulk density, field capacity, wilting point), climate information (*meteocell*, see chapter 3.3.2.3), land use (CORINE Land Cover code).
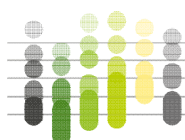
3.3.2.2 Land use

Since it is a territorial scale study, in order to associate land use information with the *singlecells* grid, we decided to proceed as follows. For each *singlecell* a clipping was performed in order to extract from the overlapping CORINE Land Cover layer only the area with the relevant, dominant[5] code. All CORINE Land Cover polygons with codes not necessary for the study, were excluded from the clipping (Figure 3-4).

The final total number of simcells included in the simulations was 25,993 for the advanced case study, with a total area of about 22,845 square km, 18,076 for the Gela strategic case study, with a total area of about 16,383 square km, and 23,361 for the Porto Marghera strategic case study, with a total area of about 20,710 square km (Table 3-5).

Table 3-5: Areas and singlecells for each case study

Case Study	simcells	Area (km^2)
Taranto	25,993	22,845
Gela	18,076	16,383
Porto Maghera	23,361	20,710
Total	**67,430**	**59,938**

In order to validate the *singlecells* creation process, which is aimed at supporting a territorial scale study, we compared the actual areas (from ISTAT website, accessed in December 2020) with those included in the case studies. For example: in the Apulia region, in the provinces included in the study, the olive tree is cultivated on 3,823 km^2, while in this case study the area is a little underestimated (3,661 km^2), with less than 5% error. The error related to the arable land is higher: in the case study the area is 7,682 km^2, versus and actual area of 6,526 km^2 (less than 18% error): this is due mainly to the great variability of arable areas from year to year and to the presence of mixed cultivation, which CORINE Land Cover resolution might miss. As for the grapevine, with a case study area of 1,254 km^2 versus actual 1,112 km^2, the error is smaller than 9%.

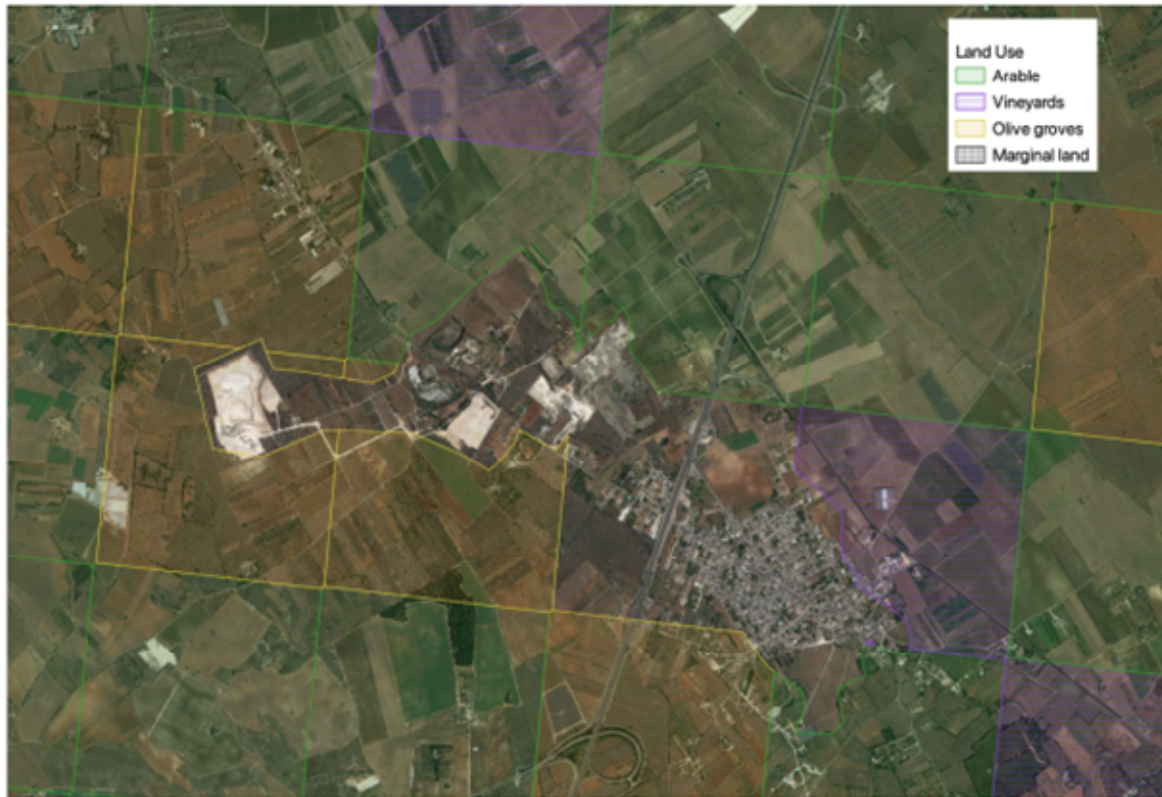[5] with the higher area within the cell

Figure 3-4: Singlecells clipped from CORINE Land Cover (in yellow olive groves, in purple vineyards, in green arable land)

3.3.2.3 Climate

All netCDF files with historical, RCP45 and RCP85 climate scenarios data were downloaded from medcordex[6]. The needed daily meteorological information (temperatures, rainfall, solar radiation) was then extracted from the netCDF files for the relevant 12km x 12km cells (hereinafter referred to as *meteocells*). The quality of the data was checked in order to exclude clerical errors such as temperatures too high or too low (from -50°C to +50°C), maximum daily temperature lower than the minimum temperature of the same day, negative rainfall or solar radiation, etc. Such errors were corrected (e.g. inverted minimum and maximum temperatures), while missing data were filled with the interpolated value from a linear regression obtained from the values of the preceding and following 5 days. Finally, the data were formatted in order to fulfil the requirements of the entire crop growth simulation model.

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[6] https://www.medcordex.eu

3.3.2.4   Soils

Soils as from the downloaded layer were classified by using the top layer texture using the USDA classification[7]. Then, each *singlecell* was associated to the relevant soil information. For each *meteocell*, the *singlecells* were grouped by homogeneous soil type (Figure 3-5).

3.3.2.5   Administrative layers

Each *singlecell* was associated with the relevant administrative information (region, province, municipality, Natura 2000 site/RAMSAR/EUAP, if applicable).

3.3.2.6   Road networks and transportation

For each *singlecell* included in the study, information for the suggested driving routes to the main site (IBC plant) were obtained by using the directions oil company Anonima Petroli Italiana (API) provided by the free service OpenRouteService, starting from the centroid of each singlecell. The following information were collected: distance (in km), duration of the trip (in seconds, obtained by setting a maximum allowable speed of 90 km/h, so to simulate the current Italian speed limits for trucks) and the complete polyline of the path. Then, all single segments of all the polylines were spatially joined so to have the most used paths (see Figure 3-6 below).

Since all the times of travel obtained from OpenRouteServicea for each *singlecell* to the main site were in seconds, while the costs for the transportation are in €/hour, we classified each singlecell using 10 half-hourly classes as in Figure 3-7 so to keep some degree of detail.

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[7] https://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/training/soilsOther/soil-USDA-textural-class.pdf
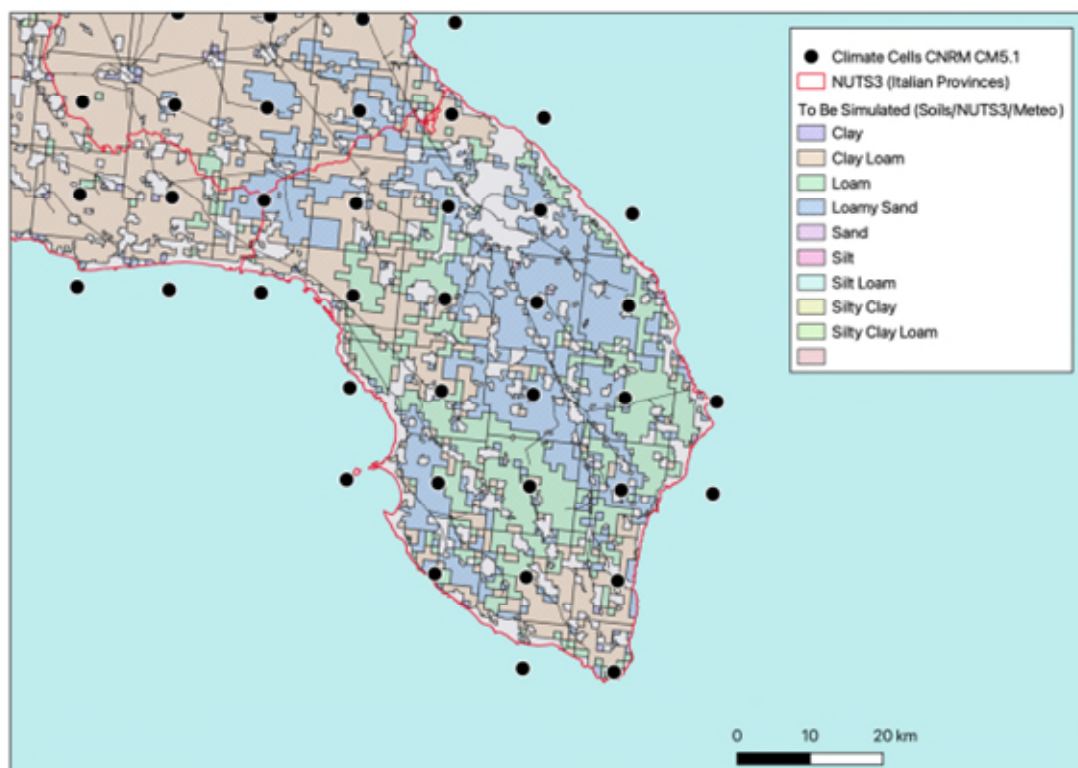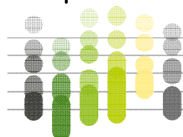
Figure 3-5: Soils, meteocells and NUTS3 (province of Lecce, Apulia Region, Taranto case advanced study)

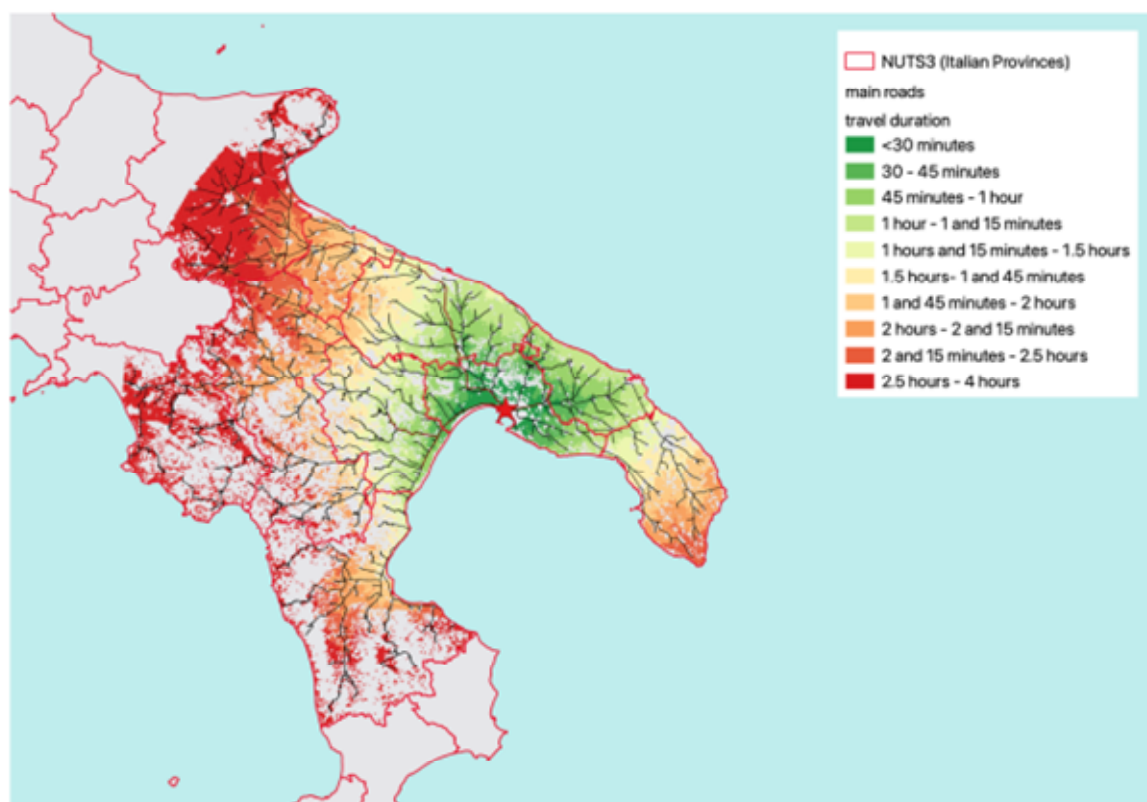Figure 3-6: All roads lead to Taranto: paths from singlecells to Taranto as from OpenRouteServices

Figure 3-7: Trip duration from each singlecell to Taranto.

In the Figure black indicates the most used path; the colour scale represent the iso-duration areas for the biomass transportation from each cell to the IBC plant placed in Taranto.

3.4   Crop models

In order to simulate the productive potential of the territories, we used three different crop growth simulation models: a multi-crop model, CropSyst (used for the three rotations and *Arundo donax*), and two crop-specific models, namely the ViteModel for the grapevine and the OLIVEmodel.CNR for the olive tree.

3.4.1 CropSYST

The CropSyst model (Stöckle et al., 2003) is a multi-crop simulation model based on detailed information about climate, soils, crops and management. It can assess both climate impact on crop performances and the environmental impacts determined by crop rotations and by different cropping (or farming) system managements. The model simulates, on daily time step, the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. It can simulate the effects of different management options, such as cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations, and residue management. The model simulates the main phenological stages of crops (emergence, anthesis, grain filling and maturation), potential

biomass accumulation, and takes into account the effects of water shortage or nitrogen stress. The model thus requires daily meteorological data (maximum and minimum air temperature, rainfall, global solar radiation) and soil parameters (Figure 3-8).
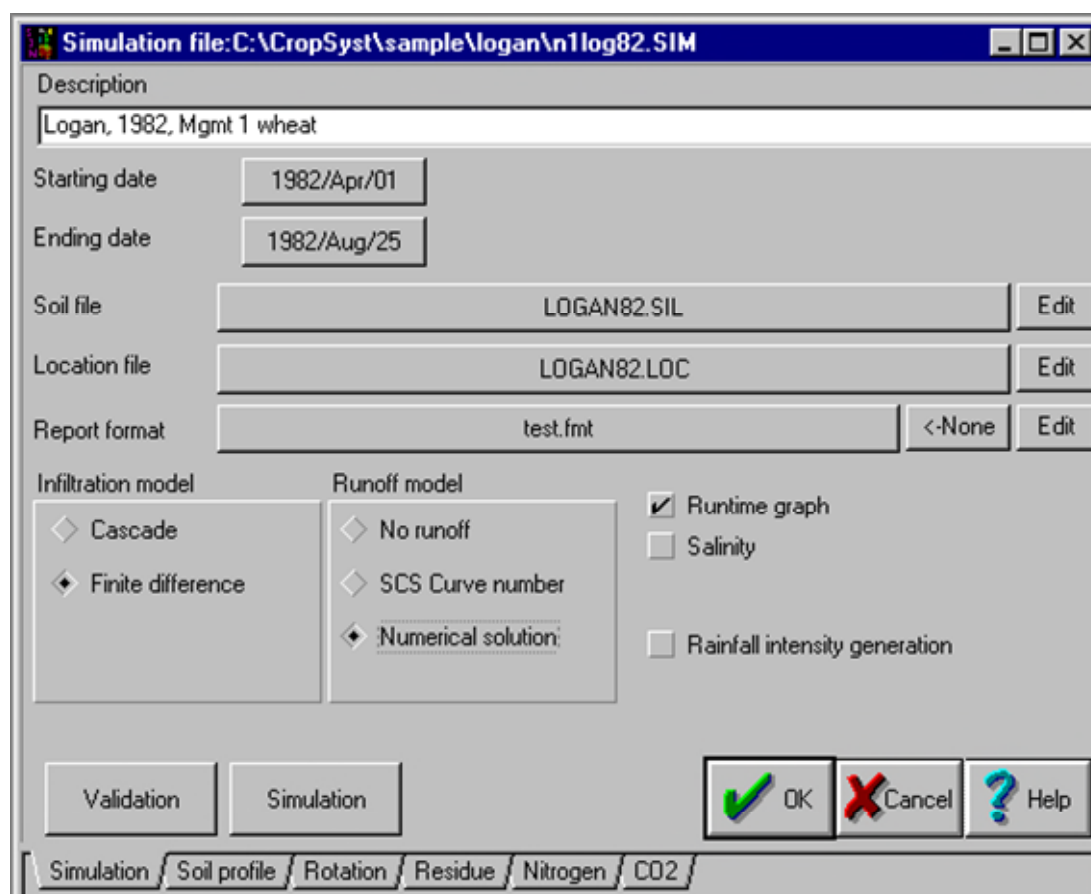

Figure 3-8: The Cropsyst graphical user interface

3.4.2 ViteModel

The ViteModel (Bindi et al., 1997) simulates the grapevine development and growth under different pedo-climatic conditions. It applies a semi-empirical approach to simulate the main processes regulating the development and growth of grapevine, divided into eight main plant processes. The model simulates the phenological development, which estimates the occurrence of bud-break, flowering, veraison and maturity (day of the year); the leaf area growth, which reproduces the plant leaf dynamics and especially the trend of the Leaf Area Index; the biomass accumulation and partitioning between the plant organs (Figure 3-9). The model requires meteorological data on a daily time step (maximum and minimum air temperature, rainfall, global solar radiation), soil available water content and management practices (plant density, number of shoots).
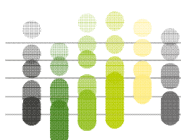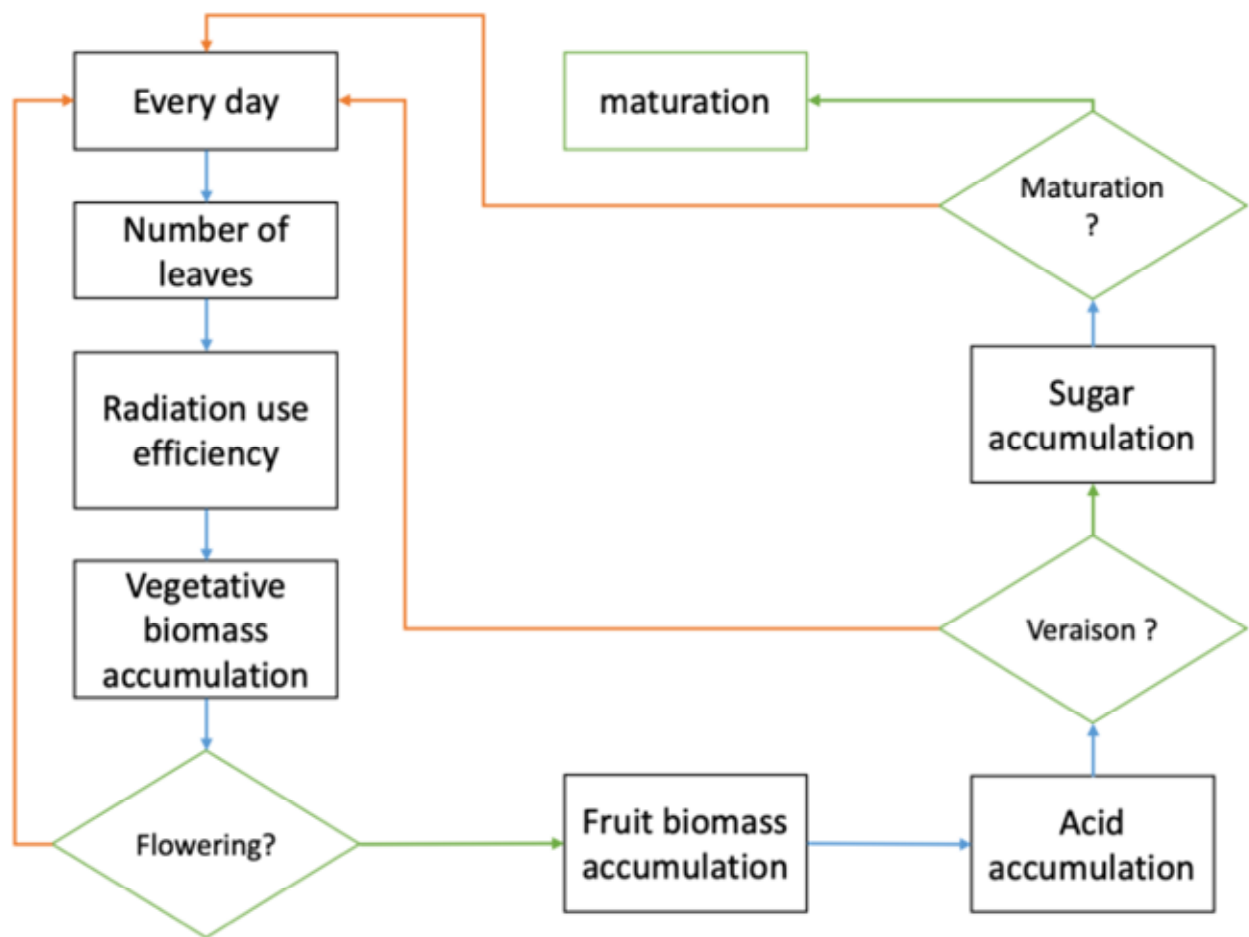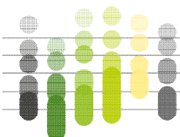
Figure 3-9: The viteModel simplified workflow

3.4.3 OliveModel

The OLIVEmodel.CNR (Moriondo et al., 2019) simulates the growth and development of olive tree on a daily time step. The growth of olive tree is simulated considering the competition for water between the plant and the grass growing under its canopy. A phenological sub model reproduces changes in biomass allocation and the final yield, which is calculated as fraction of total olive tree biomass accumulation at the end of the simulation. The main process of the model is the simulation of the daily potential biomass increase for both the plant and the grass, as dependent on the relevant intercepted radiation, daily photosynthetic active radiation, and radiation/water use efficiencies. This potential biomass accumulation is then corrected with the effect of water stress. Finally, the model takes into account both heat stress and drought at anthesis as possible reducing factors of the final yield. The model requires meteorological data on a daily time step (maximum and minimum air temperature, rainfall, global solar Radiation), soil available water content and management practices (plant density, crown dimensions and initial leaf area index) (Figure 3-10).
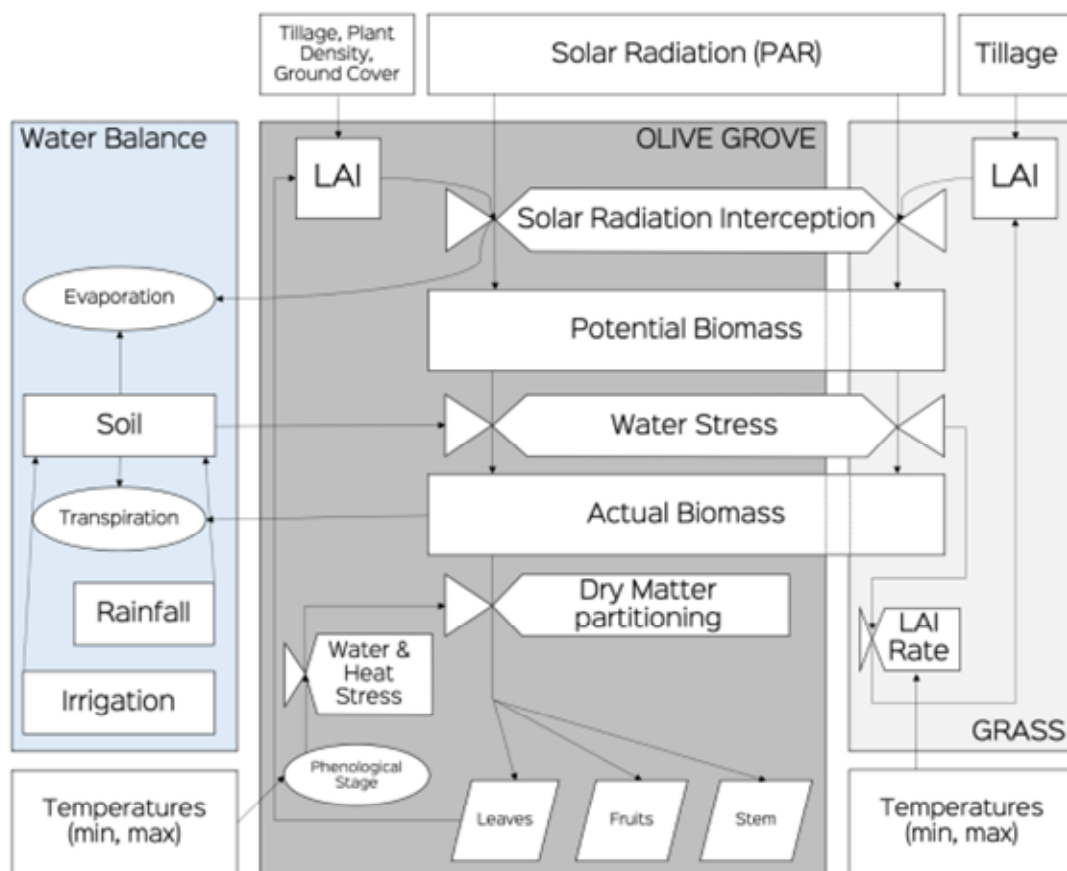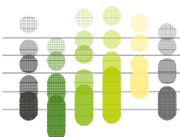

Figure 3-10: THe OLIVEmodel.CNR workflow

3.4.4 Simulations set up

The simulations needed for the case study, specifically the first round for calibration, and the second round for the outputs required by the exercise, were set up on the basis of the different gathered data (e.g. spatial coverage of climate, soils and crop productivity information, common rotation, plant density, etc.). The limiting spatial resolution was represented by the crop information (yield and phenology), which is provided by ISTAT at provincial (NUTS3) level. Consequently, the best spatial resolution could be achieved by running the simulations for the cells (hereinafter referred to as *simcells*) representing (i) each soil type available in (ii) each climate cell (12km x 12km) within (iii) each province. The number of the simcells (2425) can be derived by the following formula:

$$(A * B * C), \quad where \begin{cases} A = \text{n. of the considered provinces} \\ B = \text{n. of the climate cells for each considered province} \\ C = \text{n. of soils for each climate cell} \end{cases}$$

Each of the 67,430 *singlecells* was associated with the relevant simcell on the basis of the *meteocell* and soil.

For each simcell, we run as many simulations as the number of unique CORINE Land Cover codes were represented in all the *singlecells* related to that simcell, for each climate scenario, each rotation (and, if the rotation was including more crops, the simulation was also run as many times as the years the rotation was lasting).

We set up several scenarios on the basis of the available data and information. The scenarios in which biomass production is simulated are:

- Climate/Society: RCP4.5, RCP8.5;
- Crop Rotation: Business As Usual (BAU, the typical crop rotation of the territory), Energetic (a rotation more focused on biomass production for energy), Livestock (a rotation more focused on producing food for livestock);
- Single crops: olive trees, grapevines (not included in the crop rotation, being on other cells);
- Energy crop on marginal land (*Arundo donax*): a scenario in which the marginal land (CORINE Land Cover classes 321, 322, 324) is cultivated with *Arundo donax*.

Thus, on a global level, a total of 6+1 scenarios are evaluated; at single cell level the variability is reduced, since not all the scenarios affect all types of cells (e.g. single crops are perennial, therefore not included in rotation and affected only by Climate/Society scenarios).

Crop growth simulation models can be fed with lots of information about the cultivation, depending on the model and on the simulated crop. In this study, where applicable, all the simulations were run with optimal fertilizer application, so to simulate the potential production (as far as the farmers can be concerned), and, as it was done for the rotations, with the
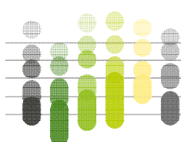
managements following the most typical practices in the different regions (e.g. plant density) (Figure 3-11).
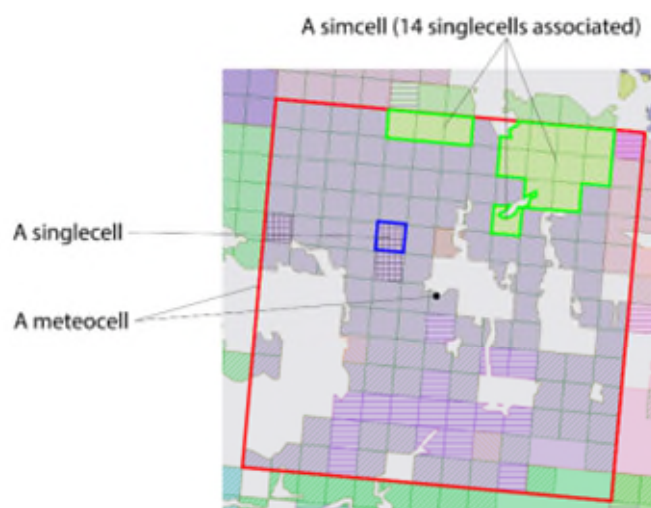

Figure 3-11: Meteocells, simcells and singlecells.

Please notice that the purple simcell includes singlecells with marginal land, arable land, olive groves and vineyards.

3.4.5 Calibration

For the calibration of the models, the phenological stages (e.g. average day of the year of flowering and maturation) and the yield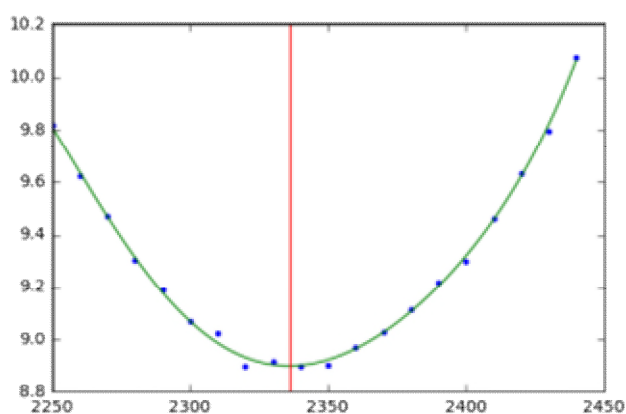s (average tons/ha) for the crops included in the simulations were used. The root mean square error (RMSE) was chosen as a method to get the relative average difference between the model estimates and the real-world measurements. First the model was run for all the simcells, for the 10 years of which observed data were available (2010-2020 decade), changing the crop parameters regulating the thermal accumulation responsible of the occurrence of the phenological stage.

Figure 3-12: Calibration: RMSE for different values of RUE (x axis). The red line represents the RUE value minimizing the RMSE.

Values were changed in order to minimize the Root Mean Squared Error between simulated and observed data of each phenological phase (day of the year): first for emergence, then flowering (where data were available), finally maturity. Then the same process was done for the calibration of the production (Kg/ha), so to minimize the RMSE between simulated and observed data. Once all the varieties were calibrated for each cell, they were used for the main run (Figure 3-12).
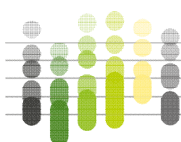
3.4.6 Simulations run

The simulations related to MUSIC Case Studies were run for all the 2425 simcells, for the two climate scenarios, for 31 years (2020-2051 time period), for all the relevant rotations (two or three, depending on the region – see Table 3-3), with as many repetitions as the number of years each rotation is lasting, so to better represent the fact that rotations are not synchronized in the real world.

As in the Figure 3-13, which shows a NUTS3 of the advanced case study (the Province of Taranto), we run as many simulations as rotations/single crops represented by each *simcell*. For example, if a *simcell* of the advanced case study is representing *singlecells* with the CLC classes 2.1.1 (therefore with a 3-years-long BAU and 6-years-long Livestock rotations), 2.2.1 (grapevine) and 3.2.1 (*Arundo donax*), the number or simulations run is:

[(2 (climate scenarios) * 6 (years of the Livestock rotation)) + (2 (climate scenarios) * 3 (years of the BAU rotation)) + (2 (climate scenarios) * 1 (grapevine is a single crop)) + (2 (climate scenarios) * 1 (*Arundo donax* is a single crop))] * 30 (considered time period) = 660 total simulations for the *simcell*.
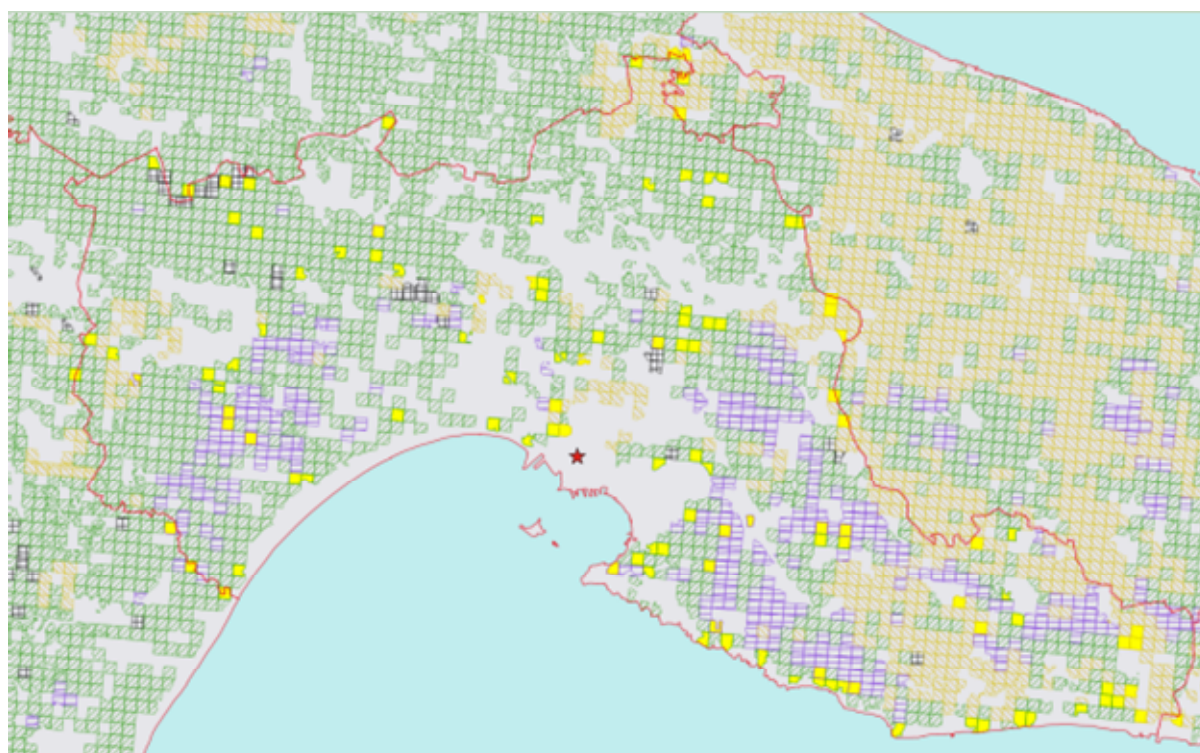

Figure 3-13: Simcells (in yellow) for the province of Taranto (Apulia) and singlecells (stripes, green: arable land; purple: vineyards; yellow: olive groves; grey: marginal land)

Finally, the results from each *simcell* were aggregated (month of harvest) and used for all the *singlecell* that the *simcell* is representing, depending on their CLC.
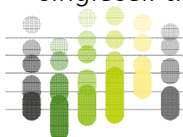
Table 3-6: Total number of simulations run for the Case Study evaluation

| Region	rcp45						rcp85						Total
	arundo	nrg	olive	BAU	grape	livest.	arundo	nrg	olive	BAU	grape	livest.	
Basilicata	876		876	438	876	876	876		876	438	876	876	7884
Calabria	978		978	489	978	978	978		978	489	978	978	8802
Campania	600		600	300	600	600	600		600	300	600	600	5400
ER	1477	1477		1055	1477	1477	1477	1477		1055	1477	1477	13926
FVG	1183	1183		845	1183	1183	1183	1183		845	1183	1183	11154
Lombardy	378	216		270	378	378	378	216		270	378	378	3240
Apulia	2736		2736	1368	2736	2736	2736		2736	1368	2736	2736	24624
Sicily	3090	3090		3090	3090	3090	3090	3090		3090	3090	3090	30900
Veneto	3556	3556		2540	3556	3556	3556	3556		2540	3556	3556	33528
Total	14874	9522	5190	10395	14874	14874	14874	9522	5190	10395	14874	14874	139458

3.4.7 Results

Data need to be extracted and processed from model outputs in order to fit into the geographical database and the logistic model. All results were converted in tons per hectare, and for each crop, the relevant coefficient for the conversion dry biomass/fresh biomass was also applied.

Each simulation provides the yield (per hectare) for each crop, for each year of simulation of each climate scenario and rotation; in order to assess the production potential in a biomass transformation perspective, we decided to analyse the yield on a monthly basis. This approach allowed to evaluate the stability of the production, and thus of the biomass supply to the IBC plant, across the year. The minimum, maximum and average yields were calculated for each crop, in each climate scenario and each rotation, along the simulated years, for each month (if applicable).

Furthermore, each *singlecell* was associated with the production data of the relevant simcell and the yield value was multiplied by the total area (clipped as mentioned before, see 3.3.2.2) of the *singlecell* itself, finally providing the absolute yield value for the area.

After the crop models runs, each *singlecell* has, besides the abovementioned linked data from data retrieval and elaboration, information about the month of harvest, the biomass type (crop and pre-processing) and availability (tons/ha) for each climate scenario and each rotation (where applicable).
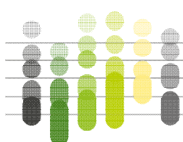
3.5   Logistics model

The objective of the logistics model is to assess the ways to bring the biomass from each production cell to the final transformation site, optimizing the process in terms of total costs and year-round availability. It takes into account:
- pre-processing / densification methods (type, operation and loading/unloading costs)
- means of transport (capacity, operation costs)
- transport routes
- monthly availability with minimum thresholds
- storage facility at the transformation site, if applicable

The model allows to optimize the process by (in order of priority):
- keeping the (average) biomass input flows constant and sufficient for the planned needs of the IBC plant, on monthly basis,
- reducing the overall loading/unloading and transport costs by choosing the optimal packaging/chipping methods, means of transportation and the optimal routes.

Moreover, the logistics model allows evaluating the (possible) optimal placements of the decentralized IBC production plants in terms of total (upstream and downstream) logistics costs, considering also biomass availability for IBC plant planned operations.

3.5.1 Supply scenarios definition

It has been assumed, for simplicity's sake, that the price for each type of on-the-field fresh biomass in the territories surrounding each transformation site remains constant, and therefore that the total biomass cost would be changing only due to different transport costs (i.e., the duration of the trip) Consequently, it has been assumed that the available biomass will be bought starting from the closest fields (in terms of time of travel), then expanding the radius of suppliers until the monthly requirements are fulfilled. We decided to create two radiuses: the minimum and the safety ones. The first one involves the lowest number of singlecells: those that are granting the needed fresh biomass production to fulfil the monthly requirement of dry biomass of the transformation site. The safety radius, instead, involves a higher number of singlecells, which would grant up to +50% of the needed monthly dry biomass requirements each month. Therefore, each singlecells production dataset (climate scenario, rotation + single crops, month) was ordered by time and distance, then the cells were progressively added to the selected sub-set until the dry biomass provided reached the threshold (e.g., for the Adv. Case Study, 25000 tons per month for the minimum, 34000 tons per month for the safety) as in the example shown for the NUTS3 Province of Taranto in Figure 3-14.

The timing of agricultural production delivery can be slightly adjusted, being strongly dependent on seasons, and severely affected by the weather conditions. However, especially at over-regional scale, it can be well planned so that the global (average) amount of the production entering the final transformation site is kept constant on monthly basis (lower time scale seems unlikely to be achievable).
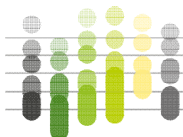
The annual distribution relative to the availability of biomass produced is concentrated above all in the summer for herbaceous crops and at the end of winter for tree crops. In the remaining periods, however, a sufficient quantity of biomass is guaranteed thanks to the production of the *Arundo donax*, which manages to cover the autumn period and the overproduction of winter wood from tree crops which covers the needs of late spring.

We found that in September the produced biomass was generally not enough, and in August, while the biomass produced was sufficient, it was located in remote production sites (in colder, mountainous areas, where maturity of wheat was simulated to be occurring later than in other, warmer areas), which meant higher purchase costs due to the transport cost. Therefore, since in July the biomass production was much higher and rather concentrated around the main transformation site, as in Figure 3-15, it has been decided to buy more biomass during July (twice as needed for the month) from (closer) singlecells, and to buy less in August and none at all in September, so to cover the needs for the three months (July, August and September) at lower costs.

Figure 3-14: Minimum and safety supply areas for January, RCP85, advanced case study.
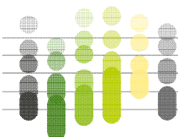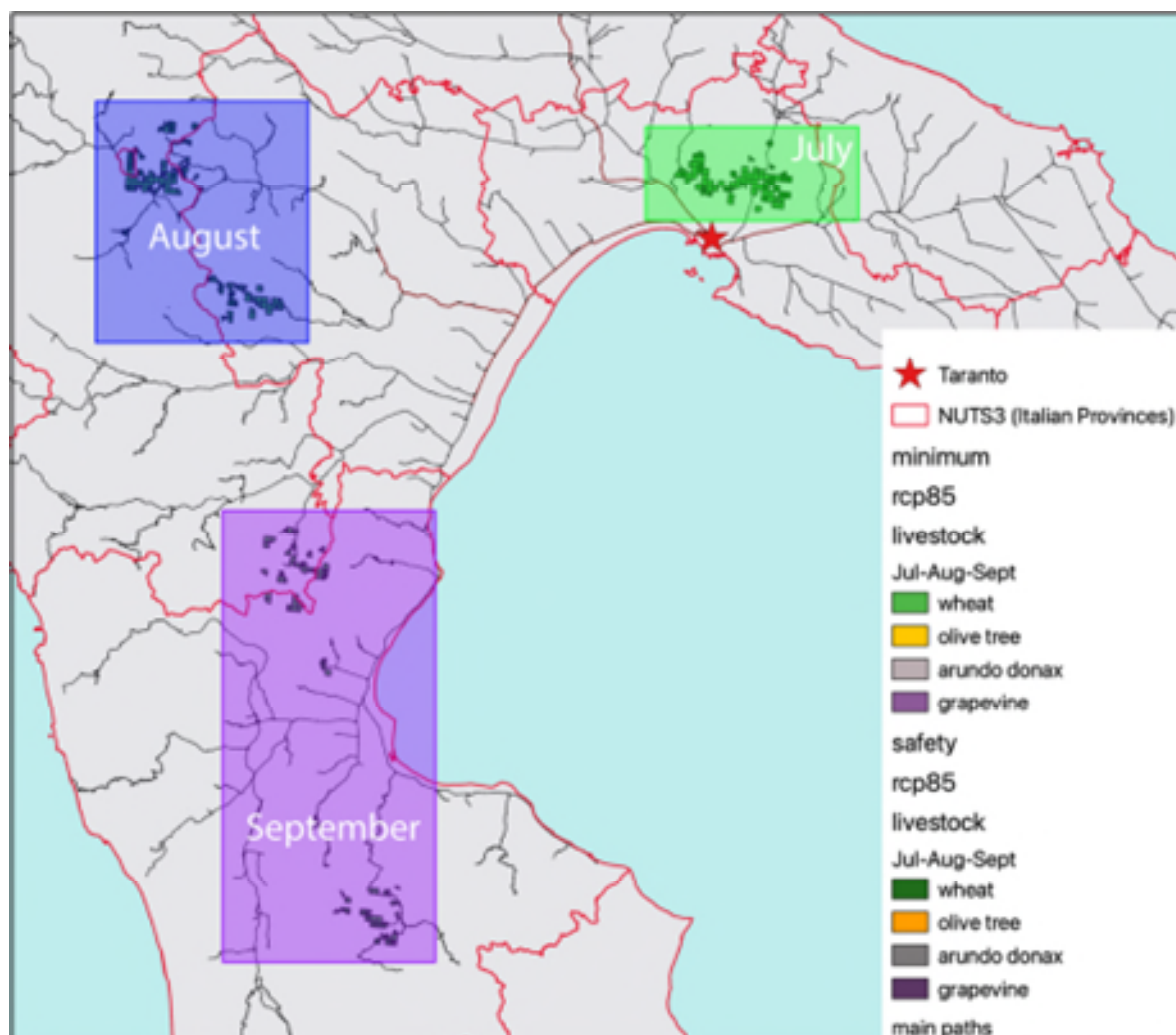
Figure 3-15: Singlecells providing biomass during July, August and September, RCP85, advanced case study

3.5.2 Field processing

The selected processes for biomass pre-treatment, at farm level, are: harvesting the residues distributed in the plot, chipping for the ligno-cellulosic residues and energy crops and the use of bales for the herbaceous residues. The processing times for the chipping of the vineyard residues are shorter than the chipping of the olive residues, due to the lower thickness of the shoots which facilitates the processing while the harvesting of the vine shoots requires more time for the espalier arrangement of the vine cultivation.

The mowing of the *Arundo donax* is a simpler process and involves lower costs for the company as shown by the final value of the *Arundo donax* wood chips compared to that relating to the vine and olive tree crops.
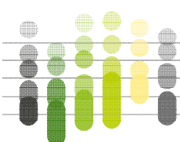
3.5.3 Transportation methods

For the transport of biomass from farms to delivery, we must choose a means of transport that is not too bulky, which can easily travel along country roads and which is not too small (e.g. tractor) in order not to increase transport costs; furthermore, by choosing the most popular medium-range trucks on the market, we will have the opportunity to compare the estimates of a greater number of contractors in order to be able to choose the cheapest.

The most suitable means for transporting pruning residues and round bales is the truck with a transport capacity from 5 to 10 tons (Figure 3-16).
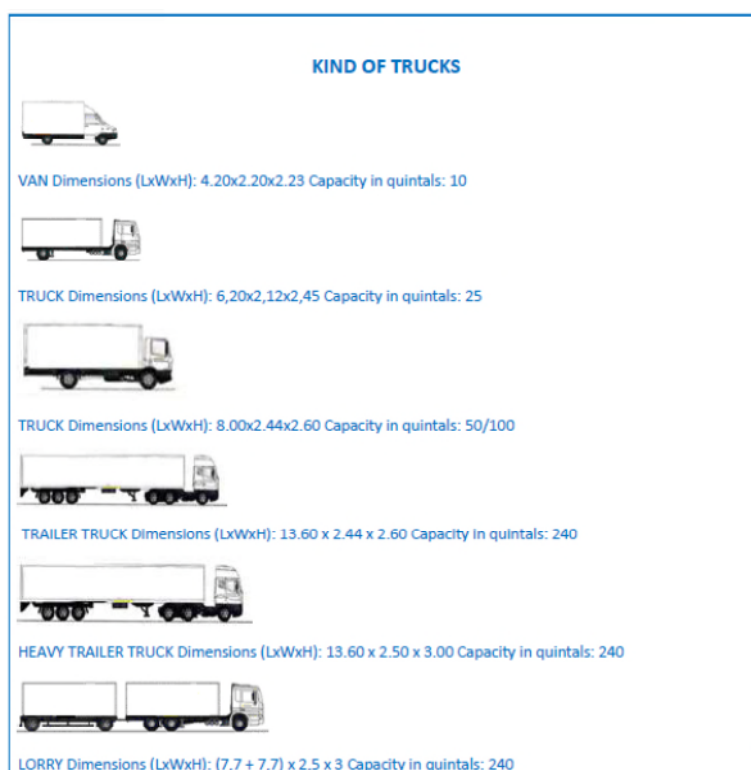

Figure 3-16: Type of trucks for the transportation

3.5.4 Overall costs calculation

For each singlecell, we realized two cost scenarios: in the first one we calculated the cost of the fresh biomass ready on the field, by multiplying the average cost per ton (BAU) by the total production. In the other scenario we applied a 15% cost reduction hypothesizing a large-scale contract.

Then, the loading/unloading cost for the whole fresh production of each singlecell was calculated by multiplying the time of loading/unloading, according to the biomass type (wood chips or bales), by the number of trucks needed on the basis of their capacity (an average value of 8 tons was used) for the simulated production, based on an hourly average price. Furthermore, the transportation cost of the fresh biomass from each singlecell to the main transformation site was also calculated using the time of travel and the hourly price. Also, here

we implemented two cost scenarios: one on the basis of the average costs (BAU) and another one with a -10% discounted price (which could be hypothesized for a large-scale contract as foreseen for the case studies). The total cost for having the whole biomass from the singlecell at the transformation site is therefore calculated as the sum of loading/unloading costs, biomass costs and transportation costs, for the BAU and the discounted scenarios.

3.6   Biomass availability and costs assessment

Given the information gathered in the previous phases and the overall choices defined for the CS, the crops/logistics model gives as output the overall biomass and logistics costs for the various centralized and decentralized CS scenarios.

These outputs are made available by the model at singlecell level; they are then aggregated to be used as inputs for the CS techno-economic model, in the corresponding scenarios.

As already described, the outputs from the crops/logistics model change across the various considered climate/crop/etc. scenarios. In the techno-economic model, this variability will likely be reduced into a set of three main scenarios, such as a worst-case, a best-case/with technical limitations and an average/most likely one. The availability of this great amount of data and scenarios as inputs could anyway be further exploited for sensitivity analyses addressing specific topics (i.e. the impact of the use of crops cultivated on marginal lands on the economics of the IBC plant).
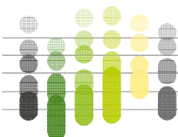
4 The Swedish Case-Study

4.1 Objective of the work

Assessing the availability of biomass and the creation of biomass supply cost curves requires information about the spatial availability of biomass resources, the costs for gaining ownership of the biomass, harvesting costs, forwarding costs from the forest to the landing (roadside), chipping costs as well as long distance transportation costs for transporting it to the preferred facility and finally distances to the facility. The existing road network can be used to calculate the transport distance from each point to the terminal.

4.2 Methodology

Biomass availability estimations and cost curve construction for the Northern Sweden case are described below:

4.2.1 From the forest to the pyrolysis facility

This model has not been applied yet in a MUSIC context. The starting point of the calculations is a (1km x 1km) raster map that contains information on the annual projected forest biomass potentials from final fellings and thinnings in Sweden of five assortments (branches, stumps, bark, pulpwood and saw logs). The projections are for the time period 2030-2050. The annual potential projections for branches, pulpwood and bark include aggregated values of Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies), Silver birch (Betula pendula) and Downy birch (Betula pubescens). Potential projections for stumps and saw log biomass included only Scots pine and Norway spruce due to environmental restrictions when it concerns extractions of birch stumps. The raster map is found in the Forest Energy Atlas homepage (https://forest-energy-atlas.luke.fi/).

For the coming calculations in the MUSIC project, the original raster with a pixel size of 1km x 1km will be aggregated to a raster with a pixel size of 10km x 10km. The original raster was containing the branches without including any ecological restrictions and neither included the tree tops (upper stem part below 6 cm in diameter) in the estimates. To correct that and provide an available amount of logging residues that is closer to reality the treetops were added to the branch biomass. It was assumed that approximately 8% of the logging residues are composed by tops. This quantity was then added to the quantity of the biomass of the branches. Further, it was assumed that only 75% of the logging residue biomass (branches and tops) is harvested while the rest remains in the forest and decomposes. Furthermore, all pixels that had a logging residue density of less than 100 dry tons per 100 km^2 were removed from the data set to make the analysis easier to handle. The distance from the center of the 10km x 10km pixels to the nearest receiving point within the region, either facility (heating plant, biorefinery, pulp mill or sawmill) or terminal, was estimated based on the Swedish road network by using the Network Analyst module in ArcGIS10.
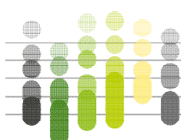
4.2.2 From sawmills to a pyrolysis facility that is located at a sa0wmill

All 28 sawmills in the region were georeferenced (Figure 4-1). For each m³ of sawn wood produced in sawmills it was calculated that 125 kg of sawdust became available for using in a pyrolysis reactor. For the purpose of the analysis one sawmill was selected as host of the pyrolysis reactor. Using the Network Analyst module in ArcGIS10 (Closest facility function), sawdust from the sawmills that were closest to the sawmill with the pyrolysis reactor was transported via the existing road network to the pyrolysis reactor. When the total demand of 80000 tons of sawdust was reached, no more transports happened. The same procedure was applied for four different sawmills (Sikfors, Kåge, Bygdsiljum and Sävar) that were assumed to serve as hosts for the pyrolysis reactor (Figure 4-1). The costs for sawdust acquisition and transport were used to construct the cost curves shown in Figure 4-2.

Figure 4-1: The occurrence of pulp mills, (green dots), heating plants (red dots) and sawmills (blue dots) in the study region (Northern Sweden).

The names of the locations of the sawmills that were assumed to act as hosts of a pyrolysis reactor are noted on the map together with the location of the Skellefteå harbor were the pyrolysis oil will be transported to.
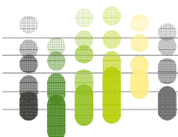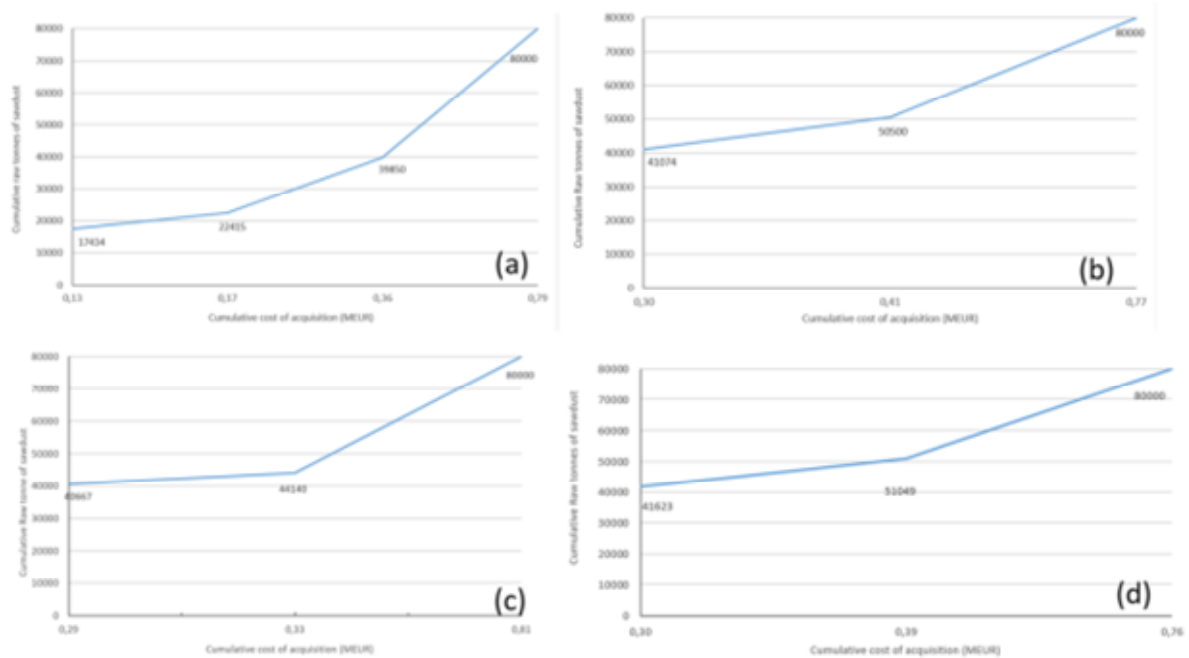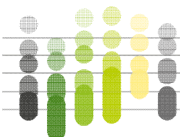
Figure 4-2: The cumulative cost of acquisition (MEUR) of a maximum of 80000 raw tonnes of sawdust (a) Sikfors, (b) Bygdsylium, (c) Sävar and (d) Kåge (EUR= 10.30 SEK)

5 Biomass supply optimization model

5.1 Objective of the work

Western Macedonia presents a significant amount of biomass potential, especially in the region of Kozani and Florina, due to the large agricultural activity. More specifically, biomass residues are widely available, though only a small fraction is collected and utilized -mostly as fodder-, while the remaining amounts are cut and left on the field or usually burned. This is due to the lack of organized biomass supply chains that can overcome its high spatial distribution and seasonality. In addition, a major obstacle is the high cost for handling, transporting and storing biomass and relevant residues. To overcome the restrictions imposed by the physical-chemical properties of biomass, the conversion of agricultural residues to Intermediate Bioenergy Carriers (IBC) is considered. IBCs are produced from biomass (forest biomass, cultivated biomass, biomass residues, and waste). Biomass is processed via different conversion routes, namely, thermo-chemical conversion, physical-chemical conversion and bio-chemical conversion to energetically denser, storable and transportable intermediate products, analogous to coal, oil and gaseous fossil energy carriers, for easier transport, storage and use than biomass residues. IBCs can contribute to energy security, reduce greenhouse gas emissions and provide a sustainable alternative to lignite in Western Macedonia.

In this context, the Greek advanced case study deals with the conversion of agricultural residues, such as corn cultivation residues, to IBCs through thermo-chemical conversion (torrefaction) and their subsequent utilization -as alternative to lignite- in the district heating plant of DETEPA (Figure 5-1).

The feasibility of such a novel value chain (biomass supply chain plus conversion to IBC) for the district heating plant of DETEPA, requires the analysis of several factors and their effect on the physical supply chain.

To this purpose, a biomass supply optimization model, based on non-linear programming, is used to determine the optimal time planning for biomass procurement and the maximum torrefaction unit capacity. The overarching goal is the cost minimization, taking into account seasonal biomass availability issues, biomass seasonal cost, storage options and cost, logistics, end-users demand, torrefaction unit operational parameters, capital expenditures (CAPEX), operational expenditures (OPEX) and biomass properties.

5.2 Description of the supply optimization model

The model is developed for a stand-alone biomass torrefaction unit that accounts for biomass procurement, storage, and utilization under variable conditions.

The fluctuations of the energy demand during a heating season require a larger capacity torrefaction reactor, allowing the production of larger amounts of torrefied product than those required for the district heating plant. The surplus torrefied biomass can be then stored for subsequent use during periods, where biomass availability is low and supply procurement costs are high, or channelled, in the domestic and international market as standardized solid energy
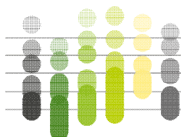
product (after further processing). On the contrary, where biomass availability is high (lower procurement cost) raw biomass is stored for subsequent conversion in the torrefaction unit. The difference between storing torrefied and raw biomass is the energy density per mass that results in higher required storage volume (additional cost for the construction and operation). On the specific model, it is assumed that biomass supply and price can vary considerably between months reflecting on a realistic situation.
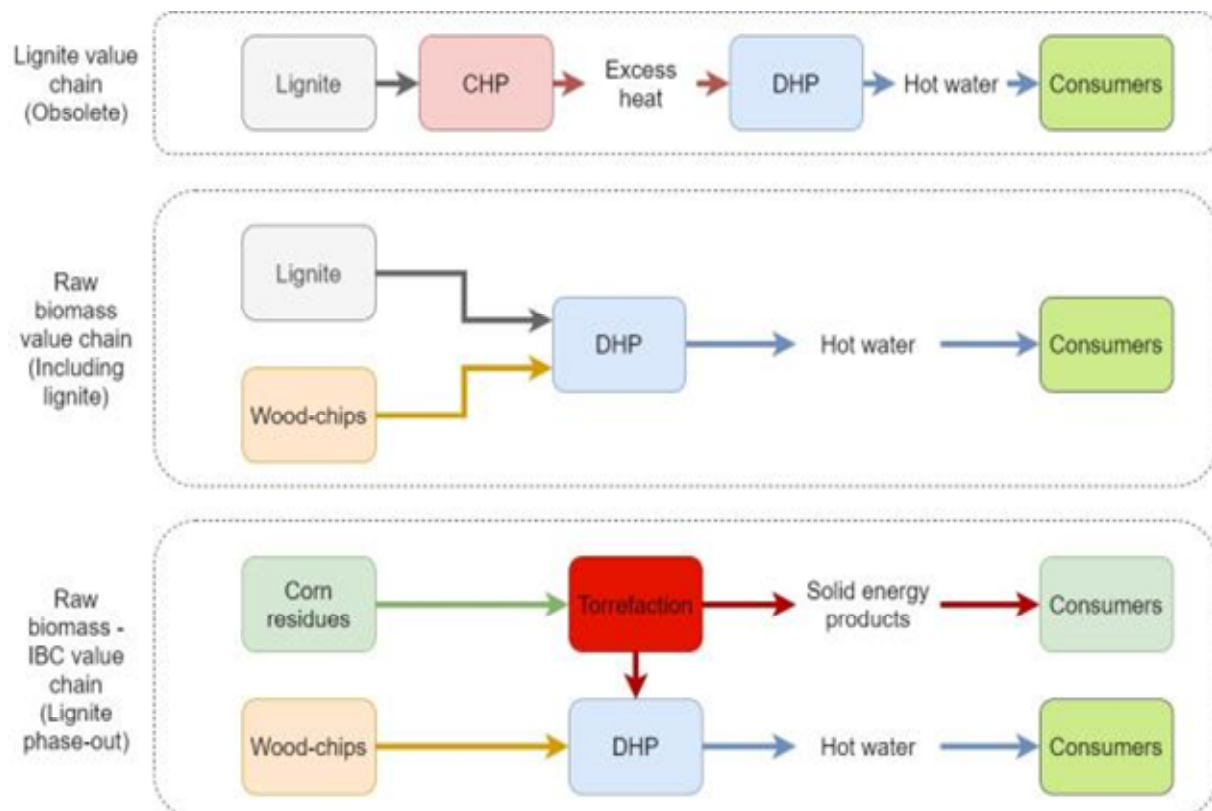

Figure 5-1: Obsolete lignite value chain – Current value chain - Novel IBC value chain.

 Logistics is defined as the process of planning, implementing and controlling the efficient and cost-effective flow and storage of raw materials, goods, equipment and personnel from the point of origin until the completion of an activity, in accordance with end-user's requirements. Proper logistics planning entails considering logistical aspects throughout the various stages of the procurement process. It contributes to efficient procurement processes, and reduces the risk of incurring problems that may lead to additional costs and delay (UN Procurement Practitioner's Handbook). In this sense, the prospect of multiple storage options, to facilitate the effective flow of raw biomass to the torrefaction unit, is explored. The total distance for the transport of biomass to the torrefaction unit is accounted for under the hypothesis of using a truck with 17 ton capacity of raw biomass.

To determine the feedstock to product ratio of the torrefaction unit, a simplified mass-energy flow model was integrated into the supply optimization model. This model is based on the

principles of preservation of mass and energy, and is composed of a simplified theoretical model. A series of process parameters (e.g., heating value of torrefied product, moisture content of biomass, energy efficiency etc.) need to be predefined while, others are calculated (e.g., heating value of torr-gas). The ash that remains after combustion is considered negligible (on both mass and energy basis) and is therefore not included in the mass and energy balance.

An important outcome of the model is to calculate the amount of process heat required from an external heat source (in case torr-gas is not enough to drive the processes of drying and torrefaction). As potential external heat sources, torrefied biomass from the torrefaction unit itself and natural gas from the Greek national grid were considered.

For the torrefaction unit, CAPEX consists of the construction of the facility, including the torrefaction reactor. This includes direct costs, such as equipment and installation while, indirect costs include the engineering design of the plant, supervision, fees and contingencies.

For the determination of the required amount of torrefied biomass for the district heating plant, the thermal efficiency and the desired share in the fuel-mix was considered.

A non-linear programming (NLP) problem is therefore developed for the calculation of the optimal schedule of biomass procurement and utilization based on the minimization of the overall costs. The model provides an optimal solution over a twelve-period planning horizon, by minimizing the non-linear objective function over a set of variables and conditioned to the satisfaction of a system of equalities and inequalities (constraints). The objective function consisted of procurement, transport and storage cost for raw biomass, storage and transport for the torrefied biomass, CAPEX and OPEX of the torrefaction unit as expressed in equation (1). The duration of a single time period for the simulation is selected as one month.

$$\min f \; Cost = \sum_{i=1}^{NP}[B[tn] \cdot PC\left[\frac{€}{tn}\right] + B[tn] \cdot BD[km] \cdot BTC\left[\frac{€}{tkm}\right] + SB[tn] \cdot SC\left[\frac{€}{tn}\right] + STB[tn] \cdot TBSC\left[\frac{€}{tn}\right] + TB[tn] \cdot TBD[km] \cdot TBTC\left[\frac{€}{tkm}\right] + (8.457 \cdot maxMPTB)^{0,7}\left[\frac{€}{tn}\right] + UF[MWh] \cdot UFC\left[\frac{€}{MWh}\right]] \; (1)$$

Where:

B = Quantity of raw biomass required.

PC = Procurement cost of raw biomass.

BD = Distance of raw biomass transport.

BTC = Cost of raw biomass transport.

SB = Quantity of stored raw biomass.

SC = Storage cost for raw biomass.

STB = Quantity of stored torrefied biomass.

TBSC = Storage cost for torrefied biomass.

TB = Quantity of torrefied biomass for transport to end-user.

TBD = Distance for torrefied biomass transport.

TBTC = Cost for torrefied biomass transport.

maxMPTB = Maximum monthly quantity of torrefied biomass produced

UF = Quantity of utility fuel (if natural gas is used as an external heat source)

UFC = Cost of utility fuel (if natural gas is used as an external heat source)

In case torrefied biomass is used as utility fuel in the torrefaction process, the cost is integrated into the biomass procurement, transport and storage cost for raw biomass, CAPEX and OPEX of the torrefaction unit.

In **Figure 5-2**

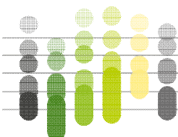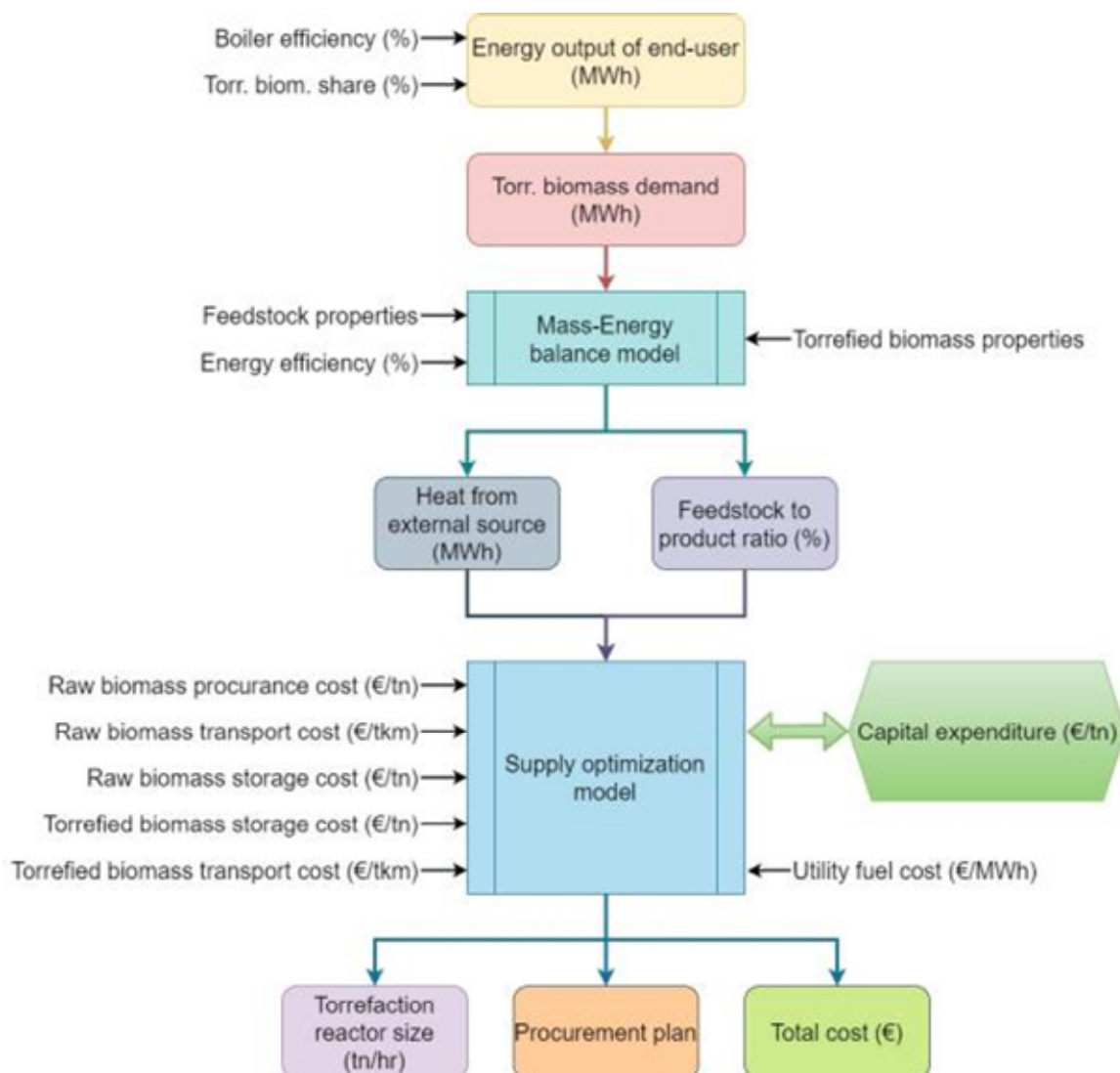**Figure 5-2** the flowchart of the biomass supply optimization model is provided:

Figure 5-2: Flowchart of the supply optimization model.

6 References

Agres Project, 2016, <https://www.aielenergia.it/public/pubblicazioni/190_Agres-bro.pdf>, accessed January 2021

Bindi M, Miglietta F, Gozzini B, Orlandini S, Seghi L (1997) A simple model for simulation of growth and development in grapevine (Vitis vinifera L.). I. Model description. Vitis 36:67–71

Biocolt project, 2010, Progetto Biocolt - Colture energetiche per il disinquinamento della laguna di Venezia (book), chapter 7 "Sostenibilità di un modello di filiera "biomasse combustibili - energia" alla piccola scala: il caso di canna comune, miscanto e pioppo con turno di ceduazione" (in Italian)

Candolo, G. 2006, Energia dalle biomasse vegetali: le opportunità per le aziende agricole, Agronomica, 4, pp. 26-35 (in Italian)

Copernicus 2018, Corine Land Cover < https://land.copernicus.eu/pan-european/corine-land-cover>

Hengl T, Mendes de Jesus J, Heuvelink GBM, Ruiperez Gonzalez M, Kilibarda M, Blagotić A, et al. (2017) SoilGrids250m: Global gridded soil information based on machine learning. PLoS ONE 12(2): e0169748. https://doi.org/10.1371/journal.pone.0169748

Herrmann M., Somot S., Calmanti S., Dubois C., Sevault F. (2011) "Representation of daily wind speed spatial and temporal variability and intense wind events over the Mediterranean Sea using dynamical downscaling : impact of the regional climate model configuration", Nat. Hazards Earth Syst. Sci., 11, 1983-2001, doi:10.5194/nhess-11-1983-2011

Hodson, David & White, Jeffrey. (2010). GIS and Crop Simulation Modelling Applications in Climate Change Research.. Climate Change and Crop Production. 10.1079/9781845936334.0245.

http://dati.istat.it/Index.aspx?DataSetCode=DCSP_COLTIVAZIONI

Masia, S., Sušnik, J., Marras, S., Mereu, S., Spano, D., Trabucco, A. 2018. "Assessment of Irrigated Agriculture Vulnerability under Climate Change in Southern Italy" Water 10, no. 2: 209. https://doi.org/10.3390/w10020209

Minambiente Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2020, PIANO NAZIONALE DI ADATTAMENTO AI CAMBIAMENTI CLIMATICI <https://www.minambiente.it/pagina/piano-nazionale-di-adattamento-ai-cambiamenti-climatici> accessed February 2021

MIT Ministero delle Infrastrutture e dei Trasporti, accessed December 2020 http://dati.mit.gov.it/catalog/dataset/grafo-stradale-anas

model. European Journal of Agronomy, 18(3): 289–307. doi:10.1016/S1161-0301(02)00109-0.

Progetto Faesi, 2012 Supplemento n.2 Rivista Sherwood n.183 anno 18 ISSN 1590-7805
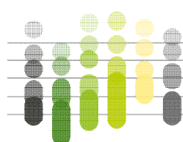
Stöckle, C.O., Donatelli, M., and Nelson, R. 2003. CropSyst, a cropping systems simulation

Streetz   Holger,   Biomass'   Role   in   Europe's   Green   Deal.   2020
    http://biomassmagazine.com/articles/16881/biomassundefined-role-in-
    europeundefineds-green-deal

Tóth B, Weynants M, Pásztor L,Hengl T. 3D soil hydraulic database of Europe at 250 m resolu-
    tion. Hydr ologic al Processes. 2017;31:2662–2666. https://doi.org/10.1002/hyp.112032666

Voldoire, A., Sanchez-Gomez, E., Salas y Mélia, D. et al. The CNRM-CM5.1 global climate model:
    description   and   basic   evaluation.   Clim   Dyn   40,   2091–2121   (2013).
    https://doi.org/10.1007/s00382-011-1259-y

Michael   Wild,   Wild&Partner   LLC,   Vienna,   Austria,   IBTC,   Brussels,   Belgium.
    'Torrefaction/Carbonization, status of the sector and todays offers to the market'.
    Presentation for the MUSIC project.

Hellenic Ministry of Transportation and Communications and Eugenidou Foundation.'
    Theoretical training of candidate truck drivers', 1999, ISBN 960-337-032-0).