Project acronym: BECOOL

Project full title: Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels
Grant Agreement Number: 744821

Project start date: 01.06.2017

Deliverable 2.5

Title:	
USER MANUALS FOR THE STAND ALONE TOOLS TO BE USED IN FURTHER CHAIN DESIGN AND EVALUATION	
Author(s):	E. Annevelink, S. Leduc, I. Staritsky, B. Elbersen & H. Stellingwerf
Reviewers	WR
Date:	27 May 2022

Dissemination Level: PU

Table of Content

1. Introduction

Task 2.3 included developing user manuals for the logistical assessment tools so that they can be used in new cases for the development of the advanced biofuels sector both in Europe and Brazil. This deliverable describes how the tools can be applied in national or regional case studies. It is not a technical user manual in the sense that it exactly describes how to operate the software of the assessment tools.

2. Manual of BeWhere

2.1 Introduction

The BeWhere model (www.iiasa.ac.at/bewhere) has been used in the BECOOL project to analyze the optimal supply chains at the national level, i.e., Italy and Germany. The model is designed to identify the optimal geographic position of possible pre-treatment facilities and biofuel production plant based on the minimization of the cost of the supply chain. The model minimizes the cost at the country level, and not at the plant level, which means that the optimal solution is a solution for the welfare of the studied area. The supply chain represents the collection of the biomass, transport of the biomass, pre-treatment, dried-biomass transport to the biofuel production plant, biofuel production and transport of the final product to the demand points. The supply chain is presented in Figure 1.

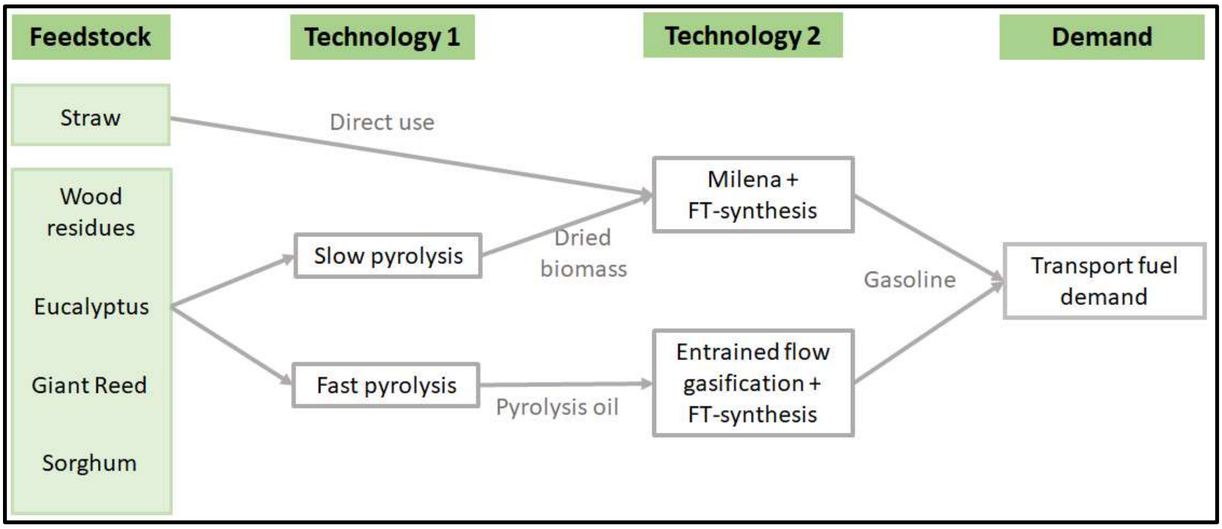

Figure 1: Supply chain studied in the BeWhere model at the national level.

The model uses input data at the grid level, which in this case defined at the 50*50 km^2 resolution. This grid is the same as the grid used by the GLOBIOM model to easily exchange the data. The BeWhere model uses indeed the biomass data generated by GLOBIOM at the European level. Input data at the grid level is used for as much as data as possible: feedstock production, cost and emission, technology 1 and 2 locations and transport fuel demand.

2.2 Network

The transport of biomass, dried biomass or final product is possible via the connection of all grid points to any other grid points. This connection is assured with the use of a digital road network for Europe (OpenStreetMap, 2019), for which all different type of roads (e.g., main street, secondary road) are assigned a relevant speed limit. Based on that and the Network analyst tool from the ARC GIS software, the fastest direction can be identified from one pixel (or grid point) to any other pixel. It may happen that the connectivity of some road may not be accurate, which unable to link one pixel to another. In that specific case, the distance between these two points is calculated based on the Euclidian straight line times a tortuosity factor. The tortuosity factor is calculated from the previous grid point connection calculated from ARC-GIS for the specific country: as a conservative value, a tortuosity factor of 3.7 and 3.1 for Germany and Italy respectively for the missing connections.

For the distance between one pixel to the same pixel, we applied a random value between 25 and 50 km, to make sure these distances are different within each other, and the neighboring pixel is not reached.

From that point, all pixels can then be connected to each other, and the transport of commodities by road is enable for the entire study region.

2.3. Biomass

The biomass data has been provided by the GLOBIOM model on a 50 km^2 grid. It has been calculated for three type of biomass yields: low, medium and high. Besides the yield, cultivation cost and emissions were available. The BeWhere model used the three types of biomass yields for each scenarios. The aggregated yields at the country level are presented in Table 1 at the country level. The emissions and costs remained the same for the three scenarios.

Table 1: Biomass productivity in the country cases studies for the BeWhere model in kdt/year.

Scenarios	**High yield**			**Medium yield**			**Low yield**		
Countries	**Italy**	**Germany**	**Total**	**Italy**	**Germany**	**Total**	**Italy**	**Germany**	**Total**
EU1	140	0	140	70	0	70	35	0	35
EU2	34	0	34	17	0	17	8	0	8
PO1	1,401	219	1,619	700	109	810	350	55	405
PO2	0	0	0	0	0	0	0	0	0
GR1	31	277	309	16	139	154	8	69	77
GR2	0	0	0	0	0	0	0	0	0
MS1	320	2,761	3,081	160	1,380	1,541	80	690	770
MS2	708	95	803	354	47	401	177	24	201
SO3	1,835	2,168	4,002	917	1,084	2,001	459	542	1,001
SO3_cereal	1,016	530	1,546	508	265	773	254	132	387
SH3_cereal	0	0	0	0	0	0	0	0	0
SH3_fallow	2,772	3,611	6,383	1,386	1,805	3,191	693	903	1,596
ST2	4,054	3,085	7,139	2,703	2,057	4,759	1,351	1,028	2,380
WR5	1,294	5,819	7,113	647	2,909	3,556	324	1,455	1,778

2.4. Technology

The technology input data has been provided by WP5 and more precisely from the deliverable *D5.5. 'Most promising value chains'*. For the technology parameters, the following input are necessary: capacity of the potential plants, setup cost, operation and maintenance cost, conversion efficiency and any other balance parameter when applicable. For each technology, it is assigned a specific feedstock (commodity that comes into the facility) and product (commodity that goes out of the facility).

2.5. Model Runs

The BeWhere model is written in GAMS as a mixed integer linear programming model (Wolsey, 1998). The model has been widely described in many publications as for example (Leduc et al., 2008, 2009, 2010, 2012; Leduc, 2009; Patrizio et al., 2017; Wetterlund et al., 2012). To run the full model, it goes into the following steps (Figure 2):

(1) Compilation of the input data into an xls file: All input data is converted in an xls document. Even the geographic explicit data will be processed into ArcGIS, and further send to an xls file format. It is important that all explicit geographic data is assigned the same identification number that defines the number of the grid cell.
(2) Run a Python code to read the xls input data and convert them into some txt file suitable for the GAMS code.
(3) Run the GAMS code. The GAMS code reads all txt file converted in the previous step, and no parameters are written in the GAMS code.
(4) Run a Python code that will process the results and convert them into a friendly user xls file and maps.

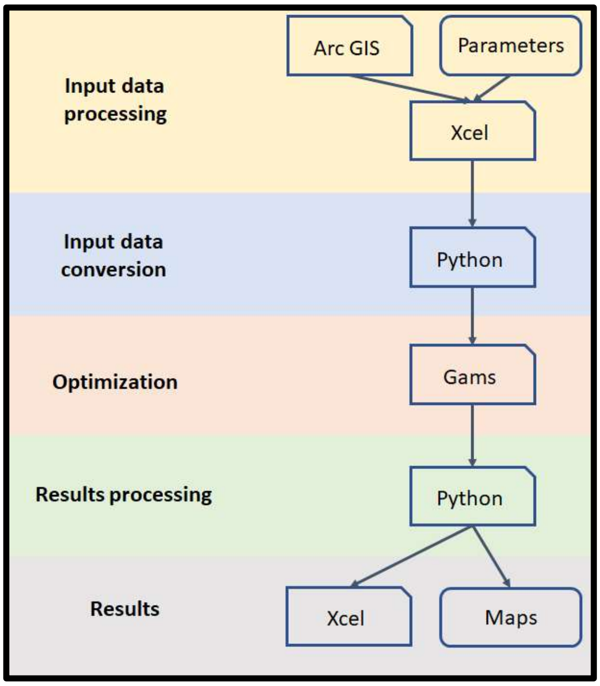

Figure 2: Overview of the steps to run the BeWhere model.

To allow a fast and accurate resolution of the model, we assume that new potential production plants can be allocated only at grid points where biomass is available instead of all the grid points of the studied area. This limits the number of potential solutions from 2,700 to half. Moreover, the GAMS optimal criteria for convergence of the optimal solution has been assigned to 0.0001%.

2.6 Example of results

The maps in Figure 3 present an example of the outcome from the BeWhere model. Four examples are presented, the first row represents the location of the first gasification facility in both Germany and Italy (left side), and the first time two different feedstock are used (left side, wood residues and straw). The second row presents the first time three and four feedstock appears for the first time in regards with the number of plants that can be setup.

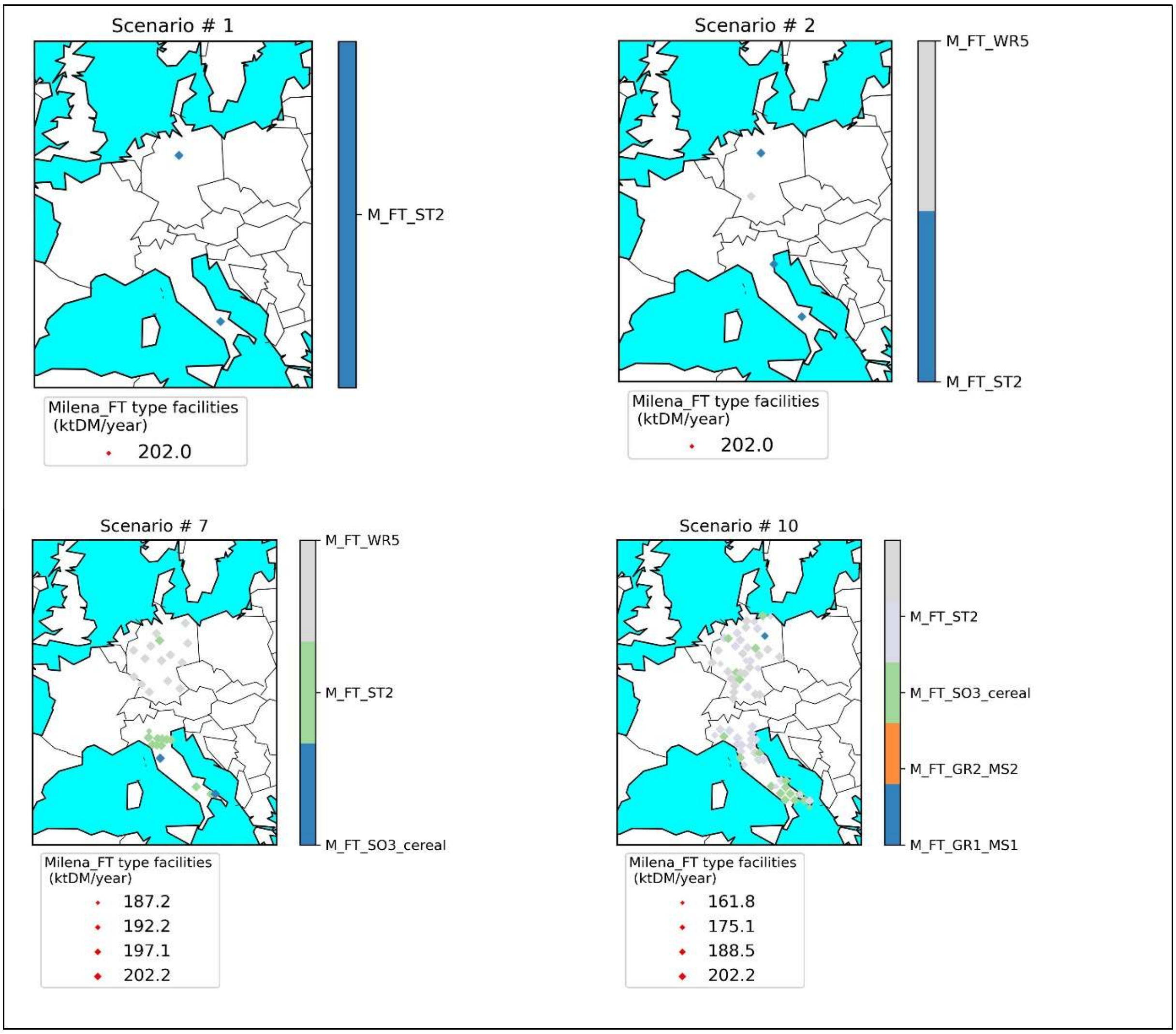

Figure 3: Location of possible Milena gasification plant. Example of results for the first Milena plant (top left), the first time two feedstock are considered (top right), the first time three feedstock are considered (bottom left) and the first time four feedstock are considered (bottom right)

2.7 Link with LocaGIStics2.0

The results from the BeWhere model are sent to the LocaGIStics2.0 model. For each run of the model, the results on the locations of both the intermediary conversion site (e.g., slow or fast pyrolysis) and the gasification facility are provided. Moreover, it is indicated which conversion site and gasification plant are connected to each other and the amount of commodity that is transferred between the two sites. The LocaGIStics2.0 model can then better simulate the use of the feedstock in the case studies.

An example of the data that is exchanged between the models is presented in Table 2. The table presents the identification number of the Slow pyrolysis plants (named *P1*) and its coordinate (*Lat_P1* and *Lon_P1*) the gasification plant to which the intermediary product is shipped to identified by *P2* and its corresponding coordinates (*Lat_P2* and *Lon_P2*). And finally, the type of feedstock (named *Intermediary product*) and its amount (*Amount kt/year*) shipped from the conversion site to the gasification plant.

Table 2: Example of the results provided to LocaGIStics2.0.

Country	P1	Lat_P1	Lon_P1	P2	Lat_P2	Lon_P2	Technology_P2	Intermediary product	Amount kt/year
Germany	P1-979	51.25	10.25	P2-1007	51.25	11.25	M_FT_WR5	dried_WR5	68.363
Germany	P1-1005	52.25	11.25	P2-1007	51.25	11.25	M_FT_WR5	dried_WR5	25.446
Germany	P1-1006	51.75	11.25	P2-1007	51.25	11.25	M_FT_WR5	dried_WR5	49.437
Germany	P1-1007	51.25	11.25	P2-1007	51.25	11.25	M_FT_WR5	dried_WR5	33.834
Germany	P1-1034	51.75	12.25	P2-1007	51.25	11.25	M_FT_WR5	dried_WR5	25.139
Italy	P1-1331	45.25	9.25	P2-1339	44.75	9.75	M_FT_SO3_cereal	dried_SO3_cereal	35.722
Italy	P1-1345	45.25	10.25	P2-1339	44.75	9.75	M_FT_SO3_cereal	dried_SO3_cereal	42.225
Italy	P1-1357	43.75	10.75	P2-1339	44.75	9.75	M_FT_SO3_cereal	dried_SO3_cereal	46.317
Italy	P1-1364	44.75	11.25	P2-1339	44.75	9.75	M_FT_SO3_cereal	dried_SO3_cereal	77.955

3. Manual of LocaGIStics2.0

3.1 Introduction

The goal of the LocaGIStics2.0 model is to calculate the costs, energy use and GHG emissions of value chains supplying biomass from the fields to the final conversion site, including possible intermediate steps. Optimization can be done on minimizing the costs, energy or GHG emissions.

LocaGIStics2.0 will need the following parameters for its calculations:

- production of biomass (cost, energy & emission);
- specific volume;
- short distance transport (max ton, max volume, cost, energy & emission);
- long distance transport (max ton, max volume, cost, energy & emission);
- loading/unloading (cost, energy & emission);
- pre-treatment (cost, energy & emission);
- drying (cost, energy & emission);
- storage (cost, energy & emission and average duration);
- conversion (cost, energy & emission).

3.2 Model structure

The LocaGIStics2.0 model consists of two parts (Figure 4).

- Spatial part: QGIS with a set of tools;
- Non-spatial part: a specially prepared Excel spreadsheet where the spatial results are processed and combined with the non-spatial calculations.

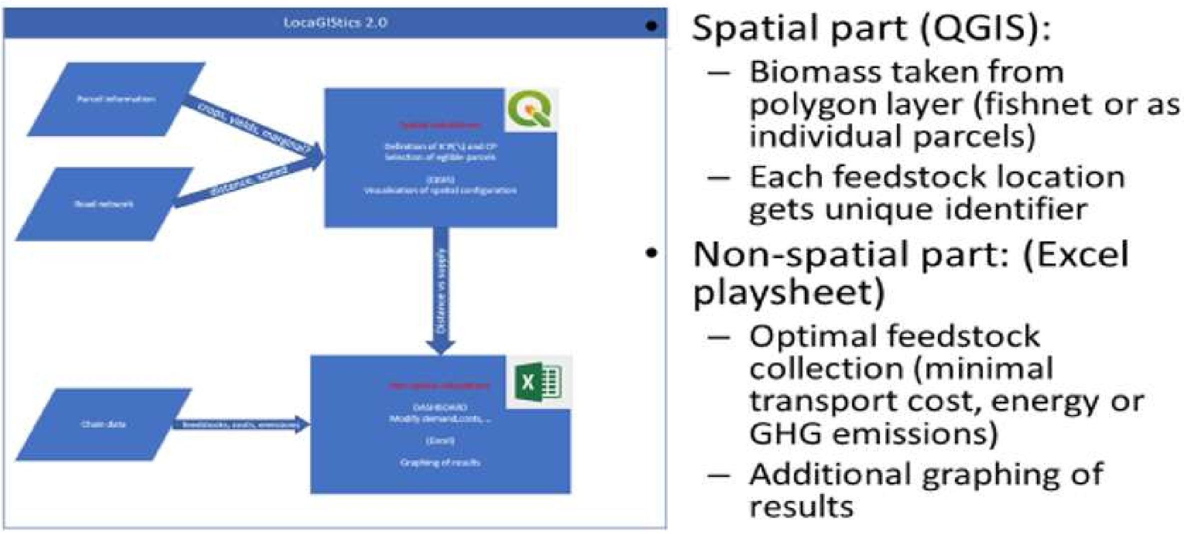

Figure 4: LocaGIStics2.0 model structure.

3.3 Spatial part of LocaGIStics2.0

LocaGIStics2.0 needs polygon layers with biomass availability for each feedstock. These polygons can be the original LPIS parcels, but in larger study areas a fishnet is created (e.g. 2.5 x 2.5 km) where in each polygon the aggregated amount of available feedstock of a certain type is added in attribute named "amount".

Next to the feedstock grids point locations should be added for intermediate collection points, and final location of the plant (Figure 5). These points are located in a place with high (combined) feedstock densities (for ICP's) and a logical location for the processing plant. Each of the point layers should have a field named "name", to identify the location.

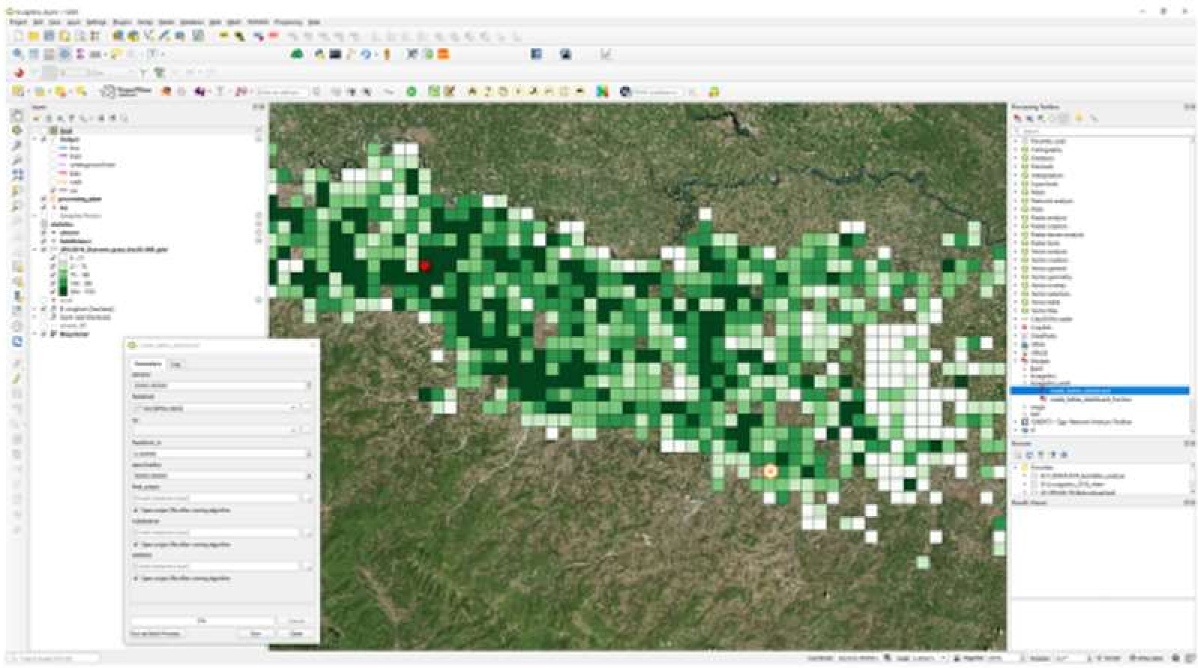

Figure 5: GIS (QGIS) part of LocaGIStics2.0 using 2.5 km "fishnet" in Emilia Romagna region.

A Python model (Figure 6) was developed, which calculated the distances from each of the feedstock polygons to the points in point layer ICP's (distances "as the crow flies"). These distances are the "short distance" transports, picked up at road side, and transported to the ICP.

The next step is to calculate the distances from the ICP's to the main plant. This is done by using a road network, roads extracted from Open Street Maps (OSM) can be used for that purposed (Figure 7). The freely available QGIS plugin QNEAT3 is used to calculate the distances along the road.

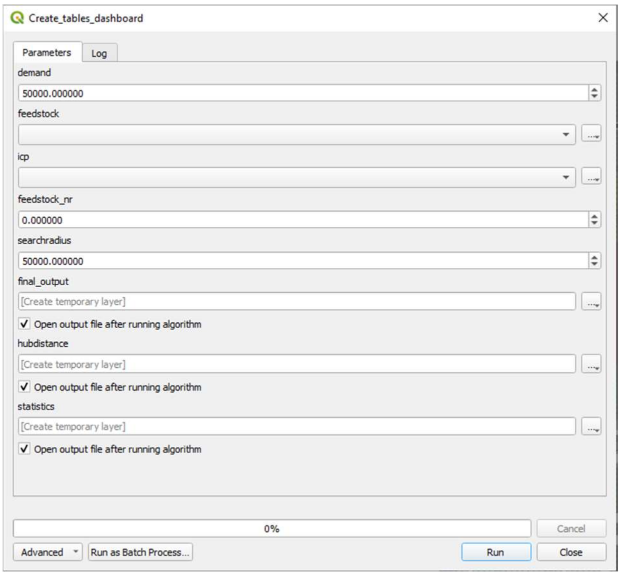

Figure 6: Python interface.

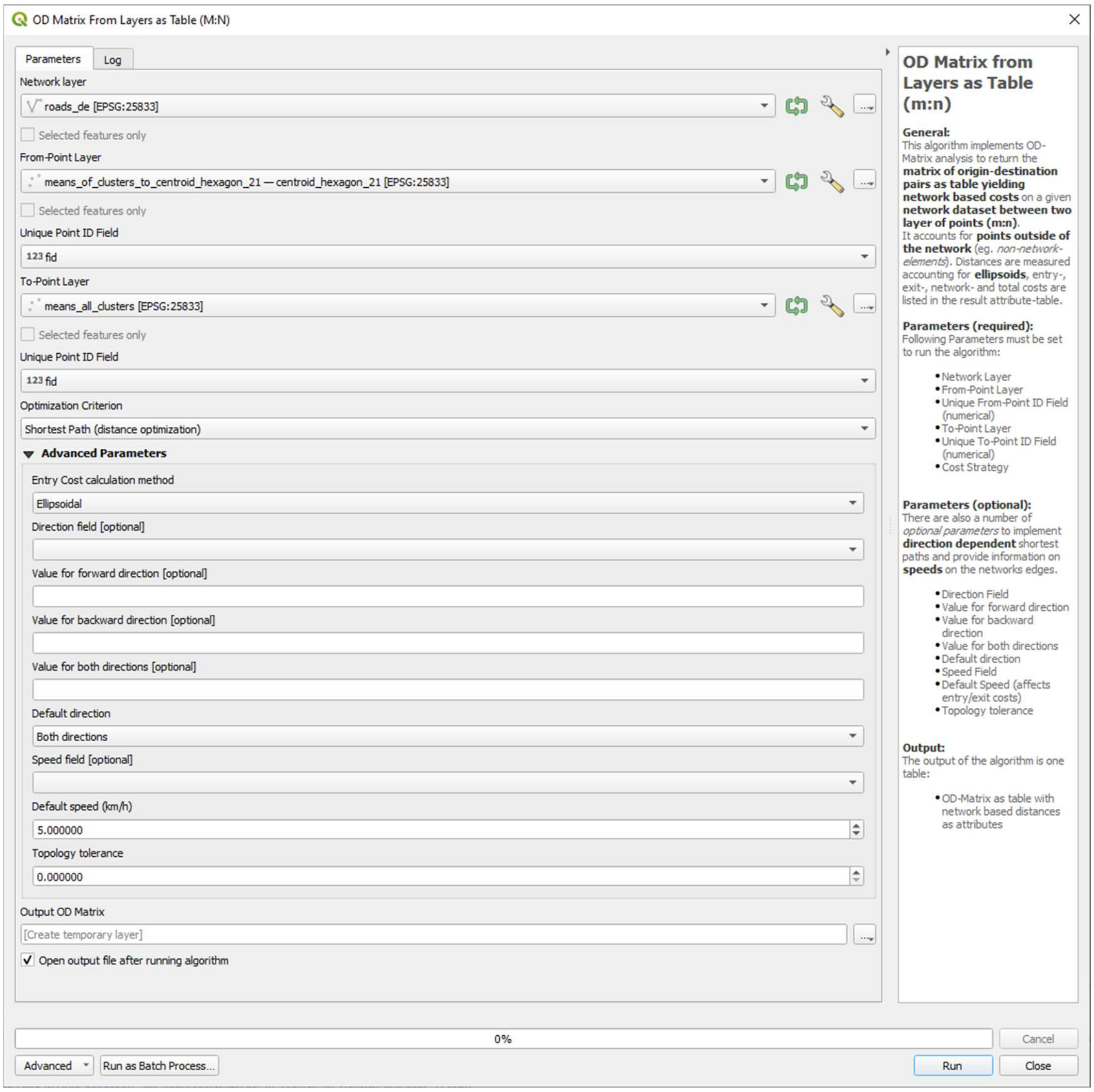

Figure 7: Interface to calculate distances.

The information produced in QGIS is exported to Excel files, and transferred to the non-spatial part of LocaGIStics2.0. In the BECOOL project we also did an analysis with clusters containing equal amounts of feedstock. The clusters were made in ArcGIS pro, using the algorithm "Build Balanced Zones" (Figure 8). An example for the German cases study is given in Figure 9.

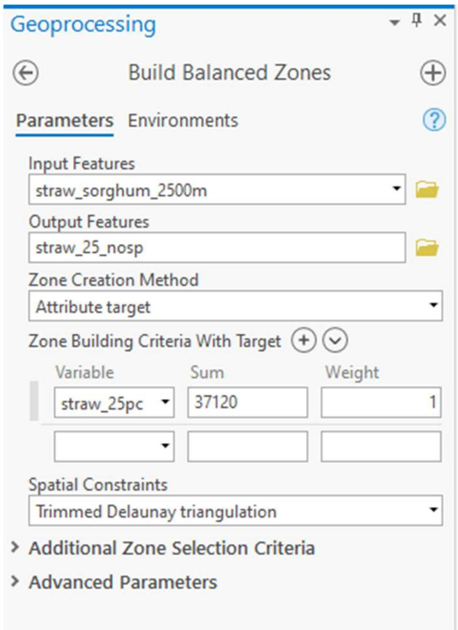

Figure 8: Interface to determine clusters (balanced zones).

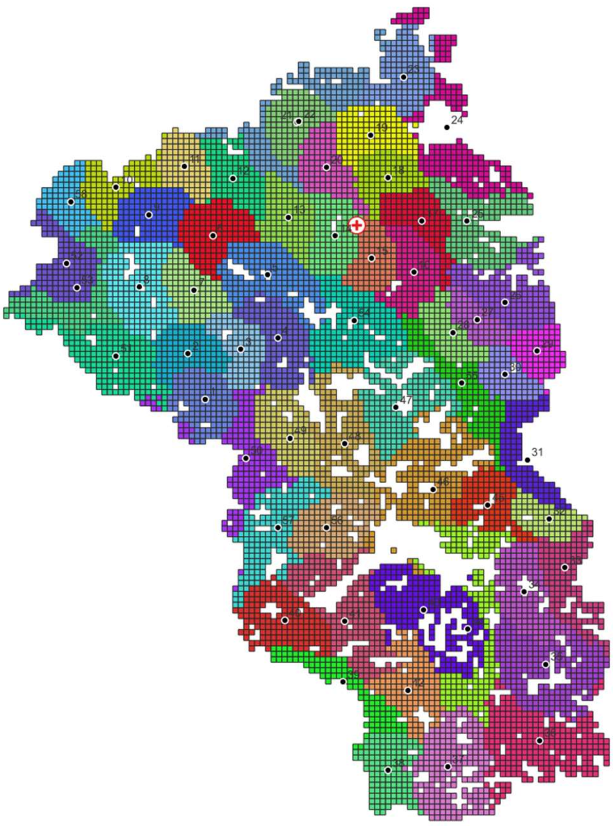

Figure 9: Clusters of equal size of feedstock for Germany case.

3.4 Non-spatial part of LocaGIStics2.0

The non-spatial part of LocaGIStics2.0 is a specially prepared spreadsheet, where the spatial information is transferred into, and the non-spatial calculations are added. This is called the “play sheet”, since you can modify the requested amount of feedstock, and the chain parameters (e.g. feedstock price, transport costs, etc.). A sort button is build into the spreadsheet, to enable the users to minimize on costs, energy or GHG emissions.

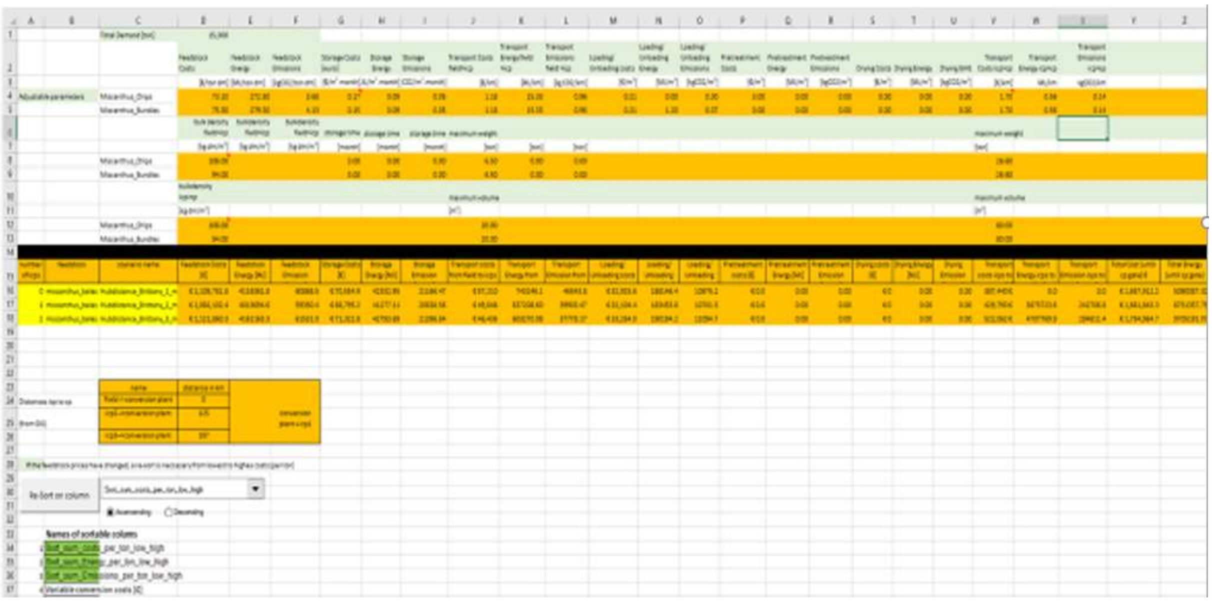

Figure 10: Dashboard for playing with pre-calculated spatial results.

3.5 Biomass (supply) considerations

The following decisions were made related to biomass type:

- two crops (Giant Reed & poplar) will be grown on marginal land;
- one crop (Biomass sorghum) is grown in a double cropping system;
- there has to be willingness from the farmers to grow the crops; this concept was implemented by assuming a 20%, 10% or 5% adoption percentage of the maximum potential;
- in case of residual biomass straw availability percentages of 25%, 50% and 75% were taken.

4. Manual of Bioloco

4.1 Introduction

The goal of using the optimisation models Bioloco is finding the optimal set-up of value chains supplying biomass from the fields to the final conversion site, including possible intermediate steps. The most likely optimization criterion will be maximizing the profit. However, also other optimization criteria could be applied, e.g. to maximize the net GHG emission reduction, or to maximize the net energy production (contained in the biofuels). In the end the trade-off between costs, energy and GHG has to be made, depending on the goal of optimization and of the decision maker.

A biomass value chain (network) in the BECOOL case studies contains the following components that are all positioned on a certain locations in a region:

- Biomass feedstocks of various types (e.g. at field side);
- Slow pyrolysis (SP) installations (1-3; the total number needs to be determined);
- Fast pyrolysis (FP) installations (7 in this case);
- Central Gasifier (CG) installation, either EFG or Milena (1 in this case).

Questions that could be answered by the Bioloco model are:

- Which biomass types are preferred for the feedstock supply (Giant reed, poplar, Biomass sorghum or straw)?
- What quantities of each biomass type can be supplied to the SPs and consequently to the FPs and the CG?
- Which biomass type should be processed by which SP location and after that in which FP location?
- What is the preferred biomass feedstock type of each of the 7 FP locations? (e.g. 3 FP locations supplied with Giant reed and 4 with Biomass sorghum, or a different ratio like 2-5 or 4-3, etc.)
- Which actual biomass sources (with depots of these biomass types) will supply to what SP/FP locations (e.g. sources at shortest distances first)?
- Which SP locations supply to which FP location?
- Which means of transport is preferred for what part of the network (e.g. tractor-farm trailer for short distances between the field and the SPs and truck trailer for longer distances between the SPs and the FP)?
- What are the optimal locations for the installations of slow pyrolysis (SP), the fast pyrolysis (FP) and the Central Gasifier (CG)? Most likely the location of the CG will be fixed, but it could also be a choice of several locations.
- Where is a drying operation performed when it this is needed (e.g. at the SP location or at the FP location)?

- What is the best size for the SP process (e.g. 3 SP installations to supply 1 FP installation, which has a fixed size or more/less SP installations per FP installation)? This question is also related to possible storage problems (heating) when the biomass cannot be dried immediately due to the limited capacity of the SP installation.

Of course not all of these questions were answered (in all case studies) due to research capacity constraints so they have been prioritized per case study (Emilia Romagna and Brandenburg).

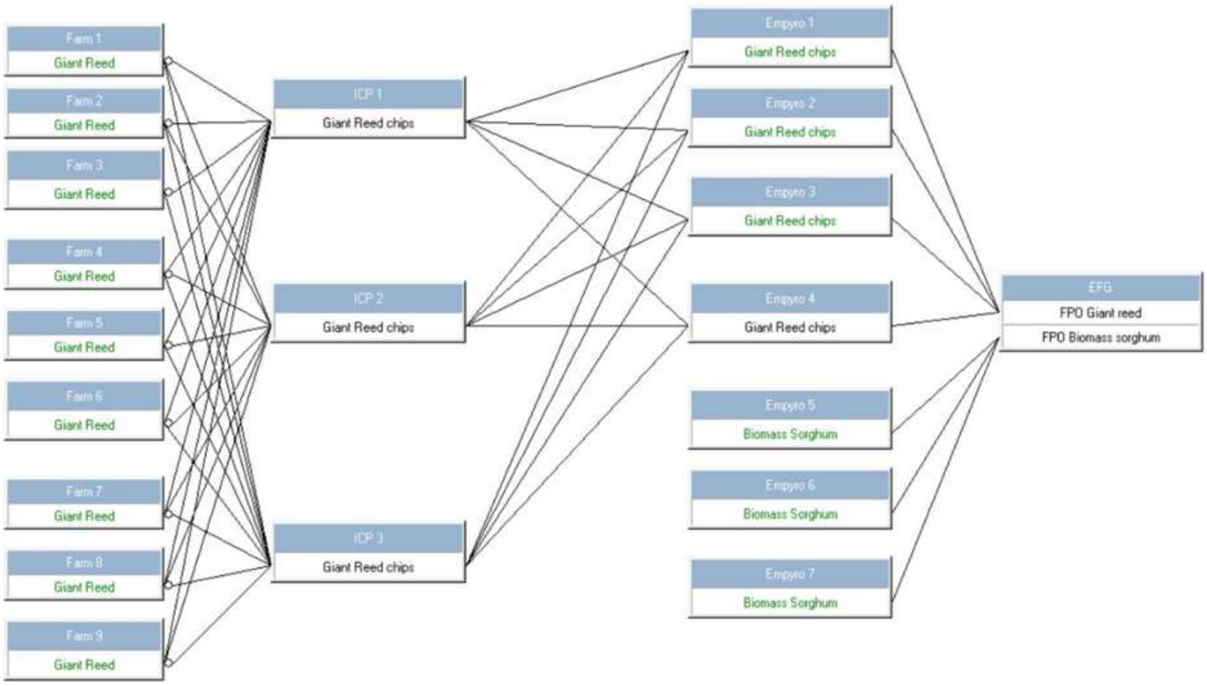

Figure 11: Example of part of the value chain towards several Fast Pyrolysis installations (nodes Empyro 1, 2, 3 and 4) that are supplying one EFG.

While designing the network structure of the regional case studies (Figure 11) the following considerations regarding the modelling approach were made regarding:

- biomass supply;
- network;
- processing;
- computation.

4.2 Biomass supply considerations

The following decisions were made related to biomass type e.g. in the Emilia Romagna case study:

- two crops (Giant Reed & poplar) will be grown on marginal land;
- one crop (Biomass sorghum) is grown in a double cropping system;
- there has to be willingness from the farmers to grow the crops; this concept was implemented by assuming a 20%, 10% or 5% adoption percentage of the maximum potential;
- in case of residual biomass straw availability percentages of 50% were taken.

4.3 Network considerations

4.3.1 Level of clustering of biomass supply

For the EFG cases study a varying number of clusters were modelled using a GIS clustering algorithm in LocaGIStics2.0, each supplying the exact amount of biomass needed by a FP installation (with or without SP installations in the biomass value chain). The amount of possible clusters depends on the available biomass (at 5%, 10% or 20% adoption rate).

For the Milena case study we model a fixed number of 53 hexagons clusters of individual biomass locations that supply (from a certain distance) to an (intermediate) collection point.

4.3.2 Transportation: direct or indirect?

If you transport straight from the field to the fast pyrolysis plant you need a drying operation at the end of the transport arc (artificial drying) when you receive the biomass. When the biomass passes through a slow pyrolysis intermediate collection point, then the drying operation will be done at that SP point (either when onloading at arc from field-SP or loading at arc from SP-FP).

4.3.3 Biomass demand at the gasifiers

Unfortunately, the current Bioloco version is aimed at producing electricity and heat, and not specifically at producing biofuels. So the supply and demand in Bioloco is driven by the energy content of the biomass. However, this energy content approach was also sufficient to optimize the biofuel network in the case studies.

4.4 Processing considerations

The following decisions were made related to pre-treatment, drying and storage:

- biomass characteristics that are relevant for the thermochemical conversion are: ash content, moisture content and particle size;
- slow pyrolysis is an optional intermediate pre-treatment to produce gas to dry the biomass and char;
- fast pyrolysis is an intermediate pre-treatment, that changes the biomass to pyrolysis oil, which is later converted by gasification and Fischer-Tropsch into a biofuel; by converting the biomass to pyrolysis oil the method of transportation becomes different (tanker wagon) and the bulk density increases per m^3.

4.4.1 Slow pyrolysis process

We needed to check how we can incorporate conversion in intermediate steps at the SP and FP nodes. How can we take into account the ‘loss of biomass’ needed for drying the biomass at SP that is transported further to the Fast Pyrolysis plant? Also how to model the degradation (heating) of the biomass that needs to wait in storage before it can be treated in the SP installation with a limited capacity (Figure 12).

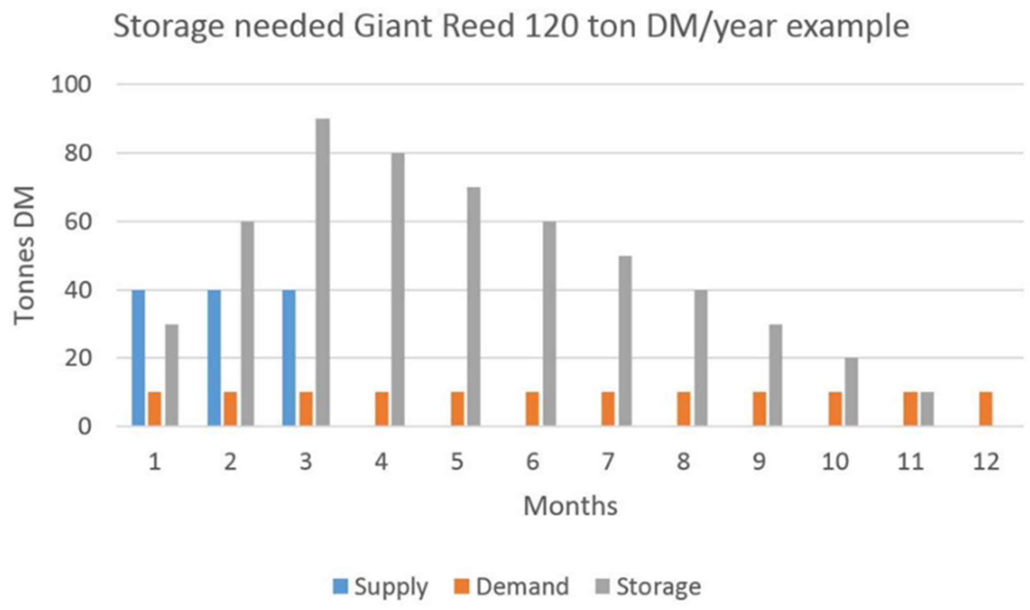

Figure 12: Storage example with 120 ton DM supply of harvested biomass in month 1-3 (blue bars) and then needs to be stored (grey bars) until it is needed to fulfil the demand (orange bars).

4.4.2 Fast Pyrolysis process

A single biomass type consumption constraint should apply to a specific FP location. So we can only assign one biomass type to supply a specific FP location in the network design. However, then we are making this choice ourselves, and it is not determined by the optimization. So it would be better if you could supply the FP location with two or more biomass types and the choice is made by the optimization. However, we have limited it to only one feedstock (e.g. the most profitable).

4.5 Computational considerations

Two step approach for the EFG chains - In the case of the EFG gasifier we worked in two steps, first from biomass to pyrolysis and then from pyrolysis (pyrolysis oil) to further conversion. We first determined the clusters of fields towards the potential Fast Pyrolysis plants with LocaGIStics2.0 (the number depends on the amount of biomass that is available under the specific adoption percentage). The second chain then uses the results for possible options of pyrolysis plants as an input of sources for the second chain which will be from the pyrolysis plant (sources) to the gasification as conversion. For this Bioloco optimized a network with seven pyrolysis plants towards the gasifier in a two-step approach. This two-step approach was a suitable method to solve this issue of two conversion processes in the value chain in Bioloco. However, some problems with this method could occur, the most prominent one indicating that the chain is only optimized in separate steps and not as a whole.

One approach for the Milena chains - We have optimized the whole network from centres of the hexagons to the Central Gasifier (Milena) as a whole using a one-step optimization approach with Bioloco.

4.6 Data requirements

The following data types are needed for Bioloco:

- Biomass type (type, costs, energy consumption & GHG emission, seasonal pattern, decay rates, ...);
- Means of transport (type, loading capacity volume-weight, costs, energy consumption & GHG emission, ...);
- Pre-treatment, drying & storage (type, costs, energy consumption & GHG emission, ...);
- Conversion techniques (type SP/FP/CG, costs, energy consumption & GHG emission, feedstock requirements (quantity and quality), technical constraints,...);
- Network specific data (geographic positions data):
    - distribution of nodes with available biomass (positions, types, quantities, ...);
    - distribution of nodes with SP, FP and CG installations (positions, types, ...);
    - allocation of transport types to specific arcs in the network (types, ...);
    - allocation of pre-treatments and drying operations to specific arcs in the network (at start or end of the arc);
    - distances between the all node locations (with different components) in the network.

These were collected from various sources:

- Data collection sheets filled by other WPs;
- Data on the generic value chains in D2.1 and D2.3-Part 1
- S2BIOM logistical components database;
- Literature.

References

Leduc, S., Lundgren, J., Franklin, O., & Dotzauer, E. (2010). Location of a biomass based methanol production plant: A dynamic problem in northern Sweden. *Applied Energy*, *87*(1), 68–75. https://doi.org/10.1016/j.apenergy.2009.02.009

Leduc, S., Schmid, E., Obersteiner, M., & Riahi, K. (2009). Methanol production by gasification using a geographically explicit model. *Biomass and Bioenergy*, *33*(5), 745–751. https://doi.org/10.1016/j.biombioe.2008.12.008

Leduc, S., Schwab, D., Dotzauer, E., Schmid, E., & Obersteiner, M. (2008). Optimal location of wood gasification plants for methanol production with heat recovery. *International Journal of Energy Research*, *32*(12). https://doi.org/10.1002/er.1446

Leduc, S., Wetterlund, E., Dotzauer, E., & Kindermann, G. (2012). CHP or biofuel production in Europe? *Energy Procedia*, *20*, 40–49. https://doi.org/10.1016/j.egypro.2012.03.006

Leduc, Sylvain. (2009). *Development of an optimization model for the location of biofuel production plants*. Luleå tekniska universitet.

OpenStreetMap. (2019). *Open Database License*. https://www.openstreetmap.org

Patrizio, P., Leduc, S., Mesfun, S., Yowargana, P., & Kraxner, F. (2017). Towards negative emissions in the US power sector: assessing the feasibility of BIOCCS for existing coal plants. *30th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2017*.

Wetterlund, E., Leduc, S., Dotzauer, E., & Kindermann, G. (2012). Optimal localisation of biofuel production on a European scale. *Energy*, *41*(1), 462–472. https://doi.org/10.1016/j.energy.2012.02.051

Wolsey, L. A. (1998). *Integer Programming (Wiley Series in Discrete Mathematics and Optimization)*. Wiley-Interscience.