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BIOPOLE: WebGIS-based Decision Support System (DSS) in bio-energy plant localization

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Abstract: energy exploitation of biomass for energy purposes, is an extremely current noteworthy theme and even more it will be so in the near future, due to the foreseen strong increase in the biomass contribution to thermal RES (Renewable Energy Sources) targets, within the framework of 2020 European Climate Action. BIOPOLE (www.bioenergis.eu – click on BIOPOLE icon) is the WebGIS based DSS (Decision Support System) developed in the *BioEnerGIS* “IEE” (Intelligent Energy for Europe) project and aimed at defining the sustainable energy exploitation of biomass resources at regional level. BIOPOLE, on the base of regional input, finds online the optimal solution in terms of power, fuel and localization of the new biomass plants feeding district heating network.

Department for Environment, Energy and Technology Grids of Lombardy Region is the coordinator of the project and one of the regional decision makers to whom BIOPOLE is targeted. The basic concept behind BIOPOLE methodology is the expectation to match, at community or district level, energy (heat) demand and biomass availability, by identifying potential bio-energy plants in terms of capacity, biofuel supply and localization. Thus, BIOPOLE, on the basis of different regional data layers, identifies opportunities for new biomass based district heating systems by assessing the optimal solutions which would minimise biomass supply transportation and maximise biomass-into-energy conversion and energy (heat) distribution to end-users. Besides, taking into account sustainability criteria, the system allows to define a not-purely-economic ranking of the identified options.

Keywords: Web-GIS based DSS; biomass; bio-energy plant.

INTRODUCTION

The European Union (EU) is bringing into play a new energy policy in order to cope with the increasing dependence on imported fossil fuels; in this wider context of sustainable development, which promotes renewable energy sources (RES), biomass could play a fundamental role. Meeting the targets of RES contribution to final energy uses for 2020, indeed, will require a broader and more intense deployment of bioenergy in all sectors.

The problem of the identification and estimation of potential biomass exploitable for energy purposes (power and thermal generation) in a sustainable manner has been tackled in the last decade with the use of GIS (Geographical Information System). The GIS is indeed a useful tool for the analysis of the spatial distribution of biomass and the optimization of bio-energy plants site selection based on spatially-defined variables (e.g. biomass resources, heat demand, transportation costs, etc.) as in Masera et al. [2006], Fiorese and Guariso [2010], Voivontas et al.

[2001] and Avella et al. [2005]. On the specific issue of bio-energy plant localization, Freppaz et al. [2004] addressed the issue in the case of Liguria, BIOSIT project [2003] in Tuscany, Panichelli and Gnansounou [2008] in the North of Spain and Viana et al. [2010] in Portugal. In this context, BIOPOLE intends to provide an online WebGIS based tool aiding decision makers to plan, with a general approach, a sustainable exploitation of biomass on a regional scale. The outcomes of BIOPOLE elaborations are the most suitable (in terms of energy, environmental and economic sustainability) sites for installing bio-energy plants dedicated to feeding district-heating networks. In this sense, the main innovation introduced by the BIOPOLE DSS, is the online simulation of the feasibility and potential localization of five different types of bio-energy plants, for each considered region. BIOPOLE users can set, on the Webapp, the specific value of various parameters (e.g. biomass categories to be included, % and type of heat demand to be satisfied, thermal-only or cogeneration plant, ...). To be "Web performing", BIOPOLE optimal location algorithms use an iterative and efficient, low-CPU-consuming method.

Four regional areas, representing as many different environmental and economic contexts, have been identified and considered as case studies to implement the system: Lombardy, Wallonia, Slovenia and North Ireland.

1. METHODOLOGY

BIOPOLE starts from the hypothesis that in each cell of 500mx500m, included in the Region under study, a bio-energy plant can be potentially placed. The methodological approach and the limit values used for BIOPOLE parameters are derived by a specific study conducted during *BioEnerGIS* project, Pointner and Waltenberger [2010], based on the statistical analysis of over 500 Austrian biomass heating networks.

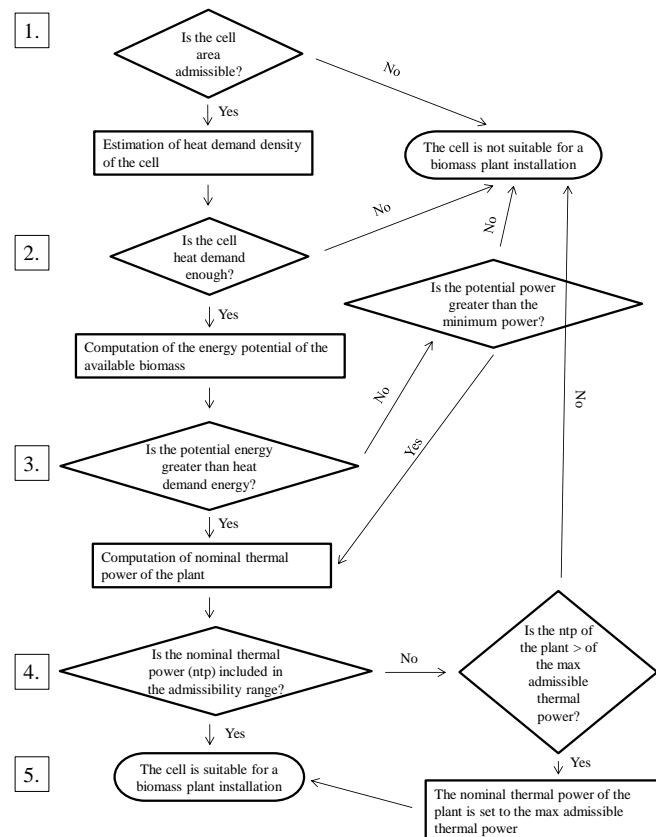


Figure 1. Logical steps to determine suitable cells to the realization of a biomass conversion facility.

The method used to determine if a cell is actually suitable for the realization of a biomass-to-energy conversion facility (to feed a district heating network), can be thought as divided into a few logical successive steps (see Figure 1):

1. Check if a cell is admissible or not for the localization of a plant.
2. Check if Heat Demand Density and Heat Capacity Density values on a cell and on the nearby cells are greater than defined thresholds.
3. Depending on the plant type, check if the Heat Demand (divided by the plant and the network efficiency) can be satisfied by the raw materials (bio-fuels) available within the considered catchment basin.
4. Check if the Required Nominal Thermal Power of the heat generation plant, in order to satisfy the heat demand on the considered cell computed on the basis of full-load equivalent operating hours, is included in a feasibility range (a size available in the market, for biomass-based heat generation systems).
5. Compute the sustainability indices of the localized plant.

1.1 Location suitability

To be considered eligible for a bio-energy plant installation in BIOPOLE, a cell must satisfy two fundamental requirements:

- The cell's "admissible area" (i.e. excluding damp areas, water bodies and areas outside the region boundaries) should cover a percentage greater than a user set value (default value is 75%).
- The maximum percentage of urbanized area of a cell should be lesser than a user set value (default is 90%).

The second condition is used to prevent localization of bio-energy plant in fully-urbanized cells where a construction site is very likely not available and the potential environmental impacts, in terms of air pollution and traffic, would be maximized.

1.2 Identify heat demand density

BIOPOLE considers separately the different types of heat demand (see Table 1), taking into account different characteristics (e.g. fluctuations in demand during the day, peaks and average demand and number of full load equivalent hours per year), when checking whether the analyzed cell has enough heat demand to be "eligible". To roughly simulate the possibility of a district-heating network, to feed a nearby urbanized area, the heat demand Q of the analyzed cell ("c" in Figure 2, i.e. where BIOPOLE is checking if the plant is feasible or not) is set equal to the maximum heat demand among the one of the cell itself and the ones in the four neighboring cells ("a, b, d, e" in Figure 2).

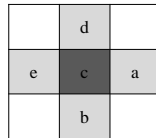


Figure 2. plant "neighboring" cells (grey) in term of heat demand (square cells of 500m x 500m)

Table 1. plant full load hours considered.

Heat demand	Full load hours
Residential	2'000
Industrial	4'000
Tertiary	2'000

Then the heat demand density in the cell c , $q^c [kWh/y \cdot m^2]$, is defined as:

$$q^c = \frac{Q^c}{A_u^c} \quad (1) \quad \text{where:}$$

$Q^c [kWh/y]$: heat demand (the maximum among the five cells in Figure 2) in the cell c .

$A_u^c [m^2]$: urbanized area in the cell c .

According to the value proposed by the specific study carried out in *BioEnerGIS* project, Pointner and Waltenberger [2010], one cell can be considered optimally suitable for a biomass DHN (district heating network) realization if:

$$q^c > 50 \left[\frac{kWh}{y \cdot m^2} \right] \quad (2)$$

An analogous check is performed by BIOPOLE on the cell's heat capacity density (i.e. the heat demand density divided by the full-load equivalent operating hours).

1.3 Identify biomass supply

BIOPOLE includes five different types of bio-energy plants, three based on combustion technology and two on anaerobic digestion (see Table 2).

Table 2. Association between Plant type and Biomass type considered in BIOPOLE.

Plant type	Biomass category	Number of sub-category
(1) Combustion	Untreated wood	15
(2) Combustion	Herbaceous	10
(3) Combustion	Treated wood	3
	Organic waste	3
(4) Anaerobic digestion	Agricultural Slurry / Manure	7
(5) Anaerobic digestion	Industrial organic waste	16
	Industrial organic by products	7

Available biomass per category is multiplied by the respective low calorific value (LCV_b) to calculate available energy and considering that each plant type can use different biomass types of the 61 considered in BIOPOLE; the following formula must be fulfilled in order to ensure that available primary energy from biomass may satisfy heat demand Q , considering also network and boiler efficiencies:

$$\sum_{b \in B(k)} (m_b \cdot LCV_b) \geq \frac{10 \cdot Q^c}{\eta_d \cdot \eta_{th,k}} \quad (3) \quad \text{where:}$$

- $b \in B(k)$: biomass types that can be used in the plant type k
- $m_b [t/y]$: annual availability of biomass b as explained below
- $LCV_b [MWh/t]$: net calorific value of the dry fuel b
- $\eta_{th,k} [\%]$: thermal efficiency of the k type of the plant
- $\eta_d [\%]$: efficiency of the distribution network

Biomass LCV refers to dry base, than BIOPOLE uses a correction method to change LCV dry base into LCV wet base, on the base of biomass water content. The annual availability of biomass m_b in each cell is computed considering that the biomass can be collected from the neighboring cells, if the distance between them is not greater than a fixed value (a radius defined by BIOPOLE user), which depends on the type of the considered biomass (see Table 3 for default values).

Table 3. Biomass collection radius for each biomass type.

Biomass type	Radius (km)
Woody biomass	30
Herbaceous	15
Agricultural slurry or manure	10
Organic waste / treated material	15

As regards biomass facility, the choice of the most suitable conversion process depends on biomass characteristics, such as moisture content, bulk density, etc., and the nature of the process may vary significantly. The same technologies utilized for non-renewable fuels may be applied to biomass-to-energy systems, including cogeneration technologies: alternated endothermic engines, external

combustion Stirling engines, gas micro-turbines and ORC (Organic Rankine Cycle). In Table 4 the different plant efficiency used in equation (3) are reported for the five plant types, differentiating if electric energy is produced in cogeneration or only thermal production is provided.

Table 4. Conversion efficiencies for different biomass types.

Type of conversion facility	Efficiency - only	Efficiency - CHP	Process
(1) Woody Biomass	0.8	0.7	Combustion
(2) Herbaceous Biomass	0.8	0.7	Combustion
(3) Woody waste	0.8	0.7	Combustion
(4) CHP Crop Biogas	0.425	0.425	Anaerobic digestion
(5) CHP Organic waste	0.425	0.425	Anaerobic digestion

BIOPOLE admissible thermal power range is 250 kW - 10 MW. It is assumed that bio-energy plants can operate both in only thermal and in cogeneration (CHP) mode, while anaerobic digestion plants can only operate in cogeneration mode. Thus, BIOPOLE considers 8 types of bio-energy plant (6 for combustion and 2 for anaerobic digestion).

1.4 Output analysis

Once BIOPOLE has reached the end of the process described in Figure 1, it is possible to identify two different kinds of cells:

- *not suitable cells*, in which the various constraints on land use, on heat demand, on biomass supply or on thermal power of the bio-energy plant are not all satisfied (it should be noted that the last two constraints depend on plant type).
- *suitable cells*, in which all the constraints are satisfied.

For each suitable cell, BIOPOLE computes:

- Type/s of biomass-to-energy conversion facility feasible in the cell; indeed, not all plant types could be feasible since different types of biomass could be available nearby.
- Thermal nominal capacity to be installed (for each feasible plant type).
- Sustainability indexes.

1.5 Sustainability criteria and output ranking

At this point, BIOPOLE could have located a few feasible plants in a single cell and many in the whole domain. The next step consists in sustainability ranking for all the feasible bio-energy plants identified, in order to point out the best realization constrained to certain criteria directly (or indirectly) expressed by the decision maker.

BIOPOLE presently implemented approach, considers the realization of each cell plant as independent with respect to all the other possible realizations in the domain, i.e. the heat demand could be satisfied by each plant and the biomass could be used in any plant. This approach is useful for the choice of the best localization of a plant at local level but not to sum up all the plants in a regional planning approach, since not all the feasible bio-energy plants could be built at the same time.

According to several interests that different stakeholders have expressed during *BioEnerGIS* consultations, three main criteria of choice have been identified and transformed into indexes (i.e. normalized between 0 and 1, representing respectively the worst and the best situations), thanks to utility functions:

- Ratio between supply and demand.
- Mean distance of the biomass from the plant.
- Involved population as a ratio of people potentially affected by environmental impact respect to people that potentially benefit of DHN.

The values assumed by these indexes are then combined in a single global index, by means of weights defined by BIOPOLE user (meeting stakeholder “focus” on the problem), in order to set up a ranking of the different plants.

1.5.1 Ratio between supply and demand index

The availability of the proper quantity of suitable raw material (biomass) is a prerequisite for the realization of a specific type of bio-energy plant. A surplus in the available biomass, with respect to the needed amount, reduces the excessive dependence of supply on single biomass sources/markets and on production variations. So, this index assesses the availability of biomass with respect to primary energy needed to satisfy heat demand:

$$i_1^c = \frac{O^c}{Q^c/\eta_a \cdot \eta_{th,k}} \quad (4) \quad \text{where:}$$

c : identifies a suitable cell to DHN installation.

O^c : biomass offer of the cell c [MWh/y] as computed in equation (3)

$Q^c/\eta_a \cdot \eta_{th,k}$: heat demand of the cell c [MWh/y] divided by the plant k and the network efficiency

1.5.2 Mean distance of the biomass index

A specific impact of a bio-energy plant is brought about by trucks transporting biomass from the harvest areas to the bio-energy plant itself. This impact clearly depends on the distance that biomass travels from where it is collected to where it is converted into energy. BIOPOLE indicator is calculated as follows:

$$i_2^c(b) = \frac{\sum_{b \in B(E_b \cdot d)} [km]}{\sum_{b \in B(E_b)} [km]} \quad (5) \quad \text{where:}$$

E_b : biomass (MWh/year) associated to plant type k .

d : distance (km) at which the biomass b is located.

1.5.3 Involved population index

A bio-energy plant is a potential source of air pollution in its surrounding territory; conversely it represents a benefit for people/households connecting to the DHN. As a first rough indicator of this “conflict” of positive and negative involvement of population, BIOPOLE considers as indicator of population the residential heat demand. Moreover BIOPOLE considers that bio-energy plant potentially pollutes the cells within a circular area of user defined radius around the bio-energy plant (default value of 2.5 km). So, the indicator could be formalized as follows:

$$i_3^j(x, b) = \frac{Q_{residential}^c(R)}{Q^c(k)} \quad (6) \quad \text{where:}$$

$Q_{residential}^c(R)$: is the residential heat demand present in a circle of user defined radius centered in the barycenter of the suitable cell c .

$Q^c(k)$: is the total demand satisfied by the plant k located in the suitable cell c .

1.5.4 Aggregation

Once the values of the three indicators are calculated for each suitable cell, they should be “normalized” before being summed up together, since they have different units of measurement and different scale. Normalization is performed by transforming the indicators (i_1, i_2, i_3) into indexes (I_1, I_2, I_3) on the same scale, between 0 and 1, through utility functions. A utility function is a specific function that reflects the satisfaction (maximum 1 and minimum 0) regarding the value of

the indicator considered. The user should then assign a weight (w_i) to each index, used in equation (7) to obtain the total sustainability index I . Through this global sustainability index BIOPOLE delivers a ranking of the different possible cell/plant localization options. Global sustainability index I varies between 0 (worst plant localization) and 1 (best plant localization):

$$I = I_1w_1 + I_2w_2 + I_3w_3 \quad (7)$$

By varying the weights assigned to each index, BIOPOLE user can change the ranking of the plants localizations.

2. THE WEB-GIS DECISION SUPPORTING SYSTEM (DSS): BIOPOLE

The methodology described in the previous chapter has been implemented in the WebGIS application called BIOPOLE, which was one of the main deliverable of *BioEnerGIS* project. The requirements set by the project have induced some methodological choices in order to reduce computation time for a Web use. BIOPOLE meets two main requirements:

- Access to primary information (biomass availability, heat demand, plant feasibility) in a consistent, structured (and comparable in the four European regions) geo-database through a simple WebGIS interface.
- User-defined scenarios for plant siting with specific requirements on biomass, heat demand and plant type to be considered.

In more detail, in BIOPOLE, a registered user (BIOPOLE registration is open to everyone) through the WebGIS interface can examine the heat demand or the biomass availability of the region considered (Figure 3). For instance the user can query the biomass availability in each cell both in terms of mass (tons) and in terms of potential energy (MWh) detailed for each biomass type. Maps could be produced for single biomass type availability and for a single sector of heat demand or for aggregated (sum) categories.

BIOPOLE user can also run a simulation of plant location (Figure 3), changing some parameters; in particular the plant type, type and percentage of biomass to be used, type and rate of heat demand to be satisfied, maximum percentage of urbanized area for a cell to be considered eligible, the weights to be assigned to each specific sustainability index. The result of the user run is made available on BIOPOLE after a period variable from some tens of seconds to a few minutes (depending on biomass and heat demand involved). This scenario contains the localizations (feasible cells) for each plant type where the user can visualize the calculated thermal power for the specific type of plant, the value of each sustainability indexes (single and global values) and the plant ranking (Figure 3). Clicking on a cell in which it is possible to build a plant, the user can view the dashboard of sustainability and a fact sheet on a *best practice* existing plant with similar characteristics (Figure 3).

CONCLUSIONS

This work presents the Web-GIS based DSS BIOPOLE for the optimal location of bio-energy plant feeding district heating systems according to biomass availability, heat demand and other parameters chosen by the user. BIOPOLE is an online tool to find the optimal solution to the problem of feasibility and macroscale-localization of bio-energy plant. So BIOPOLE is not a tool for microscale-localization and plant engineering, but aids the regional planner to individuate the most suitable territories for the realization of specific bio-energy plant and the local planner to find the most suitable localization, size and bio-energy plant type among different options. A new version is currently under development to compute the total biomass energy production iteratively by locating the best ranking plant, and then eliminating, at each step, biomass used and heat demand satisfied.

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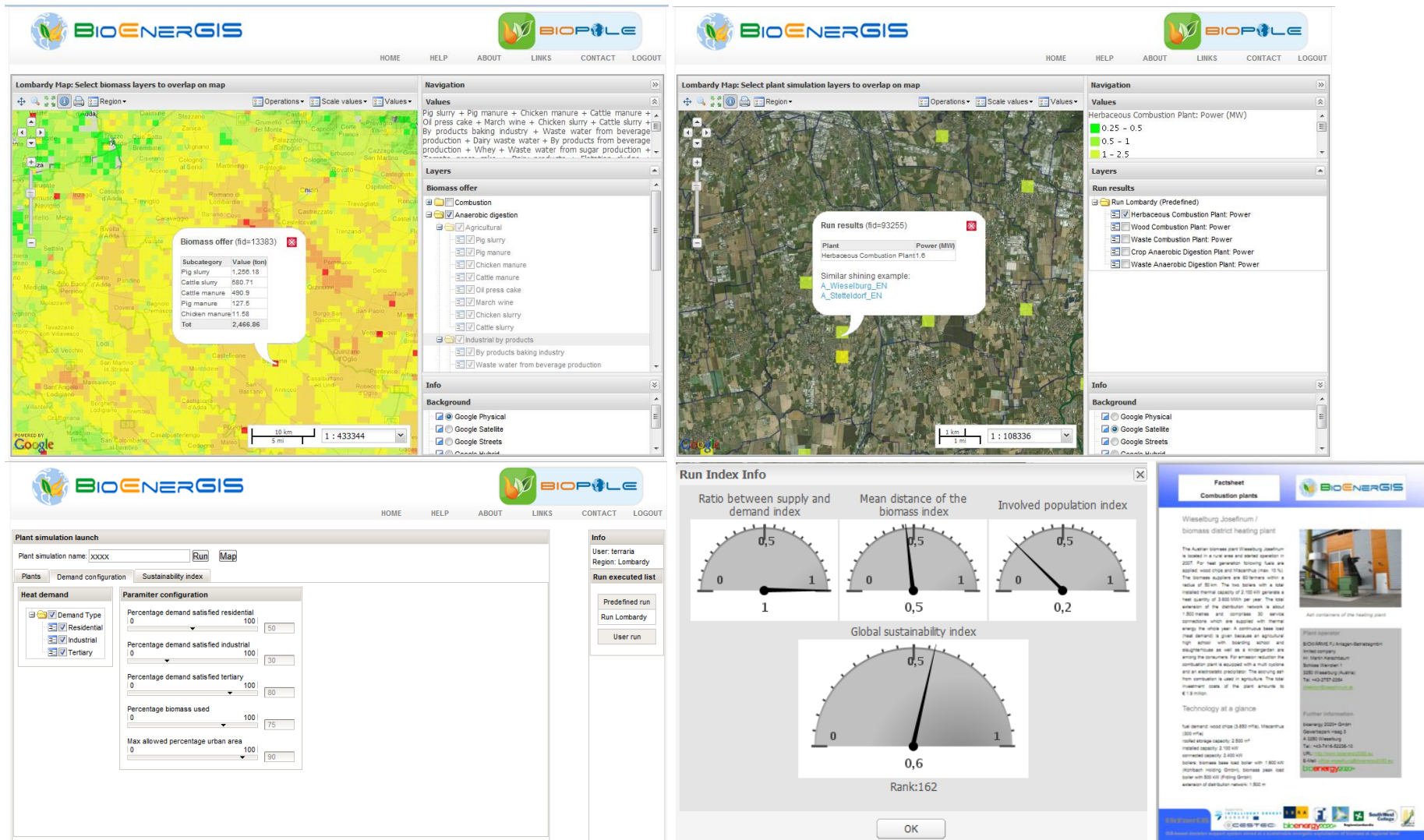


Figure 3. BIOPOLE screenshots examples: offer (biomass availability) analysis (top left), simulation plant results (top right), simulation parameters (bottom left), sustainability dashboard (bottom middle) and plant factsheet (bottom right).