Project co-financed by the European Regional Development Fund

Forest Bioenergy in the Protected Mediterranean Areas

Planning biomass based energy production at regional and sub-regional level in protected areas

D3.4.2 DSS for planning biomass-based energy production in the protected areas.

Workpackage 3 - Testing

Activity A.3.4 - Planning biomass based energy production at regional and sub-regional level in protected areas.

Partner in charge: LP – Sicily Region, Regional Department for the Rural and Territorial Development

June 2019

Deliverable 3.4.2

DSS for planning biomass-based energy production in the protected areas

Responsible Partner:

LP: Sicily Region - Regional Department for the Rural and Territorial Development

Contributing Partners:

PP1 - Municipality of Petralia Sottana

PP2 - Enviland Ltd

PP3 - Slovenian Forestry Institute

PP4 - Regional Development Agency Green Karst Ltd

PP7 - Zadar County

PP8 - Public institution Nature Park Velebit

July 2019

Project Acronym:	ForBioEnergy
Project full title:	Forest Bioenergy in the Protected Mediterranean Areas
Grant agreement number	1MED15_2.2_M2_182
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Lead Partner:	Sicily Region - Regional Department for the Rural and Territorial Development
Deliverable:	D3.4.2 DSS for planning biomass-based energy production in the protected areas.
Summary:	ForBioEnergy project developed a Decision Support System (DSS) for planning biomass-based energy production in the protected areas. The Base and Advanced Models have been developed and implemented on a GIS platform, both ArcGIS and open-source QGIS software were used. Main goals of DSS were: i) to support the Authorities responsible for simplifying, speeding up and standardizing land monitoring and strategic planning procedures; ii) the DSS will be used by the decision-making bodies to assess the impacts of various scenarios, as well as the costs and benefits about the production of energy from residual agroforestry biomass in the public administrations; iii) the DSS will also be used, within the pilot Biomass District, as a support for determining the optimum plant size (and power) for energy and heat production and the relative biomass supply area.
Authors methodology and test in the Italian study area (LP, PP1 and PP2)	Laura Cobello (PP2), Paolo Contrino (LP), Despoina Karniadaki (PP2), Donato S. La Mela Veca (LP), Gaetano La Placa (PP1), Claudia Rubino (PP2), Carlo Simonetti (PP2), Massimo Pizzuto Antinoro (LP), Sebastiano Sferlazza.
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1. OBJECTIVES OF THE ACTIVITY AND PARTNERS INVOLVED

Within the pilot protected area, through GIS (Geographic Information System) applications, a DSS (Decision Support System) will be elaborated for Public Authorities, aimed at supporting the planning for bioenergy production.

Moreover, in the pilot area, specific Administrative Units (named as "Biomass Districts" – hereafter BDs) will be identified and described, with the aim to plan biomass supply chains for energy use, in line with the principles of environmental protection, as well as promoting the territorial socio-economic development (ensuring ecological and socio-economic sustainability). Within each District, the private companies in the biomass sector will have to be identified and surveyed, in order to promote mixed management systems (public and private) with the aim of increasing employment opportunities.

The results about identification and description of the Biomass Districts have been illustrate in the Deliverable D.3.4.1 "Geographical identification and description of biomass districts in the protected areas". In this deliverable are illustrated the methodology, the structure and the testing results of the ForBioEnergy DSS (Decision Support System).

Involved partners:

Country	Pilot area	Participating partners per pilot area	
Italy	Regional Natural Park of Madonie	LP	Sicily Region
		PP1	Municipality of Petralia Sottana
		PP2	EnviLand Ltd
Slovenia	Notranjski krajinski park	PP3	Slovenian Forestry Institute
	Primorsko-notranjska region	PP4	Regional Development Agency Green Karst Ltd.
Croatia	Zadar	PP7	Zadar County
	Zadar Ličko-Senjska županija	PP8	Public institution Nature Park Velebit

Deliverable:

Title of the deliverable	Target value	Type of deliverable	Description
D3.4.2 DSS for planning biomass-based energy production in the protected areas.	1 Unit produced	Tool	Design of open source DSS for assessment of biomass energy potential. This tool can be used by decision--making bodies to assess the impacts of various scenarios and to review cost and benefits of decisions to be made.

2. DECISION SUPPORT SYSTEM (DSS) FOR THE PLANNING OF WOODY BIOMASS-BASED ENERGY PRODUCTION IN PROTECTED AREAS

2.1 Premise

Hereafter are provided the design features to set up an "open source" Decision Support System (DSS) that could be used by the decision-making bodies to assess the impacts of various scenarios, as well as the costs and benefits of the decisions to be taken about the production of energy from residual agroforest biomasses in the protected areas.

The DSS may represent an added value, useful for simplifying, speeding up and standardizing land monitoring and strategic planning procedures. The main goal is to have a decision-making framework with indicators with territorial value, which allow a synthetic vision of the main parameters characterizing the territory, which may serve for land strategic planning.

More in detail, in this activity the DSS will aim at supporting the Authorities responsible for territorial planning in the identification and description of the BDs (Basic version of DSS) within the pilot protected area. In addition, such DSS, implemented with other layers including more detailed information, which will be elaborated in the pilot BD for the preparation of the forest management plan (A.3.7) (level of accessibility of the forest areas, biomass obtainable from sustainable forest management), it can be used in the continuation of the project as support for the design of the bioenergy supply chain (A.3.8) (Advanced version of DSS).

2.2 Use of DSS in the territorial and forest planning

In the early seventies of the last century a DSS was defined as an "*information system supporting the decision-making process*". The precise knowledge of the status of available resources is a prerequisite for their effective management. It is necessary to have updated georeferenced databases and tools to make this information available, accessible and questionable. For that purpose, the GIS (Geographic Information System) tools are well suitable for the management of spatial information, for the possibility that they offer to organize and continuously update the databases, for the effectiveness of the analysis tools, for the ample possibilities of data processing as well as the multiple functionalities of representation, visualization and dissemination of results. In this perspective, in many disciplines, including forest planning and management, the DSS have been regarded as effective forecasting modeling tools to support management and planning activities (Puletti et al., 2017).

The integration of the GIS with DSS tools, that is with modules for the management of decision-making processes, and with mobile technology devices, can be considered as an efficient support capable of realizing in real time the management and monitoring of activities, as well as communication and information sharing.

The Biomasfor project, developed in the province of Trento, is an example of DSS developed in Italy for the forest sector, specifically aimed at assessing woody resources and their potential production in terms of wood for building and biomass for energy production. The model developed in the project provides a DSS dedicated to quantifying the availability of forest bioenergy, in consideration of ecological, technical, economic and social constraints. The georeferenced outputs data have allowed aggregating the values of the investigated areas at a given administrative unite (Sacchelli et al., 2013).

BIOPOLE, instead, is a DSS based on a Web-GIS technology, developed within the European project BioEnerGIS ("IEE" - Intelligent Energy for Europe) aimed at defining the sustainable use of biomass for energy use at the regional level. Based on regional inputs data and thanks to an online modeling simulation, the BIOPOLE has obtained the best solution in terms of power, type and location of biomass facilities that could supply a small local district heating network. The Lombardy Region has coordinated the BioEnerGIS project and is one of the regional decision-makers to whom the system has been addressed.

The main concept underlying the BIOPOLE methodology is the constant research, both at local and regional level, of the correspondence between the heat demand of the territory and the available thermal energy, in terms of biomass potentially usable in a sustainable way. BIOPOLE, on the basis of different regional data layers, has identified the optimal location of new biomass facilities, minimizing the distance traveled for biomass transport and maximizing the efficiency of the district heating network (Maffeis et al., 2012).

The University of Bari, PROGESA Department - Design and Management of Agro-zootechnical and Forestry Systems, has published a research about the energetic valorization of agroforestry biomasses in the Apulia region (Pellerano et al., 2007), with the general objective of verifying the feasibility of supply chains based on the energy valorisation of agroforestry biomasses and dedicated crops in the Region. With this in mind, geographic information systems represent the best tool available for the management and spatial analysis of territorial resources and for the creation of DSS.

Several other examples of DSS have already been tested about energy-territorial planning. Noon and Daly (1996) have built the “Biomass Resources Assessment Version One” (BRAVO) to guide the choice of the type of wood fuel to be used according to the cost of supply. Voivontas et al. (2001), have developed a DSS that allows to estimate the potential electricity production from agricultural residues and to choose the type and the optimal position of the biomass facilities from the economic point of view; the BIOSIT project of the Tuscany Region, aimed at assessing the potential of biomass production and costs of supply, has used GIS tools to create algorithms to optimize logistics solutions (Martelli et al., 2002).

In the study carried out by the University of Bari (2007), a GIS tool was created with the help of the ArcGIS® software. In that project, the following georeferenced information (data source) has been used to apply the proposed methodology:

- land use; in order to identify the existing agroforestry biomasses and suitable areas for the conversion to energy crops;
- administrative limits; to allow the identification of the investigated areas and the assessment of the specific potentials in a given area;
- digital terrain model (DEM); for the identification of mean altitude, slope, bioclimatic zones and accessible areas for the collection of woody biomass;
- pedological map; in order to obtain useful information for the estimation of the adaptability of energy woody crops;
- map of climatic types; to provide information on precipitation and temperatures, useful for estimating the adaptability of energy woody crops.

The proposed GIS methodology made it possible to analyze the potential and the spatial distribution of energy from agroforestry residues and energy crops in the Apulia region. In particular, the potential of agricultural residues (woody and herbaceous) has been estimated from the quantity of the main product, using appropriate residual production coefficients, obtained from literature data or from experimental evidence, and taking into account the current availability of plant residues, net of current alternative uses. The potential of forest residues, due to the lack of data about the most common forest types present in the Region, has been evaluated only through preliminary hypotheses of mean woody growth.

2.3 Objectives of the DSS

The DSS will be used as a support to identify and describe the BDs in a GIS environment (Basic version).

In the continuation of the project (A.3.7 and A.3.8), moreover, the DSS will also be used, within each Biomass District, as a support for determining the optimum plant size (and power) for the production of energy and heat and the relative biomass catchment area (Advanced version).

2.4 Architecture and functionality of DSS (hardware and software requirements)

The development process of the DSS will be characterized by four main steps:

- data acquisition and evaluation (INPUT): to be carried out with the use of advanced image visualization techniques to acquire current and detailed data;
- design and setting up of a database: structures of relational data will be developed to make clear the subject of decisions to the user. The database will have an interface that will facilitate data presentation and will be able to adequately answer to any queries that the user will want to formulate, thus allowing a continuous re-use and exchange of information;
- modeling for spatial-temporal forecasting: this is the strength of the DSS. The system will be provided with spatial-temporal analysis tools applicable to the available data and, through forecasting models, it will make it possible the analysis on “possible” scenarios as hypothesized and introduced by the user;
- visualization of the results (OUTPUT): through graphical support and three-dimensional dynamic techniques you can access a variety of maps and tables that are easy to understand and interpret.

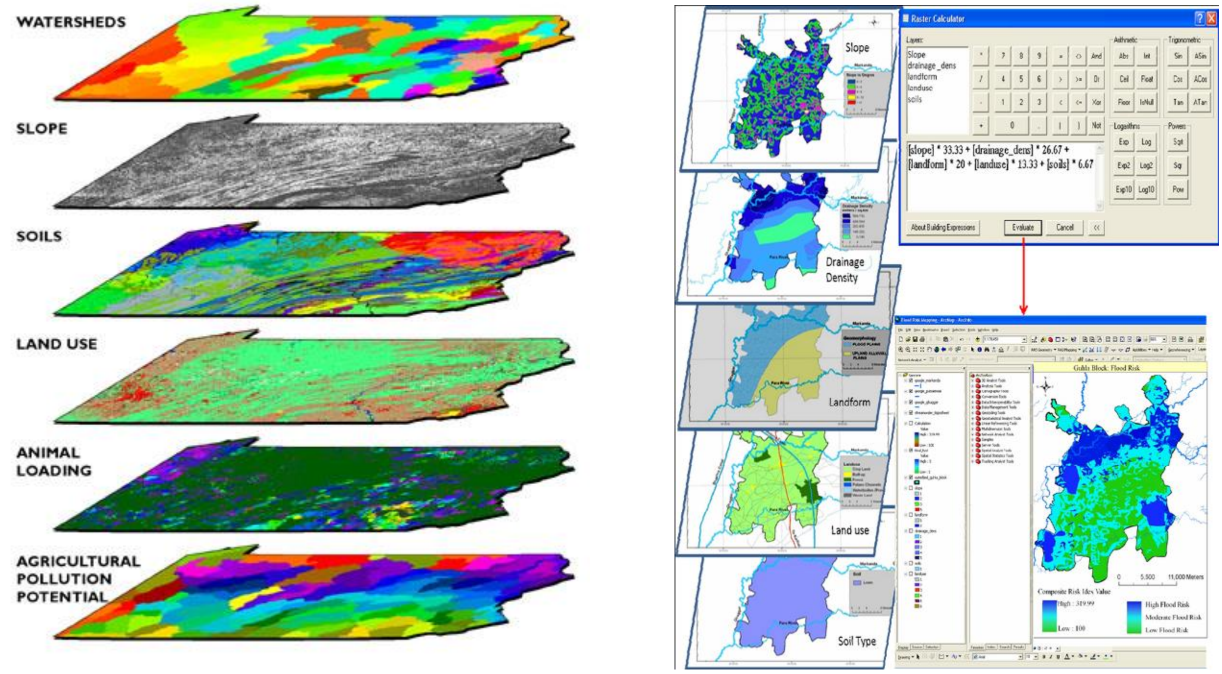


Figure 1. *Example of overlay raster.*

2.5 **ForBioEnergy DSS structure**

2.5.1 DSS basic version (A.3.4)

The basic version of DSS will be used to identify the BDs within the pilot protected area.

<u>Input data</u>

The input data to be included in the DSS are vector cartography (in shapefile format and in WGS 1984 coordinate system) of the following themes:

- delimitation of protected area, biomass districts and Municipalities also partially falling within the protected area;
- forest areas within the protected area, codified according to the Forest Type classification (CLC classification level IV if the Forest Type is not available);
- map of slope;
- road network with relative classification.

<u>Output data provided by DSS</u>

Based on the input data, the DSS will return Map of forest accessibility within the protected area, biomass districts, Municipalities.

2.5.2 DSS advanced version (A.3.7; A.3.8)

By integrating the DSS with the following input data, which will be available after the drafting of the forest management plan (Activity A.3.7), within the identified pilot BD, it will be possible to obtain the following additional output data which can be used for the design of the bioenergy supply chain (A.3.8) within the pilot BD.

Input data

Input data entered in the system:

- vector cartography (in shapefile format in WGS84 coordinate system) of the following themes:
    - forest areas intended for active management according to site accessibility (slope and availability of forest roads), and available for the removal of residual biomass within the district, codified according to the classification system in forest types (Level of forest category);
    - areas with environmental and/or legislative constraints that may specifically prevent/limit the construction of a biomass plant and/or the biomass collection;detailed classification of the forest road network necessary to biomass extraction and of the main road system for biomass transport;
    - slope map;
    - areas for biomass storage.
- estimate of the average cost per km and per ton of transported biomass (from bibliographic source);
- biomass availability for the production of heat and energy.

Output data provided by DSS

Based on the input data, the system will allow identifying:

- the most suitable areas to design and establish biomass utilization plants, for their proximity to well served urban centers, the presence of an adequate road system, and the absence of environmental and/or legislative constraints in force;

- the supply area of each biomass plant according to the energy needs of the municipalities served, of the available woody biomass and the cost/benefit ratio between the biomass supply and the energy produced.

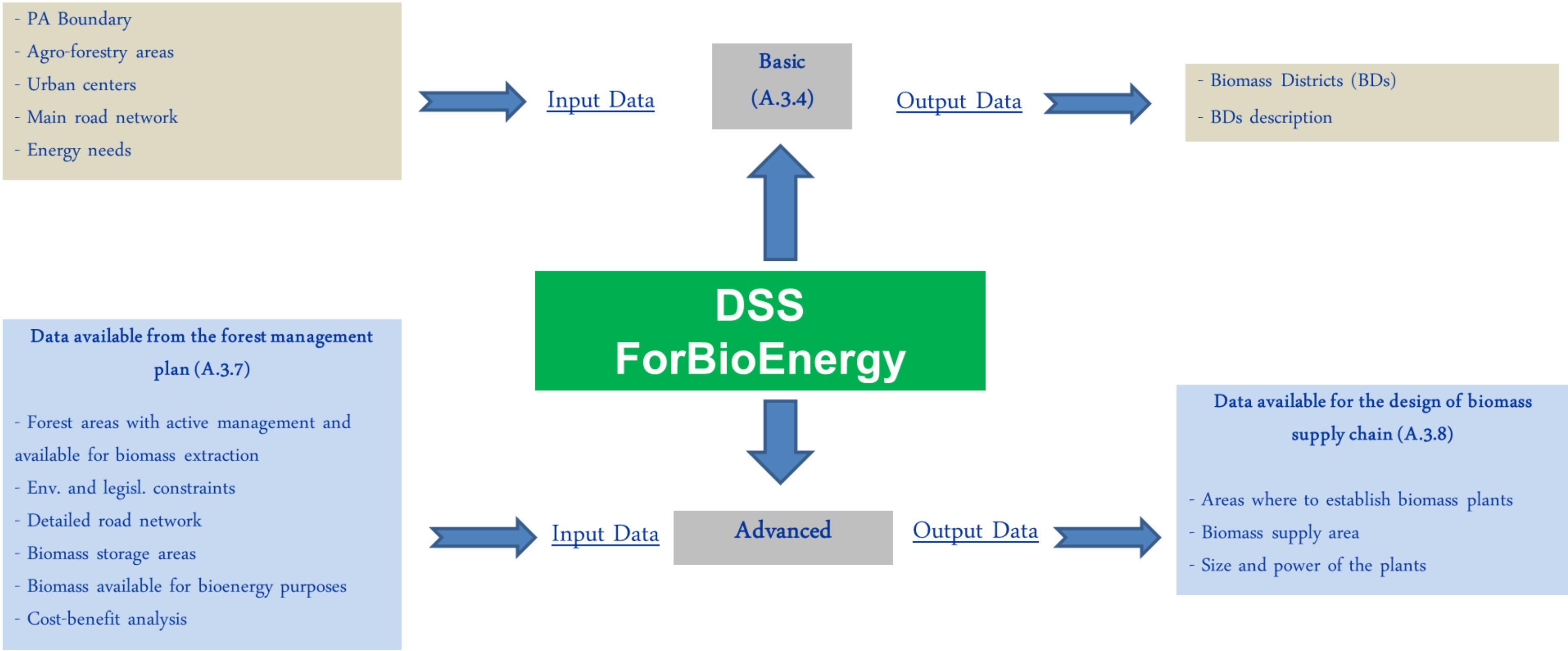


Figure 2. Structure of both DSS used in the project (Basic and Advanced).

3. METHODOLOGY

3.1 Basic DSS

3.1.1 Premise

The objective of the basic DSS, called "Forest access", is the identification of the accessible forest areas, according to slope and road conditions. Accessibility is to be understood in terms of the possibility of reaching a given portion of forest in a set period of time and it should be measured according to the time it takes an operator to reach it by foot, starting from the last available driveway stretch. The maximum time beyond which an area is considered inaccessible is equal to 1 hour in one way (Chirici et al., 2004).

To evaluate the possibility of connecting two or more points within a given Biomass District, it is necessary to carry out processing on an area larger than that of the Biomass District itself. More in detail, it is possible that it is necessary to cross territories outside the Districts to connect two points within them. Therefore, it is better that the road network used for subsequent processing includes a vast area, much wider than the area under investigation.

The necessary input data for basic DSS are:

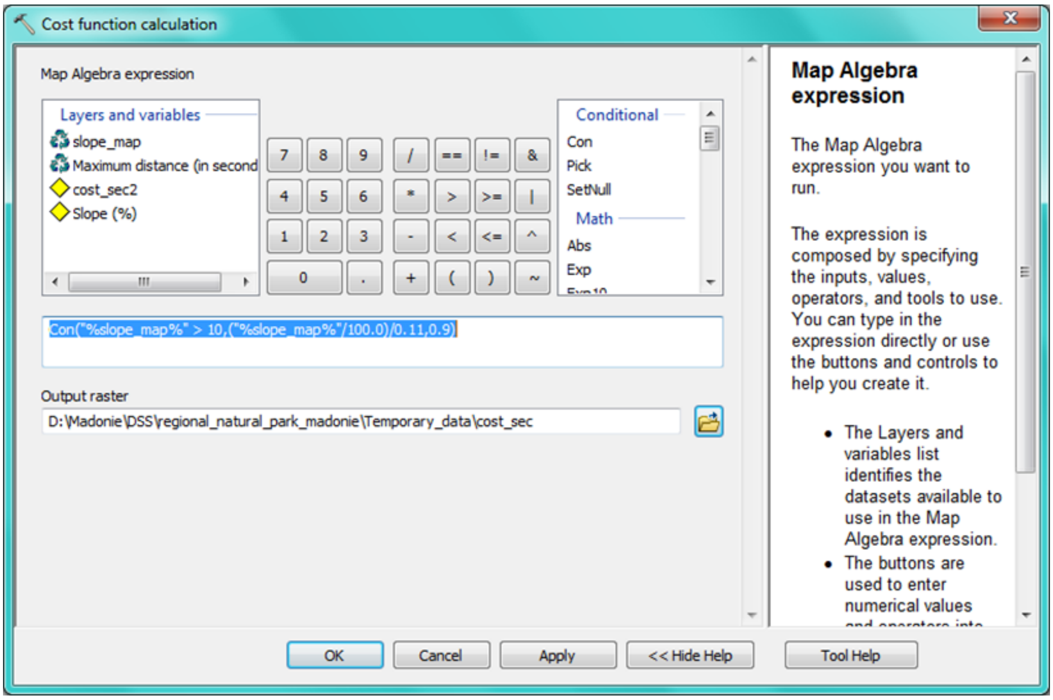
- ***slope_perc***: slope map (%), obtained from the DTM with resolution 10x10 m;
- ***work_area_roads***: road network (forest paths not included);
- ***biomass_districts***: delimitation of biomass districts;
- ***municipalities***: municipal administrative boundaries;
- ***forest***: forest map.

The methodology was developed with the ArcGIS software and subsequently replicated and tested with the open source software QGIS.

3.1.2 Processing

The calculations to be carried out to assess the accessibility of forest areas are the following:

1) To calculate the ***cost function*** starting from the raster file of slope. It is used a function to calculate the access times (in seconds) per unit of distance, and subsequent processing will automatically take into account the length of the cell depending on whether it is crossed in a straight line or diagonally. For slopes less than 10%, an advancement speed of 4 Km/h it is assumed, whereas for slopes higher than 10% this is reduced up to 0.4 Km/h. However, the cost function can be modified.



a) The calculation for slopes less than 10%, where 4 Km/h are equal to 1.11 m/s.

Hence:

$$t = x/v$$

where: t = time (in seconds); x = distance (in meters); v = speed (meters per second).

Referring to the distance unit, i.e. x = 1 m

$$t = 1/1.11 = 0.9 \text{ s}$$

b) The calculation for slopes higher than 10%, where 0.4 Km/h are equal to 0.11 m/s.

For a flat distance of x meters, the difference in height level y is given by:

$$y = x * \text{Slope (\%)}/100$$

Hence:

$$t = y/v \rightarrow t = x * \text{Slope (\%)}/100/v$$

Referring to the distance unit, i.e. x = 1 m

$$t = \text{Slope (\%)}/100/0.11$$

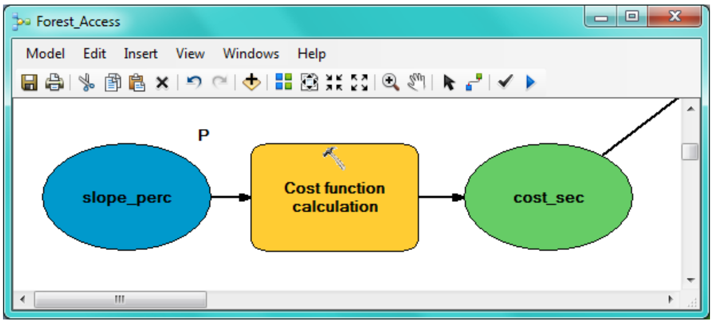
The function "***con***", applied to each cell of the slope raster file, allows to check whether the *condition* ("% slope_map%"> 10) is true or false. Based on the result, it calculates the cell value of the raster file ***cost_sec***. If it is true, it executes the operation *true* ("% slope_map%"/100.0/0.11); if it is false it executes the operation *false* (0,9).

The function "***con***" (*condition*, *true*, *false*), results therefore:

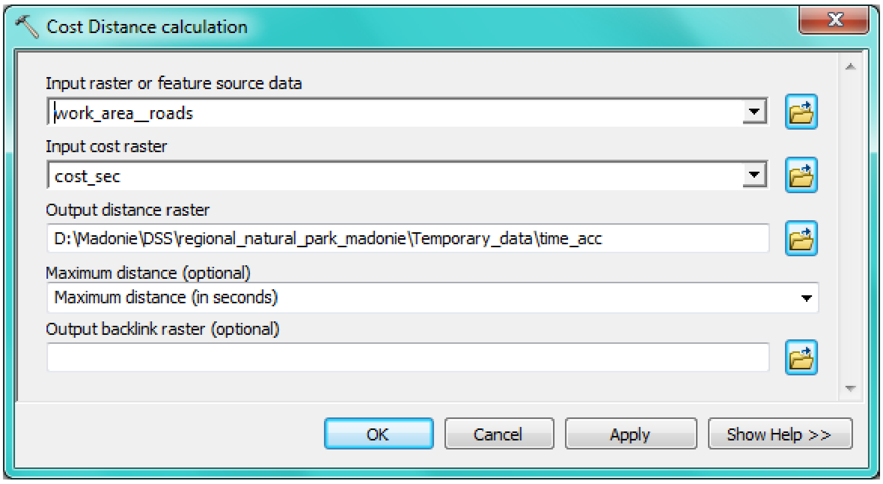
Con ("% slope_map%"> 10, ("% slope_map%"/100.0)/0.11,0.9)

INPUT: ***slope_perc***: Slope map (in %).

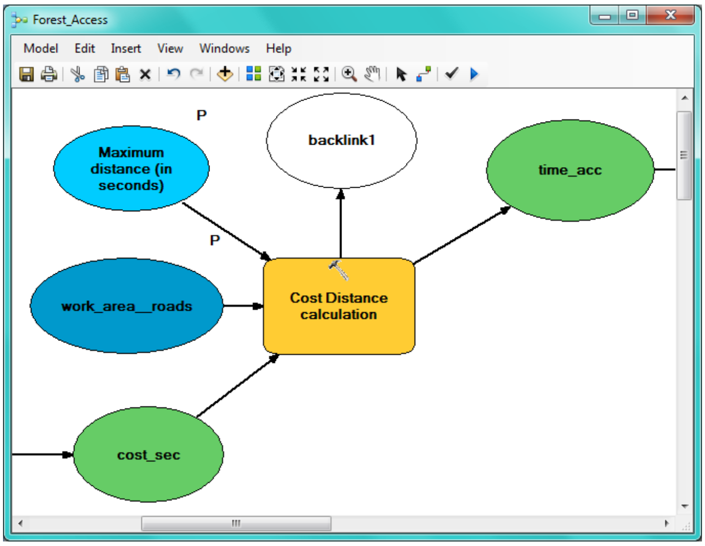
OUTPUT: ***cost_sec***: Cost function (in s/m).



2) To calculate for each cell (for example of 10x10 m) the time needed to reach it, starting from the nearest source point. It is possible to enter a maximum time beyond which the cell is considered inaccessible (in our example 3,600 s, or 1 hour) (Chirici et al., 2004)



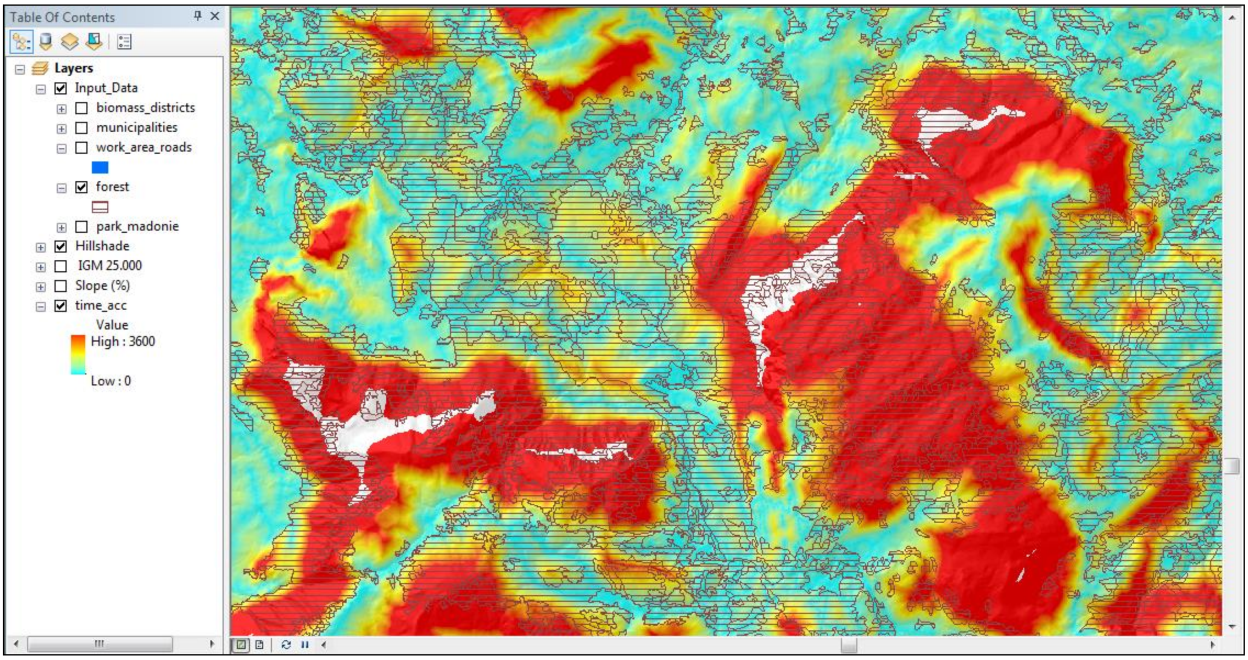
Optionally you can get a second output raster file (*backlink1*) which indicates, for each cell, which of the 8 neighboring cells ensures the minimum cost. This is useful in cases where you subsequently want to calculate the optimal routes for some destination areas



INPUT: ***work_area_roads*** (viability); ***cost_sec*** (cost function); ***Maximum distance*** (maximum time, 3,600 s).

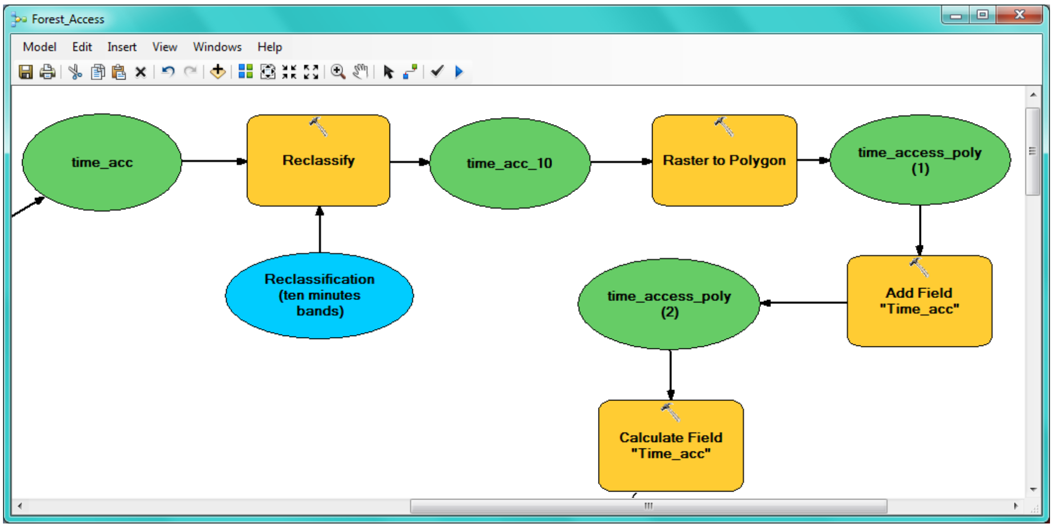
OUTPUT: ***time_acc*** total time (in seconds) to access the cell (raster file).

Below is an example of the result of processing: wooded lands are in the dash. The white areas have access times higher than 60 minutes, therefore they are considered inaccessible.



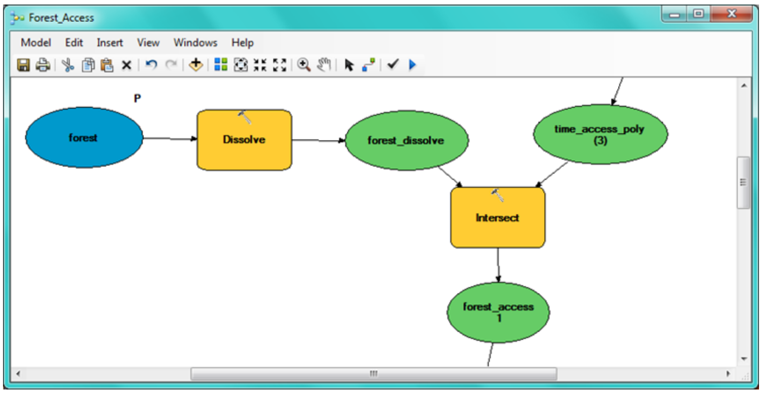
3) To reclassify the access time (e.g. in 10 minute classes) and convert the raster file into a vector file.

OUTPUT: ***time_access_poly*** vector map of access times.



4) To perform a DISSOLVE on the wooded lands to join any homogeneous adjacent areas. The INTERSECT command allows you to subdivide the wooded areas into homogeneous portions in terms of access time, and it excludes the inaccessible areas. If, conversely, the IDENTITY command is used, also the inaccessible areas remain (i.e. those with an access time higher than the maximum time entered in point 2).

5)



INPUT: ***forest*** (wooded lands); ***time_access_poly*** map of access times.

OUTPUT: ***forest_access_1*** accessibility to the woods.

6) The INTERSECT between the municipal administrative boundaries (**municipalities**) and the biomass districts (***biomass_districts***), creates a level in which each municipality is associated with the relative district (***BiomDistr_municipalities***), and, subsequently, the

INTERSECT between this and the accessibility map to the woods (***forest_access_1***) allows you to further subdivide the woods according to the territories of the municipalities and districts in which they fall.

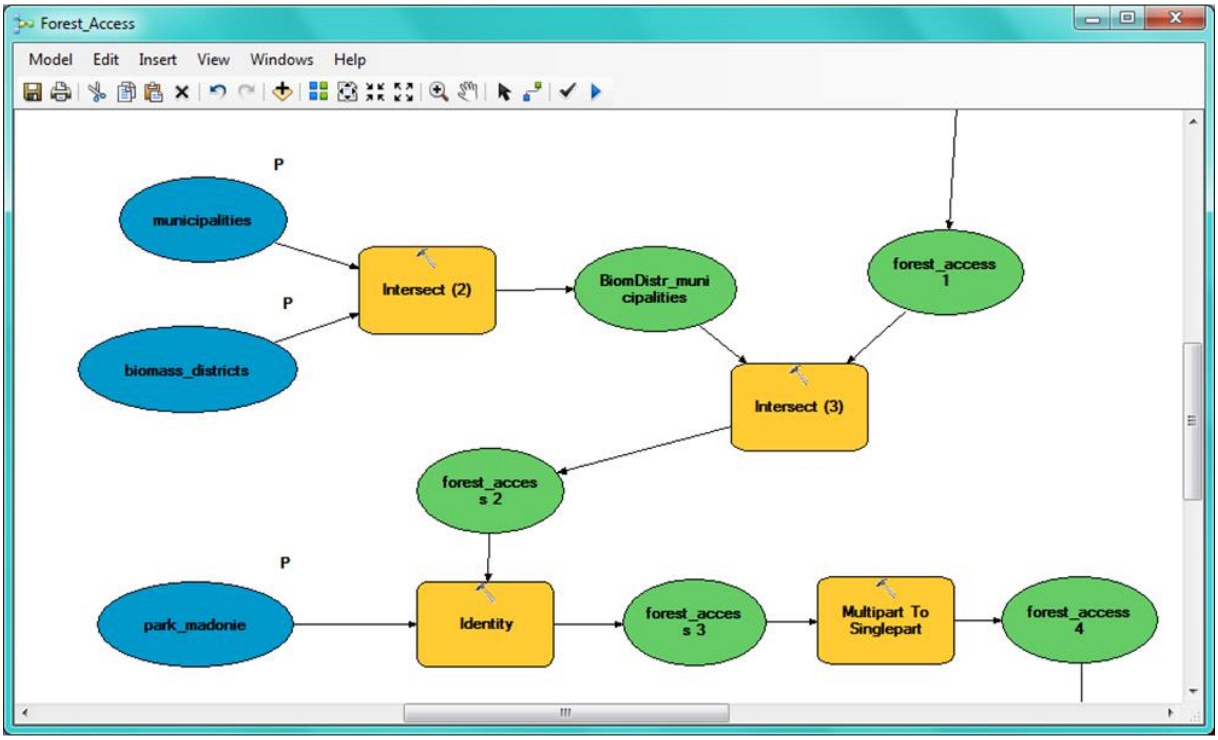
INPUT: ***forest_access*** accessibility to the woods; ***BiomDistr_municipalities*** biomass districts.

OUTPUT: ***forest_access_2*** accessibility to the woods (with attributes: category, access times, municipality, district).

7) For the intersection with the Madonie Natural Park (or another protected and/or constrained area) a command that also maintains the wooded lands falling outside the Park (in fact INTERSECT keeps only the areas in common between two input vector files) must be used. With the ARCGIS software the command is IDENTITY; this keeps the whole area covered by the first input file, partitioning the areas falling within the second file (in this case the Madonie Natural Park) in homogeneous areas with respect to Park zoning.

INPUT: ***forest_access_2*** accessibility to the woods; ***park_madonie*** Madonie Natural Park (divided into zones).

OUTPUT: ***forest_access_3*** accessibility to the woods (with attributes: category, access times, municipality, district; Park zone, A, B, C, D or none).

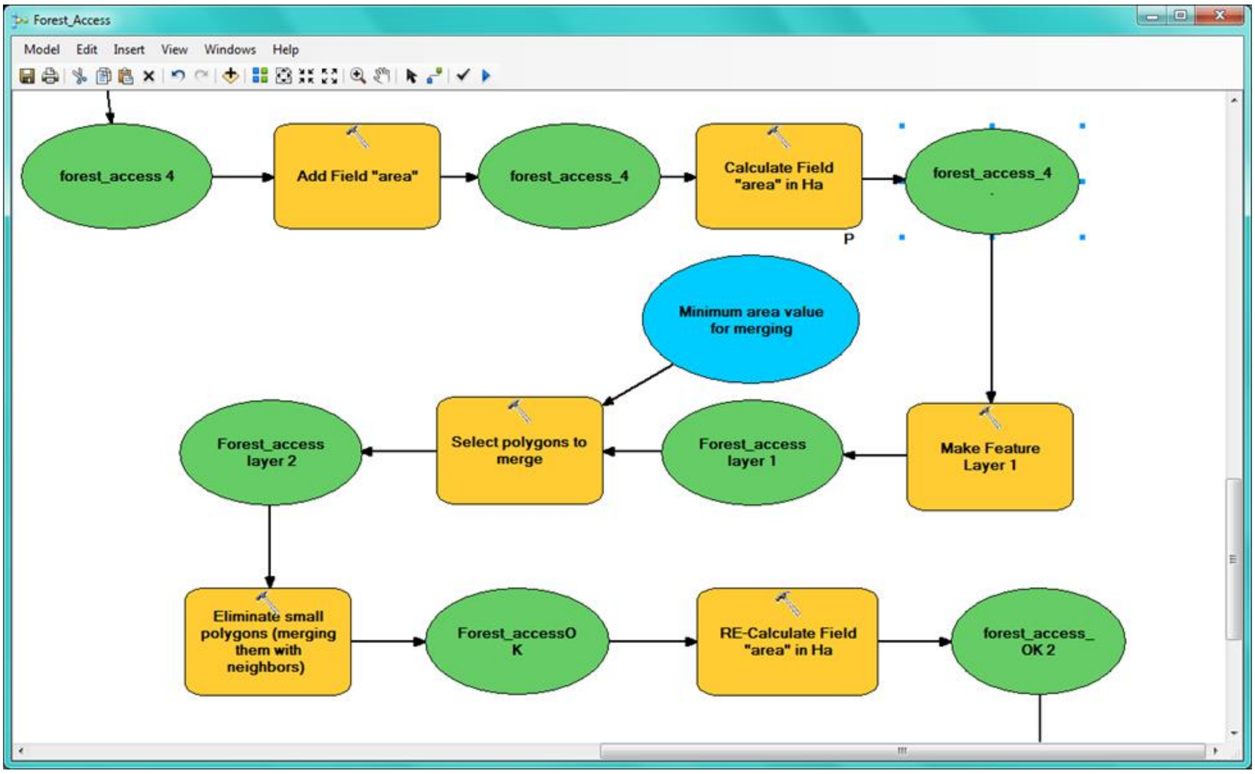


8) At this point, the groupings of several polygons which correspond to a single record in the table of attributes, or "*multipart features*", which must be separated into "*singlepart features*" with the appropriate function, as shown in the previous diagram, will be eliminated.

INPUT: ***forest_access_3*** accessibility to the woods.

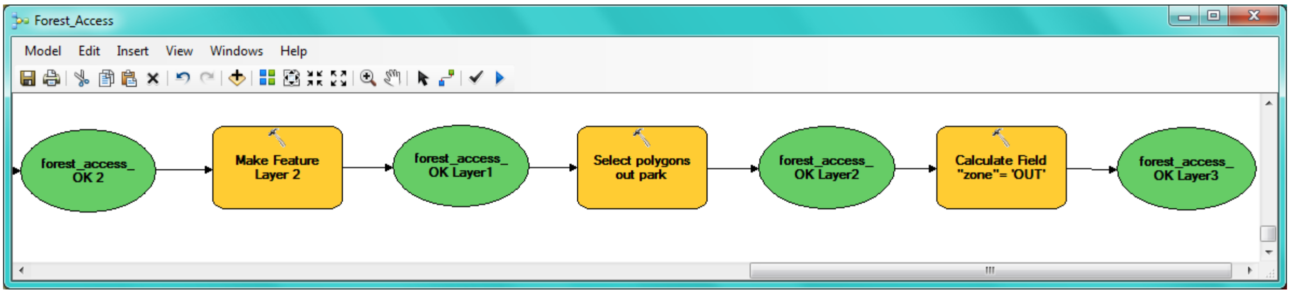
OUTPUT: ***forest_access_4*** accessibility to the woods.

9) In this phase we proceed to the calculation of the area of each polygon. Areas of non-significant size (less than 0.5 ha), that may have been generated during processing, will be selected and merged with the adjacent polygon. When the operation is completed, the calculation of the areas must be repeated.



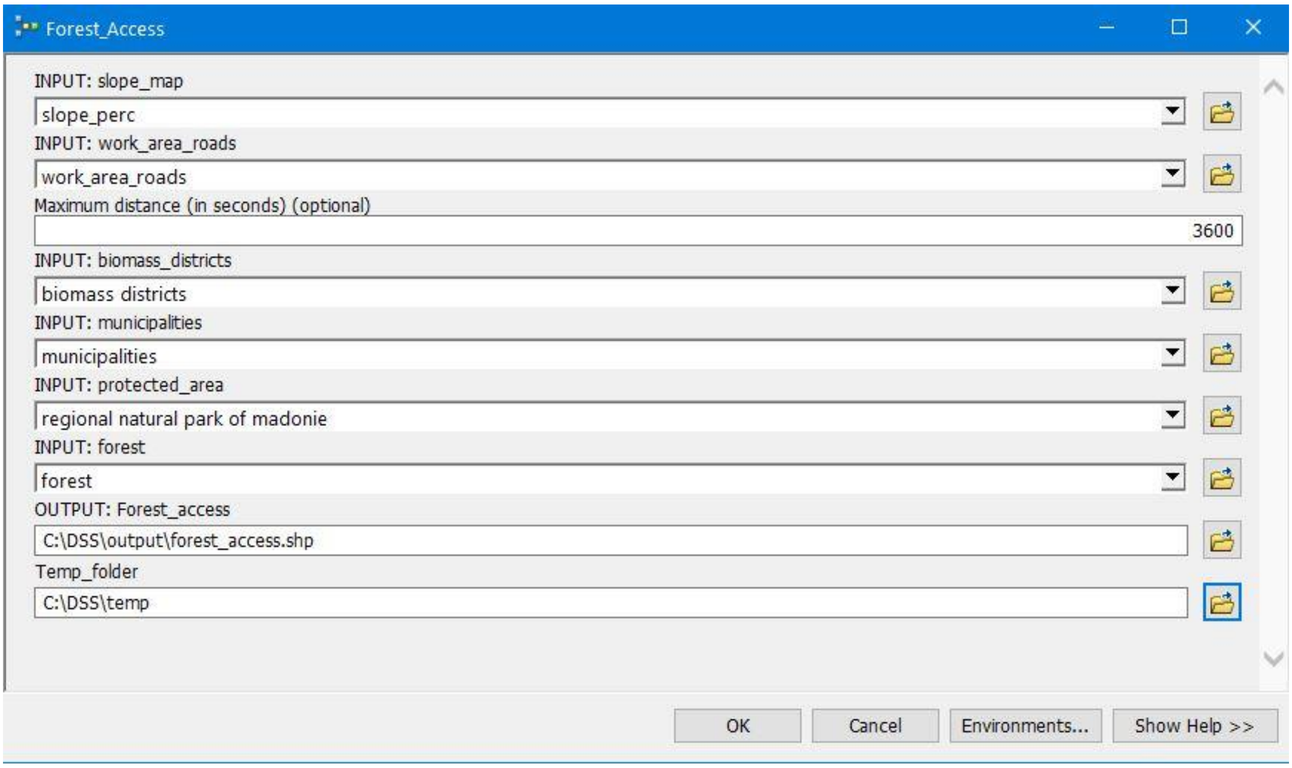
10) The final pass includes the selection of the forest areas outside the protected area, and the association of the "OUT" value with the "zone" field.

Final OUTPUT ***forest_access_OK.***



3.1.3 The model in ArcGIS software

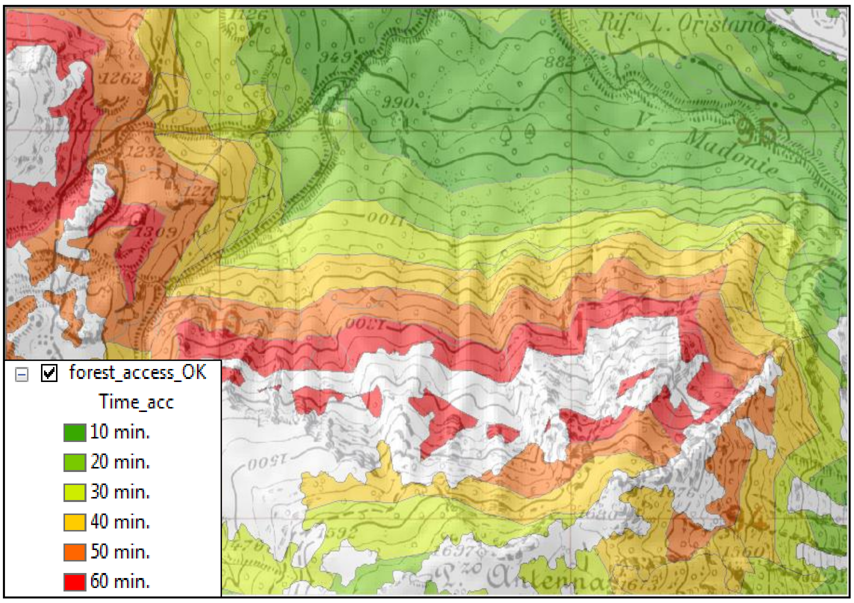
During the execution in the ArcGIS environment, the "*Forest access*" model developed to perform the processing described above is presented to the user as shown in the following figure.



All data and values displayed in the mask can be specified by the user, who can change the parameters or run the model in areas other than the Madonie Natural Park.

3.1.4 Functions of analysis

Applying the appropriate functions it is possible to carry out different analyzes. Below is a detail of the result obtained, where the accessibility map of the woods (***forest_access_OK***) has been colored based according to access times, which were subdivided into 10-minute intervals.



Below is the table associated with the ***forest_access_OK*** shapefile.

Table

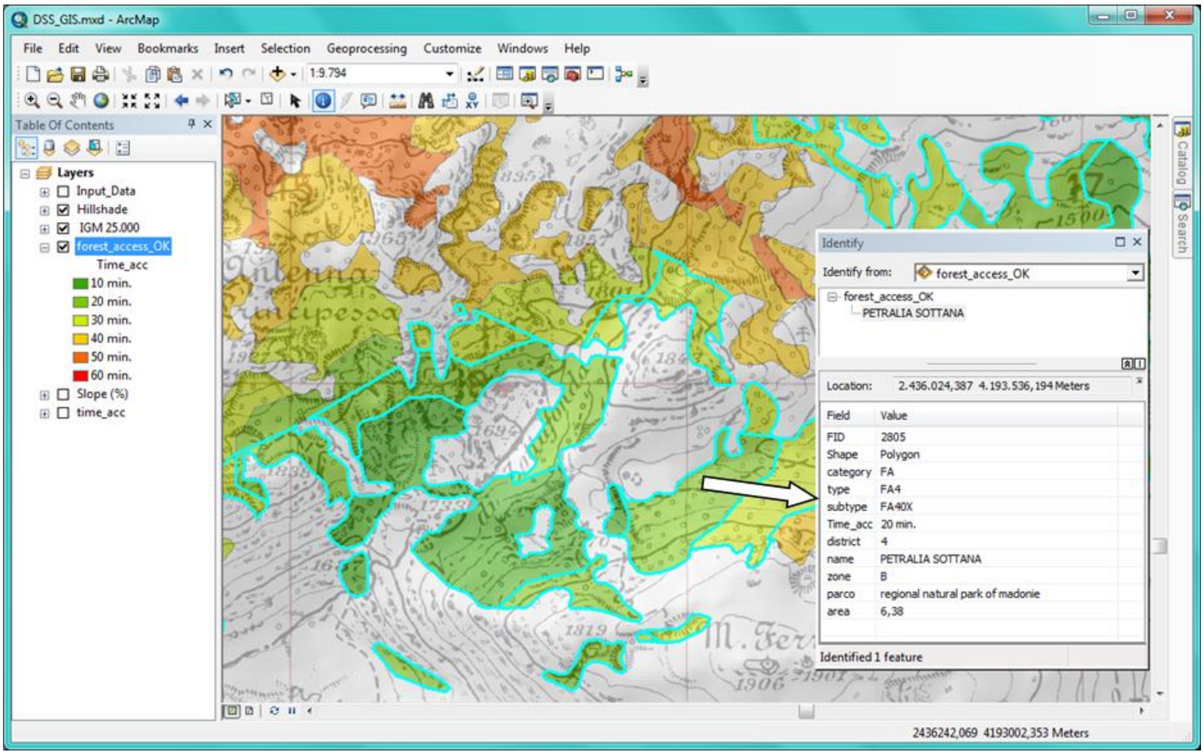
forest_access_OK

FID	Shape	category	type	subtype	Time_acc	district	name	zone	parco	area
4397	Polygon	QU	QU3	QU31X	20 min.	3	GERACI SICULO	A	regional natural park of madonie	0,59
4398	Polygon	QU	QU3	QU31X	30 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	13,13
4399	Polygon	QU	QU3	QU31X	20 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	1,73
4400	Polygon	QU	QU3	QU31X	20 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	5,25
4401	Polygon	QU	QU3	QU31X	10 min.	2	ISNELLO	A	regional natural park of madonie	2,26
4402	Polygon	QU	QU3	QU31X	10 min.	2	ISNELLO	C	regional natural park of madonie	2,54
4403	Polygon	QU	QU3	QU31X	20 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	5,71
4404	Polygon	QU	QU3	QU31X	20 min.	3	CASTELBUONO	B	regional natural park of madonie	3,32
4405	Polygon	QU	QU3	QU31X	20 min.	3	CASTELBUONO	A	regional natural park of madonie	3,99
4406	Polygon	QU	QU3	QU31X	20 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	1,59
4407	Polygon	QU	QU3	QU31X	10 min.	3	CASTELBUONO	B	regional natural park of madonie	24,83
4408	Polygon	QU	QU3	QU31X	10 min.	3	CASTELBUONO	A	regional natural park of madonie	22,97
4409	Polygon	QU	QU3	QU31X	10 min.	3	CASTELBUONO	A	regional natural park of madonie	3,49
4410	Polygon	QU	QU3	QU31X	10 min.	3	GERACI SICULO	B	regional natural park of madonie	0,73
4411	Polygon	QU	QU3	QU31X	10 min.	3	GERACI SICULO	B	regional natural park of madonie	6,39
4412	Polygon	QU	QU3	QU31X	10 min.	3	GERACI SICULO	A	regional natural park of madonie	15,75
4413	Polygon	QU	QU3	QU31X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	0,51
4414	Polygon	QU	QU3	QU31X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	1,35
4415	Polygon	QU	QU3	QU31X	10 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	10,91
4416	Polygon	QU	QU3	QU31X	10 min.	4	PETRALIA SOTTANA	A	regional natural park of madonie	3,65
4417	Polygon	QU	QU3	QU31X	20 min.	3	CASTELBUONO	B	regional natural park of madonie	1,73
4418	Polygon	QU	QU3	QU31X	20 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	0,88
4419	Polygon	QU	QU3	QU31X	10 min.	3	CASTELBUONO	B	regional natural park of madonie	6,87

1 (0 out of 5504 Selected)

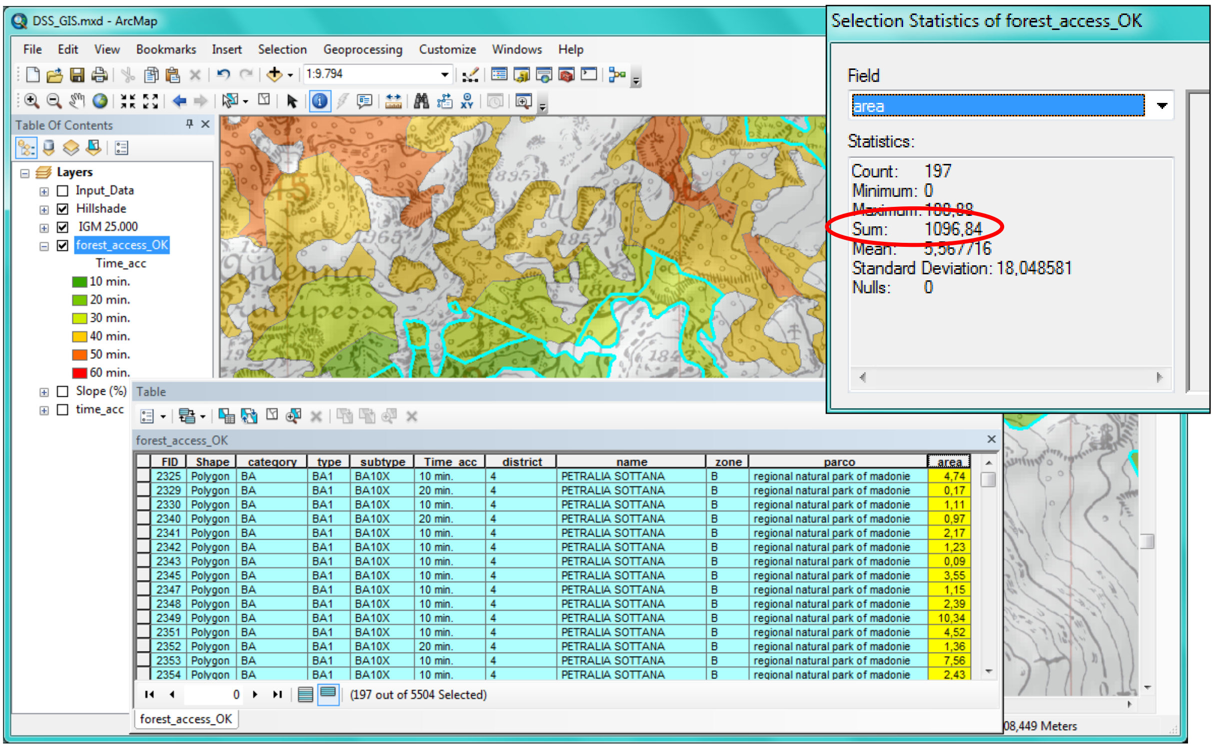
forest_access_OK

Based on these attributes, various types of queries can be made based on specific needs. For example, it is possible to select all the wooded lands of the municipality of Petralia Sottana falling into the B zone of the Madonie Natural Park, accessible within 30 minutes and also to calculate the total area.



In the following figure, some of the polygons selected with the query of one of them are showed.

The total area of the selected areas is 1,096.84 ha.



FID	Shape	category	type	subtype	Time_acc	district	name	zone	parco	area
2325	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	4,74
2329	Polygon	BA	BA1	BA10X	20 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	0,17
2330	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	1,11
2340	Polygon	BA	BA1	BA10X	20 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	0,97
2341	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	2,17
2342	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	1,23
2343	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	0,09
2345	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	3,55
2347	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	1,15
2348	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	2,39
2349	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	10,34
2351	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	4,52
2352	Polygon	BA	BA1	BA10X	20 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	1,36
2353	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	7,56
2354	Polygon	BA	BA1	BA10X	10 min.	4	PETRALIA SOTTANA	B	regional natural park of madonie	2,43

3.2 Advanced DSS

3.2.1 Premise

The objective of the advanced version of the DSS, called "Analysis", is the assessment of the quantity and type of available biomass in a given area (the supply basin). The analysis starts from a known point in which to hypothesize the design of a cogeneration biomass plant. It therefore allows to evaluate the feasibility of the plant and to estimate its power, allowing the evaluation of different possible scenarios.

The model prepared carries out an analysis of the input files by extracting the polygons that are inside the area indicated by the user, which we will call "study area". The polygons that fall on the border are cut so that only the inner portion of the area is considered.

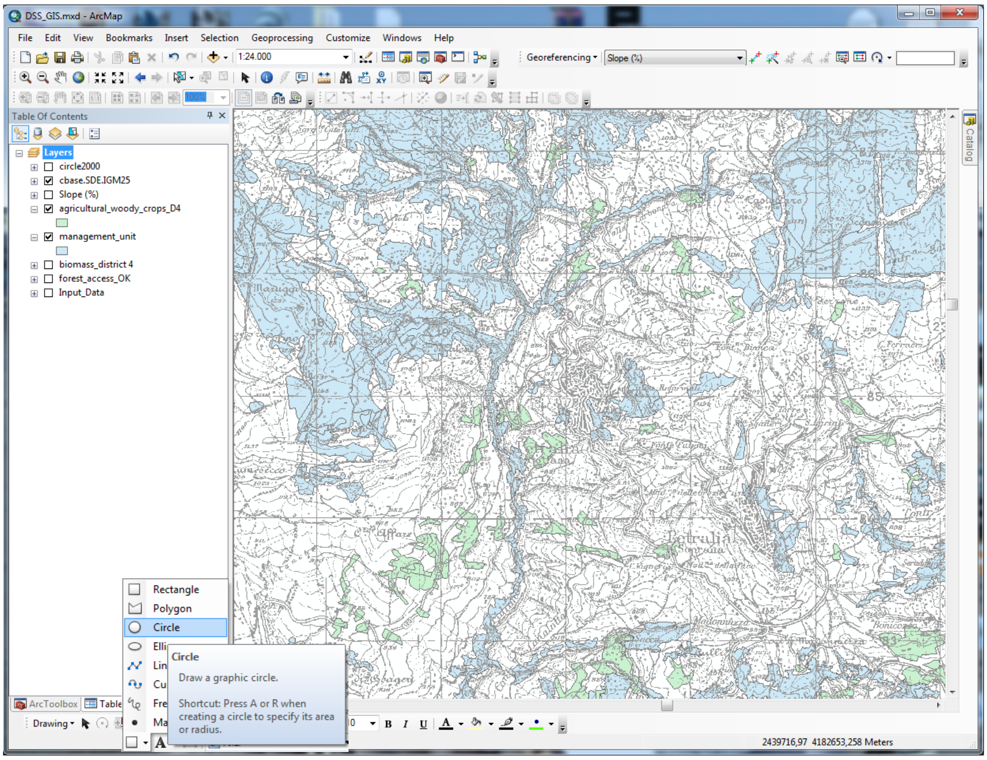
Input data (vector shapefiles)

⇨ ***Management_unit***: Management_unit vector layer of the selected biomass district. This layer includes basic information such as ownership, municipality, biomass district, surface area, growing stock, yield, biomass and timber assortment for each management unit of forest management plan.

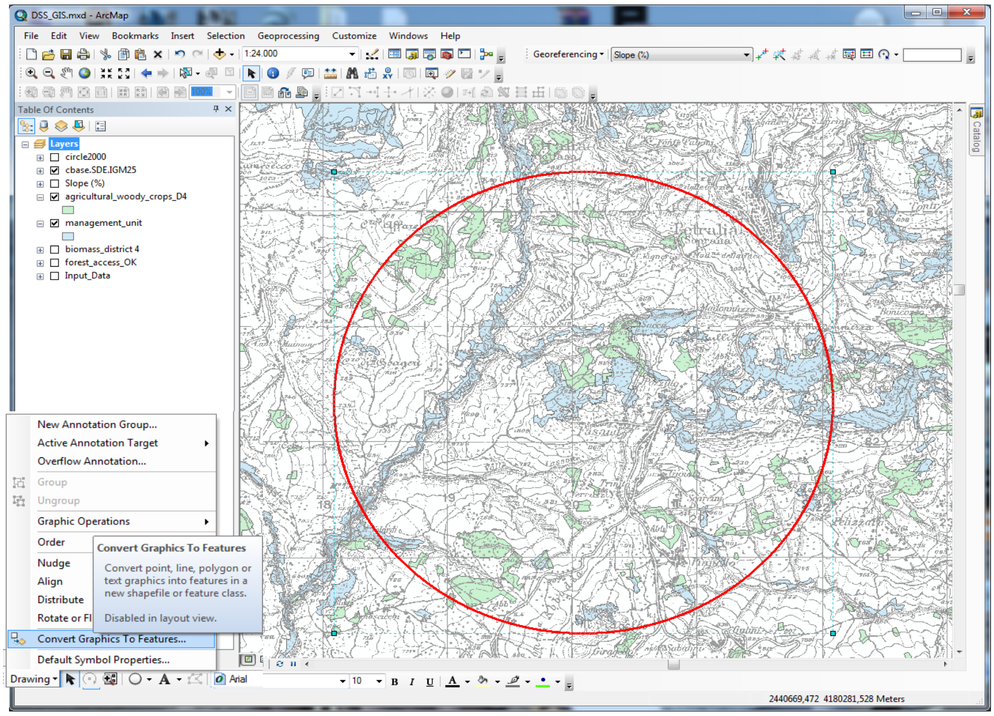
⇨ ***Permanent_crops***: Permanent_crops vector layer of the selected biomass district. It consists of the list of permanent crops following the CORINE Land Cover nomenclature (III-level): 221-vineyard, 222-fruit trees and berry plantations, 223-olive groves. This layer includes the removable biomass for each permanent crop unit;

⇨ ***Study area:*** Test_area vector layer. It includes a polygon geometry identified by user, that is a hypothetical forest biomass supply basin.

The tools of a GIS software will be used to create the shapefile of the study area. Using ArcGIS, in ArcMAP environment, from the "*Drawing*" toolbar you can interactively create an area on the map and convert it into a shapefile. In the example shown, a circular study area was hypothesized starting from a point (the center) in which to hypothesize the design of a biomass plant. Operationally, the user will instead draw a free hand polygon on the basic map according to the physiographic or administrative limits or any other notable element.

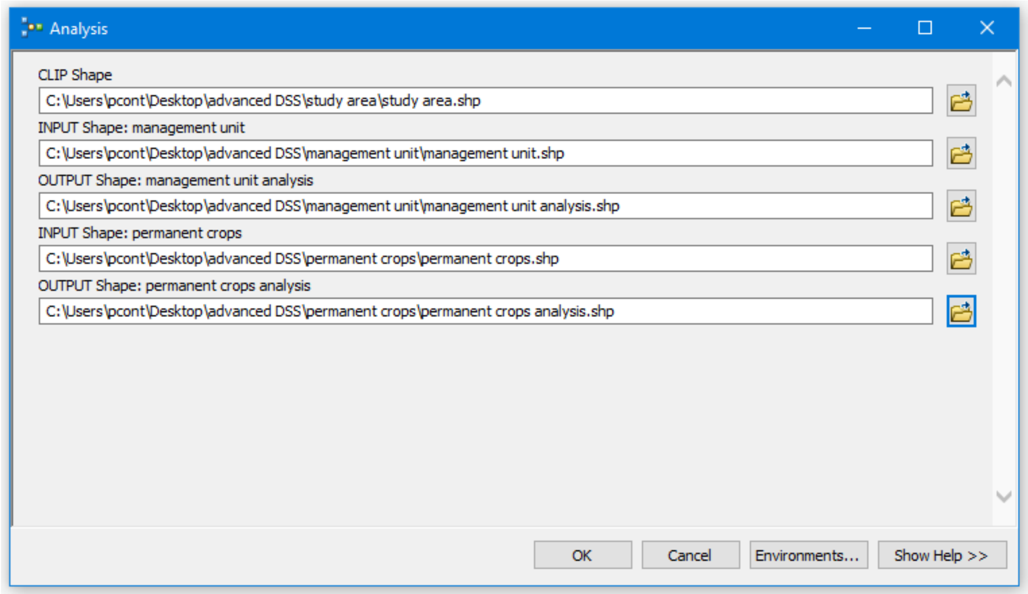


Using the "*Convert Graphics To Features*" function in the "*Drawing*" toolbar, the newly created study area will then be converted into a shapefile.



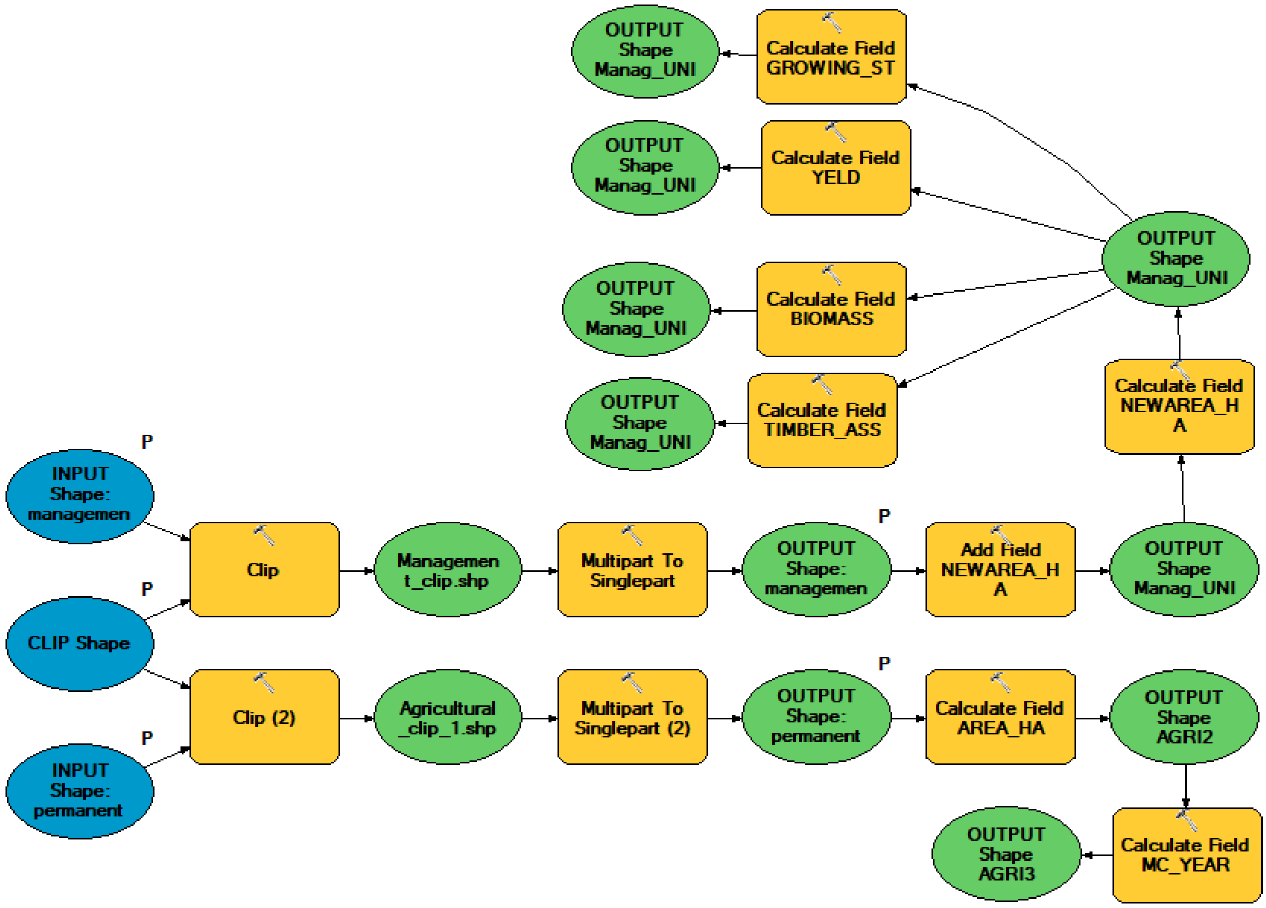
3.2.2 The model in ArcGIS and the elaborations

During the execution in the ArcGIS environment, the model is presented to the user as shown below.



1) To launch the "*Analysis*" model by setting the required data. "*CLIP shape*" identifies the shapefile previously created, and related to the study area. "*Management unit*" and "*permanent crops*" should be set as input shapefiles, also identifying the relative paths of the output files to be returned by the DSS. Particular attention should be paid to the input files "*management unit*" and "*permanent crops*". They must not contain fields incorrectly set with area values equal to 0 (zero), since the automatic recalculation functions set in the DSS (which we will discuss later) they would go wrong, blocking the whole procedure.

The architecture of the prepared model is reported in the following figure:



The input files are cut at the study area with a *Clip* command. Then, a function which corrects the type is applied (*Multipart to Singlepart*), so that each record in the associated attribute table corresponds to one and only one polygon.

2) Then, the DSS recalculates the area (in hectares) for each polygon, because for the polygons cut along the border of the study area, the total area has obviously been reduced. For the *management_unit_analysis* shapefile, it adds a new *Newarea_ha* field because, as explained in the next point, it is necessary to keep the information on the initial value of the area

3) The fields of interest are recalculated as follows:

    a. for *management_unit_analysis* the values of the fields are returned to the new extension of each polygon, multiplying each value by the ratio between the new area value and the previous one. For example, for the field *biomass*:

*[biomass] = [biomass] * [NewArea_ha] / [area_ha]*

b. for *permanent_crops*, being already present a field with the value of *mc_year* referred to the area unit (*mc_ha_year*), it is sufficient to multiply the latter by the value of the area of each polygon:

*[mc_year] = [area_ha] * [mc_ha_year]*

From the formulas reported it is clear that it is fundamental to make sure that there are no records with null values (equal to zero) of the *area_ha* field, to avoid a division by zero that would block the processing and the entire procedure. These null values are generated in small polygons, where the decimal digits chosen to express the value of the area are not sufficient to express such value in hectares. In these cases, when the software makes an approximate by defect, the value equal to zero is obtained. Therefore it is necessary to verify the absence of these polygons in the input shapefiles, possibly correcting their geometry and surface, perhaps dissolving them in the adjacent polygon given their insignificant amplitude.

In order for the connections and the different formulas set to work, the shapefiles in question must contain the following fields exactly set with the following nomenclature reported:

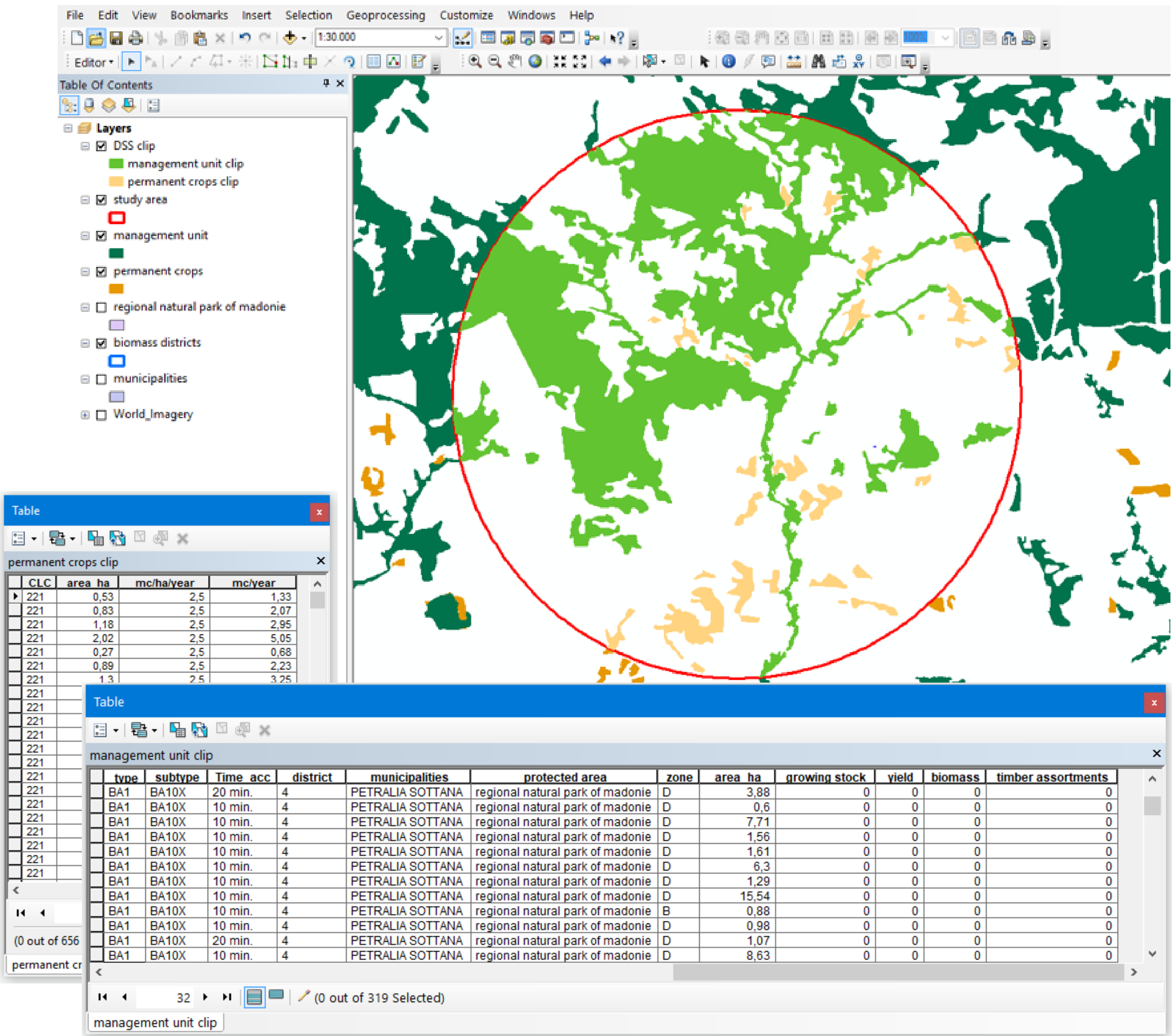
- for the shapefile ***management unit***: *area_ha*; *growing_stock*; *yield*; *biomass*; *timber_assortments*;
- for the shapefile ***permanent crops***: *area_ha*; *mc_ha_year*; *mc_year*.

Where it is necessary to appoint the aforementioned fields differently or to add new ones, the architecture of the prepared DSS can be modified ad hoc.

3.2.3 Functions of analysis

The DSS “Analysis” returns as output data two shapefiles, one of the management units and another of the permanent crops related to the study area set by the user. It works recalculating all the fields related to the areas and volumes of biomass or other woody assortments present.

Therefore, starting from a known point in which to hypothesize the design of a cogeneration biomass plant, the DSS allows us to know the type and quantity of available biomass deriving from the forest areas and from agricultural crops. Within a study area, the more information included in the input shapefiles, the greater the information returned by the DSS. This will allow to evaluate the feasibility of the plant at the hypothesized point and to estimate its power in relation to the available biomass. In the event that the available biomass is found to be insufficient, the operator can set up a new study area of larger size (in compliance with the limits set for the short supply chain) and launch the DSS again, thus obtaining new results. On the contrary, if the available biomass is found to be excessive, it would be possible to opt for a reduction of the study area (the supply basin) or for the construction of two relatively close plants of minor power that would share the same supply basin.

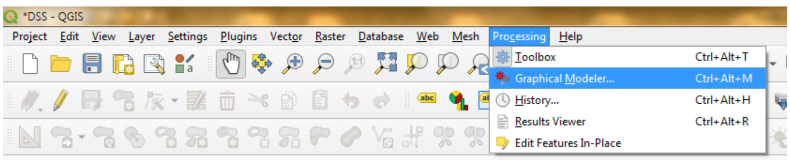


As showed, the DSS allows the evaluation of different scenarios, providing, in fact, a valid "support to the decision" in the design of the cogeneration biomass plants and in the planning of the relative supply chains of agro-forestry biomass.

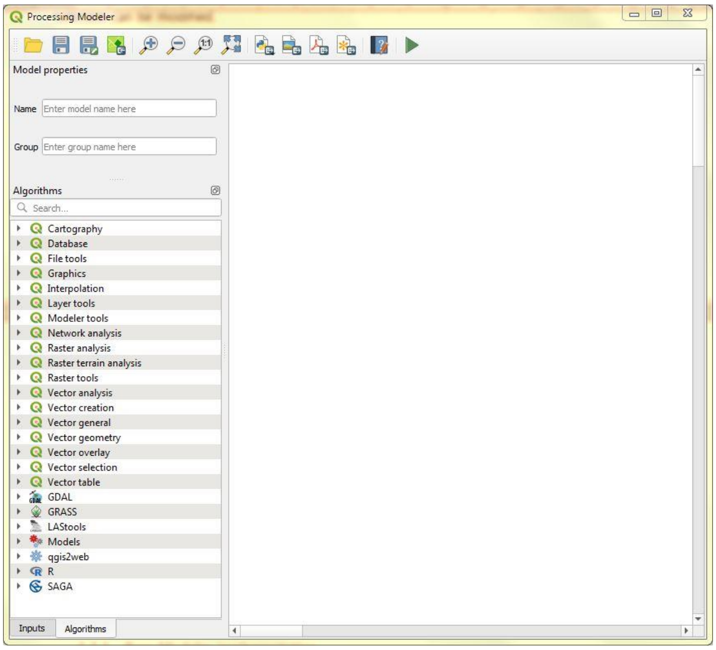
An example of data returned by the DSS "Analysis". The red circle identifies the study area set by the user as a biomass supply basin for a hypothetical cogeneration plant (planned in the center of the biomass supply basin). Within the red circle: wooded lands (management unit) are in green, and agricultural woody crops (permanent crops) in orange. The two tables show the attributes of the "management unit" and "permanent crops" shapefiles returned by the DSS. In the table related to the “management unit” shapefile the values of the last four fields displayed are currently equal to zero, as these data will derive from the activity. Management unit vector layer was an important result Forest Management Plan (FMP) of a pilot biomass district. The drafting of FMP was carried out in the framework of activity A.3.7 “Biomass oriented forest planning at local level in the protected areas”. Each Management unit includes information about ownership, municipality, biomass district, surface area, main dendrometric parameters (e.g., basal area, density), structure, growing stock, yield, biomass, timber assortment, silvicultural treatment, management horizons.

3.3 Methodological application of DSS in open source QGIS software

In this paragraph, a Decision Support System (DSS) for planning biomass-based energy production in the protected areas is presented. All functionalities have been developed in Python languages for open-source QGIS 3.6 “Noosa”. We implemented a “Base” and “Advanced Modeler” with an approach and a methodology based on free and open source software (QGIS, GRASS, SAGA, GDAL) using the “Graphical Modeler” from the “Processing” menu.



The “Graphical Modeler” allows you to create complex models using a simple and easy-to-use interface. It permits that chain of processes can be wrapped into a single process, so it is as easy and convenient to execute as a single process later on a different set of inputs. No matter how many steps and different algorithms it involves, a model is executed as a single algorithm, thus saving time and effort, especially for larger models. The modeler has a working canvas where the structure of the model and the workflow it represents are shown below. On the left part of the window, a panel with two tabs can be used to select Input layers and to define the Algorithms to apply on them.



Before saving a model, we have to enter a Name and a Group for it, using the Model properties box in the upper part of the window. Use the [Save] button to save the current model and the [Open] button to open any model previously saved. Models are saved with the [.model3] extension.

The first step in model implementation is the input dataset definition. For each added input layer, a new yellow element is added to the modeler canvas. These inputs, including raster and vector layers, will be added to the parameters window, so the user can set their values when executing the model. The model itself is an algorithm, so the parameters window is generated automatically as it happens with all the algorithms available in the processing framework.

Once the inputs have been defined, it is time to define the workflow. Using the inputs of the model, the workflow is defined by adding algorithms and selecting how they use those inputs or the outputs generated by other algorithms already in the model. To add an algorithm to a model, double-click on its name or drag and drop it, just like it was done when adding inputs. An execution dialog will appear, with a content similar to the one found in the execution panel that is shown when executing the algorithm from the toolbox. You will find an additional parameter named “Parent algorithms” that is not available when calling the algorithm from the toolbox. This parameter allows you to define the order in which algorithms are executed by explicitly defining one algorithm as a parent of the current one, which will force the parent algorithm to be executed before the current one and a new white element is added to the modeler canvas. When you use the output of a previous algorithm as the input of your algorithm, that implicitly sets the previous algorithm as parent of the current one (and places the corresponding arrow in the modeler canvas). Once all the parameters have been assigned valid values, click on [OK] and the algorithm will be added to the canvas with a white element. It will be linked to all the other elements in the canvas, whether algorithms or inputs, that provide objects that are used as inputs for that algorithm. For each generated output layer, a new green element is added to the modeler canvas. Elements can be dragged to a different position within the canvas, to change the way the module structure is displayed and make it more clear and intuitive. Links between elements are updated automatically. You can zoom in and out by using the mouse wheel. In order to use the algorithm from the toolbox, it has to be saved and the modeler dialog closed, to allow the toolbox to refresh its contents. Click on the [Run model] button in order to run it anytime.

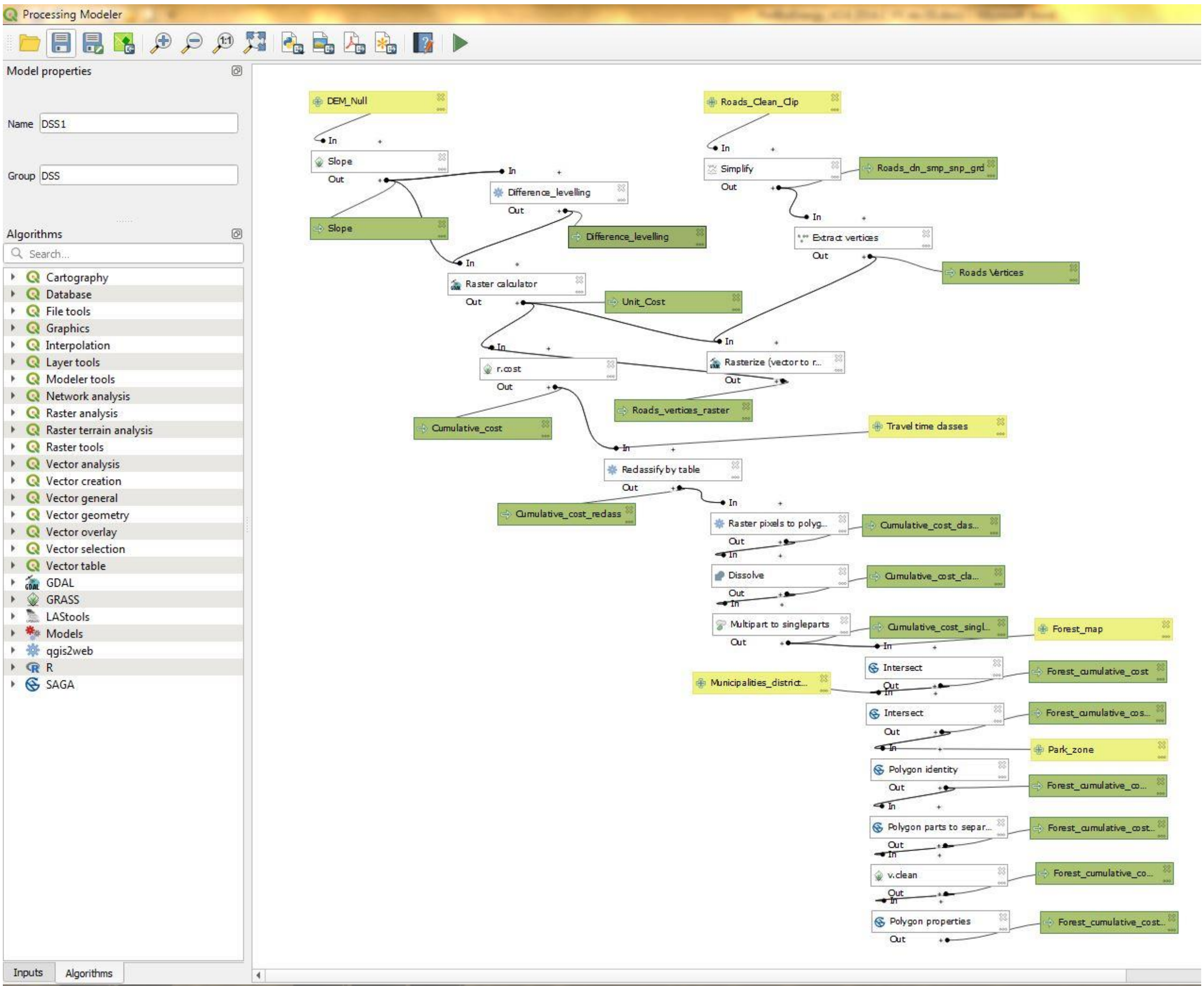
3.3.1 Base Modeler implementation

The “Base Modeler” created is showed below.

The first step in model implementation was the **Input** dataset definition: DEM, Road network, Forest map, Municipalities and Biomass districts, Park zoning, Travel time classes.

DEM_Null: We added the 100m resolution digital elevation model (DEM) of the study area. Please consider that the background pixels should be filled with null values, not with zero.

Forest_map: We added a forest map vector layer of the study area. Before adding it, 1) "Geometry Checker" plugin was used to check and fix the geometry validity of a layer, 2) algorithm "Dissolve" was used to dissolve common boundaries of adjacent polygons having the same value from a specific attribute.



Municipalities_districts_biomass: We added an administrative vector layer of the study area. The layer includes the municipalities and biomass districts boundaries.

Park_zone: We added the vector layer that includes the Madonie Regional Park boundaries and its zoning.

Roads_Clean_Clip: We added the Roads vector layer of the area. This layer includes main roads, secondary roads and forest roads. Before adding it, "Geometry Checker" plugin was used to check and fix the geometry validity of the layer.

Travel time classes: We defined six accessibility classes of 10 minutes each based on the time required for a forest worker to make a round trip on foot from the nearest road to a given point in the forest. The maximum access time is set up to 60 minutes.

The layers generated by the algorithms are just a temporary outputs that will be used as the input of another algorithm or definitive outputs. The generated **Output** are listed below.

Slope: A "r.slope.aspect" tool (GRASS) was applied to generate raster layer containing the Slope gradient in % for each pixel from an elevation raster layer (DEM) of the area.

Difference_levelling: With the tool "Raster calculator" a map of Differential levelling was generated starting from the slope map in percent. The output contains the value of Differential levelling covered for each pixel, considering a horizontal distance of 100m, using the formula: 100*(1+(slope/100)^2)^0.5

ATTENTION: The formula is right now setup with a hundred meter pixel resolution.

Unit_Cost: Considering the climbing speed of 400 m/h between two points for slopes higher than 10%, corresponding to 0.11 m/s, and the climbing speed of 4 km/h between two points for slopes lower than 10%, corresponding to 1.11 m/s, with the algorithm "Raster calculator" (GDAL) a raster layer containing information regarding the time of pixel crossing was made by the following formula:

(Difference_levelling/1.11)*(Slope<=10)+ (Difference_levelling/0.11)*(Slope>10)

Roads_cln_smp_snp_grd: The "Simplify" tool was applied to simplify the geometries in Roads vector layer. The algorithm creates a new layer with the same features as the ones in the input layer, but with geometries containing a lower number of vertices. We used "Snap to grid" as simplification method and "100" as tolerance.

Roads Vertices: The "Extract vertices" tool was applied to generate a point layer with points representing the vertices from the input lines layer (Roads_simplified). The attributes associated to each point are the same ones associated to the line that the point belongs to.

Roads_vertices_raster: The algorithm "Rasterize" (GDAL) was applied to converte the point vector file of roads (Roads_vertices) into a raster file (Roads_vertices_raster).

Cumulative_cost: The algorithm "r.cost" (GRASS) was applied to define a raster layer of cumulative cost of moving across a raster layer whose cell values represent cost. This tool determines the cumulative cost of crossing to each cell on a cost surface (input raster layer: Unit_cost) starting from specified cell(s) by raster points layer (Roads_vertices_raster). We choosed to use the "Knight's move" and to keep "null value" in output raster layer.

Cumulative_cost_reclass: The algorithm "Reclassify by table" was applied to reclassify a raster band of Cumulative_cost by assigning new class values based on the ranges specified in a fixed table. Cumulative_cost was reclassified according to six accessibility classes of 10 minutes each. The maximum access time is set up to 60 minutes. It is a Cost map, that is a raster containing information regarding the time of pixel crossing.

Cumulative_cost_class_vect: The algorithm "Raster pixels to polygons" was applied to convert a raster layer (Cumulative_cost_reclass) to a vector layer (Cumulative_cost_class_vect) by creating polygon features for each individual pixel's extent in the raster layer of input. Any nodata pixels are skipped in the output.

Cumulative_cost_class_dissolved: The algorithm "Dissolve" takes a vector layer and combines their features into new features. This algorithm was applied to dissolve features belonging to the same class (having the same value for the specified attributes) of Cumulative_cost_class_vect vector layer.

Cumulative_cost_single_part: The algorithm "Multipart to singleparts" was applied to take a vector layer with multipart geometries (input: Cumulative_cost_rec_vect_dissolved) and generate a new one in which all geometries contain a single part (output: Cumulative_cost_single_parts). Features with multipart geometries are divided in as many different features as parts the geometry contain, and the same attributes are used for each of them.

Forest_cumulative_cost: The algorithm "Intersect" (SAGA) was applied to combine features from the Input layer (Forest_map) and the Overlay Layer (Cumulative_cost_single_part), resulting in features that cover both layers' features. Features in the output Intersection layer (Forest_cumulative_cost) are assigned the attributes of the overlapping features from both the Input and Overlay layers. We imposed that Input Layer features that are partially within Overlay layer feature(s) are split along the boundary of the clip layer feature(s).

Forest_cumulative_cost_biomass: The algorithm "Intersect" (SAGA) was applied to combine features from the Input layer (Municipalities_districts_biomass) and the Overlay Layer (Forest_cumulative_cost), resulting in features that cover both layers' features. Features in the output Intersection layer (Forest_cumulative_cost_biomass) are assigned the attributes of the overlapping features from both the Input and Overlay layers. We imposed that Input Layer features that are partially within Overlay layer feature(s) are split along the boundary of the clip layer feature(s).

Forest_cumulative_cost_biomass_park_zones: The algorithm "Polygon identity" (SAGA) was applied to calculate the geometric intersection between two layers and adds the difference of layer A (Forest_cumulative_cost_biomass) less layer B (Madonie_park), that is the geometries falling outside Park boundaries. Attribute values from the input feature classes (layer A and B) will be copied to the output feature class (Forest_cumulative_cost_biomass_park_zone). This algorithm may generate multipart features in the output even if all inputs were single part and you set "Yes" to "Split Parts" option.

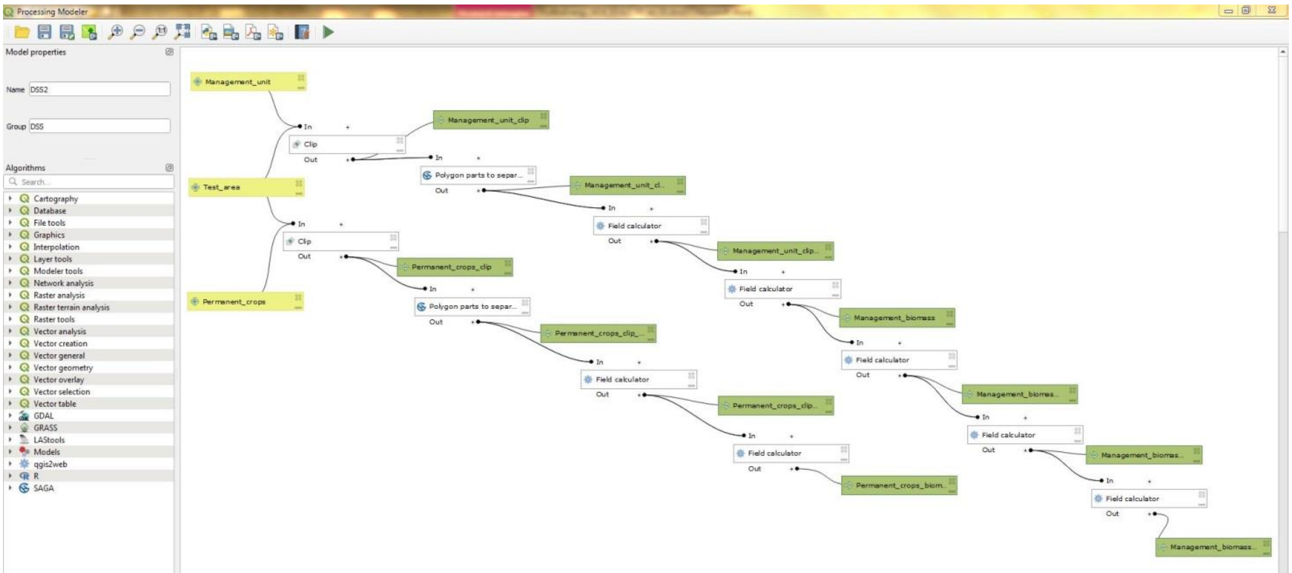
Forest_cumulative_cost_biomass_park_zone_sep_poly: The algorithm "Polygon parts to single part" was applied to splits parts of multipart polygons into separate polygons. This was done for all parts (inner and outer rings) by setting the "Ignore Lakes" option.

Forest_cumulative_cost_biomass_zone_clean: The algorithm "v.clean" (GRASS) was applied for cleaning topology of a input vector layer (Forest_cumulative_cost_biomass_park_zone_sep_poly). We choosed to remove all area <= 5000 square meters. Then, we set: "area" option as Input feature layer, "rmarea" (remove small areas, the longest boundary with adjacent area is removed) option as Cleaning tool, "5000" as Threshold in square meters.

Forest_cumulative_cost_biomass_zone_clean_area: The algorithm "Polygon properties" (SAGA) was applied to add geometric properties of polygons on a vector layer (Forest_cumulative_cost_biomass_zone_clean). We set "Yes" to "Number of parts", "Perimeter" and "Area" options. The output (Forest_cumulative_cost_biomass_zone_clean_area) contains these property attributes. It is a Forest accessibility map, that is a vector layer containing information regarding the forest type, the access time classes within 60 minutes, biomass district, municipalities, park zoning and surface area.

3.3.2 Advanced Modeler implementation

The “Advanced Modeler” created is showed below.



The first step in model implementation was the **Input** dataset definition: Management units map, Permanent crops map, Test area.

Management units map: Add Management_unit vector layer of the selected biomass district. This layer includes basic information such as ownership, municipality, biomass district, surface area, growing stock, yield, biomass and timber assortment for each management unit of forest management plan. ATTENTION: The "area" field in attribute table must be non-zero.

Permanent crops map: Add Permanent_crops vector layer of the selected biomass district. It consists of the list of permanent crops following the CORINE Land Cover nomenclature (III-level): 221-vineyard, 222-fruit trees and berry plantations, 223-olive groves. This layer includes the removable biomass for each permanent crop unit. ATTENTION: The "area" field in attribute table must be non-zero.

Test area: Add Test_area vector layer. It includes a polygon geometry identified by user, that is a hypothetical forest biomass supply basin.

The goal of Advanced Modeler was the quantification

The layers generated by the algorithms are just a temporary outputs that will be used as the input of another algorithm or definitive outputs. The generated **Output** are listed below.

Management_unit_clip: The algorithm "Clip" was applied to generate a new vector layer (Management_unit_clip) that contains only the parts of the features in the Input Layer (Management_unit) that fall within the polygon of the Overlay layer (Test_area).

Management_unit_clip_single: The algorithm "Polygon parts to single part" was applied to splits parts of multipart polygons into separate polygons. This was done for all parts (inner and outer rings) by setting the "Ignore Lakes" option.

Management_unit_clip_single_area: The algorithm "Field calculator" was applied to add new field (NewArea_ha) in attribute table of an Input layer (Management_unit_clip_single). We set "Yes" to "Create new field" and write "$area/10000" to "Formula" options. ATTENTION: For this Input layer, we add a new field "area" because it is necessary to keep the information on the initial value of the area for each record.

Management_biomass: The algorithm "Field calculator" was applied to recalculate the field "biomass" in attribute table of an Input layer (Management_unit_clip_single_area). We set "No" to "Create new field" and write ("biomass"*"NewArea_ha")/"area_ha" to "Formula" options. ATTENTION: The "area_ha" field in attribute table must be non-zero.

Management_biomass_growing: The algorithm "Field calculator" was applied to recalculate the field "growing_st" in attribute table of an Input layer (Management_biomass). We set "No" to

"Create new field" and write ("growing_st"*"NewArea_ha")/"area_ha" to "Formula" options. ATTENTION: The "area_ha" field in attribute table must be non-zero.

Management_biomass_growing_yield: The algorithm "Field calculator" was applied to recalculate the field "yield" in attribute table of an Input layer (Management_biomass_growing). We set "No" to "Create new field" and write ("yield"*"NewArea_ha")/"area_ha" to "Formula" options. ATTENTION: The "area_ha" field in attribute table must be non-zero.

Management_biomass_growing_yield_timber: The algorithm "Field calculator" was applied to recalculate the field "timber_ass" in attribute table of an Input layer (Management_biomass_growing_yield). We set "No" to "Create new field" and write ("timber_ass"*"NewArea_ha")/"area_ha" to "Formula" options. ATTENTION: The "area_ha" field in attribute table must be non-zero.

Permanent_crops_clip: The algorithm "Clip" was applied to generate a new vector layer (Permanent_crops_clip) that contains only the parts of the features in the Input Layer (Permanent_crops) that fall within the polygon of the Overlay layer (Test_area).

Permanent_crops_clip_single: The algorithm "Polygon parts to single part" was applied to splits parts of multipart polygons into separate polygons. This was done for all parts (inner and outer rings) by setting the "Ignore Lakes" option.

Permanent_crops_clip_single_area: The algorithm "Field calculator" was applied to recalculate the field "area_ha" in attribute table of an Input layer (Permanent_crops_clip_single). We set "No" to "Create new field" and write "$area/10000" to "Formula" options.

Permanent_crops_biomass: The algorithm "Field calculator" was applied to recalculate the field "mc_year" in attribute table of an Input layer (Permanent_crops_clip_single_area). We set "No" to "Create new field" and write ("area_ha"*"mc_ha_year") to "Formula" options. ATTENTION: The "area_ha" field in attribute table must be non-zero.

4 DSS FOR PLANNING BIOMASS-BASED ENERGY PRODUCTION IN THE PROTECTED AREAS WITHIN THE MADONIE REGIONAL NATURAL PARK (ITALY)

The shapefile of the accessible forest areas, including the related attributes, obtained from the basic DSS "Forest access" and conventionally named "forest_access_OK", allows us to carry out different analyzes and considerations regarding the accessibility of the woods occurring in the protected area in question and it provides a valid support for bioenergy production planning.

The advanced DSS "Analysis" returns the shapefiles of the management units and of the agricultural woody crops related to the study area (the supply basin of a hypothetical cogeneration biomass plant) set by the user. Starting from a known point in which to hypothesize the design of a cogeneration plant, the DSS allows us to know the type and quantity of available biomass deriving from forest areas and from agricultural woody crops, thus allowing the evaluation of different scenarios and providing a valid "support to the decision" in the design of cogeneration plants and in the planning of the relative supply chains of agro-forestry biomass.

Thanks to the use of specific statistical tools, it is possible to analyze and represent the data considered most significant, as shown below

4.1 Results

The woods occurring in the Madonie Natural Park are to a large extent accessible within the established time interval (1 hour). According to the zoning of the Madonie Natural Park, in fact, the accessibility of forest areas is always above 85%, with a maximum of 100% in the C zone (Table 1). The areas characterized by more restrictive levels of protection (A-B) have a lower value of forest accessibility, due to the lower diffusion of the road network.

Table 1. *Accessibility of forest areas in the different zones of the Madonie Natural Park.*

Park zone	Total forest area	Accessible forest area	
	ha	ha	%
	a	*b*	*c=b/a*100*
A	4.124,94	3.531,98	85,6
B	8.521,37	8.232,53	96,6
C	133,52	133,52	100,0
D	4.587,17	4.580,69	99,9
OUT	13.886,20	13.688,80	98,6
Total	**31.253,20**	**30.109,25**	**---**

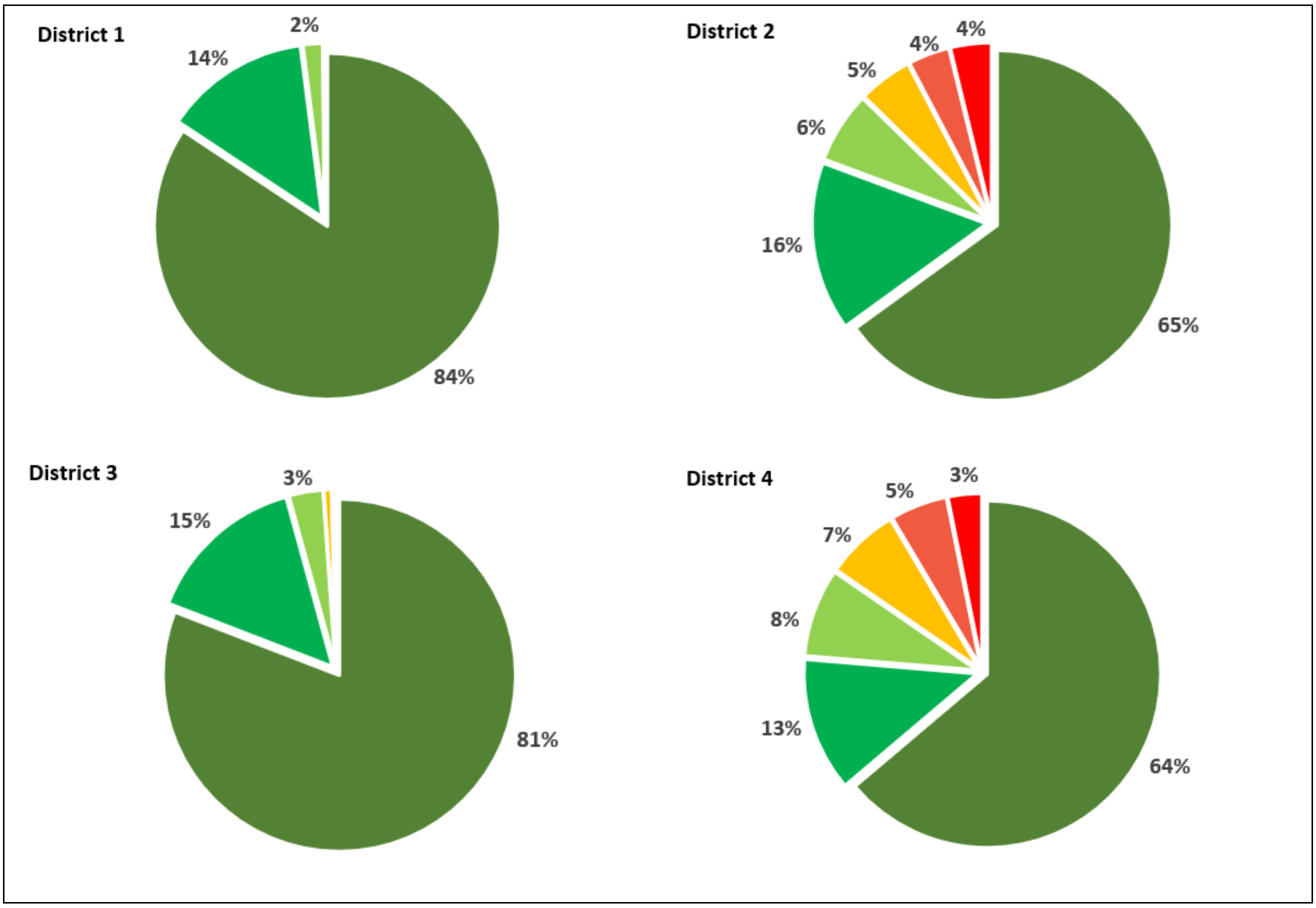
At the municipal level, the Municipality that registered the lowest level of forest accessibility is Isnello (79%). The other municipalities show values higher than 90%, with peaks of 100% recorded in Geraci Siculo, Petralia Soprana and Caltavuturo (Table 2). The Biomass District with the lowest accessibility of forest areas, is the District 2 (87.6%). The Districts 1, 4 and 5, have a forest accessibility slightly higher than 98%, and, finally, the District 3, has an accessibility of forest areas equal to 99.4% (Table 2).

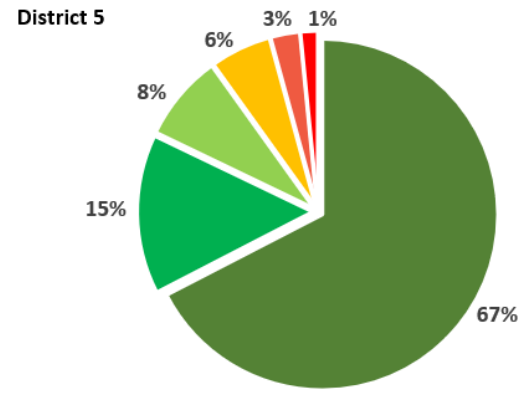
Table 2. *Accessibility of the forest areas in the Municipalities and Biomass Districts of the Madonie Natural Park.*

Biomass District	Municipality	Forest area in municipality	Forest area in district	Accessible forest areas in municipality		Accessible forest area in district	
		ha	ha	ha	%	ha	%
		a	*b*	*c*	*d=c/a*100*	*e*	*f=e/b*100*
1	Cefalù	2.406,07	9.845,86	2.347,50	97,6	9.677,64	98,3
	Pollina	2.190,67		2.154,60	98,4		
	San Mauro Castelverde	5.249,12		5.175,54	98,6		
2	Collesano	1.898,72	6.347,64	1.738,33	91,6	5.560,49	87,6
	Gratteri	1.535,64		1.521,75	99,1		
	Isnello	2.913,28		2.300,41	79,0		
3	Castelbuono	2.352,79	6.362,42	2.317,24	98,5	6.326,87	99,4
	Geraci Siculo	4.009,63		4.009,63	100,0		

Biomass District	Municipality	Forest area in municipality	Forest area in district	Accessible forest areas in municipality		Accessible forest area in district	
		ha	ha	ha	%	ha	%
		a	*b*	*c*	*d=c/a*100*	*e*	*f=e/b*100*
4	Castellana Sicula	476,88	4.583,54	472,99	99,2	4.504,66	98,3
	Petralia Soprana	643,96		643,96	100,0		
	Petralia Sottana	3.462,70		3.387,71	97,8		
5	Caltavuturo	501,66	4.113,74	501,66	100,0	4.039,59	98,2
	Polizzi Generosa	1.714,98		1.710,53	99,7		
	Scillato	531,79		494,13	92,9		
	Sclafani Bagni	1.365,31		1.333,27	97,7		
Total		**31.253,20**	**31.253,20**	**30.109,25**	**---**	**30.109,25**	**---**

The forest areas occurring in the Biomass Districts are mainly accessible in a time interval less than 30 minutes. Most of the forest areas can be reached in just 10 minutes, that is from 64% in District 4 to 84% in District 1 (Fig. 3).





Forest access time	District 1	District 2	District 3	District 4	District 5
	ha	ha	ha	ha	ha
10 min.	8.159,99	3.614,75	5.116,02	2.874,45	2.723,51
20 min.	1.322,79	870,32	941,19	563,96	593,87
30 min.	178,39	369,46	198,66	372,55	322,14
40 min.	16,47	279,37	45,62	310,04	227,76
50 min.	0,00	214,26	20,09	241,36	108,73
60 min.	0,00	212,33	5,29	142,30	63,58
	9.677,64	**5.560,49**	**6.326,87**	**4.504,66**	**4.039,59**

Legend of access time

■ 10 min. ■ 20 min. ■ 30 min. ■ 40 min. ■ 50 min. ■ 60 min.

Figure 3. *Accessibility of the forest areas in the Biomass Districts of the Madonie Natural Park (values less than 1% are not represented in the figure).*

The same analyzes carried out at the municipal level make it possible to assess the forest accessibility in the different time classes established. For instance, in the municipality of Petralia Sottana, 55% of the woods are accessible within the time interval of 10 minutes. Overall, 80% of the woods can be reached within 30 minutes (Table 3, Fig. 4).

Table 3*. Accessibility of forest areas in the Municipality of Petralia Sottana.*

Forest access time (minutes)	ha
10	1.856,69
20	488,59
30	350,89
40	307,88
50	241,36
60	142,30
Total	**3.387,71**

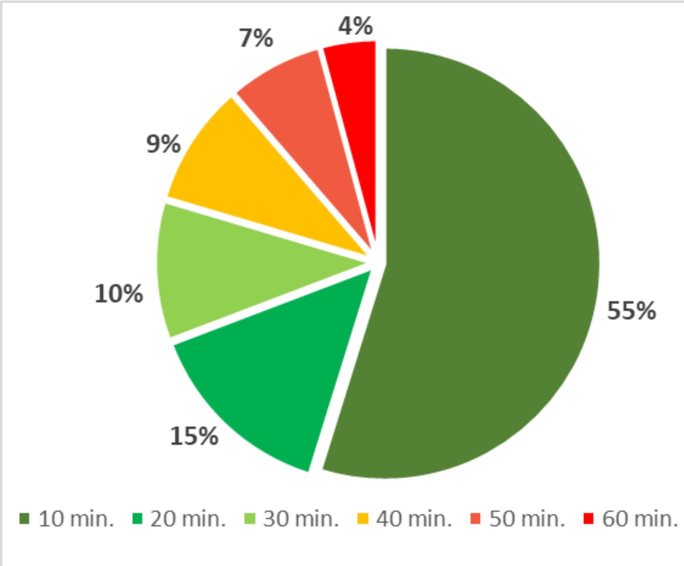


Figure 4. *The accessibility of forest areas distributed in the different access time classes (in %) in the Municipality of Petralia Sottana.*

Finally, referring to the forest categories (Forest Map of the Sicily Region, scale 1: 10,000), the following are present in the biomass districts of the Madonie Natural Park:

COD.	
CATEGORY	NAME
BA	"Woods of other broadleaf trees";
BS	"Pioneer and secondary formations";
CA	"Chestnut woods";
EC	"Turkey oak forests";
FA	"Beech forests";
FR	"Riparian formations";
THE	"Holm oak forests";
PM	"Mediterranean pine forests";
QU	"Downy oak forests";
RI	"Plantations";
ON	"Cork oak forests".

The results of the analysis of accessibility by forest category are shown in table 4. The categories showing the lowest level of accessibility are found at the highest altitudes (Beech forests 84.7%, and Turkey oak forests 90%), characterized by a less developed road network, and in forest stands colonizing even the rocky walls, such as the holm oak forests, with an accessibility of 88.9% of their total area. The remaining categories show accessibility values higher than 97% (Table 4, Fig. 5).

***Table 4**. Accessibility of forest areas by forest category in the Biomass Districts of the Madonie Natural Park.*

Forest category	**Total forest area**	**Accessible forest area**	
	ha	**ha**	**%**
	a	***b***	***c=b/a*100***
BA	1.319,30	1.308,10	99,2
BS	136,01	133,78	98,4
CA	260,52	258,01	99,0
CE	95,14	85,60	90,0
FA	2.676,31	2.266,91	84,7
FR	2.817,32	2.738,00	97,2
LE	4.356,58	3.873,53	88,9
PM	213,09	210,55	98,8
QU	9.881,57	9803,55	99,2
RI	3.339,27	3301,93	98,9
SU	6.158,09	6129,29	99,5
Total	**31.253,20**	**30.109,25**	---

The level of detail of the elaborations carried out with the DSS also allows to evaluate the accessibility of the different forest categories at the Municipal or Biomass District level to which they belong, thus allowing the planning of the interventions at the local level. The following tables 5-6 and figures 6-7, show, for example, the results obtained, respectively, for District 4 (Municipalities of Castellana Sicula, Petralia Soprana, and Petralia Sottana) and for the Municipality of Petralia Sottana. The accessibility values are to a large extent overlapping with the general data of the Biomass Districts (Table 4, Fig. 5).

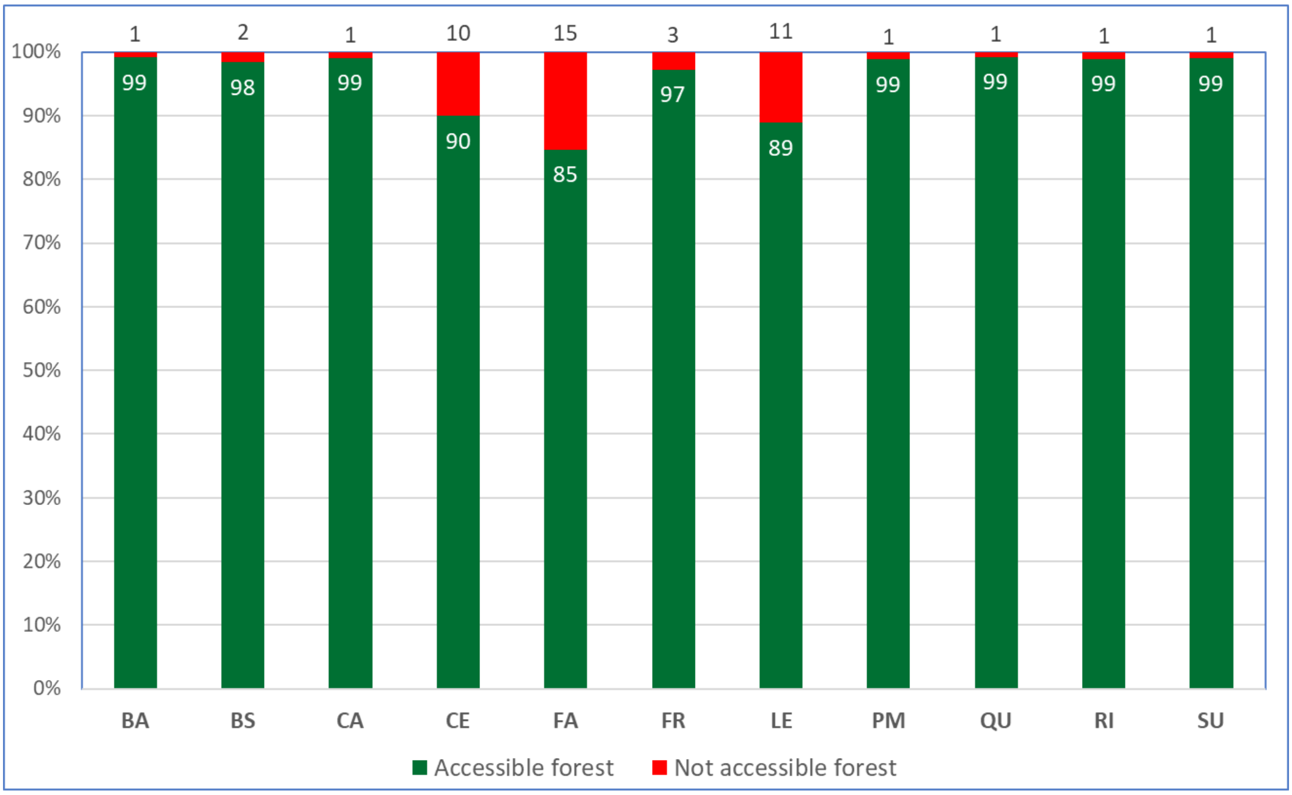


Figure 5. *Percentage distribution of the accessibility of forest areas by forest category in the Biomass Districts of the Madonie Natural Park*.

Table 5. *Accessibility of forest areas by forest category in the Biomass District 4.*

Forest category	**Total forest area**	**Accessible forest area**	
	ha	**ha**	**%**
	a	***b***	***c=b/a*100***
BA	369,26	368,97	99,9
BS	81,43	80,40	98,7
CA	45,72	45,02	98,5
FA	1.157,07	1.117,64	96,6
FR	555,62	531,65	95,7
LE	378,45	366,51	96,8
QU	837,75	837,75	100,0
RI	1.158,24	1156,72	99,9
Total	**4.583,54**	**4.504,66**	**---**

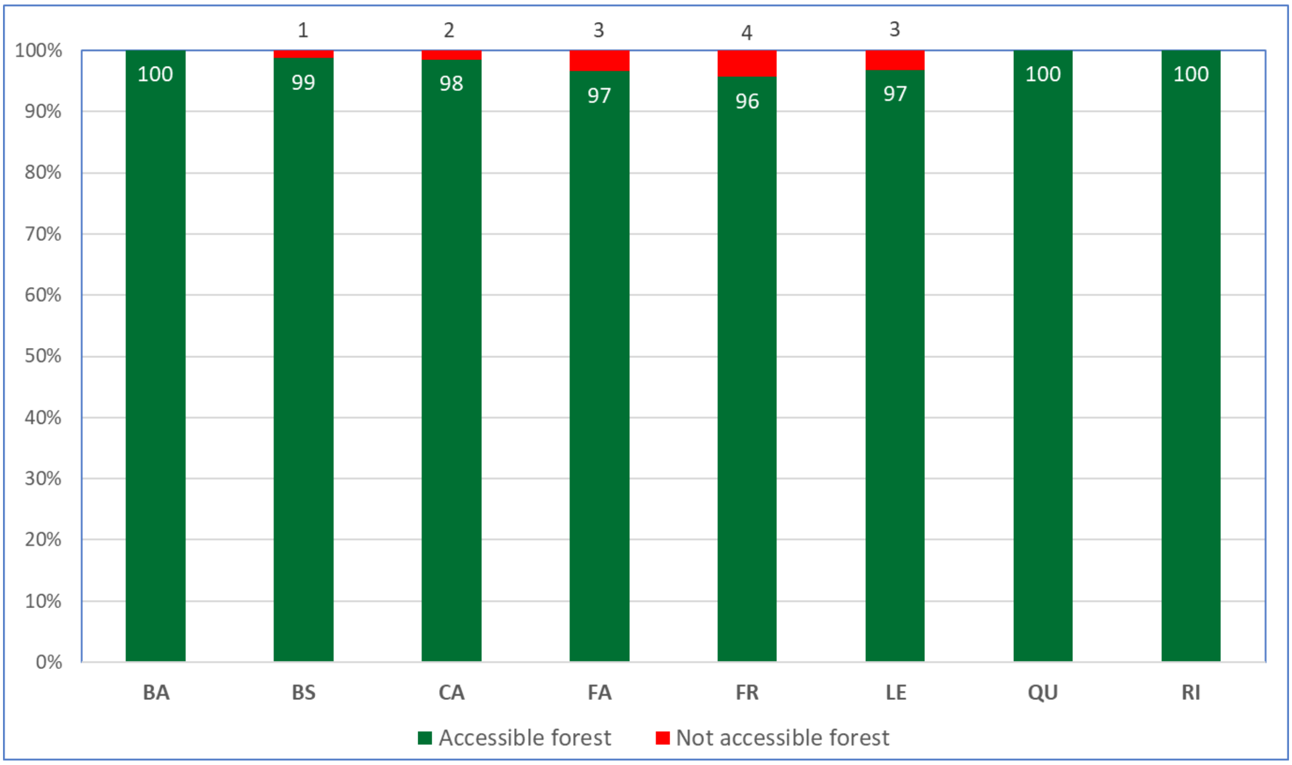


***Figure 6**. Percentage distribution of the accessibility of forest areas by forest category in the Biomass District 4.*

***Table 6**. Accessibility of forest areas by forest category in the Municipality of Petralia Sottana.*

Forest category	**Total forest area**	**Accessible forest area**	
	ha	**ha**	**%**
	a	***b***	***c=b/a*100***
BA	316,17	316,17	100,0
BS	2,95	2,95	100,0
CA	37,07	35,49	95,7
FA	1.072,85	1.032,07	96,2
FR	306,39	290,10	94,7
LE	371,89	359,70	96,7
QU	708,62	708,62	100,0
RI	646,76	642,61	99,4
Total	**3.462,70**	**3.387,71**	**---**

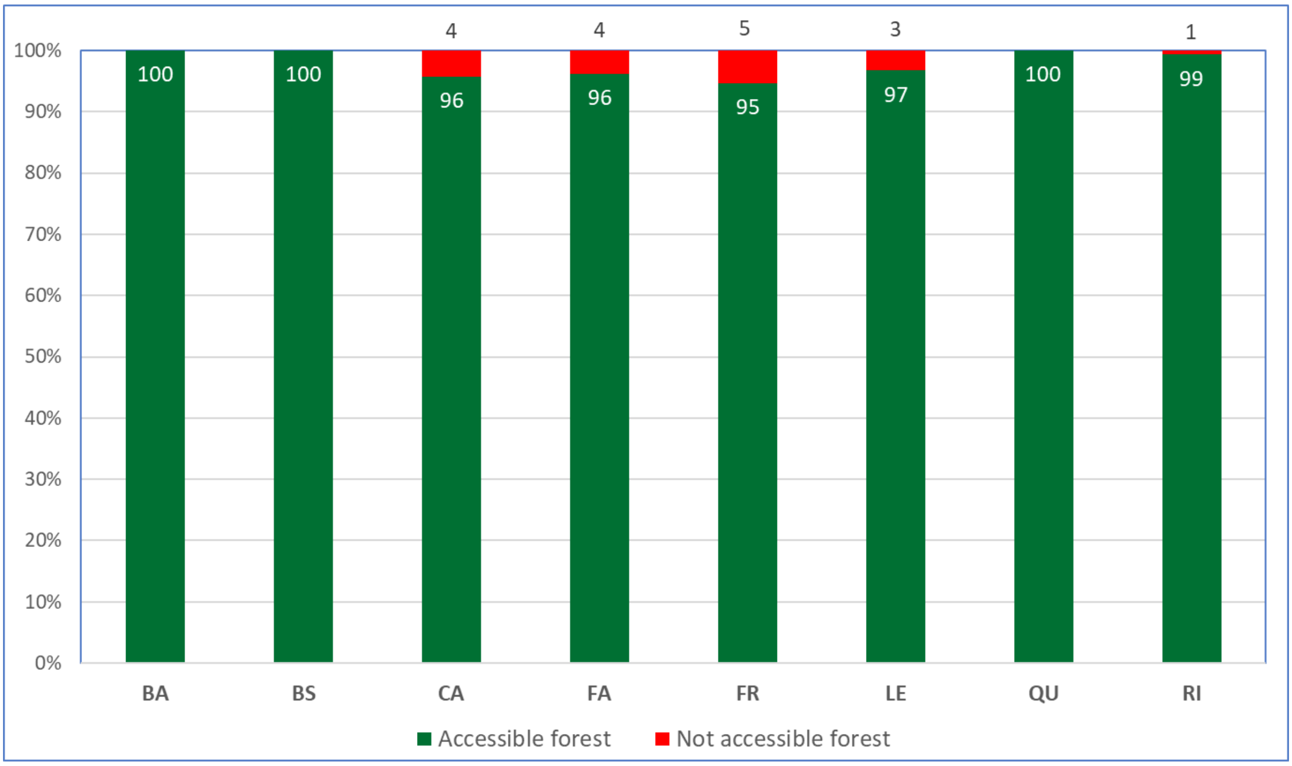


Figure 7. *Percentage distribution of the accessibility of forest areas by forest category in the Municipality of Petralia Sottana*.

7 FINAL SUMMARY

The Italian partners of ForBioEnergy project with the collaboration of other partners involved developed a Decision Support System (DSS) for planning biomass-based energy production in the protected areas. The Base and Advanced Models have been developed and implemented on a GIS platform, both ArcGIS and open-source QGIS software were used. Main goals of DSS were: i) to support the Authorities responsible for simplifying, speeding up and standardizing land monitoring and strategic planning procedures; ii) the DSS will be used by the decision-making bodies to assess the impacts of various scenarios, as well as the costs and benefits about the production of energy from residual agroforestry biomass in the public administrations; iii) the DSS will also be used, within the pilot Biomass District, as a support for determining the optimum plant size (and power) for energy and heat production and the relative biomass supply area.

The DSS models developed in ESRI ArcGIS environment and in QGIS open source environment are attached as supplemental materials.

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