Evaluation of the Northern Sardinia Forests Suitability for a Wood Biomass CHP System Installation

Geospatial systems for forest biomass estimation

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Abstract— **In this paper, the results of a preliminary feasibility study for the development of a sustainable supply chain, for the efficient production of heat and power in Sardinia, will be presented. The study area involved the state forest of Monte Olia, for which the biomass availability estimation for energy purposes has been carried out. The biomass estimate has been performed by comparing the results of three methods, using geomatics to environmental and forestry data. In particular, they provide a spatial prediction of the annual biomass supply and simulate the temporal availability for energy use.**

Keywords-geographical information systems; forest biomass; wood-energy supply chain; cogeneration

I. Introduction

The oil reserves will be able to compensate the estimated global demand for about 50 years [1], at the current consumption rates. Expecting a further world population growth and thus the per capita energy consumption, oil stocks will decrease in an even shorter time.

The chance to cope with the future demand for oil and, more generally, energy, will be based on the ability to best manage the stocks of this fuel, to promote the use of renewable energy sources and low-impact technologies for efficient energy production.

With regard to the national energy situation, in 2011, Italy was the tenth country for natural gas and oil imports, and the fourth for natural gas imports [2].

The current energy situation can be summarised on the basis of the provisional data derived from the National Energy Balance, referred to the year 2012 [3]: compared to an import of 86.278 Mt of oil, 5.397 have been produced and 29.173 have been exported, with a gross energy consumption of 63.590 Mt of oil. So, it represents the most important national energy source, followed by gas (also mostly imported). Therefore, it appears that energy consumption is high and there is a strong dependency on non-renewable energy resources imports.

The international efforts to reduce the fossil fuels consumption and to reduce the non-renewable sources dependence led to the enactment of the Kyoto Protocol, ratified by Italy in 2002, with the subsequent adoption of a National Action Plan for the greenhouse gases (GHG) emissions reduction. In the last GHG Inventory Report [4] for the EU-27, even though between 1990 and 2010 there has been a decrease in GHG emissions equal to 15.4% (excluding Land Use, Land Use Change and Forestry), between 2009 and 2010 there has been an increase of 2.4%.

Specifically, we note that in 2010 CO_2 emissions from fossil fuel combustion increased in the EU-27 by 2.8%. Italy's contribution to the total European emissions (Tg CO_2 eq.) rose from 519 to 501 between 1990 and 2010, representing the fourth nation in the EU-15 and EU-27 for the most amount of emissions. In order to reduce GHG emissions and mitigate the climate change, since 1988 the Intergovernmental Panel on Climate Change (IPCC) gives a clear view of the state of art related to the problem and its potential environmental and socio-economic impacts.

Among the possible ways to reduce GHG emissions concerning heat and power production and supply, the IPCC identified, among others, the improvement in energy conversion, transmission and distribution, including cogeneration and efficiency enhancement in energy user demand in various fields [5].

Notably, the cogeneration is a technology that allows meeting the aforementioned conditions for hazardous emissions reduction and for the improvement of energy efficiency, compared to separate production of heat and power.

Between the renewable energy sources that could be used in such systems, forest biomasses have a considerable importance because, if cropped according to sustainability criteria and with and optimization of cutting, concentration and transport phases (in order to minimize fuel consumption and related emissions), they allow effectively integrating the local energy production. In fact, by 2020, in Europe,

 ISBN: 978-1-61208-308-7

biomass will cover 19% of the renewable produced power and 78% of heating/cooling from renewable sources [6].

Currently, the ever growing energy demand does not match self-containment in energy production at a delocalised level; in this sense, the forest biomass may represent a valuable contribution to the achievement of the targets set by the Kyoto Protocol for 2020, according to forest resources sustainability. Sustainable development strictly connects all the ecological and ecosystemic components with the usability of forests in terms of leisure and use of woody and non-woody products; this is strongly interconnected with the socio-economic and cultural heritage of a territory. Is along these lines that, in 1993, the Ministerial Conference on the Protection of Forests in Europe came to a definition of sustainable forest management: "Sustainable forestry is the management and use of forests and forested areas in a way and at a pace which allows the preservation of their biological diversity, productivity, regeneration ability, vitality, as well as their capability of fulfilling relevant ecological, economic, and social functions at local, national, and global levels now and in the future, in a way which does not damage other eco-systems" [7]. From that viewpoint, where overexploitation of forests, repeated burning, extreme events and infestations impoverished the local forests, biomass removal sustainability leads to a limited and cautious use of the woody resources. The forests productivity is based on complex processes, which must be taken into account in the models for estimating the biomass for energy purposes.

For the exploitation of forest biomass for energy use it is necessary to assess not only the current availability of biomasses, but also its stability over time; in fact, the fuel supply fluctuations can also cause relevant problems on the payback time of a wood-energy chain. This type of supply chains have been developed thanks to the increasing awareness by the scientific world, institutions and industry of the fossil fuels consumption and the environmental emissions associated with their combustion.

In Italy, the commonly used biomass for heat and power production consists mainly of solid biomass derived from forestry and agriculture, agro-industrial residues, biogas and bioliquids [8].

To comply with the sustainability and efficiency criteria, a wood-energy chain has to satisfy certain characteristics: the biomass must be present in sufficient quantities in order to feed a cogeneration plant, the maximum distance from the sampling sites to the system must be less than 70 km (criterion of short chain) and the plant must be able to meet the characteristics imposed by the type of user and of biomasses.

The preliminary feasibility study for the Monte Olia state forest (North-eastern Sardinia) aimed to define the possibility of setting an efficient and sustainable wood-energy supply chain, based on the previously discussed criteria, using the Geographical Information Systems for the spatial estimation of biomass for energy purposes and the prediction of its annual availability.

Firstly, the characteristics of the study area will be presented; then, the three estimation methods applied to the territory will be explained; finally, the results will be discussed.

II. CASE STUDY

A. General Description of the Forest Resources and Territory

The study area concerns the public forest of Monte Olia, located in the North-eastern part of Sardinia (Italy) and it is part of the Forest Complex of Alta Gallura-Buddusò (10887 ha); the forest is managed by Ente Foreste della Sardegna, regional organism, whose mission is to protect, develop and promote Sardinian forests and wildlife. Between the major functions of Ente Foreste della Sardegna, there is also the involvement in research and studies aimed at the development of eco-friendly production activities that are complementary and related to forest management.

The Monte Olia state forest occupies almost 2300 hectares and is characterised, from a geological perspective, by Palaeozoic granite; in fact the area is in the central part of the Corsica-Sardinia batholith, one of the largest European intrusive complexes [9].

The soils of Gallura are generally poorly evolved and shallow. In fact, for example, plowing and repeated use of fires for new pastures creation in *Quercus suber* forests caused a significant reduction of the organic matter in soils. Particularly, in cork production areas the ectorganic horizons are well developed, while in the woody areas primarily used for grazing, the ectorganic horizons are very poorly developed [10].

The vegetation of the state forest has been significantly influenced by repeated fires; the original holm oak mesophilic forest remains in few areas in the valleys, characterised by covers lower than 20-25%, with a dense undergrowth of arbutus, heather, lavender and cistus.

The most consistent group of artificial formations dates back to about 80 years ago, and consists of a high forest of *Pinus pinea*, with dense undergrowth of *Quercus Ilex* and *Quercus Suber*. For the most recent reforestations (1990 and 1991), *Quercus ilex*, *Quercus suber*, *Quercus pubescens* had been planted as well as *Pinus pinea*, *Pinus halepensis*, *Pinus pinaster*, *Pinus nigra ssp.* Laricio. In the eastern part of the state forest pure reforestations of *Quercus Suber* had been done [11].

B. Estimation of the Sustainable Allowable Biomass

For the estimation of forest biomass for energy purposes, reference has been made to three methods:

- Forestry and Environment Regional Plan of Sardinia Region (PFAR) [12],
- Barbati A., Corona P., Mattioli W. and Quatrini A. [13],

- Nocentini S., Puletti N. and Travaglini D. [14],

and the results have been compared, in order to define the most appropriate method with respect to the case study.

Specifically, the PFAR method has been used for a rough estimate of Sardinian availability of forest biomasses; the Barbati A., Corona P., Mattioli W. and Quatrini A. method has been recently proposed in Italy for the Alta Valle dell'Aniene (Lazio), which adapts at a local level the criteria adopted from [15] for reducing the environmental pressures and it considers the current increments of forests.

The method developed by Nocentini S., Puletti N. and Travaglini D. has been developed for high forests of Mediterranean conifers in Tuscany and it takes into account the minimum forest stock.

In order to apply the three selected methods, the following georeferenced Gauss-Boaga (west zone)/Roma 40 shapefiles have been used:

a. Land use map of the Monte Olia state forest: woodland classes are identified by areas > 2000 m^2 with a width >20 m and a coverage > 20%. The minimum mapped unit is 2000 m^2.

b. Forest roads.

c. Spot elevations and contour lines.

Within the preparation of the detailed forestry plans of the state forest, the maps of land use and forest roads have been made in 2012 by assignment to Italian forestry companies. These data have been provided by Ente Foreste della Sardegna, while the two layers containing the elevation data (elevation points, contour lines) are available for free online [16].

Only the polygons of forest have been considered, for each woody class the areas have been derived (hectares).

The distribution of the land use classes is shown in Table I.

TABLE I. LAND USE SURFACES (PERCENTAGE OF THE MONTE OLIA STATE FOREST)

Land Use Class	Surface (% of the state forest)
waters	0.21
shrubs	23.91
conifers	39.14
deciduous broadleaves	0.34
rupestrian woodland	1.72
evergreen broadleaves	7.95
firebreaks	1.40
crops	0.06
maquis	16.74
pasture lands	1.64
failed reforestation	0.75
rocks	6.11
urban fabric	0.03

The woodlands occupy less than a half (47%) of the Monte Olia state forest and consist almost entirely of conifers (82%), while the remaining part is covered by evergreen broadleaf woods (only the 0.3% of the total area is covered by deciduous broadleaves).

PFAR method - The estimation of the available biomass is different for broadleaves in the state forests and conifers in the state forests.

- Broadleaves in the state forests

  The average increment of 2.14 $m^3 ha^{-1} yr^{-1}$ has been applied to the woody polygons; the surfaces have been multiplied with the usage coefficient of 20%.

In order to compare the findings of the three methods and to obtain the potential allowable cut of biomass (tons of dry matter per year), it has been necessary to multiply the result by the Wood Basic Density (WBD) and Biomass Expansion Factor (BEF) coefficients [17], whose values are reported in Table II. The BEF factor expands the growing stock volume to the volume of aboveground woody biomass (aboveground biomass/growing stock); the WBD coefficient allow converting the fresh volume of timber wood to dry weight (dry matter, 20% of humidity).

The final values for broadleaves are 79.6 t d. m. yr^{-1}.

- Conifers in the state forests

  A range minimum-maximum for the biomass stock per hectare has been assigned: 170÷200 m^3 ha^{-1}. For each limit of this range the steps are indicated below:

  - The surfaces have been multiplied by the usage coefficient 0.45 and then by the lower or upper limit of biomass per hectare (170 and 200 m^3 ha^{-1} respectively).
  - All the biomass will be cut during the next 20 years: the values obtained at the last point have been divided by 20 years.

  At the end of those steps, we applied the WBD and BEF coefficients and we obtained 2089.7 t d. m. yr^{-1} for the lower limit and 2458.5 t d. m. yr^{-1} for the upper limit.

The total available quantity of biomass for energy uses is between 2169.3 t d. m. yr^{-1} (lower limit condition) and 2538.1 t d. m. yr^{-1} (upper limit condition).

Barbati A., Corona P., Mattioli W. and Quatrini A. method - For the wooded classes indicated in the land use map, the corresponding current increments derived from the National Inventory of Forests and Carbon Sinks (INFC) [18] have been applied to the relative polygons as well as the WBD and BEF coefficients (Table II).

TABLE II. CURRENT INCREMENTS, BIOMASS EXPANSION FACTOR AND WOOD BASIC DENSITY

Forest Classes	*Current Increment (m^3 ha^{-1} yr^{-1})*	*BEF*	*WBD (tons of dry matter per m^3 of fresh volume)*
Conifer	3.4	1.37	0.43
Deciduous Broadleaf	1.3	1.47	0.53
Evergreen Broadleaf	1.3	1.42	0.67

The biomass obtained by the product of current increments, BEF, WBD and surfaces for each of the forest classes is equal to 2096.39 t d. m. yr^{-1}.

Afterwards the removal reduction coefficients have been applied, according to the accessibility of forestry vehicles, in order to estimate the net potential allowable biomass cut.

The forest accessibility is a limiting factor for cutting and skidding tracks and essentially depends on slope and distance from roads; the reduction factors proposed by the model (Table III) have been used, by changing the coefficient value from 0 to 0.25 for the slope class 21% - 30% and distance from roads 500 - 2500 m, since slopes between 20 and 35% and distances from the roads <2500 m are on average accessible [19]; for distances from roads >2.5 km, cutting and skidding costs are prohibitive and the coefficient is 0 for all slopes.

We subsequently proceeded to the generation of DEM (from the elevation values a.s.l. of the two layers of quoted points and contour lines), whose spatial resolution is 20 m × 20 m. The slopes map has been extracted from those raster files.

TABLE III. REDUCTION COEFFICIENTS

Slope class (%)	*Distance from forest roads (m)*			
	0-150	***150-500***	***500-2500***	***>2500***
0-20	0.75	0.75	0.75	0
20-30	0.5	0.5	0.25	0
30-50	0.25	0	0	0
>50	0	0	0	0

With regard to slopes, the Monte Olia forest has slopes greater than 30% for the most part (46.7%); about one third of the territory is in the slope class 0% - 20% (30.7%) and the rest falls within the class 20% - 30% (22.6%).

The distance from roads map (Figure 1) has been created by applying the *Cost Distance* algorithm (implemented in the ArcGIS software, which has been used for the biomass estimation), considering the forest roads as input.

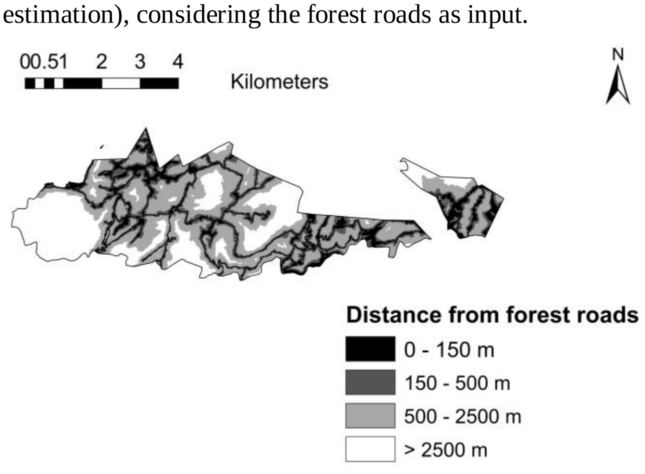

Figure 1. Map of the distances from roads, Monte Olia

The algorithm allows obtaining a map of the cumulative distances from forest roads with respect to a cost surface, the slopes map. We have decided to not apply the *Euclidean Distance* algorithm, since the territory has highly accentuated slope variations, which should be taken into account in terms of feasibility of cutting and skidding.

The raster files of slopes and distance from roads have been combined, in order to assign the coefficients of Table II to the woody cells.

The map of potential allowable biomass cut before the accessibility criterion has been multiplied by the reduction coefficients map, using the *Map Algebra*; the algorithm multiplies cell by cell the value of biomass with the reduction coefficient. The final output is a map of the net allowable biomass cut, considering the limitations due to accessibility (t d. m. yr^{-1}).

For the Monte Olia state forest 719.5 t d. m. yr^{-1} have been obtained.

The final biomass estimation map shows a limited availability of forest biomasses, with meager and fragmentarily distributed quantities, with respect to the result obtained by the application of the PFAR method.

Nocentini S., Puletti N. and Travaglini D. method - This model takes into account the theory of the systemic silviculture [20][21][22] and the notion of the Safe Minimum Standard [23].

The method is based on the concept according to which it is possible to cut the biomass if the real stock P_r is greater than the minimum stock P_m of 20% (P_r/P_m=1.2), with a removal rate depending on this ratio.

First of the application of the method, the areas with slopes >35% and distant more than 2.5 km from forest roads have been omitted.

Subsequently, the real stocks have been assigned to the remaining woodland polygons: reference has been made to [18]. Such data must be referred to an initial time t_0 for the estimate: it has been set at the year 2007, which coincides with the end of the phase 3+ of the last INFC [18].

Starting from t_0, the iterations of the method have been performed:

-at the time t_0 the Pr is equal to the stock of INFC;

-at the time t_1, Pr_1=Pr_0+the growing rate (m^3 ha^{-1} yr^{-1}).

-In the most general condition, we verify Pr_{x-1}/P_m >1.2: if true, the removal rates indicated in Table IV can be applied; if it is false, we continue by doing the comparison at the time t_x. If at the time t_{x-1} a certain amount of biomass has been removed, at the time t_x it has to be subtracted to the comparison.

For the case study, the only forest class which has a value of Pr_0 similar to P_m (equal to 100 for eliophilous species [14]) is that of the conifers, so the iterations have been done solely for this class (Figure 2), starting in 2007 and carrying out the calculations for 16 years.

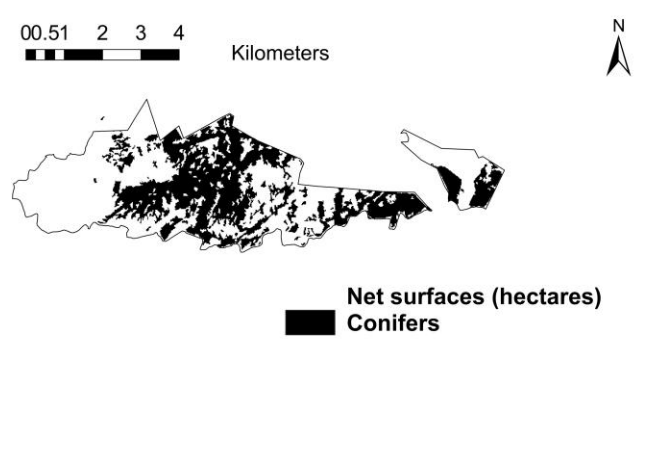

Figure 2. Map of net surfaces of conifers, Monte Olia

The results are reported in Table V and Table VI.

TABLE IV. REDUCTION COEFFICIENTS

Pr/Pm	*Annual Removal (%)*
>2	1.5
1.8÷2	1.25
1.6÷1.8	1
1.4÷1.6	0.75
1.2÷1.4	0.5

TABLE V. ITERATIONS FROM THE FIRST TO THE EIGHTH YEAR

T	Year	Pr	Pr/Pm	Value	Removal
t_0	2007	95.9	0.96	<1.2	NO
t_1	2008	99.3	0.99	<1.2	NO
t_2	2009	102.7	1.03	<1.2	NO
t_3	2010	106.1	1.06	<1.2	NO
t_4	2011	109.5	1.10	<1.2	NO
t_5	2012	112.9	1.13	<1.2	NO
t_6	2013	116.3	1.16	<1.2	NO
t_7	2014	119.7	1.197	<1.2	NO

TABLE VI. ITERATIONS FROM THE NINTH TO THE SIXTEENTH YEAR

Year	Pr	Pr/Pm	Comparison	Removal Rate (m^3 ha^{-1} yr^{-1})	Removal (Fresh volume) m^3 yr^{-1}	t d. m. yr^{-1}
2015	123.1	1.23	1.2 ÷ 1.4	0.005	442.1	260.8
2016	125.9	1.26	1.2 ÷ 1.4	0.005	452.3	266.7
2017	128.7	1.29	1.2 ÷ 1.4	0.005	462	272.6
2018	131.4	1.31	1.2 ÷ 1.4	0.005	471.9	278.4
2019	134.2	1.34	1.2 ÷ 1.4	0.005	481.7	284.2
2020	136.9	1.37	1.2 ÷ 1.4	0.005	491.5	290
2021	139.6	1.40	1.2 ÷ 1.4	0.005	501.3	295.7
2022	142.3	1.42	1.4 ÷ 1.6	0.0075	766.5	452.2

Table V shows that, for the first eight years, it is not possible to cut biomass in the Monte Olia state forest, due to the fact that the real biomass stock is less than the minimum stock.

Between 2015 and 2022 the biomass cutting will be possible and the average availability of biomass for that period is around 300 t d. m. yr^{-1}; the maximum value is 452 t d. m. yr^{-1} of total allowable timber.

From the application of this method, it appears a very limited biomass availability for energy purposes; this allows us to assert that these quantities may be used to feed a small cogeneration plant.

By comparing the results obtained by the implementation of the three above discussed methods for the Monte Olia state forest, we noticed that:

- The first method (PFAR) [12] provided a very huge quantity of biomass. This model is not good for a real estimation of the biomass availability; in fact it doesn't consider any constraints about biomass removal.

- The Barbati A., Corona P., Mattioli W. and Quatrini A. method and the Nocentini S., Puletti N. and Travaglini D. method lead to lower values; in order to decide which has to be taken into account, in order to design a wood-energy supply chain for a cogeneration system installation close to the study area, it is important to analyse them from the point of view of the forest stands and regional forest management.

Specifically for the state forest of Monte Olia, the guidelines of the silvicultural interventions are based on the systemic silviculture and the minimum forest stock [14][22]: so, the available biomass for energy purposes is strictly related to those principles. The Barbati A., Corona P., Mattioli W. and Quatrini A. method considers the current increments instead of the forest stocks: it may occur that, by applying this model, the real forest stock is lower than the minimum stock, but if we cannot take it into account, the estimation of the available biomass does not correspond to the real condition.

Furthermore, the two methods differ for the considered forest classes: in the Barbati A., Corona P., Mattioli W. and Quatrini A. model we use all the woody classes (conifers as well as broadleaves); in the Nocentini S., Puletti N. and Travaglini D. method, we must take into consideration only the classes which comply with the condition $P_r/P_m > 1.2$.

From the comparison between the three methods, it is clear that the method proposed by Nocentini S., Puletti N. and Travaglini D. is the most appropriate, because of the abovementioned reasons and also because it provides the lowest and most precautionary value.

III. CONCLUSION

The preliminary feasibility study of a sustainable supply chain for the efficient energy production in a cogeneration plant, using the Monte Olia forest biomasses, has allowed us to determine if the biomass quantities are sufficient for their use in cogeneration plants and which is the most appropriate estimation model for the case study.

The quantification of the forest biomass for energy purposes in the study area has shown a very limited biomass availability, which enables to install only a small size cogeneration plant close to the area.

By the application of the three chosen models and the comparison between their results, it has been possible to verify the significant differences and to select the most suitable methodology for the estimation of forest biomass for energy uses. The Nocentini S., Puletti N. and Travaglini D. method could be used not only for Monte Olia, but also for other public forests which have similar conditions.

The above mentioned method has been effectively used to obtain a simulated situation of the annual biomass removal for the next nine years.

The research will continue by developing the supply chain: laboratory analyses will be conducted on the most relevant forest species, in order to know the fuel characteristics; an energy audit is being carried on a service building within the study area and an economic evaluation of the supply chain will be performed.

ACKNOWLEDGMENT

The research has been funded by Ente Foreste della Sardegna through a three-year agreement.

The research has been carried out within the “Master And Back” Program of the Autonomous Region of Sardinia.

Gratefully acknowledges Sardinia Regional Government for the financial support (P.O.R. Sardegna F.S.E. Operational Programme of the Autonomous Region of Sardinia, European Social Fund 2007-2013 - Axis IV Human Resources, Objective l.3, Line of Activity l.3.1 “Avviso di chiamata per il finanziamento di Assegni di Ricerca”).

REFERENCES

[1] R. C. Duncan and W. Youngquist, Encircling the peak of world oil production. Natural Resources Research, vol. 8, n. 3, 1999, pp. 219-232.

[2] ENI Company, [online] Available at <http://www.eni.com/world-oil-gas-review-2012/static/pdf/wogr-2012.pdf> [Accessed 19 August 2013].

[3] Ministry of Economic Development of the Italian Republic, [online] Available at <http://dgerm.sviluppoeconomico.gov.it/dgerm/ben.asp> (file referred to 2012, provisional data uploaded 26 April 2013) [Accessed 19 August 2013].

[4] EEA, Annual European Union greenhouse gas inventory 1990–2010 and inventory report 2012 - Technical report no.3, 2012.

[5] Intergovernmental Panel on Climate Change, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press, United Kingdom and New York, NY, USA, 2011, p. 174.

[6] C. Panoutsou and K. Maniatis, Biomass futures: Estimating the role of sustainable biomass for meeting the 2020 targets and beyond. 2013, Biofuels, Bioproducts and Biorefining 7 (2), pp. 97-98.

[7] Helsinki Resolution H1, Second Ministerial Conference on the Protection of Forests in Europe, 1993.

[8] N. Scarlat, J. F. Dallemand, V. Motola, and F. Monforti-Ferrario, Bioenergy production and use in Italy: recent developments, perspectives and potential. Renewable Energy 57, 2013, pp. 448-461.

[9] G. Oggiano and A. Di Pisa, Introduction to the Sardinia geologic evolution. Reports of the Seminary Sciences Faculty of the University of Cagliari, Appendix Vol. 71, Issue 2, 2001.

[10] A. Vacca, Effect of land use on forest floor and soil of a Quercus suber L. forest in Gallura (Sardinia, Italy). Land Degrad. Develop., 11 2000, pp. 167-180.

[11] Ente Foreste della Sardegna, [online] Available at <http://www.sardegnaambiente.it/j/v/152?s=8661&v=2&c=1653&t=1> [Aceessed 19 August 2013].

[12] Autonomous Region of Sardinia, Department of Enviromental Protection, Environment and Forestry Regional Plan, Appendix 3, 2007 [online] Available at <http://www.regione.sardegna.it/documenti/1_73_20080129175721.pdf> [Accessed 19 August 2013].

[13] A. Barbati, P. Corona, W. Mattioli, and A. Quatrini, Forest biomass for heat energy generation: an analysis model for the Upper valley of Aniene River. Italian Journal of Forest and Mountain Environments, 67 (4), 2012, pp. 329-336.

[14] S. Nocentini, N. Puletti, and D. Travaglini, Planning and sustainable use of forest biomass in the forest-energy chain: a methodological proposal. Italian Journal of Forest and Mountain Environments, 66 (4), 2011, pp. 293-303.

[15] EEA, How much bioenergy can Europe produce without harming the environment? EEA Report no. 7, 2006.

[16] Autonomous Region of Sardinia, [online] Available at <http://www.sardegnageoportale.it/catalogodati/download/> [Accessed 19 August 2013].

[17] ISPRA, Italian Greenhouse Gas Inventory 1990-2007. National Inventory report, 2009.

[18] P. Gasparini and G. Tabacchi (edited by), The National Inventory of Forests and forest Carbon stocks INFC 2005. Second Italian national forest inventory. Methods and Results. Ministry of Agricultural, Food and Forestry Policies; State Forestry Corps. Council for Research and Experimentation in Agriculture, Research Unit for monitoring and forest planning. Edagricole-Il Sole 24 ore, Bologna, 2011.

[19] O. Ciancio, P. Corona, M. Marinelli, and D. Pettenella (edited by), Evaluation of Forest Fire Damages in Italy. Firenze: Tipografia Coppini, Oct. 2007, p. 39.

[20] O. Ciancio and S. Nocentini, Systemic silviculture: scientific and technical consequences. Italian Journal of Forest and Mountain Environments, 51, 1996, pp. 112-130.

[21] O. Ciancio, P. Corona, M. Marchetti, and S. Nocentini, Systemic forest management and operational perspectives for implementing forest conservation in Italy under a pan-European framework. Proceedings of the XII World Forestry Congress, Vol.B, Outstanding paper, Level 1, Québec City, 2003, pp. 377-384.

[22] O. Ciancio and S. Nocentini, Biodiversity conservation and systemic silviculture: Concepts and applications, Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology: Official Journal of the Società Botanica Italiana, 145:2, 2011, pp. 411-418.

[23] M. A. Toman, The difficulty in defining sustainability. Resources (published by Resources for the future), no. 106 (winter), pp. 3-6.