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Forest management and biomass production for energy: a case study in Calabria Region (Italy)

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Abstract

Among all renewable energy sources, forest biomass represents both an important alternative source to fossil fuels and an opportunity for the socio-economic development of various marginal mountain areas in Calabria. The aimof this study is to estimate the potential revenue from timber harvest in a mountainous area belonging to the Reggio Calabria District, which is showing a great interest in forest biomass production. Following a cost-benefit analysis and by considering all marketable wood assortments, the here applied assessment method allowed us to estimate the timber production of the study area,estimating the potential biomass amount production for energetic purposes. The investigated forest stands coveran area of about 12000 hectares, an appropriate spatial scale for biomass production. Results showed a significant productive capacity, estimated at about 174000 Euro year^{-1} for each type of timber product, even if the more consistent amounts derive from round wood assortments. The estimation of woody biomass available for energetic purposes, mainly deriving from residual wood and timber assortments was estimated on about 24200 tons year^{-1}. The results obtained suggested how it could be possible, in the context of the Metropolitan city of Reggio Calabria, the creation of a small biomass energetic power station,with a generating capacity of about 1 MW.

*Keywords:*renewable energy resources; forest biomass; forest types; timber harvest; potential economical income; sub-regional scale.

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1. Introduction

Forest ecosystems and urban forests, through their normal functioning, provide a range of goods and services important for human well-being, which are collectively called Ecosystem Services (ES). Forests deliver multiple ES: regulating (carbon sequestration, regulation of water-flow, erosion prevention), habitat provision and cultural (opportunities for recreation and tourism) (Marziliano et al., 2013). Particularly, forests supplies benefits in provisioning services, such timber, non-wood products and bioenergy (Bangash et al., 2013). However, a management not integrated in the ecological context and finalized only at the simple exploitation of forest resources, could cause fragmented forest landscapes and degrading quality in other ecosystem services (La Fortezza et al., 2013).

The biomass production for energetic purposes, deriving from forestry, timber industry and Short Rotation Forestry (SRF), can provide various environmental and socio-economic benefits (Neri & Brunori, 2008; Marziliano et al., 2015a; Moneti et al., 2015), and are relevant under Mediterreanean environmental and socioeconomic condition (Marziliano et al., 2015b). In fact, the use of forest biomass for energy contributes to the reduction of CO_2 emissions (Nishizono et al., 2005; Hellrigl, 2006), improving also some forest functions, such as hydrogeological and biodiversity conservation, if realized correctly. Moreover, forest biomass consumption could contribute to the socio-economic development of rural areas (Ciccarese, 2005; Sanesi et al., 2013), through the restoration of agro-forest activities and technological advances in the bio-energy field. In this context, it is important the implementation of a small-scale forest-wood-energy chain, implementing the use of local raw materials and carrying out the conversion phases in a local context. The development of such chains could contribute to reducing the supply costs of wooden materials, reducing also the costs related to the transports on large distances (Recchia et al., 2009). Moreover, the conversion of forest biomass to energy should be carried out in small sized power factories of 1-2 MW. However, a negative trait affecting the development of a bio-energetic chain could be represented by the onerous initial investment necessary for a biomass power plant (Moneti et al., 2015). However, the economic incentives, given within the European Union framework, can effectively promote and support the initial investment.

The productionofforest biomassforenergyis assuming particular importance in the Calabria Region, considering its large area covered by forests. According to the data reported by the Regional Rural Development Plan (RRDP) 2007-2013, the potential of wood production potential is estimated at approximately 1.5 million cubic meters, and the 55% of them is destined for the biomass market (e.g. large sized thermal power stations and domestic heating systems) (Zimbalatti & Proto, 2009; Proto & Zimbalatti, 2015). In order to contain the costs of transport and to strengthen the chain of energy production at sub-regional level, the RRDP encourages the creation of biomass small-sized plants that could be realized in several mountainous contexts.Therefore, an important issue regards the assessment of the real availability of forest biomass, in order to calculate the proper dimensions of a biomass factory for energy production.

In this study we considered how a quantitative estimation of the woody biomass locally available could be an useful support tool for satisfying the biomass request for energy deriving from the metropolitan area of Reggio Calabria, taking into account also the other ecosystem and economical services that forests provide. Particularly, here we give a general overview, based on silvicultural and dendrological data sets, of the forest stands occurring in the context of the ex Mountain Community of "*Versante Tirrenico Meridionale*", located in the District of Reggio Calabria. Based on this approach, we then focused on the estimation of the potential production of forest biomass in the study area where, recently, the local authorities have already demonstrated a growing interest on this topic.

2. Material and Methods

2.1. Study area

The study area encompasses the territory of the ex Mountain Community "*Versante Tirrenico Meridionale*", located along the southern side of the "*Aspromonte*"massif (Reggio Calabria District). The area is north located from the city of Reggio Calabria, in an altitudinal range of 220÷550 m a.s.l. Its extension is about 277.70 $Km^2$where the 51% of the area is located in a mountainous context (Marziliano et al., 2008). In the altitudinal range of *400*÷500 m a.s.l., the study area is characterized by forest stands often located near to the urban areas. At higher altitude, the main forest typesarecharacterized by beech (*Fagus sylvatica* L.) high forests, sometimes mixed with silver fir (*Abies alba* Mill.). Moreover, in the altitudes ranging from 800 and 1100/1200 m a.s.l., forests are characterized by coppice dominated by beech, often suffering the pressure of excessive pasture.

The central and western part of the area is characterized by chestnut (*Castanea sativa* Mill.) coppice forests, representing an important economic income for both private and public forest sector. On the contrary, the central and northern part is characterized by oak coppice forests, especially dominated by holm oak (*Quercus ilex* L.). Finally, in the municipalities of Molochio, Oppido and Varapodio, the landscape is characterized by black pine(*Pinus nigra* Arnold ssp. *laricio* - Poiret) plantationsand, to a lesser extent, of maritime and domestic pine (respectively *Pinuspinaster* Aitonand *Pinus pinea* L.) (Marziliano *et al*., 2008). Table 1 reportsthe distribution of forest typesin the examined territory and the amount of the different timber assortments retrievable (in percent) in the each forest types. Soils occurring in the mountainous part of the study area refer to the *Dystrudepts* e dei *Dystroxerepts* groups (FAO, 1998) while, in the “Gioia Tauro” plain, they are mainly linked to the *Hapludands* groups.The climate is Mediterranean, warm-temperate at the lower altitude, becaming then colder in the mountainous areas (cold-temperate).

Table 1.Distribution of forest typologies and amount of the different timber assortments retrievable (in percent) in the examined forest types.

Forest Types	Extent (ha)	Assortment typology	(%)	Forest Types	Extent (ha)	Assortment typology	(%)
Beech forests	4947.44 (43.1%)	Veneer log	40	Chestnuts woods	1948.71 (17%)	Poles	90
		Sawlog	40			Log	5
		Firewood	20			Sawlog	5
Silver fir forests	141.56 (1.2%)	Log	70	Holm oak forsts	2794.42 (24.3)	Firewood	100
		Biomass for energy	30				
Silver Fir-Beech forests	729.96 (6.4)	Log	60	Conferous reforestation	923.47 (8%)	Log	40
		Firewood	20			Biomass for energy	60
		Biomass for energy	20				
Total wood area (ha)					11485.56 (100%)		
Total area					27770.00		

2.2. Methodological approach

In the study area, sampling activities were conducted among the different forest types. Quantitative data were collected for describing the tree living components and the stand attributes, also in relation to the silvicultural approaches applied. The measurements were carried out in 80 plots (each of 600÷1500 m^2, in relation to the density and complexity of the forest stands)positioned through a systematic sampling design.Moreover, the monitoring plots were proportionally assigned to the different forest types in relation to their total extent. Therefore, the diameter at breast height (*DBH*) and the total height (*Ht*) of all the trees were measured. Moreover, on a sub-sample of standing trees (around 30%) randomly selected, an increment wood core was taken by a Pressler borer at the stem breast height, in order to calculate the current annual increment (*CAI*). The CAI derives from the estimation of the Percentage Current Annual Increment (*PCAI*) of the forest standing volume ($PCAI_{st}$). Measuring the forest standing volume of a given stand (V_{st}), the CAI is then calculated as:

$$CAI_{st} = \frac{PCAI_{st} \cdot V_{st}}{100} \qquad (1)$$

where

$$PCAI = \frac{\sum_{j=1}^{m} PCAI_j \cdot V_j}{\sum_{j=1}^{m} V_j} \qquad (2)$$

where $PCAI_j$ is the PCAI referred to the j-th DBH (tree stem diameter at breast height) class; V_j is the forest standing volume, referred to the j-th dbh class; and m is the number of DBH classes in the stand (Marziliano et al., 2012). The volume of each standing tree was calculated using double-entry volume models already applied in the Italian National Forest Inventory (Tabacchi et al., 2011). On the basis of the data obtained, the average annual removal of growing-stock volume was then calculated, considering the indications contained in the Regional Forestry Plan of Calabria (max 20% of the standing volume).

In order to assess the potential availability of woody biomass, both the residual woody productsobtained from primary conversion in forests (branches, tops and bark) and the assortment percentages retrievable from utilization and destined for energetic purposes, were considered (Table 1). In the first case, residual woodhas been assessed by applying an aliquot - expressed in percentage terms - to the potentially utilizable biomass per hectare (APAT, 2003; Giordano, 1981). Particularly, it has been assumed that all the forests were utilized each year without decreasing the standing timber stock (Ciccarese, 2006). Therefore, considering the waste volume retrieved for energy purposes and the forest area available for each year of interventions, the quantity of biomass annually achievable from residual wood was then calculated.

In order to assess the economical value of the woody products, the potential average revenue obtained annually from the landing timber sale,and the average utilization cost, were determined for each forest type (Bordone et al. 1998, 2000; Stillitano et al., 2009). The potential average annual revenue wascalculated through the estimation of the retrievable average annual timber biomass, multiplied with the average wood price. Moreover, the average utilization cost were also considered in relation to the various techniques of extraction adopted, then computing the average unit cost of utilization for each species. The study of the timber production value of a large study area implies the need for macro-assessments, in order to obtain representative values of the examined area. For this reason, the degree of local spread has been also taken into account, in order to represent the conditions that most frequently take place in the study area. For this purpose, the data have been gathered at utilization firms, at primary manufacturing industries (sawmills) using timber coming from the investigated area (Stillitano et al. 2009; Zimbalatti et al., 2005; Proto et al., 2014).

3. Results and discussion

Table 2 reports the dendro-auxometric results obtained among the different forest types investigated. Moreover, Fig. 1 showsthe tree aboundances in relation to the diameter classes, highlighting an high diameters variability for almost all the study sites, but no for coppice stands.

Table 2. Dendrometric data obtained among the different forest types

Forest types	N° of trees/ha	DBH (cm)	Hg (m)	Basal area (m^3/ha)	Volume (m^3/ha)	PCAI (%)	CAI (m^3/ha/yr)	Biomass (Mg/ha/yr)
Mono-layered beech	382	38.2	25.5	43.8	554.0	1.4	7.8	5.01
Bi-layered beech	529	29.0	23.1	34.9	400.7	2.0	8.0	5.14
Multi-layered beech	903	19.8	19.5	27.8	270.1	2.5	6.8	4.37
Silver Fir	500	36.1	22.7	51.2	565.7	2.2	12.4	4.70
Silver-Fir-Beech fir	387	25.1	17.4	19.1	163.2	2.5		
Beech	295	26.2	21.8	15.9	172.6	2.0		
Total	682			35.0	335.8	2.3	7.7	4.34
Chestnut	5589	9.0	11.0	35.6	208.7	3.4	7.1	6.49
Holm oak	8064	6.3	9.4	24.7	130.6	3.1	4.0	4.73
Coniferous reforest.	851	27.7	21.5	51.3	547.3	2.8	15.1	8.29

Beech stands are characterized by different structures, from mono-layered stands to pluristratified ones (Fig. 1A-1B-1C).The mono-layered (Fig. 1A) and bi-layered (Fig. 1B) beech stands, but also the silver fir forests (Fig. 1E), derived from long-lasting repetition of silvicultural practices, while selective cutting were applied in the silver fir-beech mixed forests (Fig. 1D) and in the pluristratified beech stands (Fig. 1C). The current structures observed in the reforested conifer stands resulted from the past intervention realized in the frame of the I and II Special Low of the

Calabrian Region. Thanks to these actions, from 1957 to 1980, reforestation and forest recovery activities interested 153.000 ha, with a consequent reduction of the erosion processes in mountainous areas.Both the reforested areas and the stands interested by long-lasting repetition of silvicultural practices are generally homogeneous structures, with a low species diversity; in these forests, the tree density ranges from around 380 to 850 trees per hectare (Table 2).On the contrary, stand structures deriving from selective cuttings are mainly characterized by an high diversity in tree species, but also by a more complex structural stratification (Fig. 1C).Additionally, in these stands also the tree density resulted higher if compared with the other forest types investigated (Table 2). The beech-silver fir mixed stands (where silver fir is dominant) is an interesting forest type, since it could represent the final stage of the natural evolution in the now beech dominated forest areas.The basal area and living tree volumes observed (Table 2) showed very high values of wood production in all the studied stands, but not for the beech pluristratified forests.Moreover, Table 2 reports also the mean values of the woody biomass potentially available each year (with a 12% of humidity content), hypotizing a 10-years cutting-cycles. These values already exclude the woody materials lost during the first stages of the forest cutting activities.

Chestnut and holm oak forests are mainly characterized by coppice stands. These stands are economically important in the regional context, since they satisfy the requests among the local woody chain, especially for firewood (holm oak) and roundwood (chestnut) of various dimensions. Their cutting cycles are variable, from 14 to 18 years for chestnut forests, 24 years in the case of holm oak stands.Chestnut stands are usually characterized, at the end of their cutting cycle, by 5-6000 trees per hectare of agamic origin (Table 2), most of them of small dimension (Fig. 1G).In these stands, hypothizing a 15-yeas cutting cycle, the woody biomass available should be around 135 cubic meters per hectare. Moreover, in the holm oak coppices, the number of trees per hectare ranges from 7000 to 9000 trees, considering a 24-years cutting period; also for holm oak, trees are often characterized by small dimension (Fig. 1H). In these stands, the woody biomass available should be around 130 cubic meters per hectare.

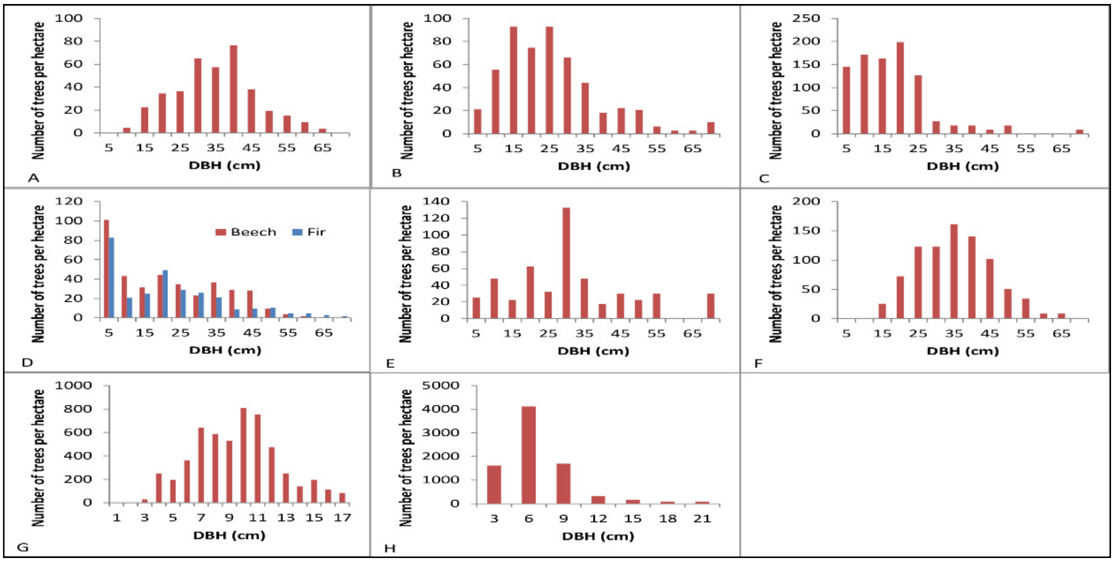

Fig. 1. Distribution of number of trees in relation to the DBH for each investigated forest type. Letters refers to the different forest types as follow: A= Mono-layeredbeech; B= Bi-layered beech; C= Multi-layered beech; D= Silver fir-beech; E=-Silver fir; F= Coniferous reforestation; G= Chestnut; H=Holm oak.

The results obtained for the average production values and the estimation of the total amounts of biomass potentially available each year in each forest typology are reported in Table 3. The production values in the examined area are of 174242.38 Euro year^{-1}. In particular, the highest values are obtained from beech forests, the unique wood typology that provides for the largest industrial wood quantity to be employed in valuable joineries. In addition, beech forests are the largest woodlands that could be mostly utilized annually. Compared to beech forests, the production value of chestnut and holm oak ones is significantly lower because of the smaller utilizable forest extent.Moreover, the economical revenue is smaller for the silver fir forests, since they are the less represented forest type. Regarding the stands reforested with black pine, even if they cover an important portion of the study area, their timber economic value is very low if compared with the other forest species here investigated.

Table 3. Assessment of the forest production values and of the total annual retrievable biomass from forest in the study area.
PAR= Potential average revenue; AUC=Average utilization cost; APV= Average production value; US=Utilized surface; FPV= Forests production value; BREP= Biomass recycling for energy purposes; RBU=Retrievable biomass from utilizations; TB= Total biomass.

Forest types	PAR ($€ ha^{-1} yr^{-1}$)	AUC ($€ ha^{-1} yr^{-1}$)	APV ($€ ha^{-1} yr^{-1}$)	US ($ha^{-1} yr^{-1}$)	FPV ($€ yr^{-1}$)	BREP ($Mg yr^{-1}$)	RBU ($Mg yr^{-1}$)	TB ($Mg yr^{-1}$)
Beech	346.90	122.38	224.52	494.74	111078.43	3250.44		3250.44
Silver Fir	346.85	217.95	128.90	14.16	1825.20	73.74	199.11	272.85
Silver-Fir-Beech	304.43	127.50	176.93	73.00	12916.25	431.69	633.15	1064.84
Chestnut	339.82	146.71	193.11	129.91	25087.26	687.48		687.48
Holm oak	307.79	170.47	137.32	116.43	15998.43	995.94	13231.80	14227.74
Coniferous reforest.	281.75	202.20	92.35	92.35	7346.82	156.18	4591.76	4747.94
TOTAL					**174242.38**			**24251.31**

Through the analysis of the different typologies of timber assortments, our results highlight that almost all the species occurring in the study area, but no the chestnut, could provide firewood and biomass for energetic purposes. More in detail, assessing the biomass production for energetic uses among the different forest types, results revealed that the silver fir forests, the mixed fir-beech forests and the coniferous reforested lands could provide biomass for 30, 20 and 60% of the total volume, respectively. Regarding the holm oak forests, it was assumed that the whole volume available would be used for the biomass production. Moreover, it must be underlined that, for the assessment of the available biomass, there were not considered the residuals available from the primary and secondary wood manufacturing.

Moreover, the biomass volume that could be obtained is estimated on about 24251.30 Mg year^{-1}(Table 3), revealing an interesting potential for an energetic enhancement of forest resources.In this study the limitations to the silvicultural interventions induced by the topographical traits and by the presence of protected areas were not considered; however these limitations are present on very small areas (Marziliano et al., 2008) and do not reduce significantly the total amount of the available biomass.In any case, we should consider also the influence of the average costs for the utilizations (Table 3): they are expensive if compared with the selling revenue (Proto et al., 2014; Proto & Zimbalatti, 2015). Particularly, the scarce level of forest mechanization and organization increases significantly the cost of labour in the forestry sites.

Anyway, the results here obtained, both economical and dendrometric, underline how it could be sustainable the utilization for energy use of forest biomass, coming from residual wood and from timber assortments. The estimated volumes could feed one or more small biomass power stations with a generating capacity that do not exceed complexively 2 MW. Therefore, the use of wood as fuel can contribute to reducing the atmospheric emissions of greenhouse gases, ensuring the public utility functions of forests and providing an opportunity for a socio-economic development in the rural areas here investigated. For these purposes, it is fundamental the knowledge of the forest stands traits and potentialities, but also a political and socioeconomic support is needed, also because it is still inadequate.

4. Conclusion

The role of forest biomass as a renewable source of energy is encouraging an increasing interest in environmental, social and economic issues. Therefore, this study has examined the potential availability both of forest resources at timber harvesting and of their retrievable biomass in the examined area. In order to increase the energetic value of forest resources, their management at large scale should be improved. Moreover, considering the rough ground topography characterizing the Aspromonte area and the resulting high thinning costs in forestry, it should be more economically sustainable the installation of small sized plants for energetic purposes, more than one unit of bigger dimension, in order to reduce the costs of transports of the woody materials.Moreover, the building of small energy conversion systems (from 200 to 500 kWe) is simple to install, even in rural and mountain environments (Proto et al., 2014).Finally, in order to continually use the forest biomass for energetic purposes, the Metropolitan City of Reggio Calabria should adopt forest planning tools useful to set up the woody chain in a long-term perspective. In fact forest planning, both at large and small scales, is essential for a sustainable management of the forest resources, also for the biomass production for the local population uses.

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