A FOSS4G model to estimate forest extraction methods and biomass availability for renewable energy production

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Abstract

The current approach to the satisfaction of energy needs envisions a mix of renewable energy sources. In a forest rich region, such as the Italian alpine area, one of the main renewable energy source is the wood biomass available in its forests. The BIOMASFOR project aims to evaluate the amount of this resource in the Trentino region (Italy) and, more important, to asses which part of biomass is actually extractable, given its quality and the energy needed to move it to the facilities where it is used. Therefore, a model based on the FOSS4G framework to estimate biomass availability for energy production in an alpine area has been developed. A considerable amount of data regarding forest management is available in Trentino, but a reliable evaluation of biomass availability must take into account the local management of forest resources and the actual possibility to reach the forest compartments, depending on infrastructures and terrain morphology. The model combines the morphological characteristics of mountain landscape and the different features of the forest extraction means and techniques in order to improve the current estimates by the local government and to create a more general tool for biomass evaluation. The complex logical structure of the model has been implemented in a tool which combines GRASS, PostgreSQL and PostGIS. The interaction between a GIS and a DBMS is essential to process and blend the spatial information and the huge and complex management plan database. Several scripts have been developed to apply the model to a wide area. Furthermore, the model has been implemented as a new GRASS module. The forests of Trentino have been classified depending on different extraction methods, providing a more accurate evaluation of biomass availability and to identify possible future location of biomass power plants, helping to define biomass potential and management guidelines.

1. Introduction

Energy production is one of the most important future challenge for human societies. The decreasing availability of traditional energy resources, such as fossil fuel, and the growing awareness that ecological responsibilities must be payed by companies (Diamond 2006), as shown by the recent

Mexican Gulf disaster on the Deepwater Horizon oil rig, are making more urgent the identification of alternative solutions. In the last years, the demand and use of renewable energy is increasing all over the world (Vasco 2009) and Bio-energy plays an essential role in the European ambitions to increase the share of renewable and indigenous energy sources. Bio-energy is the single most important renewable energy source for Europe, both in terms of real production of energy as well as in terms of technically and economically feasible potential (Andre P.C. Faaij 2004) and EU aims to triple bio-energy production compared to 1999 levels within 2010. Moreover, Openshaw (2010) highlights how bio-energy could contribute to poverty alleviation, about 13 million people could be employed in commercial biomass energy in the sub-Sahara Africa area.

In this global frame, the Autonomous Province of Trento (Provincia Autonoma di Trento, from now on PAT) a forested region in northern Italy, is going to face an increasing demand of biomass from forest extraction to produce energy (PAT, 2001). This demand can offer a good opportunity for the development of forest management, but, at the same time, the appropriate management practices must be used to guarantee a sustainable management (SAM, 2004) in order to preserve both production and ecological functions.

Bibliography researches both at local and at global level highlight that from different scenarios comparison the main divergence among the studies is due to the fact that the two most crucial parameters, land availability and yield levels in energy crop production, are very uncertain (Goran Berndes et al, 2003).

Several models have been developed to estimate availability of biomass forestry residues for energy use, at national scale (Viana et al. 2010; Buchholz et al. 2009; Vasco and Costa, 2009; Lewandowskia et al, 2006; Ranta 2005) and local/regional scale (Gutam et al.; Trink et al.; Fernandes and Costa, 2010; Alfonso et al. 2009; Frombo et al. 2009; Kinoshita et al. 2009), most of them focus on logistic problems and optimization, without taking into account that land availability depends from the extraction techniques that are used.

Therefore this problem has been tackled using an innovative approach, integrating the modeling in a GIS environment of the main and more specialized biomass harvesting techniques with the available information about the effective yield.

The aim of the GIS analysis is the creation of a model at the regional scale, which can be used to evaluate, depending on the physical features of the land, on the topsoil and on the accessibility:

- areas where skidding is possible,
- suitable vehicles and devices,
- the expoitable volume, with reference to data from forest management plans,
- eventually, the total quantity of forest biomass which can be harvested to produce energy.

The model has been implemented by means of Free and Open Source Software, and in particular software used is:

- **GRASS** 6.4 for raster processing;
- **PostgreSQL** 8.4.4 and **PostGIS** 1.5.1 for vector processing;
- **Python** 2.6.5 for GRASS scripting, connection to DB through psycopg2, units conversions (from m^3 to ton of biomass using numpy);
- **QGIS** 1.4.0 to display maps and saving images.

In literature some models are available (Krč and Košir, 2009; Lubello et al., 2006), developed with proprietary software and aimed to select forest landscape depending on extraction techniques. The model we developed in this work takes into account extraction techniques but focuses on biomass production.

2. Problem Statement

2.1 Extraction Techniques

In order to identify areas where skidding is possible, different extraction techniques and land and terrain characteristics must be taken in to account.

As first a step to evaluate the real possibility of extraction of forest biomass, a model of the extraction techniques must be created and applied to the study area, so that maps where extraction is possible can be drawn.

Different skidding techniques are currently used in the Trentino region, mainly:

- **ground skidding (see Figure 1)**:
  - on the forest ground: dip, trawl with winch;
  - on trails (skidding trails) with timber on wheeled or tracked vehicles;

Figure 1.On the left Harvester by Heikki Valve on the right Forwarder by BenFrantzDale, (from wikipedia: http://en.wikipedia.org/wiki/File:TJ_harvester i.jpg http://en.wikipedia.org/wiki/File:Forwarder.jpg).

- **overhead skidding (see Figure 2)**:
  - with cables: cable crane/sledge yarder or tower yarder;
  - aircraft: helicopters.

2.2 Extraction Limits

For ground vehicles technical limits are mainly related to terrain features and distances to round-up locations:

- maximum terrain slope of 30%, when harvesting is performed downhill, and of 20% uphill (Spinelli, 2009, Lubello et al., 2006);
- low ground unevenness (Spinelli, 2009), albeit harvester and forwarder, with main body 60 cm above the ground, are less sensible to this condition with respect to tractors;
- usually the maximum load on a forwarder trailer is of 10 t, allowing a good economy even with great distances. However, beyond 800 m the productivity is usually very low (Spinelli et al., 2004).


Figure 2. Cable Crane System (18 October 2009 Paneveggio, Trento, Italy by Chiara Lora)

Technical limits for cable devices (cable crane/sledge yarder or tower yarder) are less stringent with respect to ground vehicles:

- maximum terrain slope of 20%, to reduce the number of racks for each span, a maximum slope of 120%, to allow the movements of operators knocking down the trees;
- unevenness is not relevant, obviously a higher unevenness makes movements of vehicles and men more difficult;
- skidding distance depends on cable length, in general, for a tower yarder the maximum distance is around 1000 m, the typical distance being 600 m, while for a cable crane/sledge yarder with fixed station it is possible to reach 1500 m, usually the distance is around 1000 m.

		Harvester Forwarder	Cable crane or Tower yarder
up hill ↑	Slope	20%	20-120%
	Max distance	800 [m]	1000 [m]
	Accidental	1	Any
down hill ↓	Slope	30%	20-120%
	Max distance	800 [m]	1000 [m]

Table 1. Operational limits for different extraction techniques

This study concerns only skidding with mechanized vehicles and devices. A highly mechanized forest yard uses harvester-forwarder or a tower yarder or a cable crane/sledge yarder, while timber dressing is performed by a mechanical device removing branches and bark and trimming trunks.

After this step, biomass can be chipped or baled for delivery to a biomass power plant.

2.3 Study Area

Trentino region is in northeastern Italy, roughly in the center of the arc of the Alps. The land is covered for about its 58% by forest and the mean annual forest production is about 500.000 m^3 prescript by Forestry Plan Management, about 330.000 m^3 commercial of coniferous wood (Servizio Foreste e Fauna, 2008). Forestry management in Trentino is carried out following sustainable forest management techniques and the total final yield each year is half of forestry volume increment.

Moreover, recent studies have underlined how, in the last 50 years, the lower anthropic pressure on forests has induced its expansion, taking up areas which were used as pastures. Pastures have shrunk , decreasing landscape diversity with possible consequences on biodiversity but also accumulating extractable forest biomass (Tattoni et. Al. 2010).

Several studies indicate the high mechanization in forest extraction (Ciccarese et al., 2003; Spinelli e Verani, 2000) and the possibility to make forest residues available as chips (Dellagiacoma, 2008a; Spinelli and Secknus, 2005) as key factors to make this energy source competitive in economic terms (Dellagiacoma, 2008b).

Researches in the local area show how currently mechanization levels are still too low (Giovannini, 2009) to gain an economic advantage from the recover, chipping and movement of biomass from residues (Spinelli, 2008).

This study is focused on highly mechanized skidding for high forest areas (272.822 ha, i.e. 79% of the total forest), considering only public forests l (262.507ha, 76%) and omitting private forests (82.123 ha, 24%) (Servizio Foreste e Fauna, 2009).

The study of the coppice forest areas (72.844 ha, 21%), (Figure 3.6) is omitted due to the different management techniques and above all because the prescribed cut is mainly use as firewood, therefore the residual is scarce.

Usually biomass feasible for chipping is obtained by harvest cut, which provides lop and top and by thinning, when plants with diameters below 17.5 cm are taken, and finally from restoration and cleaning operations, which provide branches and bushes. The model focuses on products of harvest cut, which are regulated by Forest Management Plans. Therefore, the assessment of the available volume for chipping is made using the final yield estimation made in these plans.

2.4 Input Data

A large data set of georeferenced data is available for the Trentino region, providing information about terrain, morphology and forestry.

The implemented model, which is based on assumptions reported in par. 2.1 and 2.2 and is described in par. 4, is based on the physical features of the terrain (slope, unevenness), on the spatial distribution of roads and tracks and on the availability of final yield in each compartment, as indicated by the PEFO database (**P**iani **E**conomico **FO**restali - Economic Forest Plan), which contains data from the Forest Management Plans.

Available data, provided by the Forestry service of the local government (Servizio Foreste e Fauna della Provincia Autonoma di Trento) in digital form, are:

- vector data of high forest from the PEFO database, updated to 2007, containing 22604 forestry compartments, in Shapefile ESRI format;
- vector data of roads and tracks, updated to 2008, in Shapefile ESRI format;
- DEM - Digital Elevation Model, with 10 m resolution.

3. Methods

The model has been implemented to take into account the different logging systems and can be divided in two different modules, one for Harvester and Forwarder and the other one for Cable Crane, both need:

- distance from roads and tracks (DISTANCE);
- exclusion criteria are applied to areas which are not suitable for skidding criteria of Table 1 (EXCLUDE);
- two different methods have been used to convert the value of the surface [ha/comp.] where skidding is possible to timber volume [m^3] for each compartment (ESTIMATE):
    - homogeneous final yield on each compartment;
    - final yield assuming medium final yield rate per hectare;
- finally, two further methods to convert from available m^3 to tons, so that it will be possibile to convert forest biomass quantity into available energy (CONVERSION).

In the Harvester and Forwarder module, before the evaluation of movement distances, it is necessary to locate uphill and downhill areas with reference to the nearest track or road, since the limiting value for slope is different in the two cases. To discriminate between uphill and downhill logging it is necessary to find, for each pixel into which the region is divided, the nearest point on a track or on a road and to evaluate the height difference (drop). Once the difference in level and the distance are known, it is possible to apply the skidding criteria of Table 1.

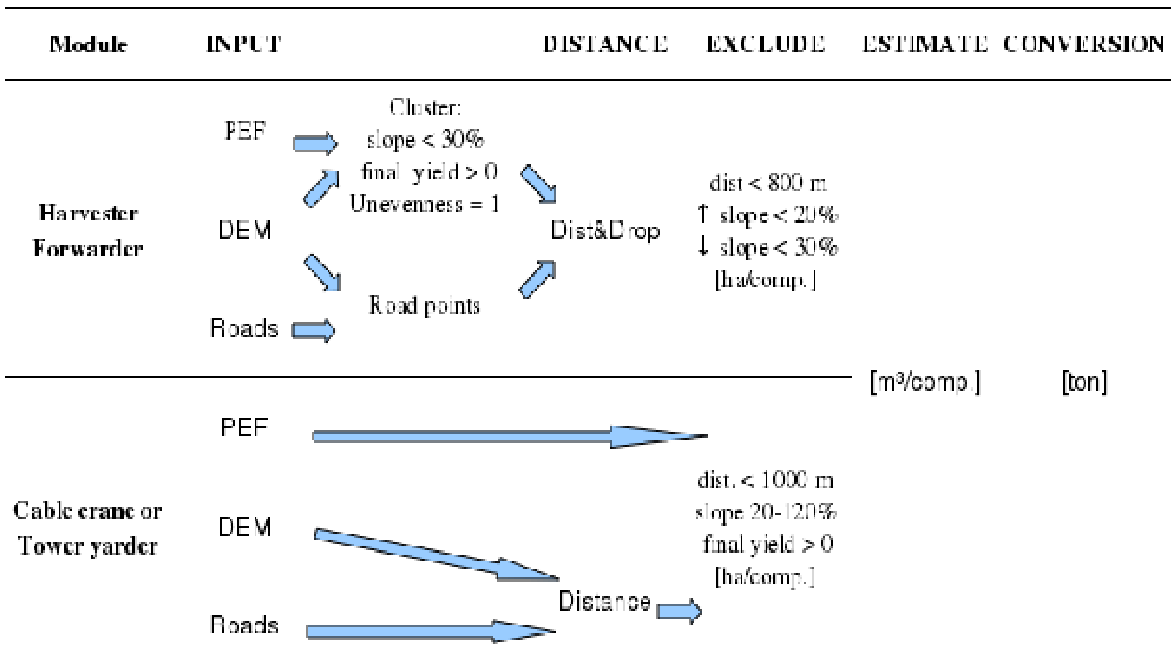

Figure 3. General scheme of the script.

4. Implementation

4.1 Harvester and Forwarder

In this section, the computational structure of the module aimed to estimate the extractable biomass by Harvester and Forwarder is described in detail. The module is composed of 4 logic blocks:

a) Identify – to identify all the extractable areas;
b) Pointify – to update the traffic and forest road network with height information;
c) DistDisl – to evaluate the distance and the height difference between each pixel and the closest point on the closest road;
d) Exclude – to remove those pixels that can not be actually extracted.

4.1.1 Identify

In this step, wholly performed using GRASS, the PEFO vector map and the DTM are used as input maps. All the forestry compartments with a positive final yield and with low unevenness are extracted from the PEFO map. The resulting vector map is then converted to a raster map. From this map, only those areas with accessible slope, i.e. slope < 30%, are therefore extracted and used in the further analyses. The terrain slope raster map is produced from the DTM.

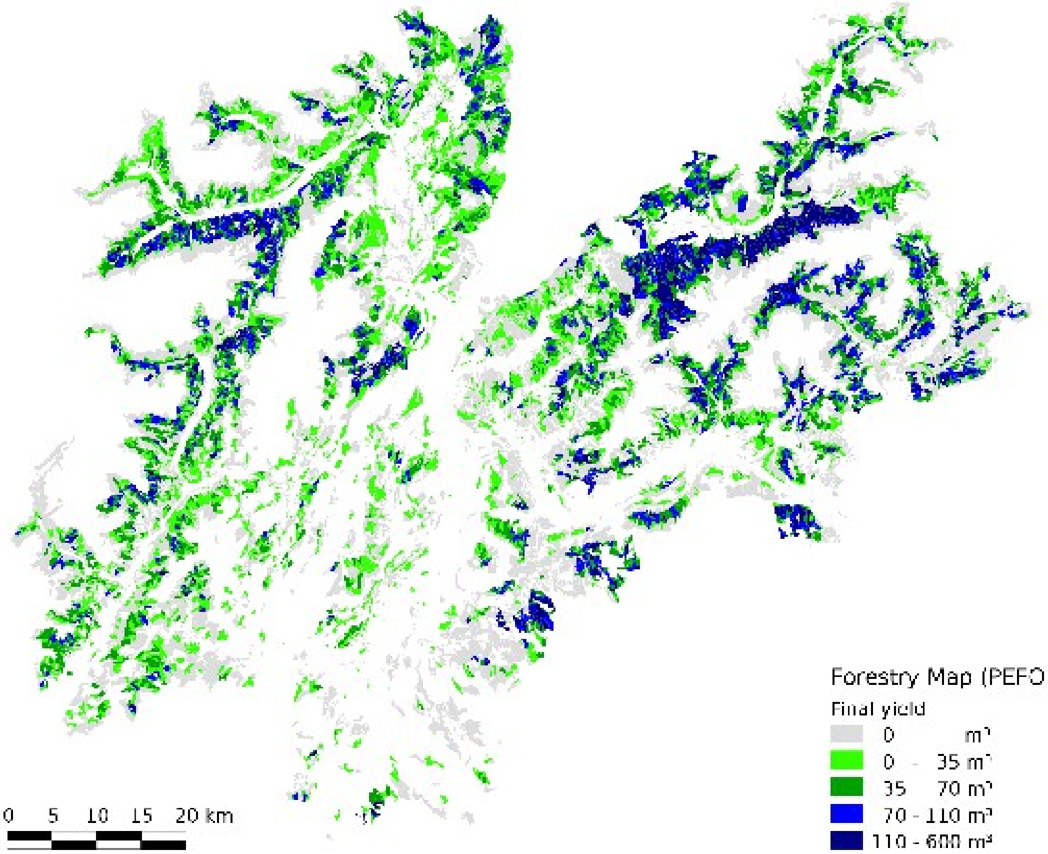

Figure 4. Final yield from Forestry map

The raster map with the result of the last extraction is then converted to a vector map where forest compartments are aggregated depending on the final yeild class. This map has been named "cluster" because, under appropriate terrain characteristics and needs, a skidding campaign involving more than one compartment could be reasonable.

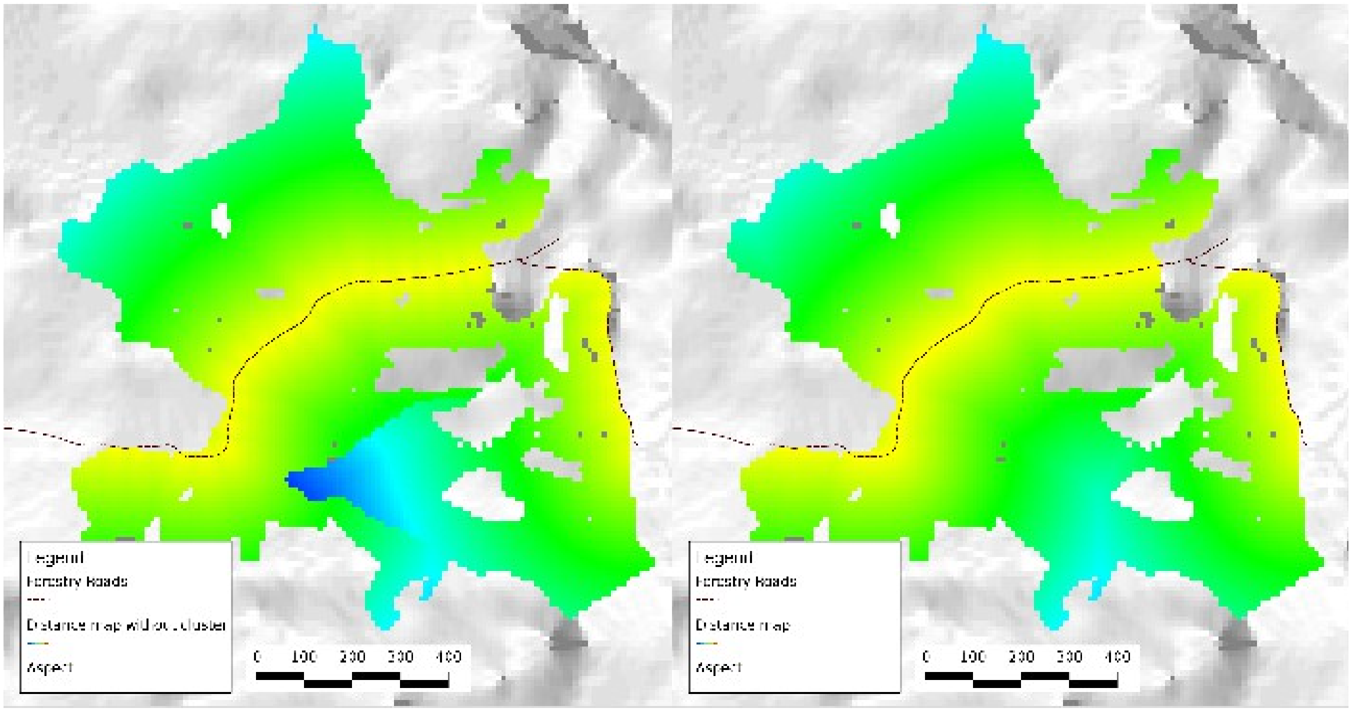

Figure 5. On the left: result of the Identify step without aggregating clusters; on the right, result of the Identify step aggregating clusters.

Finally, the cluster raster map has been also converted to a point-only vector map with the following attributes: compartment ID, cluster ID, height, slope.

4.1.2 Pointify

The vector map of the paved and forest road network is converted to a point-only vector map to speed up the further execution of the DistDisl block, by extracting the vertexes of the corresponding polylines. The attributes of the point-only vector map have then been complemented with the height value of each point using PostgreSQL and PostGIS. This step is performed by a python script to avoid the import of the geometry of the main and forest road network map in GRASS. When producing the point-only vector map, the python program interpolates the original vector vertex in order to get points which are spaced less than 50 meters.

4.1.3 DistDisl

The maps produced by the previous steps are used to compute the distance and the height difference between each pixel in the cluster map and the closest point on the closest road with PostgrSQL and PostGIS.

To reduce the computational time, the search has been performed only for those pixels within a 50 m buffer of each compartment.

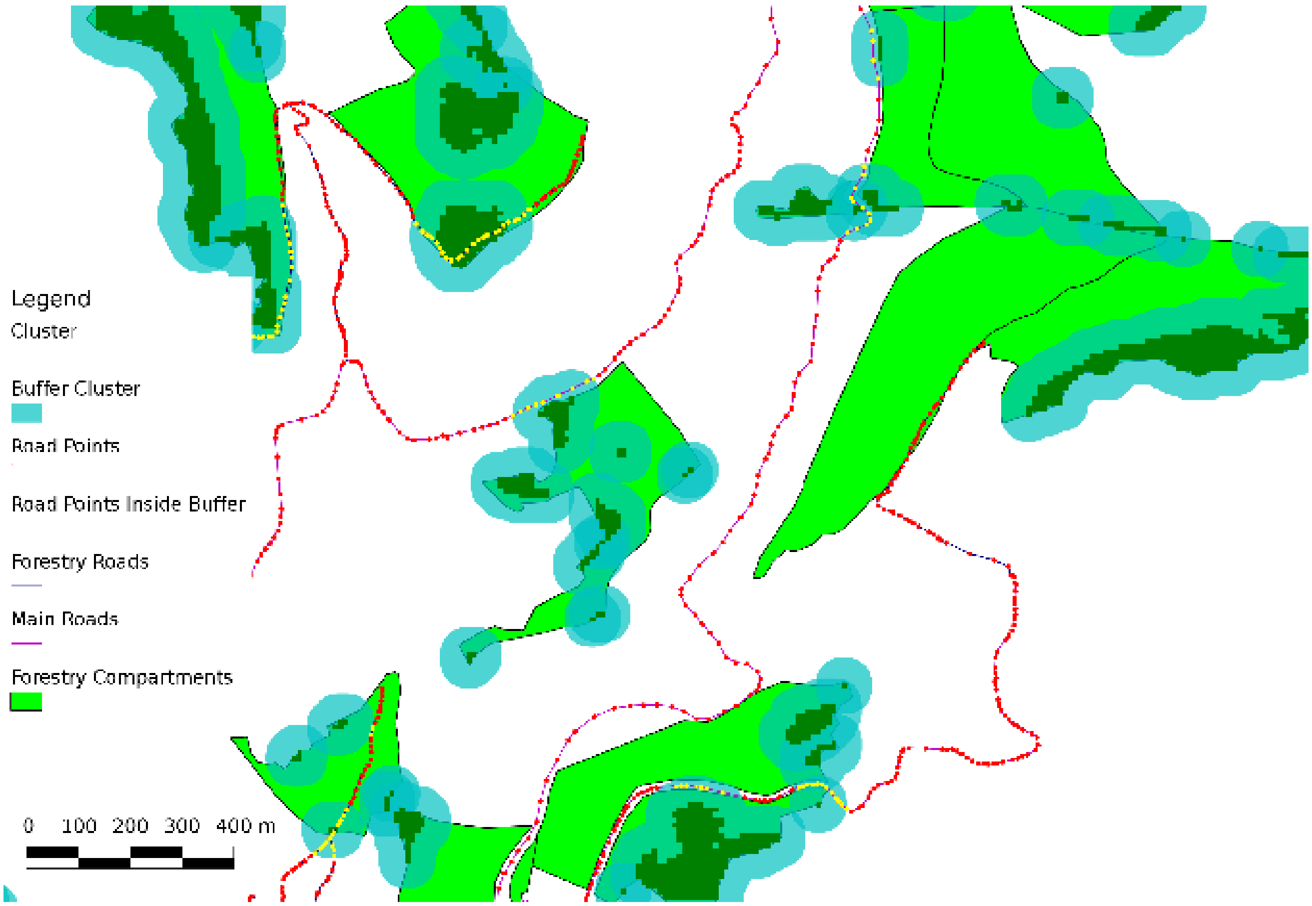

Figure 6. Cluster with buffer, roads and pointify roads and forestry compartments.

4.1.4 Exclude

This step, performed with PostgreSQL, removes the pixels not respecting the extraction requirements reported in Table 1.

Then, for each compartment, this block computes the total number of extractable pixels. A new vector map of the compartments is then created and updated with the total extractable surface by Harvester and Forwarder of each compartment.

4.2 Cable crane technique

The modeling of the cable crane extraction is simpler than that using Harvester and Forwarder, since it is no longer necessary to distinguish between uphill and downhill extraction.

The vector map of the high forest compartments has been converted to a raster map. The distance between each pixel of this map and the closest point on the closest road has then been computed using the function r.cost in GRASS. The pixels over 1000 m from a road and with high terrain slope (greater than 20%) have been removed. A new vector map of the compartments has been created and updated with the total extractable surface by cable crane of each compartment.

4.3 Estimation of the extractable volumes

By means of PostgreSQL, two different approaches have been used to estimate the extractable volumes from the total extractable surface.

- Homogeneous final yield on each compartment.

  In this approach, a homogeneous final yield is considered for the entire compartment, the extractable volume is derived directly and only from the extractable surface with any technique.

- Final yield assuming medium final yield rate per hectare.

  In general, the harvest cut are not distributed over the entire compartment, they are commonly concentrated on a part of the compartment. When specific information on this part is lacking, as in our case, it is possible to derive the extractable volume from the final yield rate per hectare (70 m³/ha in our case) under the assumption that the extraction is performed only on the extractable surface computed by the model.

4.4 Biomass conversion from volume to tons

The model implements two approaches to convert the extraction volume measured in m³ to tons, with a python script.

The first approach is based on the empirical work by Spinelli and Magagnotti (2007), who observed the production of 10-20 ton/ha from lop and top of a selection cutting of 60-80 m³/ha (for Harvester and Forwarder, HF) and the production of 30-90 ton/ha from a patch cutting of 150-300 m³/ha (for Cable Crane, CC). From these values, two conversion factors have been calculated for each extraction techniques see Table 2, one for a pessimistic assessment considers the worst case to convert the volume coming from HF and CC using a conversion factor respectively of 0.167 and 0.200; the other one uses optimistic conversion factors to estimate the max limit value that would be possible to achieve from Harvester anf Forwarder (0.250) and Cable Crane (0.300).

Type of cutting	Intensity of cutting [m³/ha]	Biomass [ton/ha]	Conversion factor [ton/m³]
Selection cutting (for HF)	60-80	10-20	0.167 - 0.250
Clear strip felling (for CC)	150-300	30-90	0.200 - 0.300

Table 2. Conversion factor from experimental data (Spinelli and Magagnotti, 2007).

The second approach is based on the volume table reported by Castellani et al. (1984) for the Trentino Alto Adige area. This table gives the total tree and lop and top volume percentage depending on the different species. The percentages used in the model are reported in Table 3, where the densities are based on the work by Pedrolli (1999).

Type of volume	Percentage in volume	Density [ton/m³]
Lop and top volume	16.30%	0.715
Bark volume	11.6%	0.5

Table 3. Conversion based on the volume table (Pedrolli 1999).

The value obtained with this approach is then reduced by 30% to consider that during the extraction operation not all the potential biomass is actually extracted (Cavalli et al., 2007).

5. Results

5.1 Harvester and Forwarder

A first result of the model is the evaluation of the total surface where it is possible to deploy Harvester and Forwarder. Due to high slope and partial unevenness of most of the areas in Trentino, ground harvester can be seldom deployed Figure 9, Therefore, more than 70% of the compartments have less than 10% of their surface suitable for skidding. Less than 7% of the forest compartments offer a wide extraction area, therefore they can be totally harvested with Harvester and Forwarder.

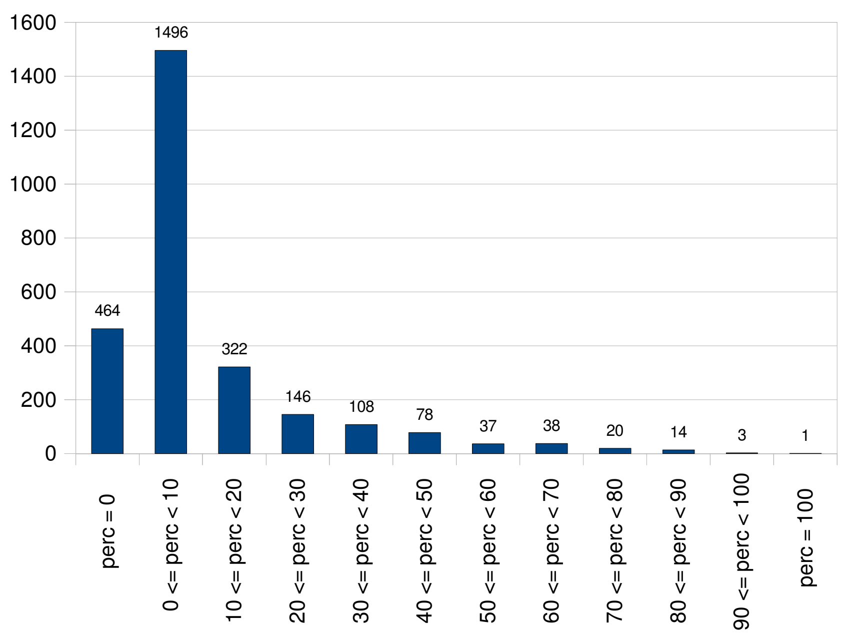

Figure 7. Number of compartments per different categories of percentage of area cover with Harvester and Forwarder.

The maximum distance from tracks where it is possible to deploy Harvester and forwarder is about 1700 m: the mean distance of the forest compartments from tracks is around 68 m.

Analyzing the distribution of the mean distance of the forest compartment from the tracks Figure 8, it is possible to note that the average distance of 94% of the compartments is less than 200 m, therefore they are easily accessible.

The model developed in this work takes into account the different techniques used in uphill and downhill skidding using the HF to make more realistic assessment leading to Table 4.

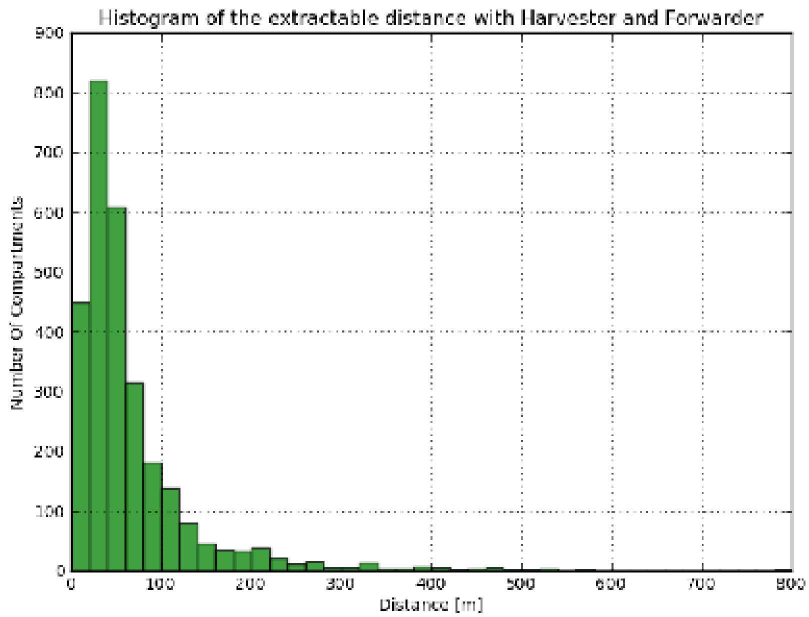

Figure 8. Number of compartments for each averege distance class with Harvester and Forwarder.

	Area [ha]	Percentage
Area extractable with HF	7936.62	100
Area extractable with HF and distance < 800 m	7895.41	99.48
Area extractable with HF and distance < 800 m and condition on drop and slope	5750.71	72.46

Table 4. Statistics data applying extraction conditions.

The annual calculated cut from the Forest Management Plans for compartments partially extractable with Harvester and Forwarder (with an extractable area greater than 1 ha) amounts to 74500 m^3/year of prescript volume, using Method 1 the amount of extracted volume is about 16000 m^3/year and using Method 2 the amount is about 69000 m^3/year as in Table 5.

	Numb. of Comp.	Cover Percentage	final yield [m³]	Method 1 [m³]	Method 2 [m³]
BORGO	89	22.62%	5,845	1,367.5	5,752.0
CAVALESE	189	17.28%	21,437	3,463.2	17,867.0
CLES	201	33.00%	9,495	3,142.8	9,418.0
MALE'	88	19.83%	6,751	1,285.5	6,486.2
PERGINE	99	20.59%	6,452	2,217.1	6,210.0
PRIMIERO	116	20.48%	9,392	1,748.9	8,922.9
RIVA	23	16.87%	766	125.4	764.5
ROVERETO	68	25.94%	3,451	908.4	3,372.1
TIONE	122	23.23%	5,836	1,264.4	5,727.4
TRENTO	123	32.18%	5,075	1,040.2	4,920.1
	1118	**23.20%**	**74,500**	**16,563.4**	**69,440.2**

Table 5. Harvester and forwarder extraction.

5.2 Cable Crane

Due to the terrain features, cable-based harvesting is the method that can be deployed on the larger number of compartments, in Table 6 it is possible to see how cable-based harvesting can be used for more than 96% of the total surface.

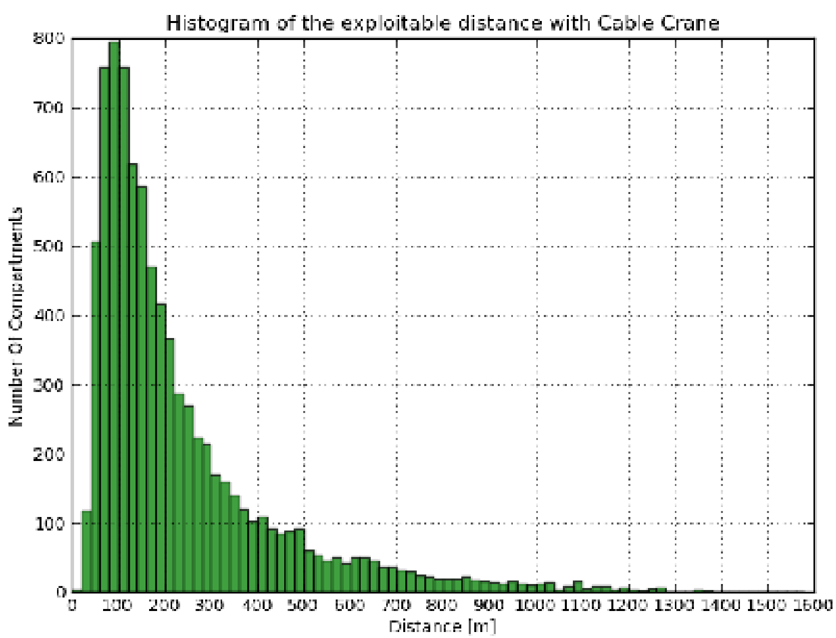

Figure 9. Number of compartments for each averege distance class with Cable Crane.

	Number of Comp.	Cover Percentage	final yield [m³]	Method 1 [m³]	Method 2 [m³]
BORGO	677	96.76%	38,489.0	37,325.5	38,489.0
CAVALESE	1204	96.70%	107,139.5	103,988.7	107,139.5
CLES	1230	95.98%	47,104.8	45,048.4	47,104.8
MALE'	924	97.27%	46,588.5	45,215.2	46,588.5
PERGINE	711	96.93%	36,413.0	35,485.4	36,413.0
PRIMIERO	796	97.22%	54,527.9	52,785.3	54,527.9
RIVA	298	94.92%	9,315.0	8,870.4	9,315.0
ROVERETO	287	93.84%	13,134.0	12,157.1	13,076.7
TIONE	1505	96.79%	64,125.5	62,303.4	64,125.5
TRENTO	750	96.29%	28,171.1	27,221.0	28,171.1
	8382	**96.27%**	**445,008**	**430,400**	**444,951**

Table 6. Cable crane extraction.

The compartments where it is not possible to deploy a cable crane are just 115 out of 8,554 compartments with prescribed yield greater than 0, this is the 1.37% of the compartments but they amounts only to the 0.81% of the prescribed volume. The amount of extractable biomass with cable crane techniques is about 430,400 m³ for the Method 1 and about 444,950 m³ for the Method 2.

A collateral output of the model is the indication of the areas where the cable crane lines start to be very long, indirectly pointing out areas where an improvement of the track coverage can make extraction operations more profitable.

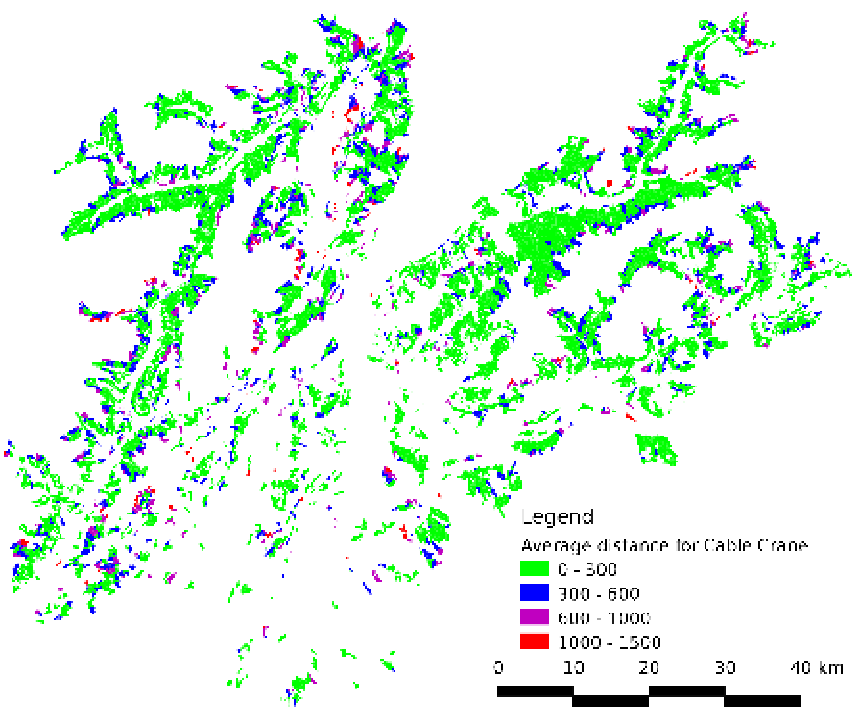

Figure 10. Average compartments distance with Cable Crane.

In many compartments it possible to deploy both Harvester and Forwarder and Cable Crane: when combining the results of the models for the two skidding techniques harvester-forwarder is used where possible, while cable cranes are used for the rest of the compartments.

Table 7 shows the total values of wood volume harvested by Harvester and Forwarder and Cable Crane using considering an homogeneous final yield (Method 1) and assuming medium final yield rate per hectare (Method 2).

		Method 1			**Method 2**		
	final yield [m³]	**hf [m³]**	**cc [m³]**	**total [m³]**	**hf [m³]**	**cc [m³]**	**total [m³]**
BORGO	38,493.0	1,367.5	35,958.8	37,326.2	5,752.0	32,741.0	38,493.0
CAVALESE	107,139.5	3,463.2	100,525.5	103,988.7	17,867.0	89,272.5	107,139.5
CLES	47,216.8	3,142.8	41,968.3	45,111.1	9,418.0	37,798.8	47,216.8
MALE'	46,588.5	1,285.5	43,929.7	45,215.2	6,486.2	40,102.3	46,588.5
PERGINE	64,125.5	1,264.4	61,039.0	62,303.4	5,727.4	58,398.1	64,125.5
PRIMIERO	54,527.9	1,748.9	51,036.4	52,785.3	8,922.9	45,605.0	54,527.9
RIVA	9,315.0	125.4	8,745.0	8,870.4	764.5	8,550.5	9,315.0
ROVERETO	13,134.0	908.4	11,248.7	12,157.1	3,372.1	9,704.6	13,076.7
TIONE	28,171.1	1,040.2	26,180.8	27,221.0	4,920.1	23,251.0	28,171.1
TRENTO	36,413.0	2,217.1	33,268.3	35,485.4	6,210.0	30,203.0	36,413.0
	445,124.3	**16,563.4**	**413,900.3**	**430,463.7**	**69,440.2**	**375,626.8**	**445,067.0**

Table 7. Final values of residual biomass.

5.3 Biomass conversion from volume to tons

On the base of the volumes reported in the Table 7 it is possible to use two different approaches to convert the volume of forest biomass in tons, see Paragraph 4.4. The values for a pessimistic assessment using the lowest rates for HF and CC estimate forestry biomass about 75'000 ton/year; while the values for an optimistic assessment estimate 130'000 ton/year, converted volumes per each methods are reported in Table 8, in this way we highlight the maximum and minimum extractable biomass obtained applying our model. At the same time, it is evident how a different cutting policy can heavily influence the amount of forest biomass which can be harvested.

		Method 1			**Method 2**		
		hf	**cc**	**total**	**hf**	**cc**	**total**
	Volume [m³]	*16,563.4*	*413,900.3*	*430,463.7*	*69,440.2*	*375,626.8*	*445,067.0*
Spinelli	optimistic assessment [ton]	2,766.1	82,780.1	85,546.2	11,596.5	75,125.4	86,721.9
	pessimistic assessment [ton]	4,140.8	124,170.1	128,310.9	17,360.1	112,688.0	130,048.1
Pedrolli	using volume table [ton]	2,882.8	72,037.3	74,920.1	12,085.7	65,376.0	77,461.7

Table 8. Convertion from biomass volume to tons.

6. Conclusions

This work is the first implementation of a model able to estimate the available forest biomass for energy production in a given region using FOSS4G software mostly based on Grass and PostgreSQL-PostGIS. The philosophy on which the model is based is aimed to balance simplicity and performance, since few but representative data have been selected as input and the whole process is highly configurable.

The model has provided reasonable results in estimating the amount of biomass that can be earmarked for energy production in the Trentino (Italy) region. In particular, the presented results clearly show the high availability in the Trentino region of forest biomass for energy production.

The model and its implementation are both quite general and based on the use of input data that can be easily found (DTM, main and forest road network, Forestry Management Plans). This simplicity allows the direct application of the model in other regions than the one considered in this work. The accuracy of the estimate can vary with the actual application of each technique. The correct interpretation of the Forest Management Plans, the direct knowledge of the region and of the local practices are very important and necessary information for the achievement of reliable results.

The Forest biomass is a renewable energy source, an alternative to fossil fuel. The knowledge of its available amount and spatial distribution are fundamental information to achieve the emission reduction requirements defined by the Kyoto protocol.

6.1 Problems and future development

The modeling of the harvester-forwarder technique is resulted to be easier than the modeling of the cable crane one mainly because of the lacking of information on the processing yard (e.g., dimension and location) and on the forest and main road network (e.g., road width, curvature radius).

In the current impementation of the model, the prescribed volume from Forest Management Plans (PEFO) model is used: this volume includes, along with the commercial volume, also the volume used in local practices especially right of forest use for local communities. It is important to underline that, for this reason, this model leads to an over-estimate of the biomass amount in the Trentino region. Therefore it will be very important to estimate the amount of biomass used in local practices in order to better the results of the model. Since right of forest use is very different from valley to valley in the Trentino region, a reliable estimate would require a challenging research work.

The characterization of the specific heat as a function of the forest stand could be a further model development useful to achieve a more accurate estimate of the actual energy amount that could be produced from the biomass.

The model could be also extended in order to consider the amount of biomass made available by thinnings. Their actual inclusion in the estimate of the total biomass availability suitable for energy production will be hence conditioned by their economical cost.

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