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A method to assess the economic impacts of forest biomass use on ecosystem services in a National Park

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ABSTRACT

The aim of the paper is to develop a method to assess the effect of forest biomass use for energy on ecosystem services (ES). Such method has been in the GRASS GIS environment, by creating an Decision Support System (DSS) called r.green.biomassfor. The method has been tested in the Triglav National Park in Slovenia. The potential forest biomass was estimated with r.green.biomassfor DSS taking into account the effects of forest biomass harvesting on ES in terms of economic value. The economic value of each ecosystem service to society has been estimated using different economic evaluation methods and were spatially located with a Geographical Information System (GIS) application. Then, a semi-structured questionnaire was administered face-to-face to the experts in order to understand the effects of forest biomass harvesting on the ES at local level. Finally, the results of the questionnaire survey were elaborated to obtain indicators useful to assess the economic gain or loss on the benefits provided by ES based on the results of r.green.biomassfor DSS.

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1. Introduction

The use of forest biomass for energy is less polluting than fossil fuels, but this renewable source has several potential effects on the environment [1]. In fact, forest biomass harvesting may have effects on landscape aesthetic [2], biodiversity and habitat quality [3], water quality and soil productivity [4]. The effects are not always negative but they depend on the category of ecosystem services (ES) [5]: removing forest residues improves the aesthetic view and tourist attractiveness [6], reduces the risk of forest fire and prevent from insect damages [7]. Fragile ecosystems with a delicate equilibrium and low resilience - as protected areas in the Alps - are the most endangered when there is a plan to exploit natural resources. Alpine region is characterized by a huge availability of natural resources that can be used for energy purposes [8], so that energy expertise refer to the Alps as the "green battery" of the central

Europe. Alpine region provides energy for the needs of its population and for the urban areas, thus causing a considerable impact on the natural resources - with special regard to the protected areas - that may result in an overexploitation. This trend suggests the necessity of effective management strategies, able to consider the effects of forest biomass use for energy in a comprehensive way [9]. Natural resource management should include the value of the ecosystem from different point of view, in order to carry out an effective renewable energy policy. ES have an economic value that includes both use values (direct-use and indirect use values) and non-use values (option and existence values) [10]. As said before, forest ES could benefit or be depleted by the use of biomass energy, so it is important to understand what the economic benefits are or losses occurred. In this sense, effective and sustainable management is not only given by the inclusion of ecological aspects in the decision-making process, but also taking into account the socio-economic aspects. Participative approaches, allowing the inclusion of social aspects in the management activities, are widely accepted to be suitable for forest management [11,12]. In addition, the public participation of the key stakeholders contributes to preserve the environment and the future availability of the natural

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resources [13], for this reason it is important to understand stakeholders' perceptions about ES and the environmental impact of forest activities [14]. The analysis of the public perceptions of using the woody biomass as a renewable energy source is a key issue in order to increase the social acceptance [15] and to reduce the conflicts between users [16].

Starting from these considerations, the aim of the paper is to develop a method to analyze the potential economic effects of forest biomass use for energy on the main ES provided by protected areas. This objective was reached by a procedure based on public perception analysis of the issue, economic assessment of the ES and spatialization of the results. The procedure was implemented in GRASS GIS and now constitutes a downloadable add-on of this software, called "r.impact". The method was applied and tested in the Triglav National Park (Slovenia).

2. Methods

The case study is the Triglav National Park (46°22′00″ N; 13°49′00″ E) in the north-western part of Slovenia along the Italian the Austrian borders. The Triglav National Park covers an area of 838 km^2 (about 3% of the Slovenian surface) and includes 25 settlements with a population of 2444 people (1018 households) for a density of 0.029 inh. ha^{-1}. The climate of the area is continental, with cold winters and warm summers. The average temperature in the warmest month range from 20 °C in the valleys and 5.6 °C in the mountains, and in the coldest month the temperature range between 0.7 °C and −8.8 °C, while the average annual precipitation is about 1500 mm. The landscape of the Triglav National Park is characterized by glacier-shaped valleys, mountain plateaus and steep mountain ridges above the tree line. Forest area covers 62% of the total land area followed by managed grasslands (10%). The main forest types in the Park are: Montane beech forests (27,981 ha), Dwarf pine forests (11,350 ha), Silver fir - beech forests (4925 ha) and Silver fir and Norway spruce forests (4191 ha). In addition, the Triglav National Park is an important touristic destination with more than 580 thousand tourists per year and an average tourists' stay of 2.5 nights [17].

The potential effects of forest biomass harvesting on ES in the Triglav National Park were analyzed using a four-steps approach (Fig. 1): (1) economic evaluation of the ES; (2) estimation of the harvestable forest biomass; (3) estimation of the potential effects of forest biomass harvesting on ES through an experts' survey; (4) analysis of the potential spatial effects of forest biomass harvesting on ES.

2.1. Step 1

In the first step, four ES were identified and analyzed from the economic point of view: wood production (timber for commercial use and fuelwood for domestic use), carbon sequestration, protection against natural hazards and outdoor recreation. The ES values were estimated using different economic evaluation methods, as shown in Table 1. Due to the importance of the spatial component for forest planning [18], the results of the economic valuation of the ES were spatialized through an open-source GIS software.

Several economic evaluation methods were applied taking into

Table 1
Economic evaluation methods and variables considered in their estimation.

Ecosystem service	Evaluation method
Wood production (timber and fuelwood)	Market Price
Carbon sequestration	Voluntary market price
Natural hazards protection	Replacement cost
Tourism recreation	Benefit Transfer

account the nature of the ecosystem service and the available data. The wood production and carbon sequestration were evaluated by market prices; the outdoor recreation was evaluated through the Benefit Transfer (BT) method [19], while the replacement cost method was used to evaluate the protection against natural hazards. The economic valuations of all benefits derived from ES have been made in reference to the year 2012.

Subsequently, the results of the economic evaluation were rendered spatially-explicit through a Geographical Information System (GIS) application. We opted for open-source software, in particular we used GRASS GIS for the main analysis, while Quantum-GIS for creating the final layout. A set of thematic layers were chosen and overlaid to analyze the spatial distribution [18]. The maps are presented with a 5-class distribution of the benefits, created by the GIS software following the natural breaks system, in order to facilitate the visualization of the impacts. Only the cultural services are presented in 3 classes of value, because the evaluation highlighted only three different point estimates.

2.1.1. Wood production

Wood production was evaluated through a market price approach considering timber for commercial use and fuelwood for domestic use. Wood production was calculated considering the harvestable quantities by tree species and quality of logs (1st, 2nd and 3rd quality) and applying the local market prices. The main tree species harvested in the Triglav National Park are the following: European beech (*Fagus sylvatica* L.), Silver fir (*Abies alba* Mill.), dwarf mountainpine (*Pinus mugo* Turra). The equation used for the estimation of respectively timber value (V_t) and fuelwood value (V_f) are the following:

$$V_t = \sum_n^i \sum_m^i Q_t \cdot p_t$$

where:

V_t = total value of timber (€);
n = number of tree species (European beech, silver fir, etc);
m = qualities of logs;
Q_t = quantity of timber subdivided per species and quality (m^3);
p_t = local price of timber subdivided per species and quality (€ m^{-3}).

$$V_f = \sum_n^i Q_f \cdot p_f$$

where:

V_f = total value of fuelwood (€);

| Evaluation of Ess economic benefits | → | Estimation of forest biomass potential (DSS) | → | Effects of biomass withdrawal on Ess economic benefit | → | Spatial effects analysis |

Fig. 1. Four-step approach used to estimate the spatial effects of forest biomass harvesting on ES.

n = number of tree species (European beech, silver fir, dwarf mountainpine);
Q_f = quantity of fuelwood subdivided per species (t);
p_f = local price of fuelwood ($\in$ t^{-1}).

The economic value of wood production was rendered spatially-explicit using the layer with the tree species composition.

2.1.2. Carbon sequestration

The quantity of sequestered carbon in the forest was assessed following the For-Est method [20], based on the IPCC "Good Practice Guidance for Land use, land-use Change and Forestry" [21]. Due to the necessity of capturing just the annual increment of carbon stored in forest, it was decided to consider two carbon pools: above-ground biomass and below-ground biomass. Other carbon pools - such as deadwood, litter and organic soil - show modification in their carbon content in a very long period, as their current contribution is negligible. The quantity of above-ground biomass (AGB) was estimated with the following formula [20]:

$$AGB = I \cdot BEF \cdot WBD$$

where:

I = annual volume increment (m^3 y^{-1});
BEF = biomass expansion factor;
WBD = wood basal density (kg m^{-3}).

Similarly, below-ground biomass (BGB) was estimated with the following formula [20]:

$$BGB = I \cdot WBD \cdot R$$

where:
R = the roots/shoot ratio, which convert AGB in roots biomass.
The coefficients BEF, WBD and R vary with tree species and were taken from the literature [22].
Finally, the total carbon sequestration was then converted in CO_2 and multiplied for the average European market price for Carbon Dioxide in 2012 [23]. The equation used to estimate the value of carbon sequestration of forests of the Triglav National Park (V_c) is the following:

$$V_c = [(AGB + BGB) \cdot 0.5] \cdot p_c$$

where:

V_c = value of carbon sequestration in above-ground and below-ground biomass ($\in$);
AGB = above-ground biomass (t);
BGB = below-ground biomass (t);
0.5 = coefficient of carbon content;
p_c = mean carbon price of the voluntary carbon market ($\in$ tC^{-1}).

2.1.3. Natural hazards protection

The economic value of the forest protection against natural hazards was calculated through the replacement cost approach, considering the cost of replacing the protective function of the forests with artificial environmental engineering works [24]. The cost of replacing can be used as a proxy of the economic value of the function itself, as it can be interpreted as an estimate of the benefits deriving from measures taken to avoid damage. The basic premise of the replacing cost approach is that the cost of replacing the ecosystem service is no greater than the benefits accruing from it. In order to apply this approach, the forests of Triglav Nation Park was subdivided into direct and indirect protective forests according

to the definition provided by 2nd Ministerial Conference for the Protection of the Forests in Europe (MCPFE). The indirect protective forests play a role in term of soil erosion and water flow regulation, while the direct protective forests are those forests that protect people and the human activities against natural hazards (i.e., landslides, rockfalls, avalanches).

In this study, the indirect protective forest was valued hypothesizing hydro-seeding as potential substitutive artificial work (lifetime of 15 years), while direct protective forest was valued supposing a simple palisade to replace the forest (lifetime of 35 years). For the annual cost (annuity) calculation, a conservative annual interest rate was chosen and fixed at 2%, according to Freeman [25] ranges. The equation used to estimate the cost of replacing the indirect and direct protective forest function is [24]:

$$V_p = \frac{uC \cdot r}{(1 + r)^{-t}}$$

where:

Vp = value of protective function of forest, estimated used the replacement costs method ($\in$);
uC = unit cost of the substitute construction ($\in$ m^{-2});
r = interest rate (2%);
t = substitute construction lifetime (y).

2.1.4. Outdoor recreation

Outdoor recreation value was assessed through the Benefit Transfer (BT) method [26,27]. BT consists on examining the results of surveys undertaken in specific contexts (study sites) and transferring them to similar unstudied situations of interest for policy making (policy site) [28]. Particularly, we used the method of average value transfer recreational services using a measure of central tendency of all subsets of relevant studies as the transfer measure for the policy site issue [19]. After an accurate literature review, we collected 28 papers dealing with recreational values in European mountain forests distinguishing between protected areas and not protected areas. We decided to focus only on European mountain forests because of the necessity to have data as much comparable as possible between the study sites and the policy site, as prescribed as Loomis et al. [29]. In addition, only studies assessing the recreational values of hiking, free camping, sightseeing, walking and picnicking were considered. Other outdoor activities - such as hunting recreation, mushrooms and berries picking and fishing - were excluded in order to avoid double counting problems with the other ES evaluated. A detailed description of the BT approach that is used in the present work is available in Grilli et al. [30]. The meta-analysis included travel cost method and contingent valuation and allowed the identification of a mean measure of welfare for the recreation in European mountain forests. Thanks to a layer indicating the recreational propensity of several areas in the forests, the average values found in the meta-analysis were spatialized into a recreational map. In particular, the recreational propensity of the different forest areas of Triglav National Park were evaluated according to the following attributes: forest type (distinguishing between pure coniferous forests, pure broadleaved forests and mixed forests), altitude (distinguishing above and below 1000 m a.s.l.), and distance from the paths. The equation used to estimated the economic value of the different forest areas is:

$$V_t = T \cdot w_t$$

where:

V_t = total value of recreation in forest area (€);

T = annual number of tourist presences;

w_t = average value of willingness to pay for outdoor activities in protected forest area (€ per visitor).

2.2. Step 2

During the second step, the energy potential from biomass was estimated, by means of r.green.biomassfor [31,32], an open source Decision Support System (DSS) [9] implemented as an add-on of GIS software GRASS 7. This DSS estimates the annual forest energy-biomass that could be extracted considering several technical, legal and economic constrains. It computes a multi-step analysis that can deal with the estimation of ecological and technical-economic biomass from forest harvesting residues.

It includes four main sub-modules (theoretical, legal, technical and economic). The four sub-modules correspond to the degree of detail in the estimation of bioenergy and their functioning is reported below. The advantage of a modular structure is the possibility to provide several scenarios of production based on changes in the legal framework, in the harvesting techniques and in the economy (i.e. changes in fuel prices and/or harvesting costs). The theoretical module analyzes the theoretical maximum potential energy, preserving the renewability of forest resources, based on the annual increment of the forest ecosystems. The legal module calculates the forest biomass availability depending on yield, forest management and silvicultural treatment: in the case of final felling, the total biomass is evaluated as a percentage of the prescribed yield expressed as cormometric volume (bark and stem without tops and branches). In thinning intervention, the total bioenergy is derived from the whole tree. The technical module introduces elements of mechanization in the biomass exploitation, through the assessment of the distance from landing site, the slope and the terrain roughness, permitting to stress the stands that are possible to reach and to exploit. The economic module evaluates the quantity of woodchips from accessible areas that are economically profitable bioenergy chain, and so only the areas with positive net revenues are considered. For further information of the algorithms on the base of r.green.biomassfor see Sacchelli et al. [9,33].

In order to apply the DSS to a case study, a large set of data was acquired. Particularly, forest management plans containing georeferenced information about the prescribed yield and the annual volume increment in the shapefile of the forest stands were acquired. Other mandatory data like the distribution of the ordinary road network and the forest road network, a digital terrain model with spatial resolution of 25 m, and a series of economic information regarding energy prices, extraction and productivity costs at local level were also collected. With the provided definitions, the economic potential is the most likely to be harvested, because producing more or less would imply an income reduction. For this reason, we show the map of the economic potential and how it may affect the value of ES. The main mandatory data for the Triglav National Park are available at the following website: http://gis.arso.gov.si/geoportal/catalog/main/home.page.

2.3. Step 3

In the third step, the potential positive and negative effects of forest biomass harvesting on ES were quantified through a questionnaire survey administered to the local experts [34]. The major selection criterion used to identify the experts was their professional experience in one of the following sectors: forest management and planning, environment conservation, and rural development. In addition, as Raymond et al. [35] pointed out, three main typologies of knowledge may occur in the field of environmental management: (1) local knowledge, (2) scientific knowledge and (3) hybrid knowledge. An experts' survey seems to accomplish the local knowledge framework and, partly, the scientific knowledge. At the end of this selection, thirteen local experts have been identified and involved in the survey. The reason of such a small sample is given by the necessity to reach respondents with a deep knowledge of bioenergy and/or ES and a detailed knowledge of the study area. Moreover, respondents should have been free from political bindings and interests in expanding the biomass utilization in the area. The cited features were necessary in order to collect data coming from experts in the field and, at the same time, not biased by personal interests. In a study area as Triglav National Park, characterized by low population density, few people reflect these characteristics and thirteen may be considered a sufficient sample. The identified local experts are mainly private actors (53.8%), followed by public actors (30.8%) and environmental associations (15.4%). In the category of public actor were included the University of Ljubljana, the Slovenian Forest Service, and the Institute of the Republic of Slovenia for Nature Conservation, while in the private actors there are the forest owners associations and the bioenergy producers. From the socio-demographic point of view, the experts are males (84.6% male, 15.4% female) with age above 50 years old (53.8% of experts have more than 50 years, 30.8% between 41 and 50 years old, and 46.2% less than 41 years old) and a high level of education (58.3% of experts have a university degree, 15.4% a post-university degree, and the remaining 25.0% a high school degree). The distribution of the sample of experts by professional sector is the following: 46.2% forestry and agricultural sector; 23.1% environmental protection sector, 15.4% eco-tourism and sustainable tourism sector, and 15.4% bioenergy sector.

A semi-structured questionnaire (Annex 1) was administered face-to-face to the thirteen local experts in order to collect the information about the potential positive and negative effects of the development of forest biomass for energy use on ES in the Triglav National Park. A first draft of the questionnaire was pre-tested with two external experts in order to highlight unclear questions. The final version of the questionnaire was made up of fourteen questions: the first nine questions focus on the personal information of the respondent (name and surname, gender, level of education, age, field of activity, role in the organization, and years of expertise in the field of activity). The following questions concern the opinion of the respondent about the development of forest biomass use for energy in the Triglav National Park and the related effects on ES and socio-economic aspects at local level. In particular, respondents were asked to express their opinion on potential effects of forest biomass harvesting on the above mentioned ES (Table 1), through a 5-point Likert scale (from +2=very positive effects to −2=very negative effects). To identify a synthetic indicator expressing the impact of the forest biomass extraction on the ES, the results of the questionnaires were further aggregated and statistically elaborated. The main descriptive statistics (mean, median and standard deviation) were provided using XLStat2012. In this process, each indicator was used as a detraction factor - expressed as a percentage - to assess the perceived economic loss or benefit of each service, as a consequence of the forest biomass use for energy. The mean value of the effect indicator was converted into a percentage, expressing the share of economic loss or benefit following the use of forest biomass for energy. The formula for the conversion was the following:

$$100 : l = m_j : x$$

where I is the width of the interval (ranging from −2 to +2), m_j is the mean score of the j-th ecosystem category and x the percentage of impact.

Table 2
Economic value of ESs in Triglav National Park.

Ecosystem service	Weighted average (€ ha^{-1})	Min (€ ha^{-1})	Max (€ ha^{-1})
Carbon sequestration	27	18.8	35.1
Natural hazards protection	644	581	707
Timber	44	0.08	88.2
Fuelwood	24.7	0.48	48.9
Tourism recreation	117	47	187

2.4. Step 4

Step fourth consists in the use of the new module "r.impact". The module requires two input maps: the map with the value of ES in the shapefile format and the raster map of the energy potential of forest biomass. The energy potential map is needed because it has been assumed that the impact on the environmental values is concentrated in the areas where biomass is harvested. The ES map should be created so that each column contains the value of one ES, the user has to indicate the name of the column of each ES and the percentage of the expected variation of value. The module then converts the shapefile with the ES values in as many raster maps as the number of evaluated ES and calculates the impact in a spatially-explicit manner. The impact on productive services, as well as on protection against natural hazards and carbon sequestration, is calculated where forest biomass is harvested by overlay procedure. There is also the possibility to include a buffer zone to account for potential proximity effects. The impact on recreation and landscape aesthetic values is assessed differently; the underlying idea is that the recreational-aesthetic experience may be affected by the view of the forested areas used for collecting biomass. For this reason, we exploited the command r.viewshed, which allows the identification of the areas where is possible to see the part of the forest where the cuts take place. The impact on the recreational and aesthetic values is supposed to occur in those areas.

Although being included in the r.green package in the GRASS add-ons, the module r.impact can actually be used without running other modules. In fact, it only requires the energy and the ES maps, which can be created with the tool that the user likes most.

3. Results

3.1. Step 1

The results of the step 1 of the proposed method show the geographical distribution of economic values of ES. This information is the fundamental starting point to estimate the potential impact of forest biomass harvesting from the geographical point of view.

The economic values of ES are included in a wide range of values (Table 2). The economic value of wood production ranges from 0.08 to 88.20 € ha^{-1}. The spatial distribution of wood production is strictly linked to the tree species composition and quality of logs (Fig. 2). Fuelwood provision has a spatial trend very similar to the timber, with a narrower but still considerable range (from 0.48 € ha^{-1} to 48.90 € ha^{-1}).

Protection against natural hazards is the most valuable ES (Fig. 3), with an estimation of 707 € ha^{-1} in the direct protection
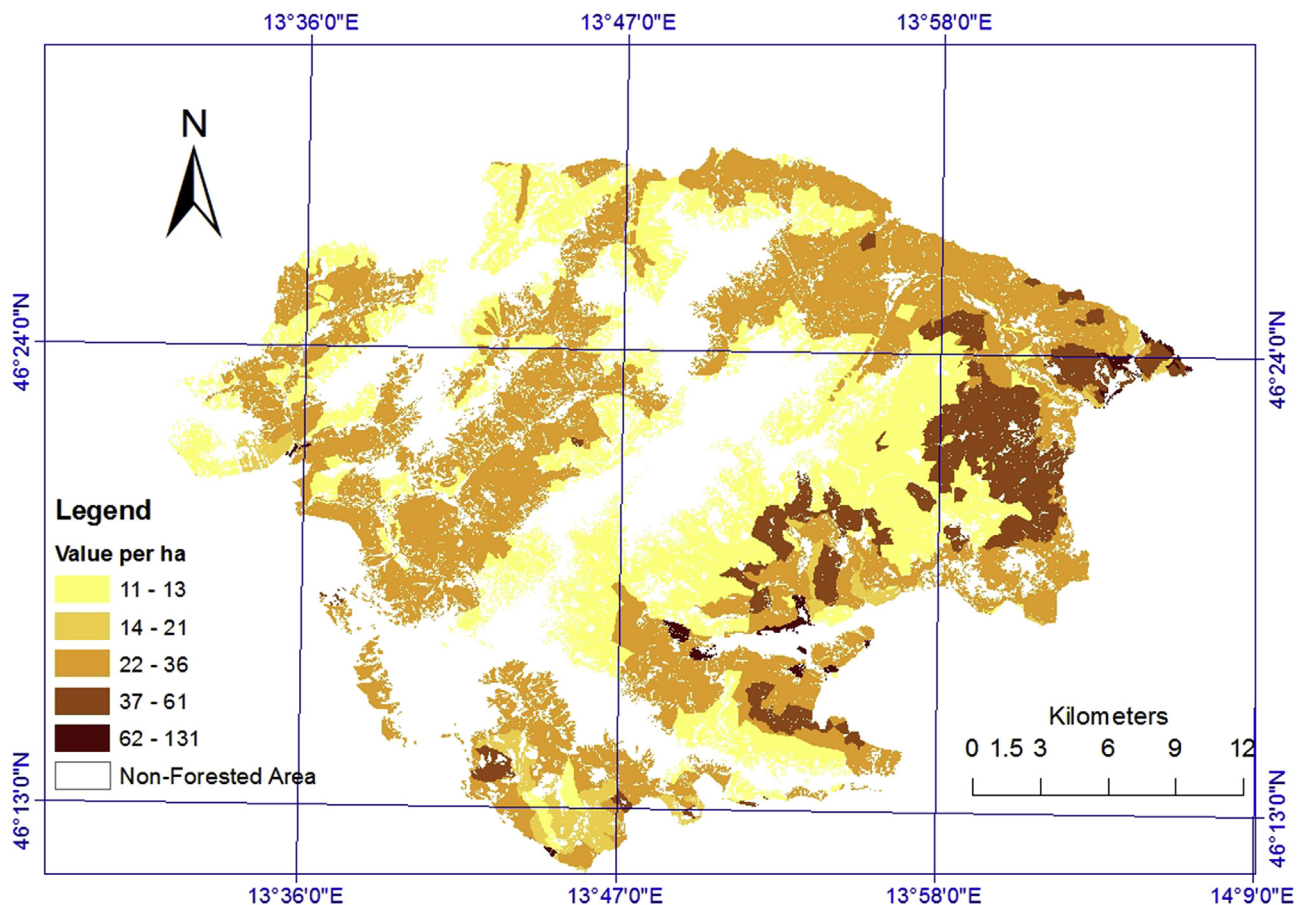

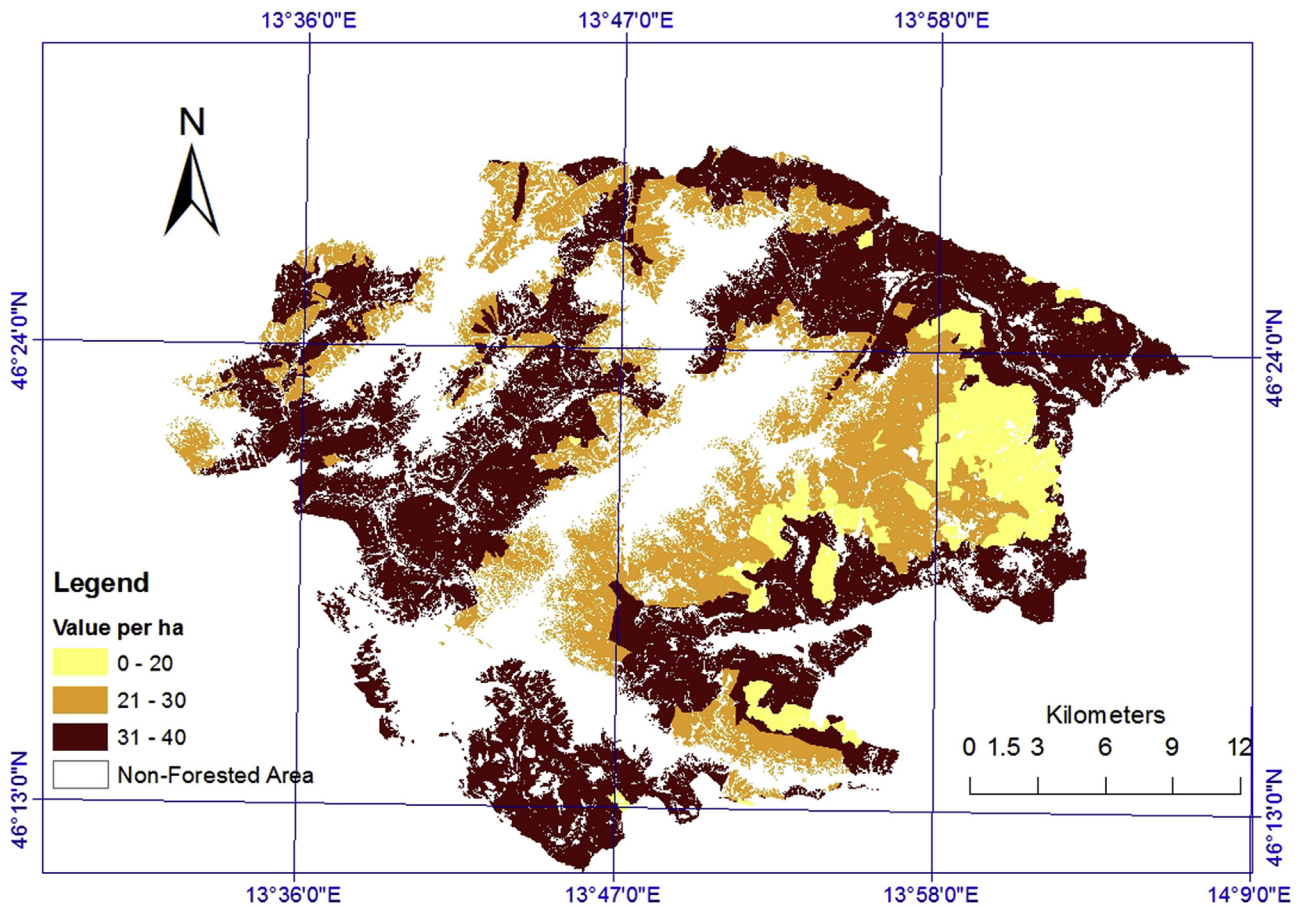**Fig. 2.** Economic value of wood production in the Triglav National Park.

Fig. 3. Economic value of natural hazards protection in the Triglav National Park.

area (i.e. landslides protection) and a value of 581 € ha^{-1} in the indirect protection area (i.e. soil erosion protection). Carbon sequestration, on the other hand, has a very smaller contribution in the computation of the economic value of regulating services, with 18.80 € ha^{-1} in the mixed forests, 22.60 € ha^{-1} in the pure broadleaves forests and 35.10 € ha^{-1} pure coniferous forests (Fig. 4). Notwithstanding the high importance of forests as carbon sinks, the market approach for valuing the quantity of stored carbon shows low figures because of the current low equilibrium price in the carbon market.

Finally, the economic values of outdoor recreation are also quite important (Fig. 5). Two main tourist zones were identified, based on the number of tourists and vocational areas for recreation. The welfare estimates were assessed to be 17.02 € per trip in the most important area and 10.57 € per trip in the second best recreational area, corresponding to 246.40 € ha^{-1} and 76.50 € ha^{-1}, respectively.

3.2. Step 2

Results of bioenergy obtained by woodchips in the Triglav Nation Park are summarized in Table 3, subdivided by the DSS submodules. The total forest area is equal to 53,384 ha, but the cutting forest surface is reduced to 31,885 ha, slightly less than the 60%. The maximum potential of energy available in the Triglav Nation Park is 126 GWh y^{-1}, about 2.35 MWh ha^{-1}, calculated based on the annual volume increment. The energy obtained by the prescribed yield plans amounts to 58,478 MWh year^{-1}, equal to 1.09 MWh ha^{-1}, equal to just fewer than 47% of the energy obtained

by the annual volume increment. The technical evaluation, based on the limits of extraction of the different methods of exploitation, reduces the surface extraction to 20,093 ha with an annual energy production of 46,077 MWh, approximately equal to 0.86 MWh ha^{-1}. The technical parameters included in the evaluation are summarized in Table 4.

Using economic parameters shown in Table 5, the economic analysis draws a scenario in which the energy production amounted to 39,276 MWh year^{-1}, equivalent to 0.73 MWh ha^{-1}, and a total surface of exploitation amounted to 16,445 ha, equal to the 67% of the total energy available based on the prescribed yield. The economic potential, which is the closest to the current harvesting, is reported spatially-explicit in Fig. 6.

3.3. Steps 3 and 4

The results of the experts' survey are summarized in Table 6, showing that the forest biomass harvesting leads to different positive and negative effects according to the characteristics of ES in the local context of the Triglav National Park.

Provisioning services seems to be the most positively affected group of ES from the biomass use (increment of 32% of value). This result is easily understandable because the increase of biomass withdrawal involves an increase of income generated by the sales. The spatial result of the value modification for wood production is shown in Fig. 7. The color scale and width of the classes before and after the impacts are the same in all maps, in order to facilitate the visual comparison.

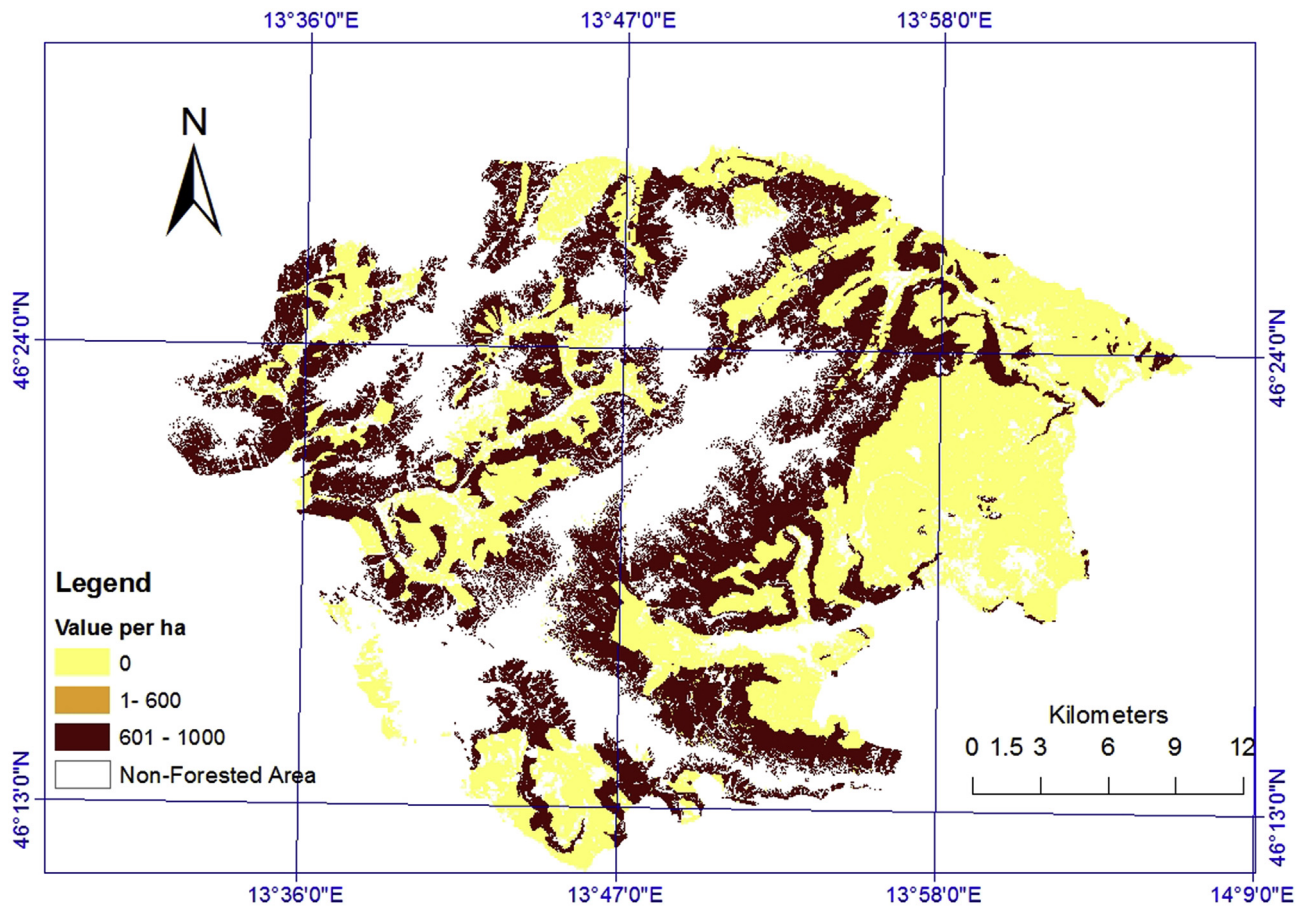The effects on natural hazards protection and carbon

Fig. 4. Economic value of carbon sequestration in the Triglav National Park.

sequestration are visible in Figs. 8 and 9. The negative effects of forest biomass harvesting on natural hazard protection is −0.23, while the negative effects on carbon sequestration is −0.15. The international literature in this field stresses that the biomass gathering removes a source of fertility for the soils [4] and damages habitat for microorganisms [35], reduces the carbon sequestration potentials and deplete the protection capacity.

Finally, the cultural services seem not to be affected by biomass withdrawals. Experts noted a very small positive effect concerning tourism that is completely counterbalanced by a negative effect on landscape aesthetic, resulting in a neutral effect, on average. Integrating the information provided by the spatial economic value of ES and the impact assessment allows a visual understanding of the areas that could be used for biomass extraction and the areas to be left for conservation, due to the high capacity of providing non-use or passive use benefits.

4. Discussions

The combined analysis of ES assessment and experts' survey shows interesting evidences. As already stated, experts declared a positive effect of biomass harvesting on provisioning services. This is understandable because increasing the exploitation of forest residues for energy means incrementing the exploitation of timber, with a related additional income. The effects of using biomass for energy purposes on natural hazards protection could be very high. The reason for this effect may be the fact that an intensive exploitation of the protective forests may deplete the capacity of protecting from natural hazards (i.e., landslides, rockfalls,

avalanches), which is the most important component of the benefit provided by forests. Such decrease in the regulating capability may be seen as a social cost of biomass harvesting [37]. Experts' idea about the impact of forest biomass on cultural services is less clear, with a general statement of neutral impact. This is also confirmed in much of the literature about ES; in fact some authors found a positive effect of harvesting wood residuals on tourist activities and landscape aesthetic [38].

The proposed methodology focuses on the external costs and benefits created by biomass harvesting. Although being sometimes criticized [39], environmental valuation is important because it allows the comparison of both financial and environmental costs and gains with the same unit of measure. Within a framework of welfare economics, the estimation of market externalities (and in general of indirect effects of plans and projects) is essential to capture the global effect of the policy measures. The main advantage of the proposed method is the capacity of reconciling the objectives of nature conservation with the satisfaction of energy needs of local population. In such a context an optimal energy planning is fundamental to balance these contrasting objectives. Ecological and economic tools were mixed and strengthened with the use of GIS. In particular, the development of such methodology in a free and open source environment, such as GRASS GIS, allows not only the replicability but also the possibility to view and (if necessary) modify the code, according to specific needs of the users. The information retrieved by the proposed methodology is important in order to plan an effective harvesting of forest biomass, capable to maintain the capacity of the forest ecosystem to provide benefits for humans. The main goal of the natural resources
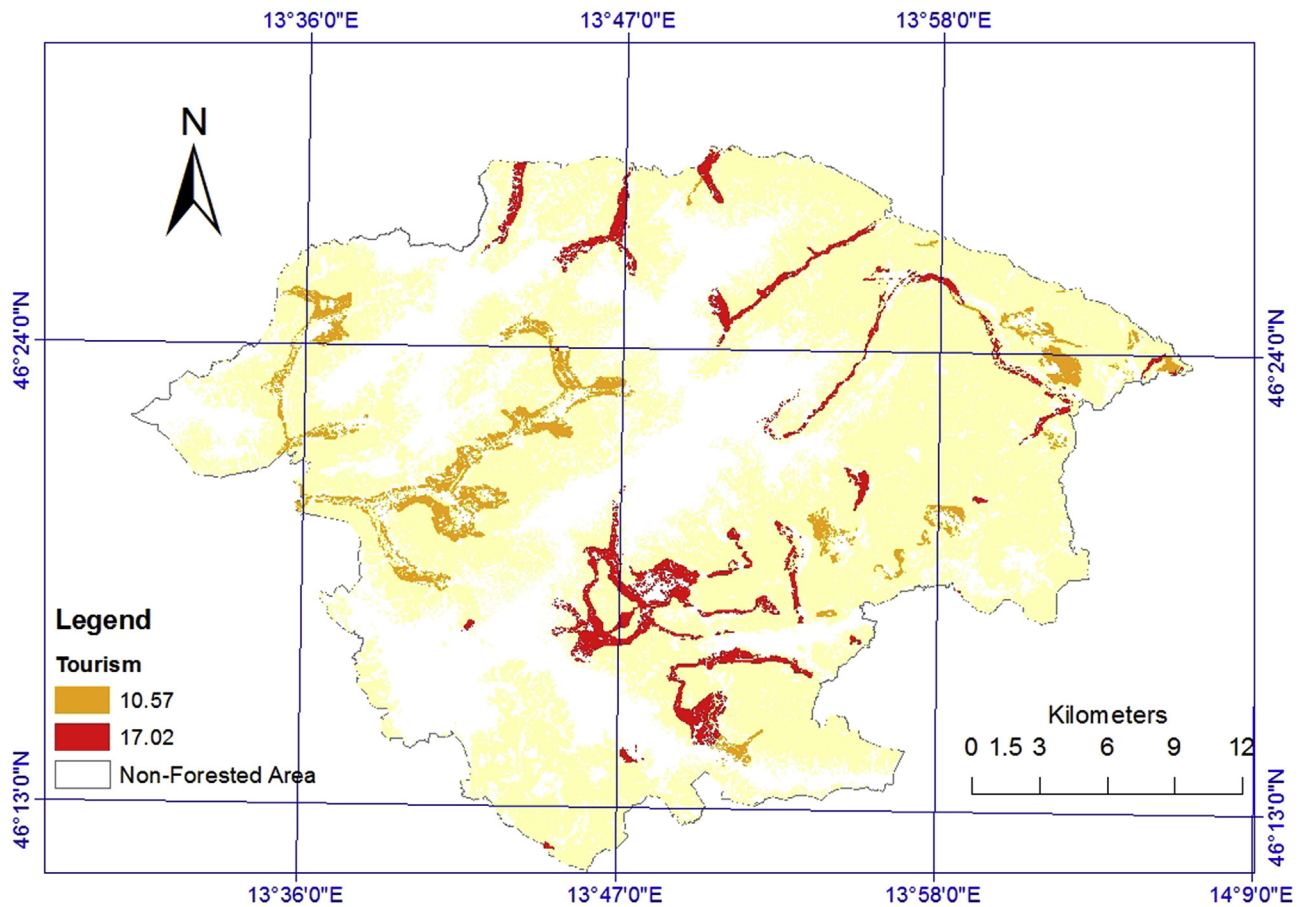
Fig. 5. Economic value of outdoor recreation in the Triglav National Park.

Table 3
Total available energy in Triglav National Park.

Description	(MWh y^{-1})	(MWh ha^{-1} y^{-1})
Theoretical bioenergy	125,559	2.35
Legal bioenergy	58,478	1.10
Technical bioenergy	46,077	0.86
Economic bioenergy	39,276	0.74
Production costs (€)	5,677,153	
Net positive revenues (€)	2,413,914	
CO2 total emission (t)	1293	
Total surface (ha)	53,384	
Yield surface (ha)	31,885	
Technical positive surface (ha)	20,093	
Economic positive surface (ha)	16,445	

approach allows the inclusion of the values of nature and the benefit for the economy at the same time. Since wood production seems to be enhanced by biomass extraction while natural hazard protection and carbon sequestration depleted, the spatial planning of biomass use should be carried out limiting the negative impacts on the areas that are important for providing such services. At the same time, biomass use may be planned effectively in the part of the territory where the positive impacts on wood production are higher. The value added of the GIS analysis is fundamental in this approach because it allows the inclusion of the spatial component into the decision making process and the computation of a huge number of data at the same time. The traditional approaches for managing the territory include ecological and geo-morphological aspects into the decision-making structure, in order to

management should be the satisfaction of human needs without running the risk of damaging the value of nature conservation; this

Table 4
Technical parameters included in r.green.biomassfor.technical.

Technical parameters	
Slope lower limit with cable crane (°)	17
Slope higher limit with cable crane (°)	45
Maximum distance with cable crane (m)	800
Slope higher limit with forwarder (°)	17
Maximum distance with forwarder (m)	600
Slope higher limit with other techniques (°)	17
Maximum distance with other technique (m)	600

Table 5
Economic parameters included in r.green.biomassfor.economic.

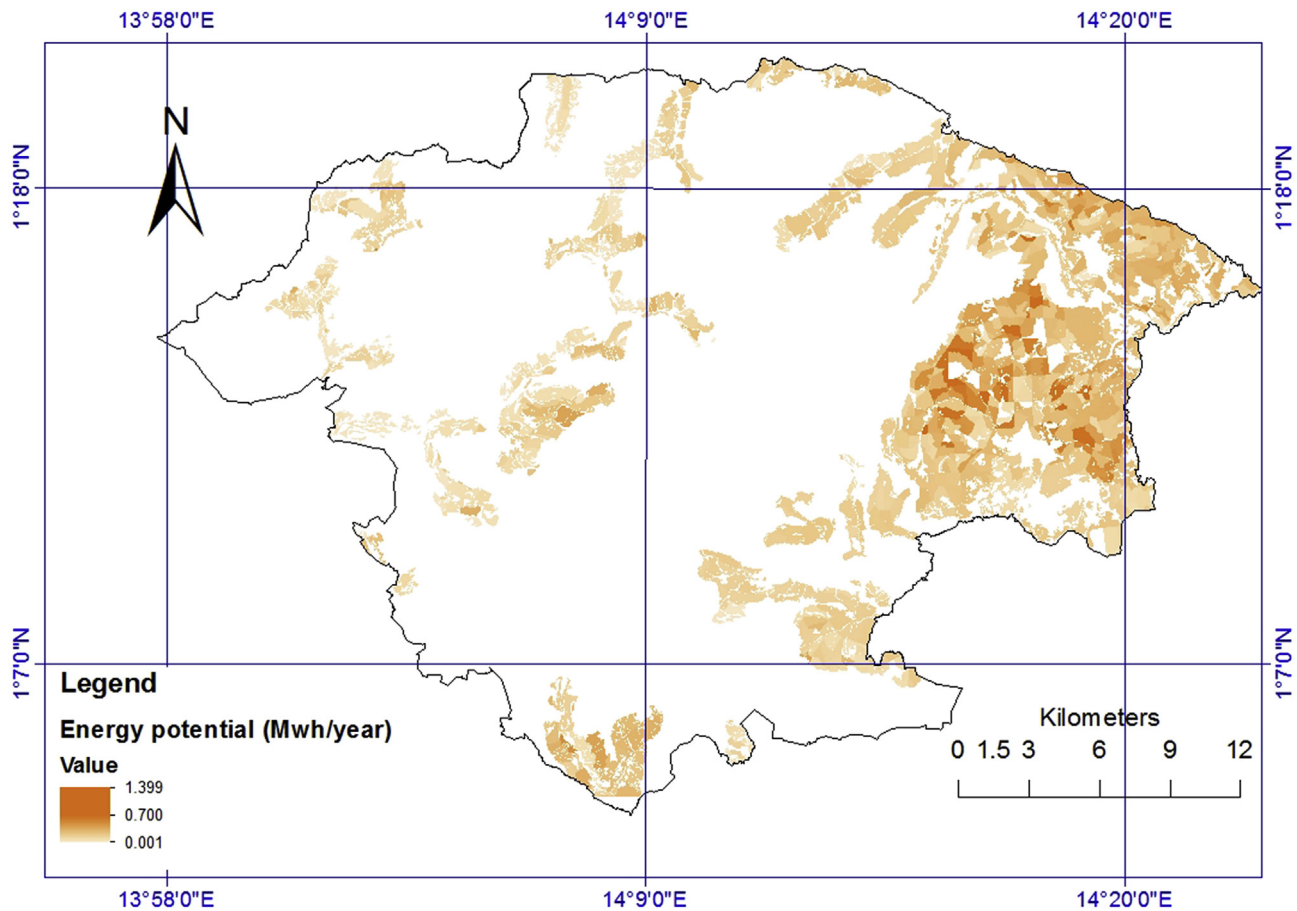| Forest type	Price (€ m^{-3})
Coniferous	78
Broadleaves	70
Harvesting costs	
Woodchip energy price	28
Felling cost with chainsaw	19.56
Processing cost with processor	36.05
Processing cost with forwarder	52.49
Cable crane cost	111
Skidder cost	41.74
Chipping cost	150.87
Truck	64.9

Fig. 6. Biomass potential from the economic module of r.green.biomassfor.

Table 6
Descriptive statistics concerning the impacts of forest biomass harvesting on ES.

ES	Mean	Median	St.dev.
Wood production	1.31	1	0.63
Carbon sequestration	−0.15	0	0.99
Natural Hazards Protection	−0.23	0	0.60
Outdoor recreation	0.08	0	0.76

understand a simple solution to reach the natural resource to be exploited. This approach provides further consideration concerning the value of nature and may change considerably the management trajectories. The main drawback of this methodology, which is common to all GIS applications, is that the quality of the results is sensible to the quality of the input data. An accurate computation of both energy potential and ES assessment requires a big amount of spatially-explicit data. The availability of high quality data is a necessary condition for obtaining reliable results. In addition, a critical part of the method is the calculation of the impact, which is highly case-specific and requires *ad hoc* measurements. The module r.impact allows the user to insert the expected impact manually, so the more accurate is such assessment and the more reliable the results would be. In order to test the methodology we assessed the expected variation of the ES values with a questionnaire survey; such survey is of course an approximation but the general trend of the effect (positive or negative) is confirmed in the literature [5]. Future development of the methodology may include the cited additional information and may foresee the use of additional spatial components in order to carry out a more precise location of

the ES values in the space. Another way to assess the impacts of biomass development could be the implementation of field studies to directly estimate the loss of the ecosystem integrity and the related economic values. In particular, the knowledge about the effects of forest biomass harvesting on cultural services may be of interest, due to the unclear real consequences that such action may produce.

5. Conclusions

This study introduced a methodology for the estimation of the energy potential from forest biomass and the expected impact of biomass harvesting on forest ES. Such application is important in order to highlight that wood harvesting is a source of income for forest owners but, at the same time, may create externalities in the environment. Identifying and quantifying such external effects is important to understand the how environmental values may be increased or depleted due to human activities and, eventually, establishing compensation measures. In addition, monetizing the environmental effects allows the incorporation of environmental values in the cost-benefit analysis, which is an important tool to assess the welfare effect of the decisions. The proposed DSS has precisely the objective of estimating potential forest biomass supply taking into account the effects on other forest ES.

The main advantage of the r.green.biomassfor is that it is a user friendly and open source DSS. Therefore, this DSS can be applied in other contexts (e.g., protected and not protected forest areas) characterized by the availability of the mandatory date such as forest types, road network and digital terrain model. The results of
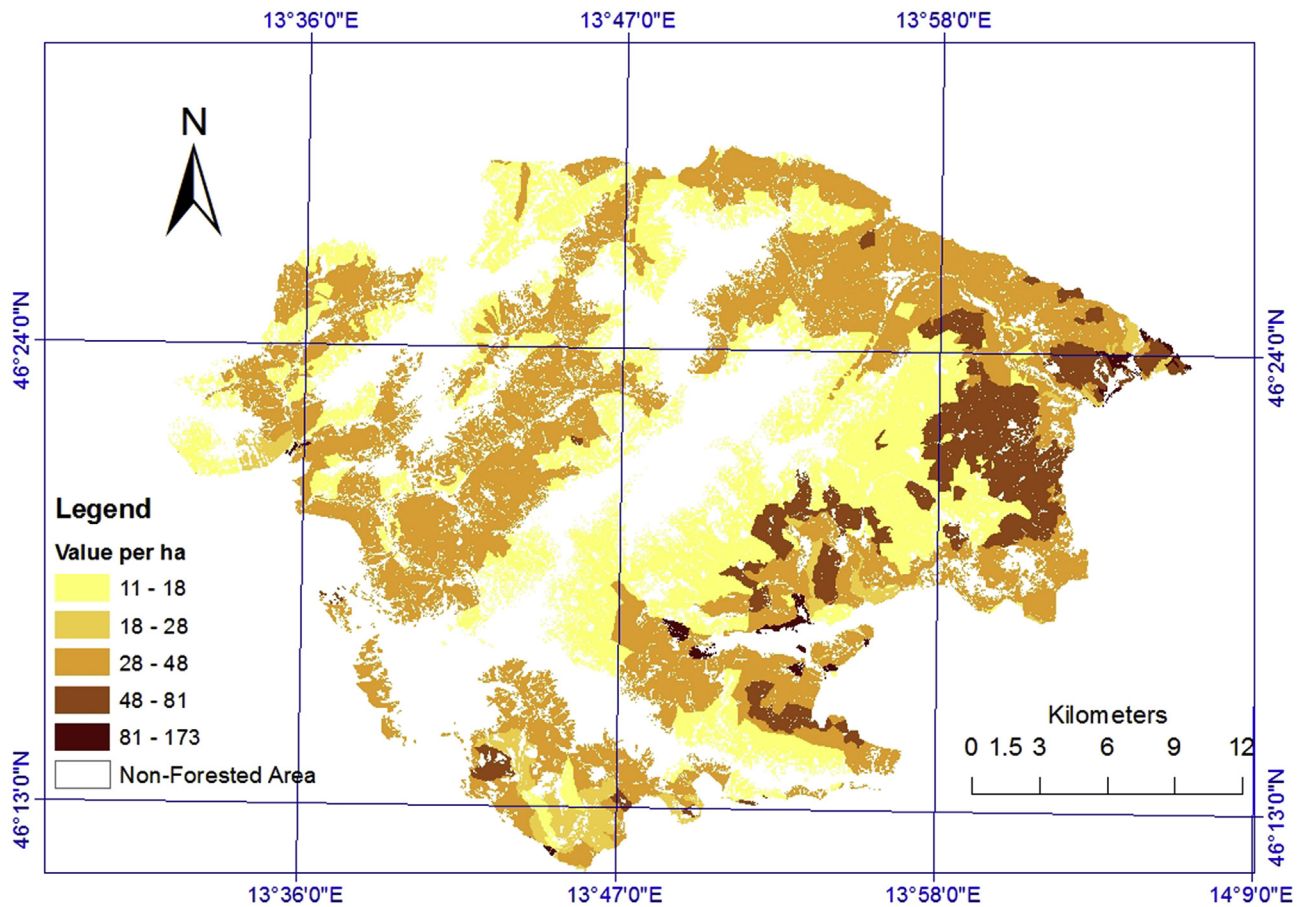
Fig. 7. Expected impact of biomass harvesting on wood production in the Triglav National Park.
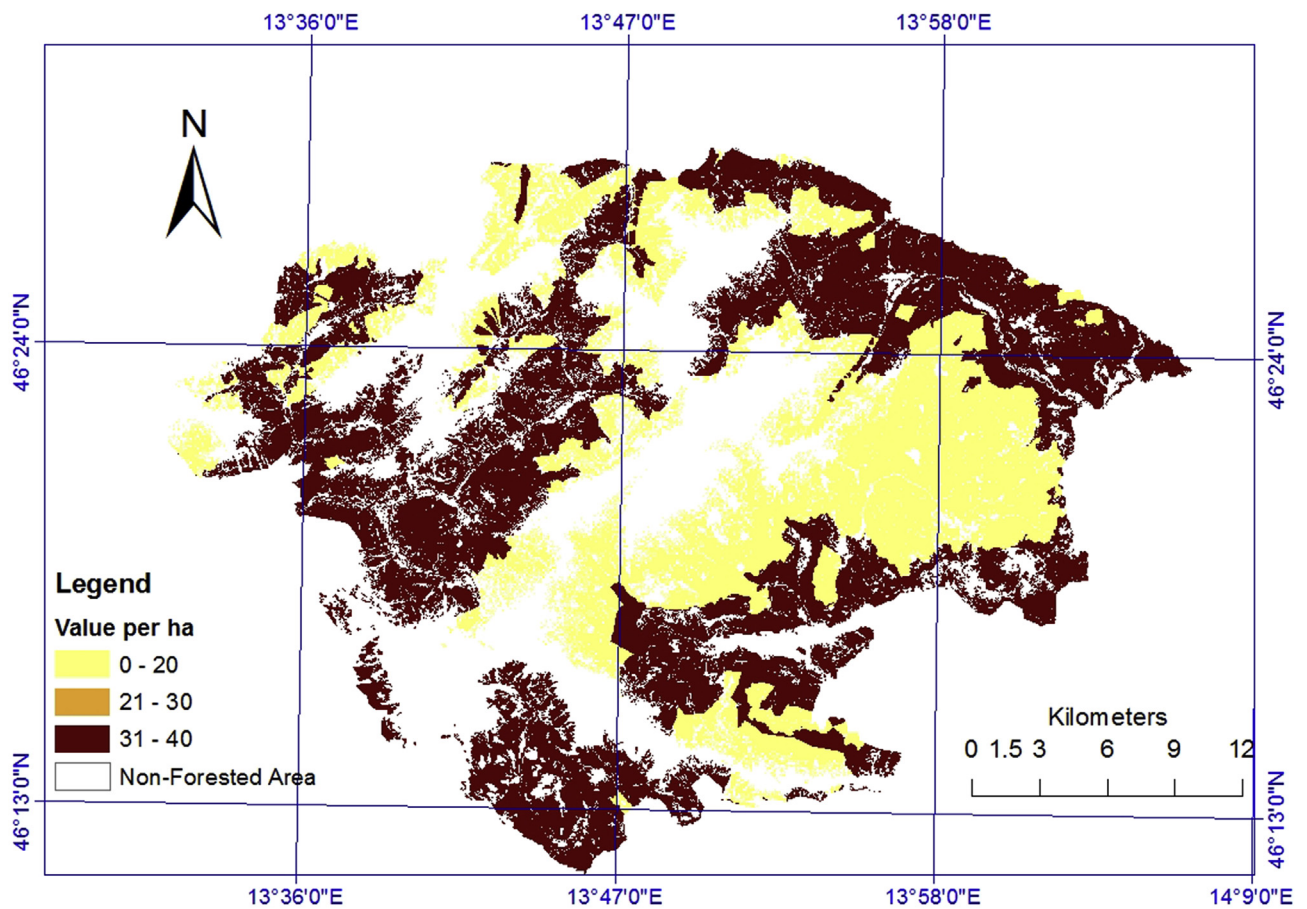

Fig. 8. Expected impact of biomass harvesting on natural hazards protection in the Triglav National Park.
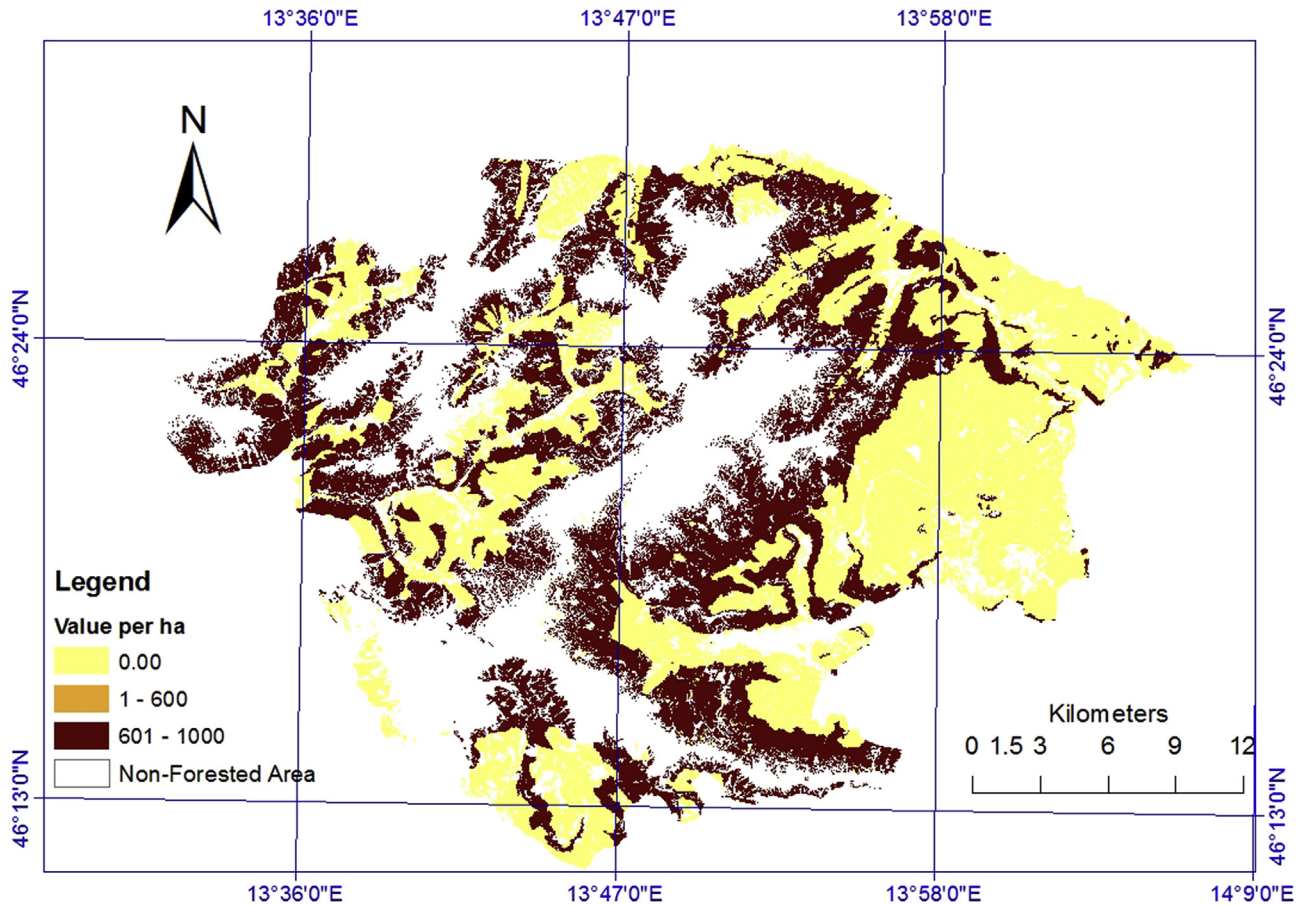
Fig. 9. Expected impact of biomass harvesting on carbon sequestration in the Triglav National Park.

the r.green.biomassfor DSS can be useful to decision makers (land planners and managers) in order to define a strategy for the improvement of the forest biomass supply while reducing negative effects on the other ES. In addition, this open source DSS has a flexible structure that can be applied from local to national scale. The main disadvantage of the r.green.biomassfor DSS is the need to have some mandatory date indispensable for its application.

In the future steps, the r.green.biomassfor DSS will be adapted and applied to other renewable sources - i.e. hydropower, wind power and solar photovoltaic power - always taking into consideration the specific impacts on ES.

Acknowledgements

Appendix A. Supplementary data

Supplementary data related to this chapter can be found at http://dx.doi.org/10.1016/j.biombioe.2017.01.033.

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