Valuing Forest Ecosystem Services for Spatial and Landscape Planning and Design

Roberta Ingaramo, Emma Salizzoni**, Angioletta Voghera****

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Abstract[1]

Forest landscapes perform a wide range of functions, which are not merely environmental but also socio-economic and cultural in nature, constituting valuable sources of Ecosystem Services (ES). In the countries of southwestern Europe, widespread fires, caused not only by climate change but also trends in land use (renaturalisation and urban sprawl, with an increase in the "forest-city" interface), jeopardise the provision of Forest Ecosystem Services (FES). Valuation and mapping of FES to better define forest fire risk and to increase awareness among institutions and stakeholders of the value of forest landscapes represent an important step towards establishing policies that are effective in preventing the risk of fires. This paper, which is the result of research conducted as part of the European project "Advanced Forest Fire Fighting" (AF3, Seventh Framework Programme), sets out a method for valuing and mapping FES in the Sardinia Region, which is particularly prone to the risk of forest fires. The method has been designed so that it can be applied if necessary by public administrators themselves, thus it does not entail the use of models but the application of both biophysical and economic GIS-based indicators. Economic valuation of FES, which refer to Total Economic Value (TEV) theory, has been based on different valuation methods, searching for an equilibrium between the reliability of valuation and its potential applicability by institutional actors.

Moreover, geo-referencing these indicators has made it possible to draw up maps of forest values, important tools to support planning policies for forest landscapes.

The paper reports the premises, structure, results and prospects of the method, applied to the forests of the Sardinia Region at both the regional and local scale. It concludes by focusing not only on the method's potential for specific awareness-raising, but also the more general implications for spatial and landscape planning, management and design policies.

1. ECOSYSTEM SERVICES, A BRIDGE AMONG NATURE, SOCIETY, AND ECONOMY FOR SUSTAINABLE PLANNING

The increasing attention paid in the spatial planning field to the topic of Ecosystem Services (ES) – construed according to a well-established definition, as the benefits which ecosystems provide humans (MEA, 2005)[2] – stems

[1] This paper - which is the result of the research coordinated by Angioletta Voghera (Interuniversity Department of Regional and Urban Studies and Planning, DIST, Politecnico di Torino) and Roberta Ingaramo (Department of Architecture and Design, DAD, Politecnico di Torino), in the framework of the AF3 European project - has been prepared jointly by the three authors. Nevertheless, the final version of Section 5 is by Roberta Ingaramo, that of Sections 1 and 3 is by Angioletta Voghera, and that of Section 4 is by Emma Salizzoni.

[2] "Goods provided by natural ecosystems are the basic building blocks of human welfare" (Krieger, 2001, p. 1).

not only from the now-widespread awareness of the need to integrate environmental issues into local policies but also the acknowledged potential of the concept of "Ecosystem Services" itself. Indeed, it connects the environmental and socio-economic sphere, biophysical-ecosystem aspects and human welfare extremely effectively, by translating environmental "values" into "benefits" for humans, thus highlighting the added value which ecosystems provide for society and the economy. It is the nature of ES as a "bridging concept" (Braat and de Groot, 2012), connected with their clearly anthropocentric perspective which underpins them (Wunder and Thorsen, 2014), which makes them a potential tool for drawing up, implementing and communicating sustainable policies which combine conservation and development perspectives effectively. This potential is closely linked to the clarification and communication of the benefits connected with ES, which must come through their assessment and valuation.

In recent year, assessment and valuation of ES has been at the core of several institutional initiatives, including the Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010) and the Common International Classification of Ecosystem Services (CICES, 2013). Some of these initiatives are still in progress, such as Mapping and Assessment of Ecosystems and their Services (MAES, 2013, 2014), designed to support the implementation of the European Biodiversity Strategy[3]. These institutional initiatives have been accompanied over the years by several academic studies which have dealt with the subject of ES assessment and valuation. Specifically, in the wake of the study – as pioneering as it was controversial (Krieger, 2001) – by Costanza *et al.* (1997), which proposed making an economic valuation of ES at the global scale, there has been a proliferation of studies which have set out to assess not only the biophysical aspect of ES but also to valuate the economic aspect (of interest in this regard is the survey study of valuation methods in Häyhä and Franzese, 2014). The advisability of a joint, complementary assessment of these two aspects is acknowledged at the international level (UN 2010), in relation to the resulting opportunity not only to take account of the effective "stock" of available natural capital but also to *communicate* the value of this natural capital in the most effective way (Häyhä *et al.,* 2015). Indeed, economic valuation of ES has unquestionable power in terms of raising awareness among social actors with regard to the role played by ES (Nasi *et al.,* 2002). In addition, it supports the development of policies "by providing useful information to policy-makers by highlighting the economic consequences of an alternative course of action" (Mavsar and Varela, 2014, p. 44).

To these ends, the mapping of ES values – which, with the development of GIS technologies, is becoming increasingly widespread and important (in this regard, see the survey of studies and methods of valuation and mapping in Maes *et al.,* 2012 and Schägner *et al.,* 2013) – takes on a crucial role. Indeed, the high "educational" value of maps is well-known (Hauck *et al.,* 2013), as they can convey otherwise complex information – in this case, the value of ES – simply and effectively. In addition, the "spatialisation" of the value of ES is essential for the development of planning policies that systematically take account of benefits provided by ES.

The valuation and mapping of ES – although not systematically integrated in planning policies yet (Lerouge *et al.,* 2017) – thus constitute two crucial steps in the development of sustainable territorial government processes at both the regional and local scale.

2. THE VALUATION OF ENVIRONMENTAL GOODS: PARADIGMS AND METHODS APPLIED TO ECOSYSTEM SERVICES

As mentioned above, economic valuation of ES has raised a growing interest during the last two decades. Since the Seventies, in the wake of the strengthening, of the "environmental awareness" (Gambino, 1997), the need of linking economy to ecology has been widely acknowledged (Bresso, 1993), so as to "give voice" to the contribution that natural resources provide to economy, which otherwise could be dangerously undervalued (Hardin, 1968). This need asked for the definition of new theoretical paradigms that allowed the valuation of environmental goods, which, as public goods, are often non-marketed and unpriced. At the beginning of the Nineties, the introduction of the Total Economic Value (TEV) concept (Pearce, 1993, Turner and Pearce, 1996) allows a "comprehensive" valuation of environmental goods, also in their non-marketed components. This approach makes it possible to estimate, in monetary terms, the economic value of benefits provided by ecosystems and so by ES.

In this perspective, the TEV of an ecosystem is made up of:

– use values – directs (consumptive, such as, wood, and non-consumptive, such as tourism) and indirect (such as hydrogeological protection) – and option values,

[3] Based on the ESclassification framework provided by CICES, in 2014 the MAES (*Mapping and Assessment of Ecosystems and their Services*, biodiversity.europa.eu/maes) working group – established as part of the Common Implementation Framework (CIF), the organisation tasked with overseeing the implementation of the European Biodiversity Strategy – has developed a study which aims to draw up a set of guidelines that can support Member States in fulfilling Action 5 of the Strategy, that is, mapping and assessing, including from an economic point of view, the state of ecosystems and related services ("Map and assess the state and economic value of ecosystems and their services in the entire EU territory; promote the recognition of their economic worth into accounting and reporting systems across Europe", Target 2: "Maintain and restore ecosystems").

related to the future availability of ES for personal benefit;

– non-use values, namely existence, altruism and bequest values, connected, respectively, to the awareness that ES exists and to the availability of ES for other people (intra-generational equity) and future generations (inter-generational equity).

In the framework of a TEV approach, there are several methods to estimate the monetary value of use values and non-use values of ecosystems. Their selection mainly depends on the scale and aims of valuation and on data availability. Usually, the following methods are used (TEEB, 2010): (i) market valuation methods (e.g. market price or cost-based methods, such as avoided and substitution costs), (ii) revealed preferences methods (travel cost method, hedonic pricing method), (iii) simulated valuation methods (contingent valuation, group valuation).

Beyond these methods, definable as "primary valuation methods", based on the use of original data, it is possible to use the so-called "value transfer methods", better known as "benefit transfer methods", that, on the contrary, refers to data already existing in context that are similar to the valuation context, to be exported (see Brander and Crossman 2017 for strengths and limits of the benefit transfer method).

This paper, consistently with a TEV approach (Table 2) and applying some of the abovementioned valuation methods, presents and discusses an experiment in the biophysical and economic valuation and mapping of ES. The paper focuses in particular on ES provided by forests, which represent landscape heritage of exceptional value not only from an environmental but also a socio-economic and cultural perspective (Ritter and Daukstra, 2011).

3. MULTIFUNCTIONALITY AND RISKS POSED TO FOREST LANDSCAPES

Multifunctionality is a typical characteristic of forest landscapes (Merlo and Croitoru, 2005; MEA, 2005). Different systems exist for the interpretation and classification of forest functions in terms of ES (for an overview of the main international classification frameworks for Forest Ecosystem Services, FES, see Forest Europe, 2014), based on different taxonomic criteria. Nevertheless, they all illustrate the wealth of functions performed by forests of an environmental nature (e.g. water regulation and filtration, hydrogeological protection, carbon sequestration, etc.), socio-economic nature (e.g. wood and non-wood forest products, etc.) and cultural nature (e.g. tourism, aesthetic and spiritual values, etc.).

However, these landscapes are subject to high risks. In Europe, while the patterns of renaturalisation which have affected large areas of abandoned farmland since World War II, particularly in mountain areas, have led to an increase in the amount of forest cover, they have also increased one of the most serious risks currently posed to forest landscapes: fire (EEA, 2008). Recent figures in fact show that the number of fires is constantly on the increase, particularly in the countries of southwestern Europe and in areas close to inhabited areas (EEA, 2016). This is due not only to the general conditions of aridity connected with increasingly evident climate change, but also to the aforementioned renaturalisation patterns which, in combination with the land use patterns that have manifested themselves in growing suburbanisation, have contributed to increase of the so-called "Wildland-Urban Interface" (WUI), that is, the area of interface between wildland and built environments, particularly subject to the risk of fire (Chas-Amil *et al.*, 2013; Modugno *et al.*, 2016).

Preventing and reducing the risk of forest fires is therefore a current challenge, not only because of their growing spread but also because of the impact that a large-scale fire may have on a forest area, with long-term consequences that have a significant impact on the resilience of these landscapes, which are no longer able to provide the abovementioned FES for long periods:

"in addition to the destruction of vegetation, forest fires produce other damaging effects […]. Among these are […] the destruction of the organic layer of the soil, and the changes in the water infiltration rates in the soil, which makes burnt areas prone to erosion, soil loss, and landslides" (EEA, 2008).

The AF3 research project (Advanced Forest Fire Fighting, Grant Agreement no. 607276, funded under the Seventh European Framework Programme, Theme SEC-2013.4.1-6, involving 19 international partners including the Politecnico di Torino, ending in July 2017) acknowledged the urgent need for effective policies to prevent and reduce the risk of forest fires and set out to overcome current shortcomings in the management of fire risk – which, it is known, also contribute to the growing spread of fires (MEA, 2005) – by developing new methods and technologies[4]. As part of the project, the DIST/DAD research group at the Politecnico di Torino[5] has developed a method for valuing FES, applying it to the Sardinian Region.

[4] "These so-called 'mega-fires' are particularly destructive and difficult to control with the technologies and systems currently available to fire fighters and emergency agencies. The AF3 project intends to provide an improvement to the efficiency of current fire-fighting operations and to the protection of human lives, the environment and property by developing innovative technologies and means to ensure a high level of integration between existing and new systems" (http://af3project.eu/description/, last accessed July 2017).

[5] The research activity developed by the Politecnico di Torino in the framework of the AF3 project was coordinated by Vittorio Verda, Department of Energy (DENERG).

4. VALUATION OF FOREST ECOSYSTEM SERVICES IN THE SARDINIA REGION

4.1 Methodological framework

The purpose of the current research regarding the valuation of FES in the Sardinia Region is twofold: to extend the definition of forest fire risks by providing a more detailed assessment of so-called "exposure" (i.e. the value of elements at risk)[6] while developing a highly communicative assessment tool to help raise awareness among both public administrators and stakeholders regarding the value of forest landscapes and to support effective fire prevention and risk reduction policies.

Considering these objectives, the method developed involves:

– not only a biophysical but also an economic valuation of FES, "spatialised" by means of GIS tools in order to draw up maps of the values of forest landscapes, which are highly communicative tools[7];

– using, for FES valuation purposes, not complex mathematical/computational models but rather indicators which can be calculated on the basis of easily accessible, updateable information, thus enabling them to be applied if necessary by public administrators for monitoring purposes.

Starting from the ES classification framework provided by CICES 2013 (Forest Europe, 2014), that classifies ES under three general classes (provisioning, regulation and cultural ES), six indicators were selected (Table 1) according to the following criteria:

– the representativeness of the main ES classes (provisioning, regulation and cultural);

– the representativeness of the main functions performed by forests as commonly identified in the literature (among the others, Pearce, 2001; Merlo and Croitoru 2005; Ciancio *et al.*, 2007);

– the importance of the FES to the local context (in this case the Sardinia Region);

– the actual possibility not only to develop, at regional local, a quali-quantitative valuation of FES, but also to "spatialise" the valuation outcomes; this purpose is in turn conditioned by the availability of data that are: (i) quali-quantitative, both biophysical and economic, (ii) geo-referable, that is, relatable to the main georeferencing source used by the research, the Sardinia Region's *Carta dell'Uso del Suolo*, CUS, 2008, (iii) homogeneous for the regional scale.

– the actual possibility to develop a FES valuation replicable by public administrators for monitoring purposes that is in turn conditioned by the availability of data supported by easily accessible, periodically updated sources.

The selected FES refer, under a TEV approach, to direct and indirect use values, while the values of non-use of forest landscape have not been assessed due to lack of data (Table 2).

Economic valuation made use of various estimation methods (market price, substitution cost, and benefit transfer) defined with respect to the valuation aim (each FES features) and data availability. In particular, simulated valuation methods, such as contingent valuation method (in this regard, see, for example, Tempesta and Marangon, 2004 and Comino *et al.,* 2013), were not applied; this choice was made with a view to making the valuation method easier to apply for individuals who are not always expert in assessment techniques, such as spatial and forest heritage government institutions, and above all to make it possible to update and monitor results.

With regard to each FES, the annual values (provisioning of FES over the course of 12 months[8]) were calculated.

4.2 Biophysical and economic indicators: tools

The *provisioning* function of Sardinia's forests[9] was assessed in relation to three FES connected with the provision of Wood Forest Products (WFP, "timber" and "fuel wood") and Non-Wood Forest Products (NWFP, "cork").

6 We should stress that risk, as commonly understood in the literature and also in the Sardinia Region's "*Piano regionale di previsione, prevenzione e lotta attiva contro gli incendi boschivi 2014-2016*" ("Regional Forest Fire Forecasting, Prevention and Fighting Plan 2014-2016"), is calculated as the relation between the factors Hazard, Vulnerability and Exposure (R=H*V*E). The method proposed intends to integrate and enhance the definition of the Exposure variable, especially with regard to vegetational aspects, which are currently considered in economic terms with reference only to "Average Agricultural Values of the Province" and, in environmental terms, by means of unspecified indices of environmental value (from 0 to 10) connected with the land use classes of wooded areas defined by Corine Land Cover (see "*Piano regionale di previsione, prevenzione e lotta attiva contro gli incendi boschivi*" 2014-2016, pp. 70-71).

7 In Italy, several studies have been developed regarding the valuation – Total Economic Value (TEV) – of FES in various regional contexts. See, for example, Marangon and Gottardo, 2001; Gios *et al.,* 2003; Tempesta and Marangon, 2004. Nevertheless, "spatialisation" of TEV has become the subject of attention only recently. Of interest in this regard is the work done by Marinelli and Marone (2013) regarding Tuscany's forests. Particularly interesting studies in an international context include Pearce (2001), Emerton and Ming Aung (2013), and Häyhä *et al.* (2015).

8 For each indicator, the year is defined by the most recent available update of the base data. Where necessary, prices have been discounted, revaluing them, to 2017.

9 "Forests" here refers to areas with tree cover comprised by forest species with a density of greater than 20%, as defined by the Sardinia Region's *Carta dell'Uso del Suolo* (CUS) or land use map. Only in relation to cork oak landscapes, as detailed later in the text, have wooded areas with lower density been referenced.

10 In 2013 CICES classification framework (https://cices.eu/), timber is classified under "materials" division and fuelwood under "energy" division (the common section is "provisioning ES").

Table 1 - *Biophysical and economic indicators for the valuation of Forest Ecosystem Services (FES) in the Sardinia Region*

	FES	Biophysical indicator	Structure	UM	Economic indicator	Structure	UM
PROVISIONING	**Timber**	Volume of timber	m^3/ha/year	m^3	Market value of timber	€/ha/year	€
	Fuel wood	Volume of fuel wood	m^3/ha/year	ma	Market value of fuel wood	€/ha/year	€
	Cork	Quantity of cork	q/ha/year	q	Market value of cork	€/ha/year	€
REGULATION	**Hydrological protection**	Surface area protected by forests from erosion phenomena	ha	ha	Substitution value of the protective function of forests	€/ha/year	€
	Carbon sequestration	Amount of carbon absorbed	t/ha/year	t	Market value of carbon absorbed	€/ha/year	€
CULTURAL	**Tourism**	Annual visitors	no. visitors/year	num	Value of annual visits	€/ha/year	€

Table 2 - *The economic valuation of FES in the Sardinia Region under the TEV approach and related valuation methods*

TEV values			FES		Economic indicator	Valuation method
USE	**Direct**	Consumptive	**Timber**	PROVISIONING	Market value of timber	Market price
			Fuel wood		Market value of fuel wood	Market price
			Cork		Market value of cork	Market price
		Non-consumptive	**Tourism**	CULT.	Value of annual visits	Benefit Transfer
	Indiretto		**Hydrological protection**	REGULATION	Substitution value of the protective function of forests	Substitution cost
			Carbon sequestration		Market value of sequestered carbon	Market price
NON USE	**Existence**					
	Altruism					
	Bequest					

WFP were valuated with reference to both timber and fuelwood – in line with some recent studies (see for instance Häyhä *et al.,* 2015) and CICES 2013[10] – to distinguish two different production aspects. The indicators *timber* and *fuel wood*, were calculated by correlating the annual production data (m^3/year) provided by ISTAT (*"Utilizzazioni legnose forestali per assortimento e tipo di bosco"*, 2015) by type of forest (broadleaf, coniferous and mixed), and the class of land cover of the three types of wood available in the CUS (three land-cover classes – 21-50%, 51-80%, >80% – to which a density coefficient was assigned, assuming that greater cover potentially corresponds to greater forest density and so timber production). The volume thus defined, i.e. the biophysical value of the two FES, was related to the average selling price for timber, once again provided by ISTAT (*"Prezzi medi all'imposto per assortimento e tipo di bosco"*, 2011[11]), in order to obtain the monetary value.

Although every indicator was calculated following different calculation procedures, hereafter it is pointed out, by way of example, the calculation and valuation steps for the first indicator, *Timber*.

Firstly, a biophysical indicator concerning the Volume of Timber (T) was calculated using the following formula (1):

$$\text{T Volume } (m^3) = \text{ha (broadleaf, coniferous, mixed) x T average production}^{12}\ (m^3/\text{ha}) \text{ x density coefficient}^{13} \quad (1)$$

This volume was then converted in monetary units through the calculation of an economic indicator concerning the Market Value of Timber (T) using the following formula (2):

$$\text{T Value } (€)\text{: T volume } (m^3) \text{ x T average price } (€/m^3) \quad (2)$$

In Table 3, numerical values connected to *Timber* indicator calculation are provided.

The FES connected with the production of *cork* –selected because of the primary role played by cork production in the island's agro-forestry economy – was assessed with reference both to cork oak forests with a density greater than 25%, as identified by the CUS, and to those characterised by lower density (5%-25%), also identified by the CUS and corresponding to wooded pastures. In this specific case, therefore, areas of woodland with a density of less than 20% (see note 8) were considered, as cork oaks interspersed with pasture land contribute significantly to cork production. The areas thus identified were assigned a homogeneous production indicator (q/year), provided by Agris Sardegna, the Sardinia Region's cork growing and forestry research service (there are in fact no forest density parameters which enable greater or lower cork productivity in the various areas to be plausibly or effectively differentiated at the regional scale; indeed, the lower forest density of some areas is compensated for by the greater diameter and therefore the greater productivity of the trees). For a monetary valuation of production, the average market price of cork (€70/q, 2016) was taken, once again provided by Agris Sardegna. In this case, in contrast to the price of wood products (see above), provided as the "selling price" (i.e. after felling), the price considered here is the so-called "standing price", the result of a visual assessment of the cork oaks prior to extraction.

The *regulating* function performed by forests was assessed with reference to two FES: hydrogeological protection and carbon sequestration.

The function of *hydrogeological protection* was assessed with specific reference to the capacity of the forests concerned to counter – by intercepting and attenuating the kinetic force of rainfall – soil erosion phenomena, which are particularly significant in Sardinia as a result of its irregular rainfall pattern. The FES biophysical assessment was based on geomorphological and species parameters (see hereafter), while the economic valuation entailed the use of the substitution cost method, highlighting the costs that would be necessary to compensate for the protective function of the forest by means of environmental engineering projects. The use of this method, although it presents some limits (Barbier, 2007; Ayres, 2007), is in line with the most common valuation approaches used to estimate the economic value of regulation ES (TEEB 2010).

In order to assess the hydrogeological protection function, information regarding the following was analysed together: (i) the slope class of land areas (<40%, 40%-70%, >70%), assuming that the protective function of the forest increases the greater the slope (not significant in the case of areas with a slope of less than 40%); (ii) type of forest (broadleaf, coniferous, mixed), with a higher or lower capacity to perform the function of protection from erosion each species;[14] (iii) vegetation cover class (21-50%,

[11] Timber: broadleaf - €74.11/m^3; conifer - €65.72/m^3 - conifer. Fuel wood: broadleaf €54.50/m^3; conifer - €24.15/m^3.

[12] Annual average production of Timber: broadleaf - 0,004 m^3/ha/year, conifer - 0,02 m^3/ha/year, mixed - 0,01 m^3/ha/year (the current very low annual timber production per unit is also confirmed by a source of several years ago, namely the Economic Atlas of Sardinia, Boggio, 1988). It is worth reminding that ISTAT (Italy's National Institute for Statistics) provides the figure only with regard to broadleaf and coniferous forests. The figure regarding mixed forests (i.e. a forest in which neither broadleaf trees nor conifers, as defined in the CUS, account for more than 75% of the forest composition), was calculated as an average value between broadleaf and conifer production. The same procedure was used to calculate the average price of timber provided by mixed forests.

[13] Density coefficient (Land cover classes): class 0: 0,98, class 1: 0,73, class 2: 1,03, class 3: 1,28. Class 0 refers to woods with no land cover class specified in the CUS. In this case the density coefficient is the average value of the other density coefficients.

[14] According to Motroni *et al.* (2004), mixed forests are those which most effectively perform the function of protection from soil erosion, followed by coniferous and broadleaf forests.

Table 3 - *Numerical values connected to biophysical and economic indicators for Timber FES*

Land use class	Land cover class	Surface (ha)	Average production (m^3/ha)	Density coefficient	T volume (m^3)	T average price (€/mc)	T value (€)
	Class 0	39.308,07	0,004	0,98	154,09	74,11	11.419,43
	Class 1	91.941,75	0,004	0,73	268,47	74,11	19.896,31
	Class 2	132.027,91	0,004	1,03	543,95	74,11	40.312,50
	Class 3	129.131,39	0,004	1,28	661,15	74,11	48.998,03
	Class 0	1.827,85	0,02	0,98	35,83	65,72	2.354,48
	Class 1	6.968,30	0,02	0,73	101,74	65,72	6.686,17
	Class 2	18.881,31	0,02	1,03	388,95	65,72	25.562,12
	Class 3	11.051,35	0,02	1,28	282,91	65,72	18.593,14
	Class 0	0	0,01	0,98	0	69,92	0
	Class 1	2.384,52	0,01	0,73	20,89	69,92	1.460,52
	Class 2	6.370,64	0,01	1,03	78,74	69,92	5.505,58
	Class 3	3.652,81	0,01	1,28	56,11	69,92	3.923,01
TOT					**2.592,83**		**184.711,29**

51-80%, >80%), assuming an increasing capacity to intercept rainfall. This biophysical assessment, which gives the surface area of the forest areas that perform a significant function of protection, was then combined with an economic assessment, which in this case used as mentioned above the substitution cost method. In order to calculate the costs, reference was made to hydro-seeding works for areas with slopes of between 40% and 70%, while for areas with a greater slope (>70%), works with live double crib walls[15] (for areas with a slop of less than <40%, the need for engineering works is generally not identified, Ciancio *et al.,* 2007). By proceeding in this way, it was possible to calculate the annual value of substitution of the protective function of forests with regard to erosion phenomena.

With reference to the *carbon sequestration* function of forests – i.e. the amount of carbon removed annually from the atmosphere through photosynthesis and storage in newly-formed plant tissues (the epigeal mass was considered here), a crucial function for climate regulation (Stern 2007, Wunder and Thorsen 2014) – the assessment was performed by applying the unit values of sequestration (t/ha), as defined by the *Inventario Nazionale delle Foreste e dei Serbatori Forestali di Carbonio* (National Inventory of Forests and Forest Carbon Pools), INFC (Gasparini *et al.,* 2013), to the different species recorded in the CUS[16]. The market price of emissions was then applied as regulated by the European Union Emissions Trading Scheme[17]. This is one of the possible methods for monetary valuation of carbon sequestration. Compared to other methods, such as the calculation of the carbon social cost or the carbon social value (Mavsra *et al.,* 2014), it has undoubted advantages in terms of valuation rapidity, but also some critical points such as the great variability of the reference price, both on the medium period (just think to the impact of the 2008 crisis on the carbon price, see hereafter) and on the short one (the price is subject to daily fluctuations).

Finally, the *cultural* dimension of FES was valuated by examining the *recreational and tourism function* performed

[15] Hydro-seeding: € 1.48/m^2; live double crib wall with interdistance of 10m: €160/m^3 (*Prezzario dei Lavori Pubblici*, Sardinia Region, 2009). The costs of the two types of work have been annualised using the initial annuity formula based on a discount rate of 1% and a period of 30 years.

[16] As the distinction between species proposed by the INFC inventory is more detailed than the one set out in the CUS – which however must necessarily be used for the geo-referencing of the qualitative and quantitative data that underpin the indicators and therefore for the mapping of forest values – a simplified summary was implemented to relate the categories of species identified in the INFC to the main categories in the CUS. The carbon sequestration indicators provided by the INFC were thus applied to the following forest categories (the combined INFC categories are given in brackets): broadleaf (oak forests, hygrophilous forests, other deciduous forests, ilex woods, other evergreen broadleaf forests), cork oak forests, chestnut woods, planted broadleaf forests, coniferous forests (Austrian pines, stone pines, other coniferous forests), planted coniferous forests, mixed.

[17] €5.16/t (http://carbon-pulse.com, last accessed March 2017).

by forests. Forests perform a wide range of cultural ES: beyond the recreational and tourism function, also aesthetic, symbolic and educational ones. However, the recreational and tourism function is the most addressed in the literature (see the survey study of valuation methods in Milcu *et al.*, 2013) due to the undeniable complexity in valuing cultural "immaterial" aspects, that, also, usually demand not economic and alternative valuation methods (see, for instance, Edwards *et al.*, 2012 or Plieninger, 2013). The choice made in this study to investigate the tourism function – that does not entail an undervaluation of the importance of other cultural FES[18] – was made considering above all data availability. The study could rely on data concerning annual numbers of visitors to the forest areas (Sardegna Foreste, 2011)[19], albeit limited to only 13 forests (13 *Unità Gestionali di Base* or Basic Management Units managed by the regional forestry Agency Fo.Re.S.T.A.S., corresponding to around 9% of the island's total forest area). The value of a tourism day visit was calculated by means of a Benefit Transfer approach, borrowing value parameters established for other similar contexts (Italian forest areas) and adjusting them to the Sardinian context ("unit value transfer", Brander and Crossman, 2017)[20].

4.3 The Sardinian forest landscape: outcomes

The valuation method was applied at both the regional scale (the total forests of the Sardinia Region, an area with 20% forest vegetation coverage) and the local scale (the state-owned forest of Monte Pisanu, in the rovince of Sassari).

Table 4 below shows the annual biophysical and economic values[21] for six indicators calculated at the regional scale as well as the TEV (which in this case does not take into account the FES relating to tourism, as this was calculated for only 13 forests).

An examination of the data – in particular the breakdown of the TEV (percentage values) – highlights the primary role played by the FES connected with *hydrogeological protection*. The high economic value, in this case, is connected to the high costs of substitution which would need to be borne in order to compensate for the protective function of the forest, especially in areas with particularly steep slopes (>70%). Indeed, although these represent only 5% of the region's forest areas, they play a crucial role in terms of protection from erosion, the "substitution" of which would have to be achieved by means of environmental engineering works such as live double crib walls which would be costly but essential to guarantee the stability of steep slopes without vegetation[22]. Hydro-seeding operations, on the other hand, which were taken as reference for the calculation of the cost of substitution of the protective function of forests situated in areas with slopes of between 40% and 70%, have a smaller impact on the economic valuation of the FES: although they constitute over 30% of the forest surface, the price of the works is in fact much lower (see note 14).

The high percentage of the TEV accounted for by the FES of hydrogeological protection is also connected to the poor performance of the other indicators. Specifically, the values relating to the production of *timber* and *fuel wood* are extremely low, as Sardinia's forests are not managed and exploited systematically for this purpose. In fact, the timber extracted from the island's forests accounts for just 0.13% of Italy's production, while for fuel wood the figure is 4%. Broadleaf forests, which are extensively present on the island, account for a very large part of the total production of timber and fuel wood. However, conifers are distinguished by higher *per-unit* (i.e. €/ha) economic values since, despite the lower timber prices (see note 10), they are characterised by markedly higher production indicators (m^3/ha), especially with regard to fuel wood (Figure 1).

Remaining on the subject of the forests' provisioning function, a much more significant contribution, compared with timber and fuelwood production, comes from *cork* production: in fact, Sardinia contributes around 80% of Italian production (over 160,000 q/year) and the pre-extraction annual value from cork oaks (that is, excluding revenues connected with processing of the material, in direct manufacturing and induced activity) totals over 11 million euros.

18 «*An overemphasis on recreation and ecotourism, although pointing to a general helplessness towards measuring other cultural ecosystem services, may lead researchers and policymakers to assume that these represent cultural ecosystem services as a whole, thereby contributing to an unconscious marginalization of other important cultural ecosystem services*» (Milcu *et al.*, 2013).

19 A rare and therefore commendable fact, as tourism data are usually provided for administrative areas – generally municipalities – and thus difficult to relate to exclusively forest areas.

20 The parameters considered were: purpose of the visit, social class of visitors, origin of visitors, type of resort and accessibility (Ciancio *et al.*, 2007); the cost of a day visit was calculated at around €6.

21 It should be pointed out that although the assessment was carried out on the basis of data that have been officially validated by means of rigorous calculation procedures, the results of the indicators are necessarily subject to a certain degree of uncertainty, connected in particular with the processes required to correlate several sources of data characterised by different assessment criteria. It should also be mentioned that the economic vauation of the FES is strongly influenced by the valuation methods chosen. It is well known, in fact, that economic valuation, despite its strategic usefulness (see Section 1), is not exempt from limitations and critical issues, above all as it is highly subjective (Spangenberg and Settele, 2010; Mavsar and Varela, 2014).

22 See the technical sheets annexed to "*Studio generale per la definizione delle Linee Guida regionali per la realizzazione degli interventi di riassetto idrogeologico con tecniche di Ingegneria Naturalistica*" published by the Sardinia Region in 2010 (http://www.regione.sardegna.it/documenti/1_327_20110208185054.pdf, last accessed July 2017).

Table 4 - *Annual biophysical and economic indicators for FES in Sardinia at the regional scale (*TEV in this case does not take into account the FES regarding tourism, as this was calculated for only 13 forests)*

	FES	Biophys. value	UM	Economic value	UM	TEV (%)
PROVISIONING	**Timber**	2,593	m^3	184,711	€	0.14%
	Fuel wood	113,921	m^3	497,148	€	4.12%
	Cork	166,091	q	11,626,376	€	8.88%
REGULATION	**Hydrogeo-logical protection**	167,241	ha	111,226,897	€	84.90%
	Carbon sequestration	497,148	t	2,565,283	€	1.96%
CULTURAL	***Tourism****	*150,764*	*num*	[*940,345*]	€	–
			TEV	130,997,261	€	100%

The value of Sardinia's forests in terms of *carbon sequestration* is lower. Indeed, despite the fact that the Sardinia region has the fourth-largest extent of forest cover at the national level, its contribution in terms of carbon sequestration is relatively small (Sardinia ranks fourteenth in Italy, Gasparini *et al.*, 2013) as species with low per-unit (t/ha) carbon sequestration values dominate. In the Region, high forest constitutes the main source of sequestration, with broadleaf arboriculture – in particular poplars – also standing out as having the highest per-unit carbon sequestration indicator (Figure 2). The low economic value of the FES concerning carbon sequestration is also connected to the price set by the European Union Emissions Trading Scheme, which has been subject to drastic reductions since 2009 as a result of the fall in energy consumption brought about by the economic crisis.

Finally, with regard to the role of the FES connected with *tourism*, as it was calculated for only 13 forests, it was not included in the calculation of the TEV at the regional scale. However, considering that around 9% of the forests on the island are visited by over 150,000 tourists, with an estimated value of approximately 940,000 euros a year, it is not inappropriate to consider tourism a significant, promising FES. Indeed, if we were to apply – in a purely technical yet meaningful operation – the same per-unit economic value (€/ha/year) calculated for the 13 forests considered to all of the forests on the island, we would obtain a n overall economic value of over 10 million euros, corresponding to around 7% of the recalculated TEV.

This is also the percentage value (TEV) accounted for by *tourism* in the state-owned forest of Monte Pisanu, a forest context situated in the province of Sassari, on which a more detailed application of the valuation method was conducted (Table 5). As it is one of the 13 areas for which data regarding tourism numbers are available, it was possible to calculate a TEV that includes all six of the indicators provided by the method. Tourism does indeed play a significant role among these indicators, and its inclusion also lead to the role of *hydrogeological protection* being "scaled back" (although it remains even in this local case the FES with the greatest "weight" in terms of its contribution to the TEV and essentially in line with regional values). Also significant is the production of *fuel wood* in the Monte Pisanu forest (while the production of *timber* is in line with the low regional values), as its value (in €/m^3) is markedly higher than the regional value, due to the extensive presence in this case of high-density areas of broadleaf forest (it is pointed out that the price fuel wood from broadleaf trees is more than double that of fuel wood from conifers, see note 10). In contrast, the "weight" of the contribution of *cork* production to the TEV of the forest is lower than the regional figure, as only 112 ha of cork oaks trees are present. Finally, the values or *carbon sequestration* are in line with the regional values (€/t).

4.4 From valuation to planning

Although the valuation method described has been developed for the Sardinia Region, it is also applicable to other contexts. The method's strengths lie in the definition of a FES indicators set that is at the same time agile and comprehensive, and that allows a "spatialised" biophysical and economic valuation, thus useful to spatial and landscape planning policies. The pretty easy method's applicability, that guided also the selection of the different valuation methods (e.g. the use of indicators instead of models, or, more specifically, the carbon sequestration valuation based on market price, or the focus on tourism function with relation to cultural FES) is in line with the intention to provide public administrators with a valuation tools to be applicable by themselves: «Incorporating ES in decision-making can make the planning process more complex. This is a significant challenge that might be alleviated by developing (…) simple but robust methods and tools (…)» (Albert *et al.*, 2017, p. 306).

These method's strengths correspond also to its partial limitations since they addressed it to a necessary procedural simplification.

With respect to possible methodological development prospects, it is possible to envisage that indicators could be based on more detailed data, also appropriate to a

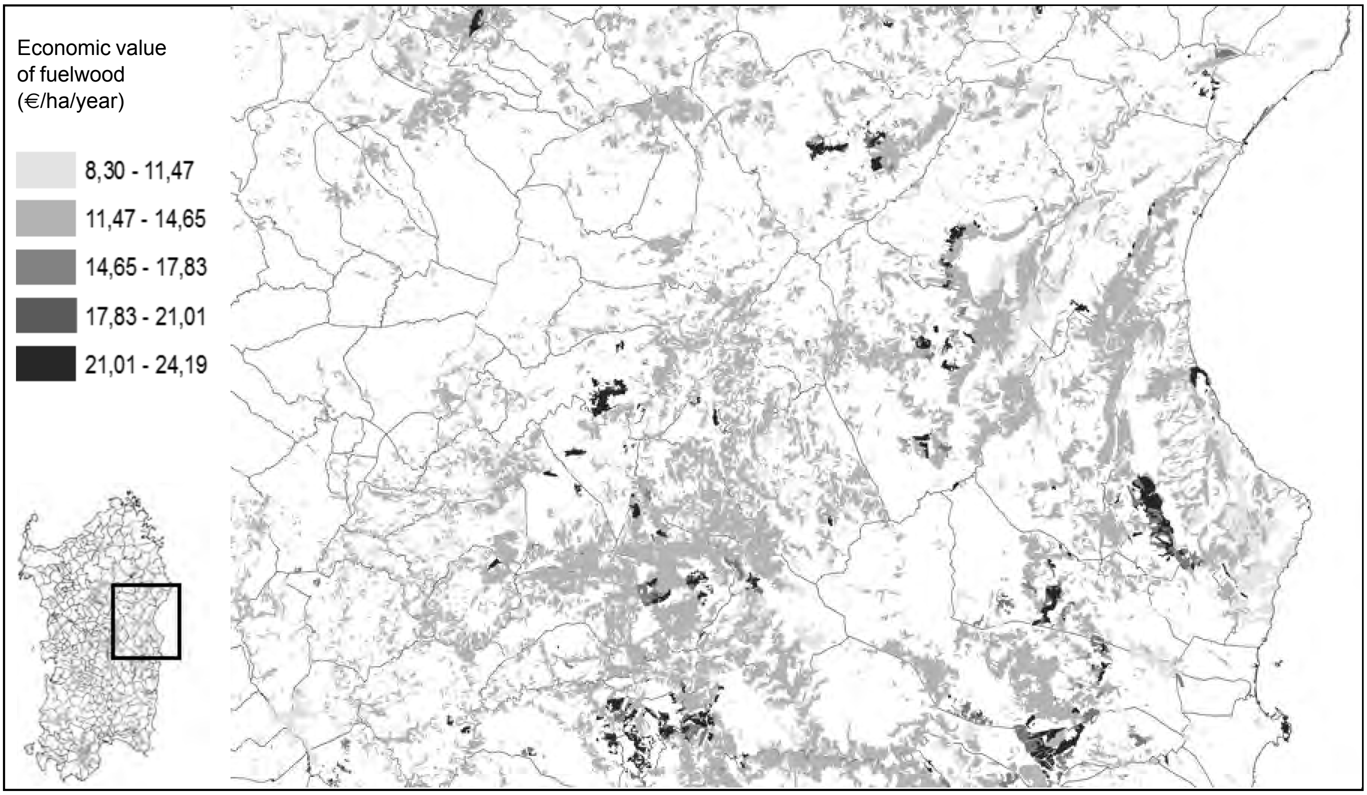

Figure 1 - *Per-unit and annual economic values (€/ha/year) for fuel wood production (central-western Sardinia, Gulf of Orosei). Coniferous forests are shown in dark grey and black.*
Source: *authors' own work, with the collaboration of Antonio Cittadino, LARTU, Laboratorio di Analisi e Rappresentazioni Territoriali e Urbane (Laboratory of Territorial and Urban Research), Politecnico di Torino*

valuation at local scale. Moreover, it should be pointed out that, in the perspectives with regard to the contribution of FES valuation to planning policies, the view of assessment proposed in this paper must necessarily be integrated with a trade-off analysis between the various FES (de Groot *et al.,* 2010). This analysis could identify conflicts and synergies between the variety of functions of forest landscapes and define possible scenarios (Lerouge, 2017) to support planning but also management choices, as outlined in the next Section.

5. VALUATION OF FOREST ECOSYSTEM SERVICES FOR PLANNING, DESIGN AND MANAGEMENT

Putting to one side the specific aims of the method – that is, to raise awareness among institutions with regard to the risks connected to forest fires and to establish effective prevention policies (see Section 4.1) – it is worth pointing out the additional, more general implications that it may have for spatial and landscape – in particular forest – planning, management and design policies.

In general, taking the subject of FES into account in forest landscape *planning* policies supports planning from a perspective of sustainable development (see Section 1) and biodiversity conservation. The value of biodiversity is implicit in ES: ensuring the provision of ES means guaranteeing a high level of biodiversity[23] (for a discussion of the greatly debated relationship between ES and biodiversity, see UWE 2015), thus sustaining a view of forests in planning policies as sites of natural assets and biodiversity as well as constituent elements of the ecological network.

With specific reference to the context of the Sardinia Region and looking at how the method proposed can interact with and support the main planning instrument for forest areas, it must be pointed out first of all that although the *Piano Forestale Ambientale Regionale* (PFAR,

[23] "In summary, the answer to the central question – will use of the ecosystem services approach protect biodiversity? – is likely to be a qualified yes. As long as the approach is implemented via policies based on sound evidence, and in conjunction with strategies that recognise the intrinsic value of biodiversity, it has the potential to be a powerful instrument in the struggle to halt biodiversity decline." (UWE, 2015).

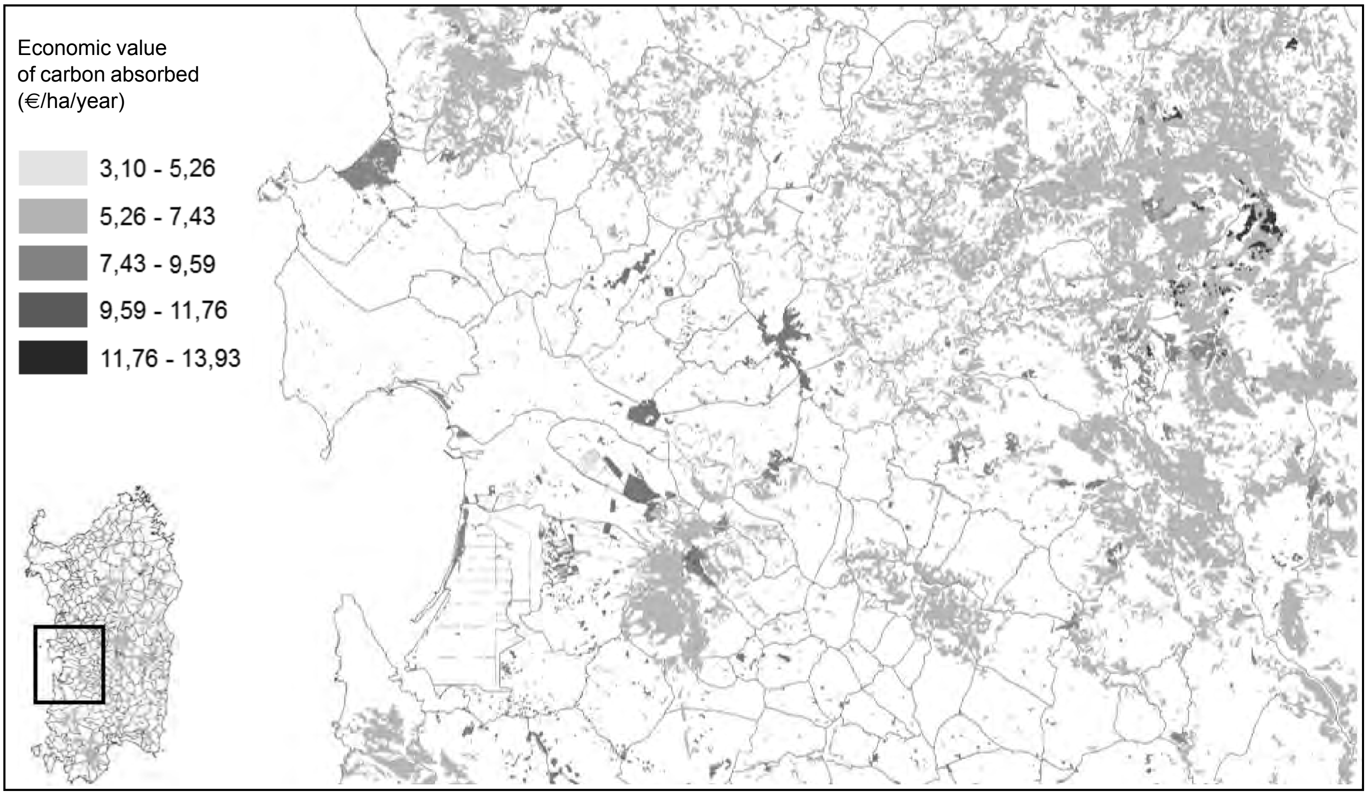

Figure 2 - *Per-unit and annual economic values (€/ha/year) for carbon sequestration (central-western Sardinia, plain of Oristano). Areas of broadleaf cultivation (poplars) are shown in dark grey.*
Source: *authors' own work, with the collaboration of Antonio Cittadino, LARTU, Laboratorio di Analisi e Rappresentazioni Territoriali e Urbane (Laboratory of Territorial and Urban Research), Politecnico di Torino*

Regional Environmental Forest Plan, 2007) and the *Piano Paesaggistico Regionale* (PPR, Regional Landscape Plan, 2006) aim towards a virtuous integration of aims and regulatory requirements – particularly with regard to aspects of conservation and management of forests' natural features, the PFAR provides a more detailed description of forest environments than the PPR, seeing them as systems with clear value in terms of protective and regulating functions (hydrogeological protection and carbon sequestration), naturalistic and landscape features, production (agro-forestry), and cultural and social aspects (research, education and awareness-raising). The PPR, in contrast, describes forests primarily in terms of their natural features and use (distinguishing between "natural areas", "semi-natural areas" and "areas for agro-forestry use"). The FES valuation method set out here is in line with the complex interpretation of forests provided by the PFAR, and is proposed as a potential support for it, in helping to highlight the value of forests in terms of protection and regulation (hydrogeological protection and carbon sequestration), production (timber and fuel wood, cork) and socio-cultural (tourism). The valuation of FES, in addition, can support the local action of the PFAR through the *Progetti Operativi Strategici* (POS, Strategic Operational Projects), the action programmes directly promoted by the PFAR), thanks to the development of a detailed map which emphasises the wealth of forest values at the local scale (Figs. 1 and 2). Such a perspective makes it easier to convey forest planning and management policies between different scales of territorial government, ensuring that each level, including the municipal level, (*Piani urbanistici comunali*, municipal land use plans), can contribute to the promotion, enhancement and management of forests, while also helping to make the measures funded by the Rural Development Programme (RDP)[24] more effective.

With regard to the PPR, on the other hand, given the prospect of its extension from coastal to inland areas (the current Plan is being extended to the whole region), an interpretation of forest areas also based on an valuation of FES may also provide effective support in drawing up a

[24] Interesting in this regard are the experiences of the Puglia and Tuscany regions in connection with the assessment of the effectiveness of forestry measures in their Rural Development Programmes (De Blasi *et al.*, 2011; Locandro and Saccheli, 2014). Assessment of FES may constitute a measurement of the effectiveness of public spending in relation to the specific forestry measures contained in rural development programmes.

Table 5 - *Annual biophysical and economic indicators for FES in the Monte Pisanu forest (the TEV takes into account the tourism FES, as the Monte Pisanu forest in the province of Sassari is one of the 13 forests for which this was calculated)*

	FES	Biophys. value	UM	Economic value	UM	TEV (%)
PROVISIONING	**Timber**	12	m^3	870	€	0.35%
	Fuel wood	540	m^3	26,504	€	10.51%
	Cork	134	q	9,417	€	3.73%
REGULATING	**Hydrogeolo-gical protection**	353	ha	187,765	€	74.44%
	Carbon sequestration	1.833	t	9,458	€	3.75%
CULTURAL	**Tourism**	2.921	num	18,219	€	7.22%
			TEV	252,233	€	100%

complete, detailed analysis of forest landscape values (not only in terms of their natural features and use, as is currently the case) and thus set out, at every spatial planning level, protection (specifying and distinguishing between restrictions relating to forests, as landscape heritage), management and planning measures.

From a pure *management* perspective, the method proposed may help to justify the costs of managing forest resources, which are generally considerable (in Sardinia they are estimated to be around 100 euros per year; see the interview with the regional Agency Fo.Re.S.T.A.S., June 2017), by highlighting the social benefits. This may be particularly beneficial with regard to firefighting activity which – at least in the Sardinia Region – accounts for around 30-40% of the regional Agency's activities. In fact, if the values measured by means of the method described herein are interpreted in terms of "damage avoidance" with regard to fire phenomena, they are easily repaid in terms of the biophysical and above all economic benefits for society of the Agency's management and monitoring activities.

Finally, from a *design* perspective, the assessment of ES is particularly useful for the construction of an ecological network on a local scale[25], insofar as it helps to identify strategic areas for the network and highlight their potential for reinforcing ecological functions, in terms of the provision of FES, as a result of renaturalisation projects. In this regard, the ecological network is obviously understood as bringing a multitude of values, not only those strictly connected with biodiversity but also with landscape, exploitation and the economy.

[25] On this topic see the researches developed in the last four years by Politecnico di Torino, with ENEA and Città Metropolitana, on the Ivrea territorial area an on the Bruino and Chieri municipal areas, coordinated by Angioletta Voghera (Voghera and Negrini, 2016; Voghera, 2016).

* **Roberta Ingaramo**, *Dipartimento di Architettura e Design (DAD), Politecnico di Torino.*
e-mail: *roberta.ingaramo@polito.it*
** **Emma Salizzoni**, *Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio (DIST), Politecnico di Torino*
e-mail: *emma.salizzoni@polito.it*
*** **Angioletta Voghera**, *Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio (DIST), Politecnico di Torino.*
e-mail: *angioletta.voghera@polito.it*

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