



Original research article

The contribution of Utility-Scale Solar Energy to the global climate regulation and its effects on local ecosystem services

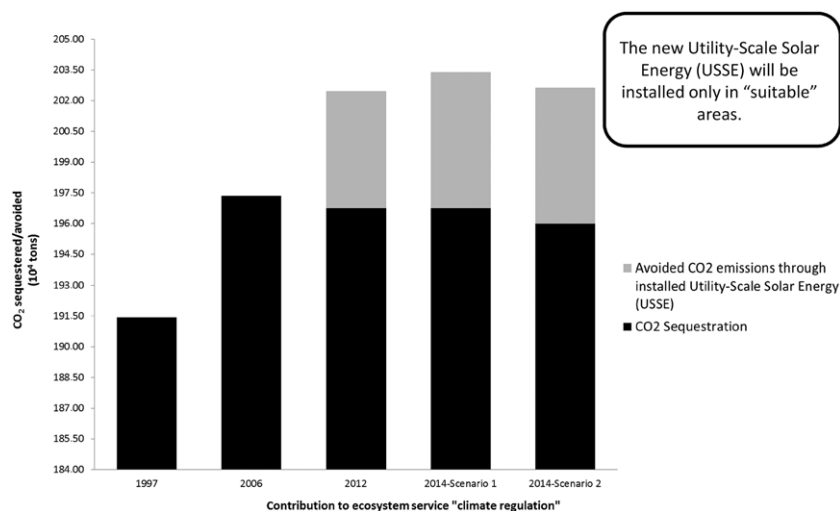


Antonella De Marco^a, Irene Petrosillo^{b,*}, Teodoro Semeraro^b,
Maria Rita Pasimeni^a, Roberta Aretano^b, Giovanni Zurlini^b

^a Department of Innovation Engineering, Ecotekne, University of Salento, Prov.le Lecce Monteroni, Lecce, Italy

^b Department of Biological and Environmental Sciences and Technologies, Ecotekne, University of Salento, Lecce, Italy

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 18 July 2014

Received in revised form 24 September 2014

Accepted 9 October 2014

Available online 29 October 2014

ABSTRACT

One solution to mitigate climate change can be the production of renewable energy. In this context, the aims of this paper are: (1) the identification of local unsuitable areas for the installation of Utility-Scale Solar Energy (USSE) in a municipality in southern Italy; (2) the assessment of the effects of their installation on local natural CO₂ sequestration and on avoided CO₂; and (3) the evaluation of their contribution to the global climate regulation through scenario analysis. Since 2007, 82 authorizations have been obtained for the installation of USSE in the municipality and 42 over 64 already completed have been installed

* Correspondence to: Lab. of Landscape Ecology, Department of Biological and Environmental Sciences and Technologies, University of Salento, Lecce, Italy. Tel.: +39 0832 298896; fax: +39 0832 298626.

E-mail address: irene.petrosillo@unisalento.it (I. Petrosillo).

<http://dx.doi.org/10.1016/j.gecco.2014.10.010>

2351-9894/© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/3.0/>).

Keywords:

Sustainable renewable energy use
 Spatial ecosystem service trade-offs
 Renewable energy–ecosystem services
 interaction

in unsuitable areas. For what concerns the remaining USSE, two short-term scenarios are analysed in order to take into account their contribution in terms of climate regulation service. The first scenario is called Business As Usual with new planned USSE installed by 2014 also in unsuitable areas, and the second one with the new USSE installed only in suitable areas identified in this study. Surprisingly, Scenario 2 is characterized by a reduced natural capacity to sequester CO₂ emissions and by a lower contribution of vegetation in providing the ecosystem service climate regulation in comparison with Scenario 1.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/3.0/>).

1. Introduction

For centuries humans have modified terrestrial systems to meet basic energy needs as well as to satisfy other requirements, leading to major changes in global land cover, increased concentrations of greenhouse gases (GHG) (IPCC, 2012), and reduced potential for land to sequester carbon in the future (Dale et al., 2011). Human use of carbon-intensive and non-renewable energy is the major driver of climate change and it challenges our ability to live sustainably, by guaranteeing human well-being, environmental protection, and industrial and economy development (EC, 2010a).

The European Directive 2001/77/EC has recognized the role played by renewable energies in mitigating climate change, as well as in providing wider benefits (IPCC, 2007). Furthermore, to be in line with Kyoto targets, European Commission has approved the European Directive 2009/28/EC, the so-called 20–20–20 Directive (EC, 2010b) with the aim of reducing GHG emissions by 20% compared to 1990 levels, increasing the share of final energy consumption from renewable energy sources by 20% and the energy efficiency by 20% compared to 2005 (EC, 2007a,b). On the basis of the European directives, the promotion of renewable energies has become a national priority for Italy, where the Legislative Decree n. 387/2003 have been set. In order to accelerate the procedures for authorizing the construction of renewable energy plants, Apulia Region (southern Italy) has approved specific guidelines (Regional Regulation n. 24/2010), which allow the identification of unsuitable areas for the installation of specific types of renewable energy plants. The unsuitability of the areas is defined according to municipal and regional criteria related to the environmental and landscape protection: parks, natural reserves UNESCO sites, cultural heritage, buildings and areas identified as of significant public interest, coastal areas, lakes, rivers, streams and waterways, forests, archaeological sites, caves, ravines and slopes.

Among renewable energies, a feasible short- and long-term solution against climate change is represented by the generation of electricity from sunlight (IPCC, 2012), directly through photovoltaic systems and indirectly (solar concentration systems), providing significant environmental benefits in comparison to the conventional (fossil) energy production (Tsoutsos et al., 2005; Hernandez et al., 2014). The main advantages of solar energy are represented more in detail by (Tsoutsos et al., 2005; Wang and Qiu, 2009; Saidur et al., 2010; Hernandez et al., 2014): (1) the reduced emissions of GHG (mainly CO₂, NO_x) or toxic gasses (SO₂, particulates); (2) the increase of regional/national energy independence; (3) the diversification and security of energy supply; and (4) the acceleration of rural electrification in developing countries. In addition to them, Hernandez and colleagues (2014) recognize that the use of solar energy can enhance the utilization of degraded lands and the possible spatial coexistence of solar panels and agriculture.

Due to the legislative scenario that has to date characterized the energy policy, generation of electricity from photovoltaic systems has grown exponentially in the last decade (Hernandez et al., 2014), rising from 38.2 GW in 2010 to 97.1 GW in 2012. However, the expansion of solar energy development, particularly the Utility-Scale Solar Energy (USSE), has increased interest in understanding the environmental effects of this technology, and how it may interact with the drivers of global environmental change including land-use change (Denholm and Margolis, 2008; Abbasi et al., 2011; Hernandez et al., 2014).

The increasing in the use of land-based renewable energies, like solar energy and wind farms, can cause new challenges for landscape planning and management, because, for instance, the installation and use of Utility-Scale Solar Energy (USSE) represent an important form of landscape transformation (McDonald et al., 2009; Ong et al., 2013) and involve a complex set of environmental trade-offs throughout the lifespan (construction, operation and decommissioning) (Hernandez et al., 2014). In particular, when these energy systems are installed, biophysical characteristics of the land may change (Lambin et al., 2001; Fthenakis and Kim, 2009), with effects on the role played by soil and vegetation not only as sink and source of carbon (Freibauer et al., 2004; Seneviratne et al., 2006; Richter et al., 2011; Vaccari et al., 2012), contributing to the global climate regulation ecosystem service, but also as providers of other ecosystem services at local scale such as-pollination, soil formation, etc. Therefore, both factors that have played a relevant role in the increase of USSE spread and factors that have given rise to some concerns about the PV technology in local Governments and communities have recently grown up (Chiabrando et al., 2009). In this context, Zoellner and colleagues (2008) remarked that even if at a general level a considerable support for renewable energy policy exists, at a local level many residents feel that a renewable energy system may limit their quality of life for some reasons as the change of the landscape or the noise. Therefore, a sustainable energy development requires methods and tools for assessing these effects, in order to associate the use of these energy systems with conservation of ecosystem goods and services. The recent increase of USSE underlines the urgency of: (1) understanding their direct and indirect environmental effects, including their impact on land-use/cover change (Hernandez et al., 2014); and (2) identifying suitable/unsuitable areas for their installation at local scale that, from the literature review, has resulted

the most appropriate scale to address, understand and inform on the nexus of land, energy and environmental conservation (Pasimeni et al., 2013).

In this context, the aims of the paper are: (1) the analysis of the legislation which regulates the authorizations for installation of USSE, through the identification of unsuitable areas in the Municipality of Lecce (Apulia Region) used as case study; (2) the assessment of the effects of their installation on natural CO₂ sequestration and on avoided CO₂; and (3) the evaluation of their contribution to the ecosystem service climate regulation through scenario analysis taking into account not only USSE already installed but also those authorized but not yet installed.

2. The environmental impacts of USSE

The scientific literature recognizes that renewable energy has a large potential to contribute to the sustainable development of specific areas by providing a wide variety of socio-economic and environmental benefits (Tsoutsos et al., 2005; del Río and Burguillo, 2009; Wang and Qiu, 2009; Saidur et al., 2010). Most land-based renewables, like USSE, have a lower energy content than fossil fuels and, consequently, they require a large amount of land not only for producing more energy but also for accommodating the PV modules, guaranteeing their access and maintenance, and avoiding the shading effect (Fthenakis and Kim, 2009; Chiabrando et al., 2009).

In the last years considerable progress has been made in the assessment of environmental impacts of USSE (Alsema et al., 2006), which have been the subject of several studies focused mainly on environmental aspects related to avoided GHG emissions, to the generation and end-of-life phases of solar equipment, and to the energy and environmental impacts, both direct and indirect (Neff, 1981; Aguado-Monsonet, 1998; Alsema et al., 2006; Ausubel, 2007; Denholm and Margolis, 2008; Varun et al., 2009; Omer, 2009; Fthenakis and Kim, 2009, 2010, 2011; Fthenakis et al., 2005, 2008, 2011; Turney and Fthenakis, 2011; Burgess et al., 2012; Howard et al., 2012; Zhai et al., 2012; Horner and Clark, 2013), demonstrating substantially positive environmental effects (Chiabrando et al., 2009). These systems, in fact, only marginally alter the balance of carbon into the atmosphere, since their production, use and decommissioning produce emissions that are lower than those generated during the production of the same amount of energy from fossil fuels (Angelis-Dimakis et al., 2011). In particular, the analysis of the environmental impacts of photovoltaic systems is largely conducted through Life Cycle Assessment (LCA) techniques, taking into account the production, operation and decommissioning of all components of the system (Sørensen, 1994; Baumann et al., 1997; Aguado-Monsonet, 1998; Dones and Frischknecht, 1998; Frankl et al., 1998; Pacca et al., 2007; Raugei et al., 2007; Stoppato, 2008). Furthermore, few studies have considered in detail the landscape impacts of USSE (Baltas and Dervos, 2013; Calvert et al., 2013; Hernandez et al., 2014), with effects on human well-being and the safeguard of ecosystems and land (MEA, 2005; Slootweg et al., 2010; TEEB, 2010a,b; Dale et al., 2011; Geneletti, 2011; Haines-Young et al., 2012; Partidario and Slootweg, 2012).

2.1. Trade-offs between global climate regulation service and other local ecosystem services

The effects of USSE massive expansion on landscape can be seen in terms of ecological functions' and structures' changes, which could be comparable to urban sprawl and could affect ecosystem goods and services (Sala et al., 2000; MEA, 2005; de Groot, 2006). In particular, ecosystem goods and services are defined as "the benefits people obtain from ecosystems" (MEA, 2005), interacting with one another in complex, nonlinear and often unpredictable ways (Farber et al., 2002; Peterson et al., 2003; Turner et al., 2003; van Jaarsveld et al., 2005; Chan et al., 2006; Rodriguez et al., 2006; Brauman et al., 2007; Bennett et al., 2009; Carpenter et al., 2009; Daily et al., 2009). This definition includes both the benefits people perceive, and those they do not (Costanza, 2008). In addition, ecosystem services can be classified according to their spatial characteristics in five groups (Costanza, 2008): (1) global non-proximal, because their provision does not depend on proximity (i.e. climate regulation), (2) local proximal, because their provision depends on proximity (i.e. pollination, storm protection, disturbance regulation), (3) directional flow related, because their move from the point of production to the point of use (i.e. water supply, nutrient regulation), (4) in situ, because their provision and their use are in the same place (i.e. soil formation), and (5) user movement related, because their provision requires the flow of people to unique natural features (i.e. recreation potential).

Each landscape function is potentially affected by changes in the landscape structure, which affects the provision of ecosystem services across a range of scales, from local to global (MEA, 2005; Petrosillo et al., 2009, 2010; Howard et al., 2012). Ecosystem goods and services are the benefits people obtain from ecosystems (MEA, 2005), interacting with one another in complex, nonlinear and often unpredictable ways (Farber et al., 2002; Peterson et al., 2003; Turner et al., 2003; van Jaarsveld et al., 2005; Chan et al., 2006; Rodriguez et al., 2006; Brauman et al., 2007; Bennett et al., 2009; Carpenter et al., 2009; Daily et al., 2009). Over time, humans have modified the provision of several ecosystem services by enhancing the delivery of a particular service (Rodriguez et al., 2006), causing trade-offs among ecosystem services (MEA, 2005). In fact, although USSE massive expansion on landscape on a global scale seems to support the provision of the ecosystem service climate regulation (global non-proximal) by avoiding the emissions of GHG, there is a growing recognition that their installation may have substantial impacts on a range of local proximal ecosystem services (i.e. pollination, storm protection, disturbance regulation) (Omer, 2009). Given the significant contribution provided by vegetation to the reduction of atmospheric CO₂, both at global and local scales, land-use/cover conversion and change due to USSE installation can affect on a local scale the natural capacity of soil and vegetation to sequester CO₂ (Ostle et al., 2009; Dominati et al., 2010; Dale et al., 2011; Robinson et al., 2012; Scholes and Smart, 2013). Specifically, land uptake constitutes what is known as the terrestrial carbon sink

(Scholes and Smart, 2013), but when USSE are installed, the biophysical characteristics of the land may change (Lambin et al., 2001; Fthenakis and Kim, 2011) affecting the capacity of soil and vegetation to sequester carbon (Schulp et al., 2008; Ostle et al., 2009).

In addition, land-use/cover conversion and change for energy purposes can produce habitat fragmentation and loss with effects on the movement of genetic resources (user movement-related ecosystem service), pollination, disturbance regulation and storm protection (local proximal ecosystem services), water supply (directional flow-related ecosystem services), recreation potential (user movement-related ecosystem services) and, therefore, on biodiversity, wildlife, food production, water resource, and beautiful sceneries (Turney and Fthenakis, 2011). However, the lack of studies on the evaluation of the effects of USSE on land-use change needs to be improved in order to identify areas for careful integration of the new elements in the landscape recognizing the value of ecosystem goods and services and to associate the use of renewable energy sources with the maintenance of ecosystem goods and services and landscape social-cultural identity (Mikusiński et al., 2012; Hernandez et al., 2013). In other words, it is important to understand how these new energy systems could be integrated and harmonized with other potential landscape functions (Srinivasan, 2009; Wissen and Grêt-Regamey, 2009; Dale et al., 2011), in order to maintain landscape multi-functionality and to avoid trade-offs among ecosystem services, which refer to the increase of the provisioning of one ecosystem service and the simultaneous decline of another service at the same or across spatial and temporal scales (Holling and Meffe, 1996; MEA, 2005; Rodriguez et al., 2006).

Our understanding of how to deploy energy production technologies to minimize negative local impacts and maximize energy benefits is usually incomplete and inconsistent. Ecosystem services have been largely neglected (Alanne and Saari, 2006) and where they have been examined they are usually considered at the national or larger scales, rarely considering local impacts, interactions and multiple effects (Haughton et al., 2009).

3. Materials and methods

3.1. Study area

The study area is the Municipality of Lecce (Apulia Region, southern Italy) (Fig. 1).

It covers about 238.4 km² (ISTAT, 2012), and even if agricultural intensively cultivated areas dominate the landscape, the study area is particularly rich in natural habitats and biodiversity, not only along the coastal areas, but also in the inland in association with dry meadows and forests. In particular, the coastal area is characterized by the highest concentration of natural parks, such as the Regional Park Bosco e Paludi di Raucio, and Sites of Community Importance (SCIs), according to the European Habitat Directive 92/43/EC.

Lecce is the leading municipality in the Apulia region in terms of energy production from renewable sources, and it can represent a model that can inform other regions on the nexus of land, energy, and conservation. This result is due to the advent of policies, like the Italian IV Conto Energia program, which provided a highly profitable and innovative incentive mechanism for the installation of renewable energy power plants (GSE, 2010). Even if some wind farms are present, for what concerns photovoltaic systems, the number of PV systems already installed in the Apulia region is 22,926 with a total capacity of 2186.2 MW. In addition, the region records the highest percentage of Utility-Scale Solar Energy (78%), with a total installed capacity of 2449 MW. In this context, the Municipality of Lecce has the highest installed capacity (647.4 MW) in comparison with the other municipalities of Apulia region (GSE, 2011) and, according to the official data provided by the National Institute of Statistics, its consumption of electric energy for household use amounts to 1222.8 kWh per capita (ISTAT, 2012). Therefore, given the capacity installed and the energy demand, Lecce could easily supply renewable energy to neighbouring municipalities.

3.2. Criteria to determine and to map unsuitable areas for USSE

The Apulia Regional Regulation n. 24/2010 identifies the environmental criteria to identify unsuitable areas for the installation of specific renewable energy systems. The map of unsuitable areas for USSE has been developed through the integration of the following information and data in ArcMap 10.1 ©ESRI environment:

1. Apulia regional criteria for the authorization of renewable energy power plants based on the Regional Regulation n. 24/2010 (Apulia Region, 2010) that takes into account European, Italian and regional regulations (Table 1):
 - the criterion of Natural areas presence;
 - the criterion of Cultural heritage presence;
 - the criterion of Urban Area + buffer of 1 km.
2. Municipal criteria mainly regarding the required infrastructures at local scale (Table 1):
 - Roads + buffer zones (40 m);
 - Railway line + buffer zones (30 m);
 - Power lines.

These first two criteria have been used to realize the map of the regional criteria and the required local infrastructures for the installation of USSE in the study area. In addition to them, three criteria have been used to analyse land-use change and map the installed USSE.



Fig. 1. Study area: Municipality of Lecce (Apulia Region, southern Italy).

3. Land-use map of the study area, with reference to 1997 and 2006, in order to analyse land-use change before the first USSE installation.
4. Orthophoto of Bing Maps of the study area, referring to 2012 and available on ArcMap 10.1 to update the land-use map of 2006 and to identify new installed USSE.
5. List of authorizations of USSE already installed from 2007 to 2012, and their energy capacity.
Finally, we used:
6. Orthorectified aerial photos of the study area, referring to July 1954 to realize the map of Potential century-old olive groves that, in each land-use map realized, have been distinguished from the generic class Olive groves. This map was realized in order to take into account the Regional Law n. 14/2007 (Apulia Region, 2007), which declares century-old olive trees as “monumental elements” of the landscape that deserve to be protected. Since the Municipality of Lecce does not currently have a complete census of century-old olive trees, to better distinguish century-old olive groves from the new ones, a comparison between the spatial distribution of olive groves identified in 2012 and those identified in 1954 has been carried out. The comparison is based on the assumption that the olive groves already present in 1954 can be considered as century-old in 2012. It is important to highlight that such olive groves have been called “potential century-old” because of their age, while the monumental character of the trees can be determined only after appropriate censuses.

3.3. Assessment of the effects of USSE on CO₂ sequestration and short-term scenario analysis

3.3.1. Land cover changes and vegetation carbon stock

Vegetation carbon density (ton ha^{-1}) is the most important component of carbon sequestration (McPherson et al., 1994; Shao et al., 2008) and indicates the natural carbon sequestration ability of the vegetation, and also reflects the degree of disturbances in terms of land-use/cover change (Nowak et al., 2007; Desai et al., 2008; Potter et al., 2008).

In this paper a comprehensive approach based on the analysis of land-cover changes has been implemented, by using the land-use/cover maps of Lecce for 1997, 2006 and 2012 and the related C-density values derived from the literature

Table 1
Municipal criteria and regional criteria for USSE with capacity >20 kW.

Municipal criteria	Regional criteria	Legal requirements
		R.L. n. 19/1997 R.L. n. 25/2002 R.L. n. 31/2008 N.L. n. 394/1991 EU Dir. N. 43/1992 DPR n. 357/1997
Roads + buffer zones (40 m) line + buffer zones (30 m)	Natural areas (protected areas, areas of landscape value, areas for agri-food quality, and other areas part of the regional ecological network)	DPR n. 120/2003 R.R. n. 24/2005 DGR N. 1157/2002 R.L. n. 31/2008 Provincial thematic landscape planning R.L. n. 31/2008 R.L. n. 14/2007 D.M. 1996/07/20 D.M. 1996/08/13 DGR n. 1/2010
Railway Power lines		N.L. n. 1497/1939 D.Lgs. n. 42/2004 D.Lgs. n. 42/2004 D. Lgs. N. 42/2004 N.L. n. 1089/1939
	Cultural heritage	
	Building urban area + buffer of 1 km	Lecce municipal plan

(Cruickshank et al., 2000; Badiou et al., 2011; Muñoz-Rojas et al., 2011; Chiti et al., 2012). This methodology represents a first approach that does not intend to provide accurate absolute values, but it could be meaningful in relative terms, allowing to compare C vegetation stocks for different land-use/cover classes and C sequestration trends associated to land-use/cover changes (Muñoz-Rojas et al., 2011).

To estimate the total amount of C stored and, therefore, the amount of CO₂ sequestered from the atmosphere over time three steps have been performed (Table 2): (1) vegetation carbon density (C-density) values have been associated to each CORINE Land Cover (CLC) class at third level in 1997, 2006 and 2012. These values comply with the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (Houghton et al., 2001; IPCC, 2007; Muñoz-Rojas et al., 2011) and take into account stems, branches, foliage and roots (aboveground and belowground biomass), but do not include litter, microbial biomass and Soil Organic Carbon; (2) vegetation carbon sequestration for each land-cover has been calculated by multiplying the C-density value of each land-cover class by land-cover areas (ha) in 1997, 2006 and 2012; finally, (3) the stock of CO₂ was calculated by applying a conversion factor of CO₂/C ratio equal to 3.67 to the data of carbon sequestration (CISA, 2007).

3.3.2. Estimates of avoided CO₂ emissions

In the case of land-cover class “Road and rail networks and associated land (Photovoltaic)” the avoided CO₂ emissions into the atmosphere have been estimated. In particular, to produce one kilowatt-hour of electric energy (kWh) from renewable sources, an amount equivalent to 2.56 kWh of fossil fuel is burned. As a result, approximately 0.53 kg of CO₂ (Italian emission factor) is emitted into the atmosphere (Italian Ministry of the Environment, 2011). So, for each kWh produced through USSE the emission of about 0.53 kg of CO₂ can be avoided.

The electricity produced by each USSE installed or authorized in the study area has been estimated through the methodology proposed by Aste and colleagues (2007) represented by the following formula:

$$E_{PV} = P_{PV} \times \eta_{BOS} \times K_{PV} \times S / I_{STC}$$

where,

E_{PV} is the annual electricity production by the PV system (kWh/year),

P_{PV} is the peak power of the PV system (kWp),

η_{BOS} is the efficiency of BOS (inverter, wiring, etc.) assumed as 0.9,

K_{PV} is the reduction coefficient due to the real operational conditions deviated from the standard test conditions (STC), considered as 0.8,

S is the annual solar irradiance (kWh/m² year),

I_{STC} indicates the solar irradiance in STC, equal to 1 kW/m².

Finally, two short-term scenarios have been proposed in order to analyse the effects of the installation of USSE on the natural capacity of vegetation and soil to sequester CO₂ and on the amount of avoided CO₂ emissions in the atmosphere. In particular, Scenario 1—Business As Usual, which represents a situation that does not vary significantly from the current

Table 2

Vegetation C-density and CO₂ sequestration for each CORINE Land Cover class at level 3, and avoided CO₂ emissions for the class Networks road, rail and technical infrastructure (PV).

CORINE Land Cover classes	Vegetation C-density (ton ha ⁻¹)	ha			CO ₂ sequestration/avoided CO ₂ (ton)		
		1997	2006	2012	1997	2006	2012
1.1.1. Continuous urban fabric	0.00	932.87	901.31	954.34	0.00	0.00	0.00
1.1.2. Discontinuous urban fabric	3.23	1806.08	1944.66	1933.90	5833.65	6281.25	6246.50
1.2.1. Industrial or commercial units	0.00	786.36	845.78	846.78	0.00	0.00	0.00
1.2.2. Road and rail networks and associated land	0.00	522.39	667.64	674.33	0.00	0.00	0.00
1.2.2. Road and rail networks and associated land (Photovoltaic)	–	–	–	101.21	–	–	65,333.77
1.2.3. Port areas	0.00	3.22	4.35	3.22	0.00	0.00	0.00
1.2.4. Airports	0.50	17.75	82.02	27.18	32.65	150.92	50.00
1.3.1. Mineral extraction sites	0.00	204.20	288.91	261.82	0.00	0.00	0.00
1.3.2. Dump sites	0.00	5.02	5.48	5.48	0.00	0.00	0.00
1.3.3. Construction sites	0.00	112.42	206.16	167.41	0.00	0.00	0.00
1.4.1. Green urban areas	6.46	33.50	29.32	34.54	794.15	695.20	818.80
1.4.2. Sport and leisure facilities	6.46	121.26	145.22	135.97	2874.76	3442.90	3223.65
1.4.3. Cemeteries	6.46	23.37	23.37	23.37	569.44	569.44	569.44
2.1.1. Non-irrigated arable land	5.00	7696.61	7605.22	7746.39	141.23*10 ³	139.55*10 ³	142.15 * 10 ³
2.1.2. Permanently irrigated land	5.00	4.31	4.55	5.04	79.13	83.52	92.55
2.2.1. Vineyards	21.00	43.93	105.18	80.19	3386.03	8106.20	6180.48
2.2.2. Fruit trees and berry plantations	21.00	12.04	19.15	18.28	928.04	1476.00	1408.72
2.2.3. Olive groves	51.50	7988.29	8312.00	8291.81	150.98*10 ⁴	157.1 * 10 ⁴	156.71 * 10 ⁴
2.4.1. Annual crops associated with permanent crops	13.00	211.94	296.50	223.20	10,111.45	14,146.14	10,648.73
2.4.2. Complex cultivation patterns	11.52	25.24	46.98	31.13	1067.30	1986.04	1316.27
2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	11.37	39.77	83.48	42.10	1659.52	3483.51	1756.91
3.1.1. Broad-leaved forests	28.24	108.57	110.82	112.49	11,252.40	11,485.47	11,658.66
3.1.2. Coniferous forests	59.48	347.95	327.62	357.28	75,954.56	71,517.20	77,991.57
3.1.3. Mixed forests	40.80	50.03	45.45	44.13	7491.29	6805.51	6607.84
3.1.4. Tree-lined meadows and wooded pastures	3.04	74.66	69.68	55.97	832.97	777.44	624.45
3.2.1. Natural grasslands	3.04	3479.34	2338.38	2417.54	3,8818.30	2,6088.84	2,6971.99
3.2.2. Moors and heathland	17.74	2.44	3.66	3.66	159.13	238.29	238.41
3.2.3. Sclerophyllous vegetation	17.74	1257.08	1293.50	1240.04	8,1843.30	8,4214.33	8,0733.57
3.2.4. Transitional wood land-scrub	17.74	4.21	7.08	7.08	274.21	460.71	460.71
3.3.1. Beaches dunes sands	0.00	65.62	65.59	75.47	0.00	0.00	0.00
3.3.2. Bare rocks	0.00	3.03	2.78	3.19	0.00	0.00	0.00
3.3.3. Sparsely vegetated areas	1.52	16.47	27.58	10.11	91.86	153.83	56.38
4.1.1. Inland marshes	2.70	374.54	419.75	395.74	3711.36	4159.35	3921.39
5.1.1. Water courses	0.00	1.73	1.73	1.73	0.00	0.00	0.00
5.1.2. Water bodies	0.00	51.50	56.40	52.93	0.00	0.00	0.00
5.2.1. Coastal lagoon	0.00	11.56	11.62	11.60	0.00	0.00	0.00

trends, contemplates the new USSE installed by 2014 in suitable or unsuitable areas according to their design. On the other side, Scenario 2 represents the alternative to the current trend, which contemplates the new USSE installed by 2014 only in suitable areas, in agreement with the Apulia Regional Regulation n. 24/2010 and with the results of the present research.

4. Results

4.1. Characterization of unsuitable areas

The Municipality of Lecce is mainly constituted by agricultural lands, as shown in the land-use map of the study area (Fig. 2), predominately represented by “Non-irrigated arable lands” (31%) and “Olive groves” (30%). For what concerns the spatial distribution of potential century-old olive groves (Fig. 2), they account for about 5019 ha (71% of the total olive groves extent and about 22% of the total municipal area).

The study area is characterized by USSE installed and proposed with ranges of capacity > 20 kW. On the basis of the presence of potential century-old olive groves (Fig. 3(a)), and considering the infrastructural and regulatory constraints (Table 1), the map of unsuitable areas for the installation of USSE with ranges of capacity > 20 kW has been produced (Fig. 3(e)) by integrating: the map of natural areas (Fig. 3(b)), which includes protected areas, areas of landscape value, areas for agri-food quality, and other areas that are part of the regional ecological network, the map of infrastructural constraints (Fig. 3(c)), and the map of cultural heritage (Fig. 3(d)). The extension of unsuitable areas is about 18,563 ha, accounting for about 78% of the municipal area (Fig. 3(e)). In addition, Fig. 3(e) shows the spatial distribution of USSE both installed and authorized

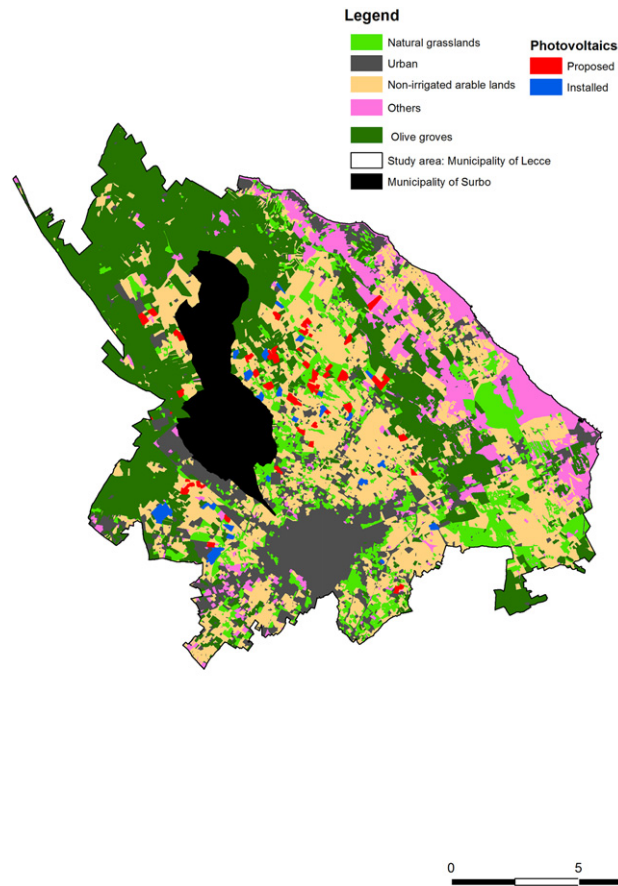


Fig. 2. Land-use map of the Municipality of Lecce (southern Italy).

but not installed yet. The analysis highlights that since 2007 there have been 82 requests for the installation of USSE, and only 64 of them have been already installed in 2012. Surprisingly, Fig. 3(e) highlights that some of the installations (42) have been already installed in unsuitable areas, with consequences for areas with natural and cultural values.

The suitable areas are, mainly, represented by Non-irrigated arable lands (7.05%), followed by Urban (2.82%) and Olive groves (2.55%) (Fig. 4). In particular, Urban class suitable for the installation of USSE with capacity >20 kW represents only 9% of the total urban area.

4.2. Estimated emissions of sequestered and avoided CO₂ and scenario analysis

Table 2 shows the vegetation C-density (tons/ha), derived from the literature (Cruickshank et al., 2000; Muñoz-Rojas et al., 2011; Badiou et al., 2011; Chiti et al., 2012), the CO₂ sequestration performed by each land-cover class characterizing the study area, and the avoided CO₂ emissions due to the presence of the class Networks road, rail and technical infrastructure (PV) from 1997 to 2012. Among the classes that show the highest capacity to sequester CO₂, Olive groves (more than 1.5 million tons of CO₂) and Non-irrigated arable lands (about 1.5 million tons of CO₂) provide the largest contribution.

In order to take into account the contribution in terms of “climate regulation” service, the natural sequestration capacity and the avoided CO₂ emissions due to the use of USSE are analysed, by hypothesizing two short-term scenarios. In particular, Fig. 5 shows that the CO₂ naturally sequestered by the vegetation increases from 1997 to 2006, mainly due to land-use/cover changes from classes characterized by lower natural capacity to others with higher capacity of CO₂ sequestration. Afterwards, this trend shows a slight decrease in 2012, probably due to a change in land-use/cover due to the installation of USSE. However, in 2012 a positive contribution of USSE to climate regulation service in terms of avoided CO₂ emissions is evident.

Finally, two short-term scenarios are built. The first aims at taking into account the spatial distribution and the contribution in terms of climate regulation service not only of the USSE already installed in 2012, but also of those new systems that will be installed within 2014 (Scenario 1—business as usual). Fig. 5 shows that in the case of Scenario 1 the natural capacity of vegetation to sequester CO₂ is more or less constant, while the amount of avoided CO₂ increases, because of new USSE. To build up the second scenario, it is assumed that the new USSE will be installed within 2014 only in suitable areas, according to the results reported in Fig. 4 and the Apulia Regional Regulation n. 24/2010. Therefore, this condition should guarantee the

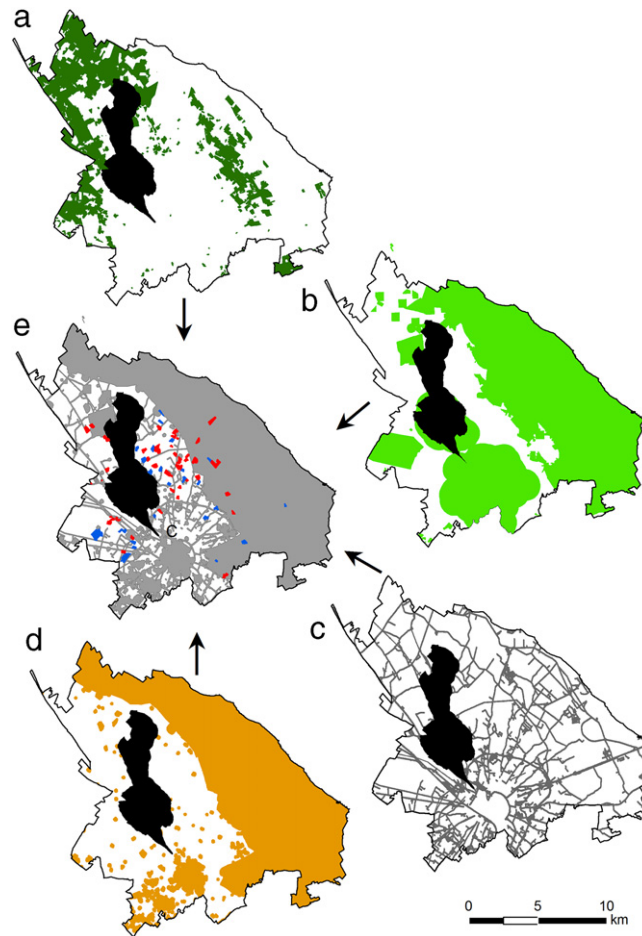


Fig. 3. (a) Map of potential century-old olive groves (Regional Law n. 14/2007); (b) map of natural areas, including protected areas, areas of landscape value, areas for agri-food quality, and other areas part of the regional ecological network; (c) map of infrastructural constraints; (d) map of cultural heritage; and (e) map of unsuitable areas for the installation of USSE and spatially explicit representation of USSE installed (blue) and proposed (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

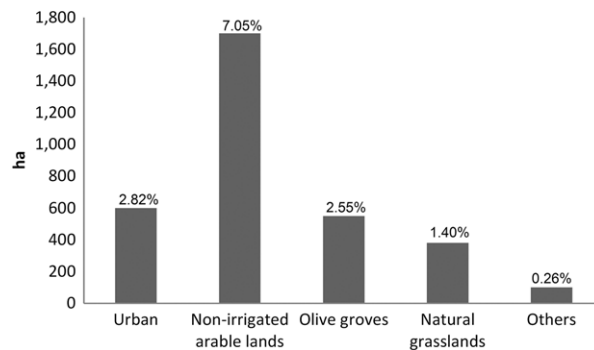


Fig. 4. The distribution of suitable areas (%) among the land-use classes for USSE.

satisfaction of the regional criteria for the identification of unsuitable areas, based also on European and Italian regulations, avoiding the presence of USSE in those areas. Surprisingly, Fig. 5 highlights that Scenario 2 is characterized by a reduced natural capacity to sequester CO₂ emissions, while the amount of avoided CO₂ emissions remains constant in comparison with Scenario 1.

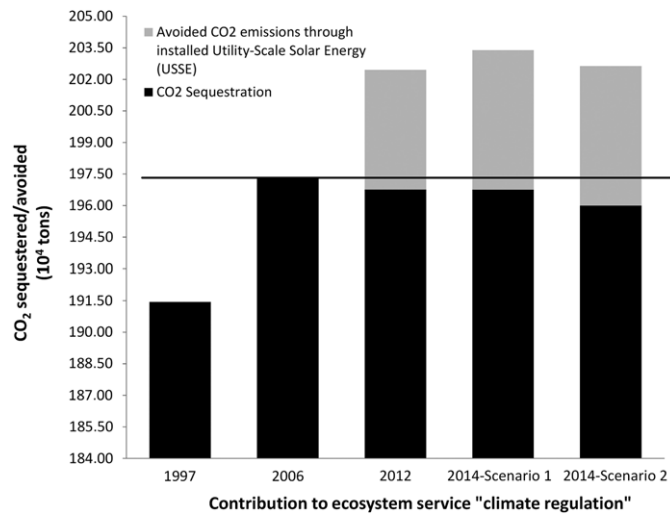


Fig. 5. CO₂ naturally sequestered by vegetation (black) and avoided CO₂ emissions (grey) in 1997, 2006 and 2012, and both in Scenario 1—business as usual and in Scenario 2.

5. Discussion and conclusions

Decision-makers very often do not know exactly the spatial distribution of many installed USSE and the socio-cultural and environmental constraints applied to each area of interest; in other words they do not know “where to develop”. The spatial distribution of USSE highlights that about 66% of them have been installed in “unsuitable” areas with potential adverse effects on the landscape. From the results it is clear that the identification of unsuitable areas based only on the application of regulatory frameworks should not take into account some environmental aspects that can increase the unsuitability. These aspects can be represented by local peculiarities like, for instance, the increasingly recognized ecological role played by potential century-old olive groves in the Apulia Region, which as permanent cultivation play the role of sinks along with forest and natural areas with respect to disturbances across multiple spatial scales (Zurlini et al., 2007; Zaccarelli et al., 2008), providing the local proximal disturbance regulation ecosystem service. Therefore, the results of this research highlight the need to include this land-use in the list of criteria for the identification of the unsuitable areas in order to guarantee the maintenance not only of this ecosystem service, but also of the cultural value associated to century-old olive groves.

In addition, it should be clear that the identification of unsuitable areas does not mean that all the remaining areas are suitable (Fig. 4). As highlighted by the results in Fig. 5 (Scenario 2), when the new USSE are located in suitable areas they cause a reduction of the natural vegetation capacity to sequester CO₂ and, consequently, a lower contribution of vegetation in providing the ecosystem service climate regulation. Finally, the temporal scale should be taken into account. The estimates of vegetation capacity to sequester CO₂ presented in this paper are clearly static, but this capacity changes with the seasons and across the years.

Although direct solar energy provides only a very small fraction of global energy supply today, it has the largest technical potential compared with the other energy sources. In general, the promotion of energy production from renewable sources is one of the environmental priority targets (20–20–20 targets) that the European Commission has to achieve within 2020 in the energy sector to reduce climate change (EC, 2007a,b), aiming at the protection of the environment and energy security (Baltas and Dervos, 2013). In particular, the development of power plants from renewable sources contributes to the achievement of the European target +20% of energy production from renewable sources compared to 2005. However, the predicted rise in global energy demand and atmospheric CO₂ levels underscores the importance of understanding the nexus of energy, land, and the environment. In fact, at the landscape level, the land-based renewable energy affects and limits alternative uses of land, requiring suitable space and land-use conversion and change (Denholm and Margolis, 2008; Gleick, 2009; Dale et al., 2011). In addition, land-use conversion at local scale can reduce the sequestration of GHG emissions, with effects on the provision of some ecosystem services from local to global scales (climate regulation). A few studies have compared the land-use/cover change of solar energy with other energy systems (McDonald et al., 2009; Fthenakis and Kim, 2009; Copeland et al., 2011) and some of them use solar land-use/cover change data coming from single power plants. Land-use/cover changes due to USSE are relatively small when compared to other energy systems including wind, hydro-electric, and biomass (McDonald et al., 2009). In particular, the land occupation related to a photovoltaic system is about 9900 m²/GWh in comparison with biomass, which entails the greatest land occupation (380,000 m²/GWh), followed by nuclear-fuel disposal (300,000 m²/GWh) (Fthenakis and Kim, 2009).

The results of this research have highlighted that the regional renewable energy policy, which has set some criteria to define an area as unsuitable for the installation of USSE, seems to be not properly correct since it does not take into account the assessment of ecosystem services' flow. Therefore, given the general validity of possible local criteria in order to identify

the unsuitable areas, a regional energy policy needs to include the evaluation of ecosystem services' flow provided by the landscape in order to plan more effectively the renewable energy development at multiple scales.

The increase in the use of local renewable energy sources should become the focus of energy policy within a comprehensive multifunctional planning of landscapes, in which local authorities are obliged to play a role in carrying out environmentally oriented strategies to efficiently plan and manage energy resources (Beccali et al., 2007; Comodi et al., 2012; Pasimemi et al., 2013). In response to such requirement, the introduction of suitable planning policies and programs must be supported by tools like the Geographic Information Systems (GIS) able to increase the socio-environmental awareness of policy-makers (Beccali et al., 2007). In this context, there are already several examples of GIS application for the identification of suitable sites for USSE, in terms of site characterization (Azoumah et al., 2010; Charabi and Gastli, 2011), solar radiation mapping (Charabi and Gastli, 2010; Gastli and Charabi, 2010; Gastli et al., 2010), assessment of potential site for photovoltaic systems (Fluri, 2009; Charabi and Gastli, 2010; Clifton and Boruff, 2010), linking the energy system with ecosystem services in real landscapes (Burgess et al., 2012; Howard et al., 2012). At a broader scale, for instance, the European Commission has developed the Photovoltaic Geographical Information System (PVGIS database), providing a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. It represents a research, demonstration and policy-support instrument for geographical assessment of the solar energy resource in the context of integrated management of distributed energy generation (JRC, 2013).

In conclusion, energy planning must take into account social and environmental factors that are related to renewable energy systems, and it has to be carried out through the optimal exploitation principle. Energy planning is a powerful tool for understanding the consequences of certain energy policies, which helps decision-makers to choose the most suitable strategies to promote the spread of cleaner technologies that take into account environmental impact and costs to the community and the territory (Dicorato et al., 2008).

In this respect, one critical aspect is, then, to understand how landscape functions and services can respond to the large variety and number of existing landscape patterns, including those resulting from intentional planning and design (Jones et al., 2013). Therefore, new spatial planning and design strategies for energy production are needed to involve the design and management of landscape elements and structures through the strategic placement of managed land-uses (included USSE) and natural system, in order to enhance across landscape the provision of services (e.g. water regulation, pollination, reduced land erosion, soil formation) (Zurlini et al., 2013; Jones et al., 2013).

The preliminary results of this paper can be further developed, through researches based on the environmental impacts' modelling of USSE construction, operation, and decommissioning phases, and others based on quantifying land-atmosphere interactions in order to integrate effects of USSE infrastructure. Several studies have attempted to project the future land-use impacts of USSE under specific renewable energy goals (e.g., Copeland et al., 2011) and our results may integrate these projection models, to improve and better understand the land-use/land-cover change related to USSE.

References

- Abbasi, T.M., Premalatha, M., Abbasi, S.A., 2011. The return to renewables: Will it help in global warming control? *Renewable Sustainable Energy Rev.* 15 (1), 891–894. <http://dx.doi.org/10.1016/j.rser.2010.09.048>.
- Aguado-Monsonet, M.A., 1998. The environmental impact of photovoltaic technology. Joint Research Centre of the European Commission. Institute for Prospective Technological Studies, Sevilla [online] URL: <http://ftp.jrc.es/EURdoc/eur18058en.pdf>.
- Alanne, K., Saari, A., 2006. Distributed energy generation and sustainable development. *Renewable Sustainable Energy Rev.* 10 (6), 539–558. <http://dx.doi.org/10.1016/j.rser.2004.11.004>.
- Alsema, E.A., de Wild-Scholten, M.J., Fthenakis, V.M., 2006. Environmental impacts of PV electricity generation—a critical comparison of energy supply options. Presented at the 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4–8 September 2006 [online] URL: https://www.bnl.gov/pv/files/pdf/abs_193.pdf.
- Angelis-Dimakis, A., Biberacher, M., Dominguez, J., Fiorese, G., Gadocha, S., Gnansounou, E., Guariso, G., Kartalidis, A., Panichelli, L., Pinedo, I., Robba, M., 2011. Methods and tools to evaluate the availability of renewable energy sources. *Renewable Sustainable Energy Rev.* 15, 1182–1200. <http://dx.doi.org/10.1016/j.rser.2010.09.049>.
- Apulia Region, 2007. Regional Law n. 14/2007 on the protection and enhancement of the landscape of monumental olive trees in Apulia Region. Official Bulletin of Apulia Region, June 07, 83/4-10; 2007 [online] URL: http://file:///C:/Users/Utente/Downloads/N83_07_06_2007_supplemento.pdf.
- Apulia Region, 2010. Regional Regulation No. 24/2010 on the identification of unsuitable areas and sites for the installation of specific types of systems powered by renewable sources in the Region of Puglia. Official Gazette of Apulia Region, December 29, 195/35598-35753; 2010 [online] URL: http://file:///C:/Users/Utente/Downloads/N195_31_12_10.pdf.
- Aste, N., Adhikari, R.S., Tagliabue, L.C., 2007. Evaluation of energy policies for promotion and dissemination of photovoltaic technology in Italy. *Prog. Photovolt. Res. Appl.* 15, 449–460. <http://dx.doi.org/10.1002/pip.751>.
- Ausubel, J.H., 2007. Renewable and nuclear heresies. *Int. J. Nuclear Governance, Economy and ecology* (ISSN: 1742-4194) 1 (3), 229–243.
- Azoumah, Y., Ramdé, E.W., Tapsoba, G., Thiam, S., 2010. Siting guidelines for concentrating solar power plants in the Sahel: case study of Burkina Faso. *Sol. Energy* 84, 1545–1553. <http://dx.doi.org/10.1016/j.solener.2010.05.019>.
- Badiou, P., McDougal, R., Pennock, D., Clark, B., 2011. Greenhouse gas emissions and carbon sequestration potential in restored wetlands of the Canadian prairie pothole region. *Wetl. Ecol. Manag.* 19, 237–256. <http://dx.doi.org/10.1007/s11273-011-9214-6>.
- Baltas, A.E., Dervos, A.N., 2013. Special framework for the spatial planning %26 the sustainable development of renewable energy sources. *Renew. Energy* 48, 358–363. <http://dx.doi.org/10.1016/j.renene.2012.05.015>.
- Baumann, A.E., Hill, R., Hynes, K.M., 1997. Environmental impacts of PV systems: ground-based vs. BIPV. In: Photovoltaic Specialists Conference, Record of the Twenty-Sixth IEEE, pp. 1361–1364. <http://dx.doi.org/10.1109/PVSC.1997.654343>.
- Beccali, M., Cellura, M., Mistretta, M., 2007. Environmental effects of energy policy in Sicily: the role of renewable energy. *Renewable Sustainable Energy Rev.* 11 (2), 282–298. <http://dx.doi.org/10.1016/j.rser.2005.02.001>.
- Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple eco-system services. *Ecol. Lett.* 12, 1–11. <http://dx.doi.org/10.1111/j.1461-0248.2009.01387.x>.
- Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annu. Rev. Environ. Resour.* 32, 67–98. <http://dx.doi.org/10.1146/annurev.energy.32.031306.102758>.

- Burgess, P.J., Rivas Casado, M., Gavu, J., Mead, A., Cockerill, T., Lord, R., van der Horst, D., Howard, D.C., 2012. A framework for reviewing the trade-offs between renewable energy, food, feed and wood production at a local level. *Renewable Sustainable Energy Rev.* 16, 129–142. <http://dx.doi.org/10.1016/j.rser.2011.07.142>.
- Calvert, K., Pearce, J.M., Mabee, W.E., 2013. Toward renewable energy geo-information infrastructure: applications of GIScience and remote sensing that build institutional capacity. *Renewable Sustainable Energy Rev.* 18, 416–429. <http://dx.doi.org/10.1016/j.rser.2012.10.024>.
- Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Diaz, S., Dietz, T., Duraipapp, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholtes, R.J., Whyte, A., 2009. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci. USA* 106 (5), 1305–1312. <http://dx.doi.org/10.1073/pnas.0808772106>.
- Centro Innovazione per la Sostenibilità Ambientale (CISA), 2007. Progetto di ricerca 2006/07—Rapporto conclusivo “Gestione Forestale, lotta ai cambiamenti climatici e utilizzo energetico delle biomasse forestali” [online] URL: <http://www.centrocisa.it/materiale/Pubblicazioni/RicercaCO2.pdf>.
- Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C., 2006. Conservation planning for ecosystem services. *PLoS Biol.* 4, 2138–2152. <http://dx.doi.org/10.1371/journal.pbio.0040379>.
- Charabi, Y., Gastli, A., 2010. GIS assessment of large CSP plant in Duqum, Oman. *Renewable Sustainable Energy Rev.* 14, 835–841. <http://dx.doi.org/10.1016/j.rser.2009.08.019>.
- Charabi, Y., Gastli, A., 2011. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renew. Energy* 36, 2554–2561. <http://dx.doi.org/10.1016/j.renene.2010.10.037>.
- Chiabrando, R., Fabrizio, E., Garnero, G., 2009. The territorial and landscape impacts of photovoltaic systems: definition of impacts and assessment of glare risk. *Renewable Sustainable Energy Rev.* 13 (9), 2441–2451. <http://dx.doi.org/10.1016/j.rser.2009.06.008>.
- Chiti, T., Gardin, L., Perugini, L., Quarantino, R., Vaccari, F.P., Miglietta, F., Valentini, R., 2012. Soil organic carbon stock assessment for the different cropland land uses in Italy. *Biol. Fert. Soils* 48, 9–17. <http://dx.doi.org/10.1007/s00374-011-0599-4>.
- Clifton, J., Boruff, B.J., 2010. Assessing the potential for concentrated solar power development in rural Australia. *Energy Policy* 38, 5272–5280. <http://dx.doi.org/10.1016/j.enpol.2010.05.036>.
- Comodi, G., Cioccolanti, L., Polonara, F., Brandoni, C., 2012. Local authorities in the context of energy and climate policy. *Energy Policy* 51, 737–748. <http://dx.doi.org/10.1016/j.enpol.2012.09.019>.
- Copeland, H.E., Pocerwicz, A., Kiesecker, J.M., 2011. Geography of energy development in western north America: potential impacts to terrestrial ecosystems. In: Nauge, D.E. (Ed.), *Energy Development and Wildlife Conservation in Western North America*. Island Press, Washington, DC, pp. 7–22.
- Costanza, R., 2008. Ecosystem services: multiple classification systems are needed. *Biol. Conserv.* 141, 350–352. <http://dx.doi.org/10.1016/j.biocon.2007.12.020>.
- Cruickshank, M.M., Tomlinson, R.W., Drew, S., 2000. Application of corine land cover mapping to estimate carbon stored in the vegetation of Ireland. *J. Environ. Manag.* 58, 267–278. <http://dx.doi.org/10.1006/jema.2000.0330>.
- Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: time to deliver. *Front. Ecol. Environ.* 7 (1), 21–28. <http://dx.doi.org/10.1890/080025>.
- Dale, V.H., Efrogmson, R.A., Kline, K.L., 2011. The land use-climate change-energy nexus. *Landsc. Ecol.* 26, 755–773. <http://dx.doi.org/10.1007/s10980-011-9606-2>.
- de Groot, R.S., 2006. Functions-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscape. *Landsc. Urban Plann.* 75 (3–4), 175–186. <http://dx.doi.org/10.1016/j.landurbplan.2005.02.016>.
- del Rio, P., Burguillos, M., 2009. An empirical analysis of the impact of renewable energy deployment on local sustainability. *Renewable Sustainable Energy Rev.* 13 (6–7), 1314–1325. <http://dx.doi.org/10.1016/j.rser.2008.08.001>.
- Denholm, P., Margolis, R.M., 2008. Land-use requirements and the per-capita solar footprint for photovoltaic generation in the United States. *Energy Policy* 36, 3531–3543. <http://dx.doi.org/10.1016/j.enpol.2008.05.035>.
- Desai, A.R., Noormets, A., Bolstad, P.V., 2008. Influence of vegetation and seasonal forcing on carbon dioxide fluxes across the Upper Midwest, USA: implications for regional scaling. *Agricult. Forest Meteorol.* 148, 288–308. <http://dx.doi.org/10.1016/j.agrformet.2007.08.001>.
- Dicorato, M., Forte, G., Trovato, M., 2008. Environmental-constrained energy planning using energy-efficiency and distributed-generation facilities. *Renew. Energy* 33, 1297–1313. <http://dx.doi.org/10.1016/j.renene.2007.07.011>.
- Dominati, E., Patterson, M., Mackay, A., 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecol. Econ.* 69, 1858–1868. <http://dx.doi.org/10.1016/j.ecolecon.2010.05.002>.
- Dones, R., Frischknecht, R., 1998. Life-cycle assessment of photovoltaic systems: results of Swiss studies on energy chains. *Prog. Photovolt. Res. Appl.* 6, 117–125. [http://dx.doi.org/10.1002/\(SICI\)1099-159X\(199803/04\)6:2%3C117::AID-PIP209%3E3.0.CO;2-M](http://dx.doi.org/10.1002/(SICI)1099-159X(199803/04)6:2%3C117::AID-PIP209%3E3.0.CO;2-M).
- (EC) European Commission, 2007a. An energy policy for Europe. COM (2007) 1 Final, Brussels [online] URL: http://ec.europa.eu/energy/energy_policy/doc/01_energy_policy_for_europe_en.pdf.
- (EC) European Commission, 2007b. Limiting global climate change to 2C—the way ahead for 2020 and beyond. COM (2007) 2 Final, Brussels [online] URL: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0002:FIN:EN:PDF>.
- (EC) European Commission, 2010a. Energy 2020 a strategy for competitive, sustainable and secure energy. COM(2010) 639 final, Brussel [online] URL: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0639&from=EN>.
- (EC) European Commission, 2010b. Europe 2020—a strategy for smart, sustainable and inclusive growth. COM(2010) 2020, Brussels [online] URL: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0202&from=EN>.
- European Parliament and Council, 2001. Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. Official Journal of the European Communities, Brussels [online] URL: <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0077&from=EN>.
- Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing eco-system services. *Ecol. Econ.* 41, 375–392. [http://dx.doi.org/10.1016/S0921-8009\(02\)00088-5](http://dx.doi.org/10.1016/S0921-8009(02)00088-5).
- Fluri, T.P., 2009. The potential of concentrating solar power in South Africa. *Energy Policy* 37, 5075–5080. <http://dx.doi.org/10.1016/j.enpol.2009.07.017>.
- Frankl, P., Masini, A., Gamberale, M., Toccaceli, D., 1998. Simplified life-cycle analysis of PV systems in buildings: present situation and future trends. *Prog. Photovolt. Res. Appl.* 6, 137–146. [http://dx.doi.org/10.1002/\(SICI\)1099-159X\(199803/04\)6:2%3C137::AID-PIP208%3E3.0.CO;2-N](http://dx.doi.org/10.1002/(SICI)1099-159X(199803/04)6:2%3C137::AID-PIP208%3E3.0.CO;2-N).
- Freibauer, A., Rounsevell, M.D.A., Smith, P., Verhagen, J., 2004. Carbon sequestration in the agricultural soils of Europe. *Geoderma* 122, 1–23. <http://dx.doi.org/10.1016/j.geoderma.2004.01.021>.
- Fthenakis, V.M., Blunden, J., Green, T., Krueger, L., Turney, D., 2011. Large photovoltaic power plants: wildlife impacts and benefits. In: *Photovoltaic Specialists Conference*, 2011. 37th IEEE, pp. 2011–2016. <http://dx.doi.org/10.1109/PVSC.2011.6186348>.
- Fthenakis, V.M., Fuhrmann, M., Heiser, J., Lanzirotti, A., Fitts, J., Wang, W., 2005. Emissions and encapsulation of cadmium in CdTe PV modules during fires. *Prog. Photovolt.* 13, 713–723. <http://dx.doi.org/10.1002/ppv.624>.
- Fthenakis, V.M., Kim, H.C., 2009. Land use and electricity generation: a life-cycle analysis. *Renewable Sustainable Energy Rev.* 13 (6–7), 1465–1474. <http://dx.doi.org/10.1016/j.rser.2008.09.017>.
- Fthenakis, V., Kim, H.C., 2010. Life-cycle uses of water in US electricity generation. *Renewable Sustainable Energy Rev.* 14 (7), 2039–2048. <http://dx.doi.org/10.1016/j.rser.2010.03.008>.
- Fthenakis, V.M., Kim, H.C., 2011. Photovoltaics: life-cycle analyses. *Sol. Energy* 85 (8), 1609–1628. <http://dx.doi.org/10.1016/j.solener.2009.10.002>.
- Fthenakis, V.M., Kim, H.C., Alsema, E., 2008. Emissions from photovoltaic life cycles. *Environ. Sci. Technol.* 42, 2168–2174. <http://dx.doi.org/10.1021/es071763q>.
- Gastli, A., Charabi, Y., 2010. Solar electricity prospects in Oman using GIS-based solar radiation maps. *Renewable Sustainable Energy Rev.* 14, 790–797. <http://dx.doi.org/10.1016/j.rser.2009.08.018>.

- Gastli, A., Charabi, Y., Zekri, S., 2010. GIS-based assessment of combined CSP electric power and seawater desalination plant for Duqum–Oman. *Renewable Sustainable Energy Rev.* 14, 821–827. <http://dx.doi.org/10.1016/j.rser.2009.08.020>.
- Geneletti, D., 2011. Reasons and options for integrating ecosystem services in strategic environmental assessment of spatial planning. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manage.* 7 (3), 143–149. <http://dx.doi.org/10.1080/21513732.2011.617711>.
- Gestore Servizi Energetici (GSE), 2010. Solare fotovoltaico. Rapporto statistico 2009. GSE, Roma [online] URL: <http://file:///C:/Users/Utente/Downloads/%252fIL-SOLARE-FOTOVOLTAICO-2009.PDF>.
- Gestore Servizi Energetici (GSE), 2011. Rapporto statistico 2011. Solare fotovoltaico in Italia, Roma [online] URL: <http://corrente.gse.it/GSE%20Documenti/Solare%20Fotovoltaico%20Rapporto%20Statistico%202011.pdf>.
- Gleick, P.H., 2009. Three Gorges Dam Project, Yangtze River, China. *Water Brief* 3. [online] URL: <http://www.worldwater.org/data20082009/WB03.pdf>.
- Haines-Young, R., Potschin, M., Kienast, F., 2012. Indicators of ecosystem service potential at European scales: mapping marginal changes and trade-offs. *Ecol. Indic.* 21, 39–53. <http://dx.doi.org/10.1016/j.ecolind.2011.09.004>.
- Houghton, A.J., Bond, A.J., Lovett, A.A., Dockerty, T., Sunnenberg, G., Clark, S.J., Bohan, D.A., Sage, R.B., Mallott, M.D., Mallott, V.E., Cunningham, M.D., Riche, A.B., Shield, I.F., Finch, J.W., Turner, M.M., Karp, A., 2009. A novel, integrated approach to assessing social, economic and environmental implications of changing rural land-use: a case study of perennial biomass crops. *J. Appl. Ecol.* 46 (2), 315–322. <http://dx.doi.org/10.1111/j.1365-2664.2009.01623.x>.
- Hernandez, R.R., Easter, S.B., Murphy-Mariscal, M.L., Maestre, F.T., Tavassoli, M., Allen, E.B., Barrows, C.W., Belnap, J., Ochoa-Hueso, R., Ravi, S., Allen, M.F., 2014. Environmental impacts of utility-scale solar energy. *Renewable Sustainable Energy Rev.* 29, 766–779. <http://dx.doi.org/10.1016/j.rser.2013.08.041>.
- Hernandez, R.R., Hoffacker, M.K., Field, C.B., 2013. Land-use efficiency of big solar. *Environ. Sci. Technol.* 48, 1315–1323. <http://dx.doi.org/10.1021/es4043726>.
- Holling, C.S., Meffe, G.K., 1996. Command and control and the pathology of natural resources management. *Conserv. Biol.* 10, 328–337. <http://dx.doi.org/10.1046/j.1523-1739.1996.10020328.x>.
- Horner, R.M., Clark, C.E., 2013. Characterizing variability and reducing uncertainty in estimates of solar land use energy intensity. *Renewable Sustainable Energy Rev.* 23, 129–137. <http://dx.doi.org/10.1016/j.rser.2013.01.014>.
- Houghton, J.T., Ding, Y., Griggs, D.J., Noguier, M., van der Linden, P.J., Dai, X., Maskell, K., Johnson, C.A., 2001. *Climate Change 2001: The Scientific Basis*. Cambridge University Press, ISBN: 0521 80767 0.
- Howard, D.C., Burgess, P.J., Butler, S.J., Carver, S.J., Cockerill, T., Coleby, A.M., Gan, G., Goodier, C.J., Van der Horst, D., Hubacek, K., Lord, R.K., Mead, A., Rivas-Casado, M., Wadsworth, R.A., Scholefield, P., 2012. Energyscapes: Linking the energy system and ecosystem services in real landscapes. *Biomass Bioenergy* 55, 17–26. <http://dx.doi.org/10.1016/j.biombioe.2012.05.025>.
- Intergovernmental Panel on Climate Change (IPCC), 2007. *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge, [online] URL: http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf.
- Intergovernmental Panel on Climate Change (IPCC), 2012. *Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, [online] URL: <http://www.cambridge.org/9781107607101>.
- Istituto Nazionale di Statistica (ISTAT), 2012. Dati ambientali nelle città. [online] URL: <http://www.istat.it/>.
- Italian Ministry of the Environment, 2011. Fotovoltaico: costi, vantaggi e mercato. [online] URL: <http://www.minambiente.it/pagina/costi-vantaggi-e-mercato>.
- Joint Research Center (JRC), 2013. Institute for Energy and Transport. About PVGIS. [online] URL: <http://re.jrc.ec.europa.eu/pvgis/>.
- Jones, K.B., Zurlini, G., Kienast, F., Petrosillo, I., Edwards, T., Wade, T.G., Li, B.L., Zaccarelli, N., 2013. Informing landscape planning and design for sustaining ecosystem services from existing spatial patterns and knowledge. *Landsc. Ecol.* 28 (6), 1175–1192. <http://dx.doi.org/10.1007/s10980-012-9794-4>.
- Lambin, E.F., Turner II, B.L., Geist, H., Agbola, S., Angelsen, A., Bruce, J.W., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T., Vogel, C., Xu, J., 2001. Our emerging understanding of the causes of land-use and-cover change. *Global Environ. Change* 11, 261–269. [http://dx.doi.org/10.1016/S0959-3780\(01\)00007-3](http://dx.doi.org/10.1016/S0959-3780(01)00007-3).
- Legislative, Decree 28 December 2003 n. 387. Implementation of Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. Official gazette n. 25 of 31 January 2004 [online] URL: http://www.minambiente.it/sites/default/files/D.Lgs._29-12-2003_n_387.pdf.
- McDonald, R.I., Fargione, J., Kiesecker, J., Miller, W.M., Powell, J., 2009. Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America. *PLoS One* 4 (8), e6802. <http://dx.doi.org/10.1371/journal.pone.0006802>.
- McPherson, E.G., Nowak, D.J., Rowntree, R.A., 1994. Chicago's urban forest ecosystem: results of the Chicago urban forest climate project, vol. 1. United States Department of Agriculture Forest Service, pp. 1–201 [online] URL: http://www.nrs.fs.fed.us/pubs/gtr/gtr_ne186.pdf.
- Mikusiński, G., Blicharska, M., Antonson, H., Henningson, M., Göransson, G., Angelstam, P., Seiler, A., 2012. Integrating ecological, social and cultural dimensions in the implementation of the landscape convention. *Landsc. Res.* 38, 384–393. <http://dx.doi.org/10.1080/01426397.2011.650629>.
- Millennium Ecosystem Assessment (MEA), 2005. *Ecosystems and Human Well-being*. Island Press, Washington, DC, ISBN: 1-529726-040-1.
- Muñoz-Rojas, M., De la Rosa, D., Zavala, L.M., Jordan, A., Anaya-Romero, M., 2011. Changes in land cover and vegetation carbon stocks in Andalusia. Southern Spain (1956–2007). *Sci. Total Environ.* 409, 2796–2806. <http://dx.doi.org/10.1016/j.scitotenv.2011.04.009>.
- Neff, T.L., 1981. *Social Cost of Solar Energy. A Study of Photovoltaic Energy Systems*. Pergamon Press, New York.
- Nowak, D.J., Hoehn, R., Crane, D.E., 2007. Oxygen production by urban trees in the United States. *Arboric. Urban For.* 33, 220–226. [online] URL: http://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf.
- Omer, A.M., 2009. Energy use and environmental impacts: a general review. *J. Renew. Sustain. Energy* 1 (5), 1–29. <http://dx.doi.org/10.1063/1.3220701>.
- Ong, S., Campbell, C., Denholm, P., Margolis, R., Heath, G., 2013. Land-use requirements for solar power plants in the United States. *NREL/TP-6A20-56290*. National Renewable Energy Laboratory.
- Ostle, N., Levy, P.E., Evans, C.D., Smith, P., 2009. UK Land use and soil carbon sequestration. *Land Use Policy* 26, 274–283. <http://dx.doi.org/10.1016/j.landusepol.2009.08.006>.
- Pacca, S., Sivaraman, D., Keoleian, G.A., 2007. Parameters affecting the life cycle performance of PV technologies and systems. *Energy Policy* 35, 3316–3326. <http://dx.doi.org/10.1016/j.enpol.2006.10.003>.
- Partidario, M.R., Sloatweg, R., 2012. Spatial planning and environmental assessments. In: Heidi, Wittmer, HariPriya, Gundimeda (Eds.), *TEEB, The Economics of Ecosystems and Biodiversity in Local and Regional Policy and Management*. Earth Scan from Routledge, Abingdon, New Tor, pp. 165–194. 978-3-9812410-2-7.
- Pasimeni, M.R., Petrosillo, I., Aretano, R., Semeraro, T., De Marco, A., Zaccarelli, N., Zurlini, G., 2013. Scales, strategies and actions for effective energy planning: a review. *Energy Policy* 65, 165–174. <http://dx.doi.org/10.1016/j.enpol.2013.10.027>.
- Peterson, G.D., Beard, D., Beisner, B., Bennett, E., Carpenter, S., Cumming, G., Dent, C.L., Havlicek, T.D., 2003. Assessing future ecosystem services: a case study of the northern highland lake district. *Conserv. Ecol.* 7 (3), 1. [online] URL: <http://www.ecologyandsociety.org/vol7/iss3/art1>.
- Petrosillo, I., Semeraro, T., Zurlini, G., 2010. Detecting the 'conservation effect' on the maintenance of natural capital flow in different natural parks. *Ecol. Econ.* 69 (15), 1115–1123. <http://dx.doi.org/10.1016/j.ecolecon.2009.12.006>.
- Petrosillo, I., Zaccarelli, N., Semeraro, T., Zurlini, G., 2009. The effectiveness of different conservation policies on the security of natural capital. *Landsc. Urban Plan.* 89, 49–56. <http://dx.doi.org/10.1016/j.landurbplan.2008.10.003>.
- Potter, C., Gross, P., Klooster, S., Fladeland, M., Genovesi, V., 2008. Storage of carbon in US forests predicted from satellite data, ecosystem modeling, and inventory summaries. *Clim. Change* 90, 269–282. <http://dx.doi.org/10.1007/s10584-008-9462-5>.

- Raugei, M., Bargigli, S., Ulgiati, S., 2007. Life cycle assessment and energy pay-back time of advanced photovoltaic modules: CdTe and CIS compared to poly-Si. *Energy* 32, 1310–1318. <http://dx.doi.org/10.1016/j.energy.2006.10.003>.
- Richter, D.D., Bacon, A.R., Mobley, M.L., Richardson, C.J., Andrews, S.S., West, L., Wills, S., Billings, S., Cambardella, C.A., Cavallaro, N., DeMeester, J.E., Franzluebbers, A.J., Grandy, A.S., Grunwald, S., Gruver, J., Hartshorn, A.S., Janzen, H., Kramer, M.G., Ladha, J.K., Lajtha, K., Liles, G.C., Markewitz, D., Megonigal, P.J., Mermut, A.R., Rasmussen, C., Robinson, D.A., Smith, P., Stiles, C.A., Tate, R.L., Thompson, A., Tugel, A.J., van Es, H., Yaalon, D., Zobeck, T.M., 2011. Human–soil relations are changing rapidly: proposals from SSSA's cross-divisional soil change working group. *Soil Sci. Soc. Am. J.* 75, 2079–2084. <http://dx.doi.org/10.2136/sssaj2011.0124>.
- Robinson, D.A., Hocley, N., Cooper, D.M., Emmet, B.A., Keith, A.M., Lebron, I., Reynolds, B., Tipping, E., Tye, A.M., Watts, C.W., Whalley, W.R., Black, H.I.J., Warren, G.P., Robinson, J.S., 2012. Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation. *Soil Biol. Biochem.* 57, 1023–1033. <http://dx.doi.org/10.1016/j.soilbio.2012.09.008>.
- Rodriguez, J.P., Beard Jr., T.D., Bennet, E.M., Cumming, G.S., Cork, S.J., Agard, J., Dobson, A.P., Peterson, G.D., 2006. Trade-off across space, time, and ecosystem services. *Ecol. Soc.* 11 (1), 28. [online] URL: <http://www.ecologyandsociety.org/vol11/iss1/art28/>.
- Saidur, R., Islam, M.R., Rahim, N.A., Solangi, K.H., 2010. A review on global wind energy policy. *Renewable Sustainable Energy Rev.* 14 (7), 1744–6217. <http://dx.doi.org/10.1016/j.rser.2010.03.007>.
- Sala, O.E., Chapin III, F.S., Armesto, J.J., Berlow, R., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. *Science* 287, 1770–1774. <http://dx.doi.org/10.1126/science.287.5459.1770>.
- Scholes, R.J., Smart, K., 2013. 4.09 carbon storage in terrestrial ecosystems, Reference Module in Earth Systems and Environmental Sciences, from Climate Vulnerability, Roger Pielke (Ed.), Oxford, pp. 93–108. <http://dx.doi.org/10.1016/B978-0-12-384703-4.00411-1>.
- Schulp, C.J.E., Nabuurs, G.J., Verburg, P.H., 2008. Future carbon sequestration in Europe-Effect of land use change. *Agr. Ecosyst. Environ.* 127, 251–264. <http://dx.doi.org/10.1016/j.agee.2008.04.010>.
- Seneviratne, S.I., Luthi, D., Litschi, M., Schar, C., 2006. Land–atmosphere coupling and climate change in Europe. *Nature* 443, 205–209. <http://dx.doi.org/10.1038/nature05095>.
- Shao, G.F., Qian, T.J., Liu, Y., Martin, B., 2008. The role of urbanization in increasing atmospheric CO₂ concentrations: think globally, act locally. *Int. J. Sust. Dev. World* 15, 302–308. <http://dx.doi.org/10.3843/SusDev.15.4:3a>.
- Slootweg, R., Rajvanshi, A., Mathur, V.B., Kolhoff, A., 2010. Biodiversity in Environmental Assessment: Enhancing Ecosystem Services for Human Well-Being. In: *Ecology, Biodiversity & Conservation Series*, Cambridge University Press, Cambridge, UK, [online] URL: http://assets.cambridge.org/97805218/88417/frontmatter/9780521888417_frontmatter.pdf.
- Sørensen, B., 1994. Life-cycle analysis of renewable energy systems. *Renew. Energy* 5, 1270–1277. [http://dx.doi.org/10.1016/0960-1481\(94\)90161-9](http://dx.doi.org/10.1016/0960-1481(94)90161-9).
- Srinivasan, S., 2009. The food vs fuel debate: a nuanced view of incentive structures. *Renew. Energy* 34 (4), 950–954. <http://dx.doi.org/10.1016/j.renene.2008.08.015>.
- Stoppato, A., 2008. Life cycle assessment of photovoltaic electricity generation. *Energy* 33, 224–232. <http://dx.doi.org/10.1016/j.energy.2007.11.012>.
- The Economics of Ecosystems and Biodiversity (TEEB), 2010a. Mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB [online] URL: <http://www.unep.org/pdf/LinkClick.pdf>.
- The Economics of Ecosystems and Biodiversity (TEEB), 2010b. A quick guide to the economics of ecosystems and biodiversity for local and regional policy makers [online] URL: http://www.teebweb.org/media/2010/09/TEEB-D2-Local-and-Regional-quick-guide_English.pdf.
- Tsoutsos, T., Frantzeskaki, N., Gekas, V., 2005. Environmental impacts from the solar energy technologies. *Energy Policy* 33 (3), 289–296. [http://dx.doi.org/10.1016/S0301-4215\(03\)00241-6](http://dx.doi.org/10.1016/S0301-4215(03)00241-6).
- Turner, R.K., Paavola, J., Cooper, P., Farber, S., Jessamy, V., Georgiou, S., 2003. Valuing nature: lessons learned and future research directions. *Ecol. Econ.* 46, 493–510. [http://dx.doi.org/10.1016/S0921-8009\(03\)00189-7](http://dx.doi.org/10.1016/S0921-8009(03)00189-7).
- Turney, D., Fthenakis, V., 2011. Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable Sustainable Energy Rev.* 15 (6), 3261–3270. <http://dx.doi.org/10.1016/j.rser.2011.04.023>.
- Vaccari, F.P., Lugato, E., Gioli, B., D'Acqui, L., Genesio, L., Toscano, P., Matese, A., Miglietta, F., 2012. Land use change and soil organic carbon dynamics in Mediterranean agro-ecosystems: the case study of Pianosa Island. *Geoderma* 175–176, 29–36. <http://dx.doi.org/10.1016/j.geoderma.2012.01.021>.
- van Jaarsveld, A.S., Biggs, R., Scholes, R.J., Bohensky, E., Reyers, B., Lynam, T., Musvoto, C., Fabricius, C., 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAFMA) experience. *Phil. Trans. R. Soc. B* 360, 425–441. <http://dx.doi.org/10.1098/rstb.2004.1594>.
- Varun, Prakash R., Bhat I.K., 2009. Energy, economics and environmental impacts of renewable energy systems. *Renewable Sustainable Energy Rev.* 13 (9), 2716–2721. <http://dx.doi.org/10.1016/j.rser.2009.05.007>.
- Wang, Q., Qiu, H.N., 2009. Situation and outlook of solar energy utilization in Tibet, China. *Renewable Sustainable Energy Rev.* 13 (8), 2181–2186. <http://dx.doi.org/10.1016/j.rser.2009.03.011>.
- Wissen, U., Grêt-Regamey, A., 2009. Identifying the regional potential for renewable energy systems using ecosystem services and landscape visualizations. In: European IALE Conference, Salzburg.
- Zaccarelli, N., Petrosillo, I., Zurlini, G., Riitters, K.H., 2008. Source/sink patterns of disturbance and cross-scale effects in a panarchy of social-ecological landscapes. *Ecol. Soc.* 13 (1), 26. [online] URL: <http://www.ecologyandsociety.org/vol13/iss1/art26/>.
- Zhai, P., Larsen, P., Millstein, D., Menon, S., Masanet, E., 2012. The potential for avoided emissions from photovoltaic electricity in the United States. *Energy* 47 (1), 443–450. <http://dx.doi.org/10.1016/j.energy.2012.08.025>.
- Zoellner, J., Schweizer-Ries, P., Wemheuer, C., 2008. Public acceptance of renewable energies: results from case studies in Germany. *Energy Policy* 36, 4136–4141. <http://dx.doi.org/10.1016/j.enpol.2008.06.026>.
- Zurlini, G., Petrosillo, I., Jones, K.B., Zaccarelli, N., 2013. Highlighting order and disorder in social–ecological landscapes to foster adaptive capacity and sustainability. *Landsc. Ecol.* 28 (6), 1161–1173. <http://dx.doi.org/10.1007/s10980-012-9763-y>.
- Zurlini, G., Riitters, K.H., Zaccarelli, N., Petrosillo, I., 2007. Patterns of disturbance at multiple scales in real and simulated landscapes. *Landsc. Ecol.* 22, 705–721. <http://dx.doi.org/10.1007/s10980-006-9055-5>.