Deploying ecosystem services to develop sustainable energy landscapes: a case study from the Netherlands

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Advancing the relationship between renewable energy and ecosystem services for landscape planning and design: A literature review

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ABSTRACT

The transition to a low carbon future is starting to affect landscapes around the world. In order for this landscape transformation to be sustainable, renewable energy technologies should not cause critical trade-offs between the provision of energy and that of other ecosystem services such as food production. This literature review advances the body of knowledge on sustainable energy transition with special focus on ecosystem services-based approaches and methods. Two key issues emerge from this review: only one sixth of the published applications on the relation between renewable energy and landscape make use of the ecosystem service framework. Secondly, the applications that do address ecosystem services for landscape planning and design lack efficient methods and spatial reference systems that accommodate both cultural and regulating ecosystem services. Future research efforts should be directed to further advancing the spatial reference systems, the use of participatory mapping and landscape visualizations tools for cultural ecosystem services and the elaboration of landscape design principles.

1. Introduction

The transition to renewable energy sources is inevitable for sustainable development (United Nations, 2012, 2015; IPCC, 2014). Fluctuations of oil price, uncertainty about the stock of fossil fuels and environmental impacts motivate energy transition. Renewable energy sources (RES), including solar, water, wind, biomass and geothermal energy, can be utilized by humans employing renewable energy technologies (RET) to provide Renewable Energy (RE). Photovoltaic cells (PV), for example, generate electricity from the solar irradiation. The majority of RETs has a spatial footprint in the landscape, such as the land needed to locate a PV park. Fossil fuel technologies too have a spatial footprint but RET require more space, considering that most RES have lower energy density (Pasqualetti and Stremke, 2018). In this paper we refer to the definition of landscape provided by the European Landscape Convention: "Landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (ELC, 2000, art. 1, a).

RETs not only require large areas but also energy networks which, in turn, affect the landscape infrastructure (Pang et al., 2014). We understand *landscape infrastructure* as the natural or constructed physical or beta-structure of the landscape delivering material or immaterial benefits and services and the recycling of energy and materials (Bélanger, 2013). Landscape infrastructure thus is inclusive of the concepts of *green infrastructure* and *gray infrastructure*, as well as any form of non-physical network through the landscape as the visual aspects. The impact of RET on the landscape infrastructure and the delivering of material or immaterial benefits or ecosystem services (ES) can be critical. For example, the installation of an off-shore wind farm can affect the seaside view, reducing cultural ES (landscape beta-structure). A hydro-power installation, another example, can modify the river course (landscape physical structure) and consequently affect the ecological integrity and the regulating ES. The sustainability of the renewable energy landscapes is based on the fact that the introduction of RET should not cause crucial trade-offs for ES (Stremke and van den Dobbelsteen, 2012).

So, RET provide the supply of RE from different RES and may compromise the supply (both in quality and quantity) of different ES,

Abbreviations: EL, energy landscapes; PV, photovoltaic panels; RE, renewable energy; REES, Renewable Energy Ecosystem Services; RES, renewable energy sources; RET, renewable energy technologies

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generating possible spatial trade-offs among ES (Coleby et al., 2012; Hastik et al., 2015; Stremke, 2015). Rodríguez et al. defined trade-offs as situations where “the provision of one ES is reduced as a consequence of increased use of another ES” (2006, p. 28). This review aims to advance the knowledge on the sustainability of energy transition with special focus on the potential critical relation between ES and RE, in order to provide insights in approaches and methods for decision making and landscape planning and design.

Communities often oppose the installation of RET because of the associated landscape transformation, and the unavoidable trade-offs occurring in the supported ES in time and space: “landscape modification is the most important factor driving the (lack of) local acceptance for most technologies” (Bertsch et al., 2016, p. 473). While discussing so-called renewable energy landscapes, Pasqualetti stated that most people believe that their landscape will not change, it is a sort of faith, they would expect permanence in their landscapes (Pasqualetti, 2000, 2011). NIMBY (Not In My BackYard) syndromes and other sociocultural phenomena such as the emergence of associations dedicated to the protection of landscapes against RET, show how communities often oppose changes in the supply of cultural ES (CES). Many times, discussions evolve around the supply of CES, the “aesthetics and heritage” group of ES in particular.

In early ES publications, renewable energy provision has not been regarded as an ES (for instance, M.E.A., 2005a,b). However, more recently the Common International Classification of ES (CICES) (Haines-Young and Potschin, 2011) does consider renewable energy as a provisioning ES. The CICES ES group “renewable abiotic energy” includes the service types “wind”, “hydro”, “solar”, “tidal” and “thermal”. The CICES ES group “renewable biofuels” includes the ES types “plant based resources” and “animal based resources”. Very recently Schetke et al. (2018) defined them as REES, Renewable Energy Ecosystem Services.

The concept of ES has been identified by de Groot et al. (2010) as a potential tool for strategic spatial planning and landscape planning and design. Literature shows how “the ES approach adds new information and perspectives to traditional information, its presentation, and its contribution to decision-support in landscape and spatial planning” (Galler et al, 2016, p. 126). Moreover, it can contribute to the understanding of the trade-offs between RE and landscape (Howard et al., 2013) in terms of benefit and services provided by the landscape.

Traditionally, landscape planning and design have different tasks but share the same values (von Haaren et al., 2014). Landscape design finds new solutions to the change of the landscape infrastructure. Nassauer and Opdam (2008) define landscape design as: “intentional change of landscape pattern, for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values” (p. 635). The task of landscape planning is to manage the change of the land use and its ecological, cultural and economic functions, in order to preserve biodiversity, sustainability and beauty (Termorshuizen et al., 2007).

ES trade-off analysis represents a promising tool to study the relationship between RE and landscape in particular as a trade-off between REES and CES (van der Horst and Vermeylen, 2011). As recently stated in Turkelboom et al. (2017) we refer to the term trade-offs not from an impact assessment perspective (the effect of a driver on a bundle of ES) but from a landscape planning and design perspective, as the choice between different land use and management options or landscape scenarios, with stakeholders put at the core of the ES trade-off analysis. The use of an ES approach to evaluate spatial trade-offs with REES (e.g. land use trade-offs) is still in an early stage (Kienast et al., 2017). However, the risk of trade-offs must be recognized to avoid conflicts between different policies and targets (Howard et al., 2013).

The landscape change induced by RET needs to be strategically planned and designed through participatory processes at local scale, in order to overcome the lack of acceptance by communities (Stremke and Picchi, 2017). Yet the adoption of participation to safeguard local communities’ rights to landscape is a relevant aspect to be investigated (ELC, 2000; Arler, 2011; Van der Horst and Vermeylen, 2011). Communities receive benefits both from ES and RE; the involvement of stakeholders in participatory processes is relevant to determine the demand and the perceived ES benefit areas (Van Berkel and Verburg, 2014; Cortinovis and Geneletti, 2018). Yet, it requires acknowledging the local scale because this is the scale at which most stakeholders take decisions. Also Bennett et al. (2009) and more recently Geneletti et al. (2018) recognize the importance to study trade-offs among ES at the local scale, but also warn to avoid generalizations as some of the mechanisms that relate two ES may be unknown. Yet these trade-offs analysis should be more concrete and close to the work of planners (Turkelboom et al., 2017).

Consequently the mapping and the spatial reference system are relevant when assessing trade-offs among ES for management and planning and design (De Groot et al., 2010; Maes et al., 2012; Howard et al., 2013; Fernandez-Campo et al., 2017; Turkelboom et al., 2017). A review from Crossman et al. (2013) on ES mapping, revealed how the spatially explicit definition of ES depends on the considered ES. Different ES require different spatial information that can be provided by different spatial reference systems. For example, some provisioning ES groups as biotic materials production can be efficiently described by the information on the land use and land cover classes (LULC). Some regulating ES, on the contrary, would need additional information on the landscape infrastructure such as the green and blue networks (Zardo et al., 2017). Cultural ES may require spatial information gathered through participatory processes and social mapping activities (Fagerholm et al., 2012) together with the calculation of metrics on people preferred land cover patches for recreation through tools as the Shannon diversity index or the Index of Function Suitability in the landscape (Frank et al., 2012; Pinto-Correia and Carvalho-Ribeiro, 2012). In this perspective, there is a need to study which spatial reference system can help to examine trade-off among ES.

The objective of this paper is to report which approaches and methods can be found in literature to analyze the spatial relationship between RET and ES themes and groups, and, more particular, which spatial reference systems better describe the spatial trade-offs among ES in landscape planning and design. We reviewed studies on RE and landscape based on specific parameters, and used the results to identify types of approach and relative knowledge gaps.

The following section describes the methods we adopted to conduct the review. Section three presents the results that are then discussed in section four. In the concluding section, we provide a summary of the results, highlight new knowledge gaps and identify future research challenges.

2. Methods and materials

2.1. Selection of the sample of papers

For the review, a literature search was conducted in two stages (Fig. 1). The first stage aimed to understand whether and according to what approaches and methods the ES framework is currently used to analyze the relationship between renewable energy (RE) and landscape. The second stage aimed to understand which methods and spatial reference systems are used to apply spatial trade-offs among ES in landscape planning and design, in particular in regard to CES. The search focused on empirical articles, published in English between the years 2005 and 2016, and excluded review papers. We used two online databases of peer-reviewed academic articles: *Sciencedirect* and *Scopus*. Sciencedirect includes the majority of peer review journals in *social sciences* and *humanities*; Scopus includes the majority of peer review journals on *landscape architecture and planning* and other relevant journals in which landscape architecture scholars publish (Kempenaar et al., 2016).

The literature search was based on keywords relevant for this

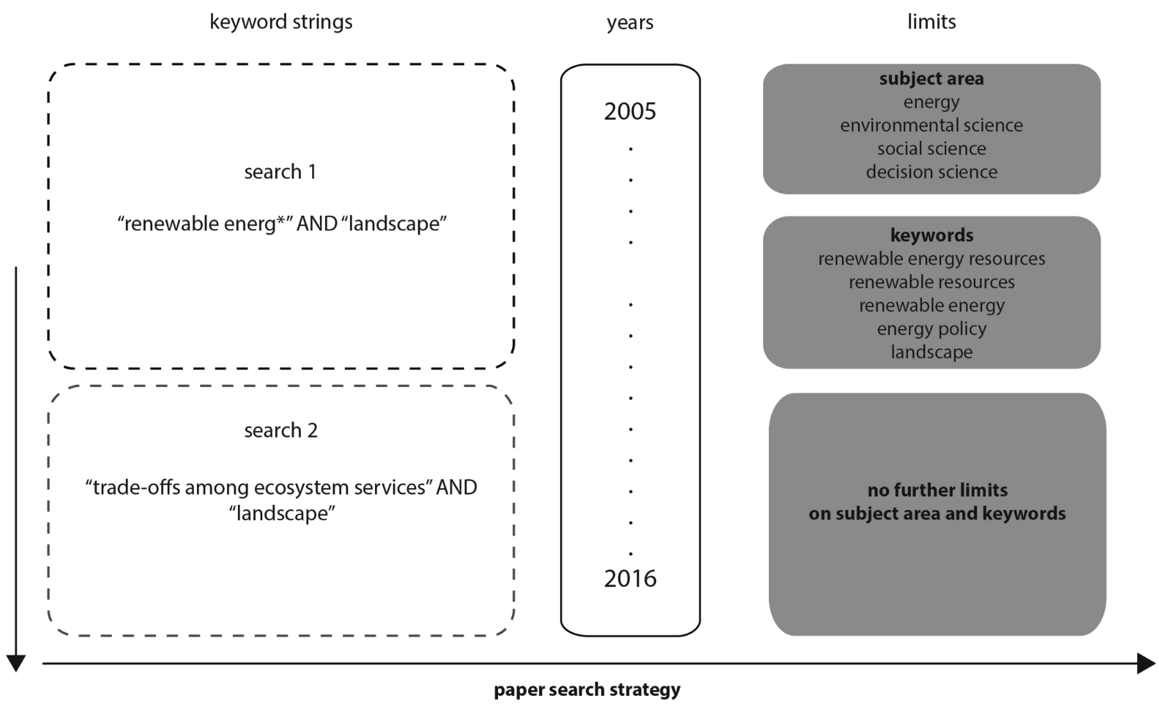

Fig. 1. Flowchart of the search strategy.

research. For stage one, the terms "renewable energy" and "landscape" were used. To exclude the huge amount of literature on RE production technologies concerns, we applied a number of filters, namely the subject areas "energy" and "environmental science". By this way, we focused on papers considering energy in the field of environmental science (e.g. environmental impact assessment, environmental planning, ES assessment). The subject areas "decision science" and "social science" were additionally chosen to safeguard the inclusion of papers considering the socio-cultural concerns related to RE. We selected the keywords "Renewable Energy Sources", "Renewable Sources" and "Renewable Energy" to guarantee the topic of renewable energy, "Energy Policy" to guarantee the topic of the governance of the energy transition, and "Landscape" to safeguard landscape related topics (e.g. landscape change, CES, landscape planning and design, etc.) (Fig. 1). For stage one, according to a snow-ball technique (Kumar, 1999), the review was supplemented with peer reviewed literature known by the authors or suggested to us by other scholars, extending in relevant cases to literature published in 2017.

Stage two was based on the terms "trade-off among ecosystem services" and "landscape" in which we expected to find papers concerning ES trade-off analyses used for landscape planning and design. No further limits and keywords were used since the search terms were specific and this topic is widely studied in literature (Bennett et al., 2009; De Groot et al., 2010).

2.2. Review of the papers

The selected papers were analyzed for a set of parameters. These parameters were based on some general aspects for procedural knowledge of applied research strategies and methodologies, as well as on factors identified as key for the assessment of the relation between RE and landscape as described in the introduction.

Within the former group, two parameters were established based on the work of Creswell (2003) about research design, namely: *strategy of inquiry* and *method of inquiry*. *Strategy of inquiry* helped to indicate whether a quantitative strategy, qualitative strategy or mixed strategy of inquiry was applied. The second parameter, the *method of inquiry*, indicated whether the method of inquiry was exclusively expert-based or including participatory processes.

The latter group of parameters is described as follows. The parameter *spatial scale* was used to understand at what scale the relationships between RE and landscape and trade-offs among ES were evaluated: at the national, regional or local scales (Bennett et al., 2009; Turkelboom et al., 2017). The parameter *ecosystem services themes and groups* was used to indicate which ES the authors evaluated in the assessment. For this purpose, we used the themes and groups from the Common International Classification of Ecosystem Services, CICES (Haines-Young and Potschin, 2011). In the scope of this paper RES were not considered as attribute of the parameter ES themes and groups (Renewable Energy ES) but as distinguished parameter, so the results will be reported in terms of ES and RES.

It is relevant to understand if and how different ES and their combinations can require different strategies and methods. For example, CES groups often require qualitative strategies and participatory methods, while provisioning ES groups often require quantitative strategies and expert based methods (Table 2). We, therefore, first made a distinction between studies that used the ES framework and ones that did not: for the latter, we interpreted the attributes and values in terms of pertaining to ES groups. The studies assessing for example the visual impact of wind farms or PV fields were considered as assessing the impact on the ES group C1 "aesthetic, heritage", since assessing the impact on the aesthetic and the heritage values, while the studies assessing the impact of Biomass RET on the food production were considered as assessing the impact on the ES group P1 "terrestrial plant and animals".

The parameter *renewable energy sources* concerns which RES were considered in the study and whether one RES or bundle of RES were considered. According to the definition of sustainable energy landscapes, the sustainability of the energy transition is safeguarded when RES are multiple and provided locally (Stremke and van den Dobbelsteen, 2012). The parameter *participatory mapping* was used in stage two to understand whether or not the authors incorporated a participatory mapping of ES supply in the spatial trade-off analysis, producing social maps (Fagerholm et al., 2012). The parameter *spatial reference system* was used in stage two of the search to analyze which spatial reference system was applied (Fig. 2).

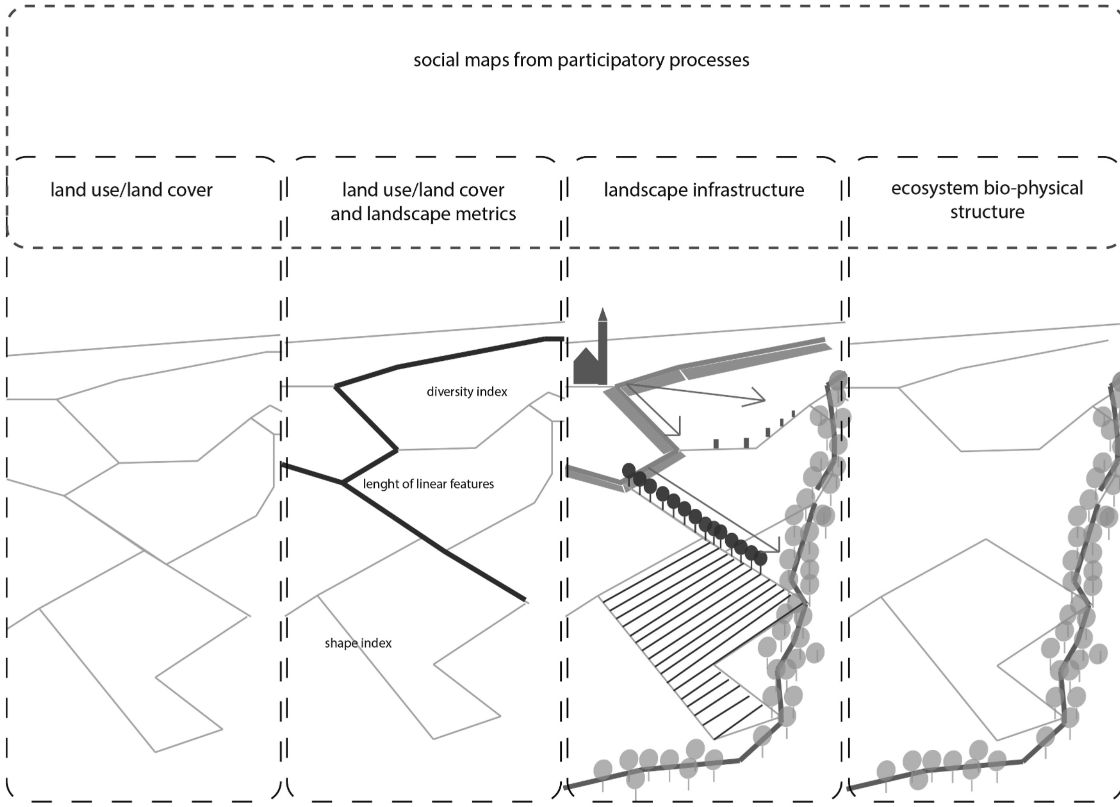

Fig. 2. Illustration of the spatial information that different spatial reference systems support; the "Participatory mapping" is a tool that can be combined with each spatial reference system.

Four typologies of spatial reference systems were found, namely: *land use/land cover*, when CORINE or a national or regional land use/ land cover classes was used (Howard et al., 2013); *land use/land cover with the calculation of landscape metrics* as the patches diversity (Shannon diversity index), density, specialization, the measure of linear features as how much meters of walls or tree lines, ore the counting of punctual features (Uuemaa et al., 2009; Frank et al., 2012); *landscape infrastructure*, refers to the physical or beta structure of the landscape such as green and blue network, roads, tree rows, edges and specific local features or specific landscape views and not visible networks (De Groot et al., 2010); *bio-physical structure of ecosystems* the complex of the physical structure of a singular ecosystem (e.g. a woodland association of Picea excelsa and Larix decidua) plus the complex of the vegetal and animal species living in it, as described and also defined "process" in the cascade model by Haines-Young and Potschin, (2011) and recently re-stated by Costanza et al. (2017) (Fig. 2).

All these spatial reference systems can be considered a tool to synthesize the description of the landscape. In addition, the study of the relationship between the RE generation and the landscape has been simplified in this review as a study between the RET installation and the modification of the spatial reference systems. The reasons for this choice must be found under the scope of this paper: we decided to refer to the most common spatial reference systems as in literature to safeguard consistency throughout the papers analysis. Yet the landscape infrastructure parameter refers to all the landscape networks as the green and blue infrastructure, the gray infrastructures as heritage roads or built features and the visual aspects. In addition, in the cultural background of the European Landscape Convention, the parameters *method of inquiry* and *participatory mapping* can inform whether the studying the relationship between the RE generation and the landscape adopted participatory processes as addressed by the Convention (ELC, 2000, Explanatory Report, paragraph 64).

The parameters were applied at the two searches as summarized in the Table 1.

The results from search stage one were summarized per parameter and combination of parameters. Further the papers encountered in search one were interpreted in four main types of approach distinguished per main objective, and characterized by recurrent results for the parameters *strategy of inquiry*, *method of inquiry*, *spatial scale*, *RES* and *ES themes and groups* (Table 2). The approach categories were functional to gather the information by the analysis of parameters in an empirical way. The aim was to interpret different types of approaches to individuate the most suitable, or the most suitable combination and integration among them, useful to advance the planning and design of renewable energy landscapes.

3. Results

3.1. The relationship between renewable energy and landscape

The first search stage resulted in 64 papers. The RE and landscape topic is addressed in several research domains, from tourism to environmental psychology. Papers have been published in journals from very diverse disciplinary fields such as e.g. Tourism Science, Geography, Environmental Planning, Environmental Psychology, Landscape Ecology and Energy. Nevertheless, journals dedicated to energy are recurrent. For example, *Energy Policy* that published 12 of the 64 selected papers followed by *Renewable and Sustainable Energy Review* with seven papers. It is relevant to note that a journal with a specific scope as *Ecosystem Services* appeared few times, publishing papers on planning approaches. In the following section, the results per parameter and combination of parameters are described, after which we outline the main findings per approach type.

Only 11 of the 64 examined papers applied the ES framework (Gee and Burkhard, 2010; Burgess et al., 2012; Howard et al., 2013; Verkerk et al., 2014; Lupp et al., 2015; Schulze et al., 2016; Scognamiglio, 2016; Tayyebi et al., 2016; Fernandez-Campo et al., 2017; Kienast et al. 2017;

Table 1
Parameters and options used in the review; the value codes used in this table have been adopted throughout the paper.

Parameters	Values	Search 1	Search 2
Method of inquiry	**E**/ expert	x	x
	P/ participatory	x	x
Strategy of inquiry	**A**/ quantitative	x	x
	B/ qualitative	x	x
	C/ mixed	x	x
Spatial Scale	**N**/ national	x	x
	R/ regional	x	x
	L/ local	x	x
ES themes and groups (CICES, 2011)	**Provisioning groups**	x	x
	P1/ terrestrial plant and animal		
	P2/ freshwater plant and animal		
	P3/ marine plant and animal		
	P4/ potable water		
	P5/ biotic materials		
	P6/ abiotic materials		
	Regulating groups	x	x
	R1/ bioremediation		
	R2/ dilution and sequestration		
	R3/ air flow regulation		
	R4/ water flow regulation		
	R5/ mass flow regulation		
	R6/ atmospheric regulation		
	R7/ water quality regulation		
	R8/ pedogenesis and soil quality regulation		
	R9/ lifecycle maintenance and habitat protection		
	R10/ pest and disease control		
	R11/ gene and pool protection		
	Cultural groups	x	x
	C1/ aesthetic, heritage		
	C2/ spiritual		
	C3/ recreation and community activities		
	C4/ information & knowledge		
Renewable energy sources	**W**/ wind	x	
	S/ solar	x	
	H/ hydropower	x	
	BIO/ biomass	x	
	T/ tidal	x	
	G/ geothermal	x	
	RE S/ all sources in general	x	
Spatial reference systems	**LULC**/ land use/land cover		x
	LULCM/ land use/land cover and landscape metrics		x
	LI/ landscape infrastructure		x
	BSS/ bio-physical structure of ecosystems		x
Participatory mapping	**SM**/ social maps		x

Pang et al., 2017). The most considered ES in all 64 papers were the cultural ES C1 “aesthetic, heritage”, the regulating ES R9 “lifecycle maintenance and habitat protection” and the cultural ES C3 “Recreation and community activities”. Table 3 presents a ranked overview of ES (based on CICES) according to the number of papers addressing the respective ES groups.

34 out of 64 papers are concerned with the assessment of wind power development, 13 with biomass and two times four papers with solar energy and hydropower. The most debated RES in terms of landscape issues is wind and, in particular, the landscape impact of wind farms and wind farm planning. Table 4 shows the encountered RES and the combinations of RES ranked according to the number of papers.

A large number of papers (24 out of 64) adopted a qualitative strategy and participatory method of inquiry. In some of these studies, the local people’s attitude towards the wind farms development was assessed (Ek, 2005; Kaldellis, 2005; Ladenburg, 2008; Graham et al.,

Table 2
Four main types of approach.

Approach type	Main objective	Strategy of inquiry	Method of inquiry	ES groups	RES
Social attitude approach	**To assess the social attitude** of stakeholders towards RE in relation to one or more RES, or a specific RET pertaining specific social, cultural and economic aspects	B	P	Cultural groups	W
Impact assessment approach	**To assess the environmental impact** of a specific RES/RET on a specific ES	A	E	Cultural groups	W
Planning approach	**To plan development** scenarios for decision-making and landscape planning, including in the scenario assessment a specific RES/RET and its trade-offs with at least two groups or a bundle of ES	C	E	Regulating groups-Cultural groups	BIO
Integrated planning approach	**To plan development** scenarios for decision-making and landscape planning at local scale, including in the scenario assessment diverse and integrated RES/RET, and their trade-offs with at least two groups or a bundle of at least two ES	B	P	Provisioning groups-Cultural groups	W-S-BIO

Table 3
Number of papers addressing directly or indirectly ES, based on the CICES classification.

	ES groups	N. papers
C1	Aesthetic, heritage	48
R9	Lifecycle maintenance and habitat protection	29
C3	Recreation and community activities	20
R11	Gene pool protection	12
R6	Atmospheric regulation	15
P1	Terrestrial plant and animal	11
R5	Mass flow regulation	9
R8	Pedogenesis and soil quality regulation	5
R7	Water quality regulation	5
C2	Spiritual	5
P5	Biotic materials	4
C4	Information & knowledge	3
P6	Abiotic materials	3
R4	Water flow regulation	3
P4	Potable water	2
P3	Marine plant and animal	2
R10	Pest and disease control	2
P2	Freshwater plant and animal	1
R3	Air flow regulation	1
R2	Dilution and sequestration	1

Table 4
Number of papers per RES and RES combinations.

Renewable energy source	n. papers
W Wind	34
BIO Biomass	13
S Solar	4
H Hydropower	4
RET no specific source	4
W-BIO Wind-Biomass	1
W-H Wind-Hydropower	1
W-S Wind-Solar	1
W-S-BIO Wind-Solar-Biomass	1

2009) with open-ended questions, such as: what do you think about wind development, or do you think this would afflict the cultural value of the landscape? In other studies, the impact of wind farms plans on the perception of locals on their landscape was examined (Ladenburg, 2009; Gee and Burkhard, 2010).

Regarding spatial scale, 26 out of 64 papers were set at local scale, 24 at regional scale. The local scale was adopted to study the social attitude of communities towards wind farms development in their own landscape through questionnaires and surveys (e.g. Ek, 2005; Warren and McFadyen, 2010; Frantál and Kunc, 2011; Rygg, 2012; Batel et al. 2015; Petrova, 2016; Delicado et al., 2016). The local scale was also adopted to study the impact of PV fields and wind farms on CES (e.g. Chiabrando et al., 2009, 2011; Kapetanakis et al., 2014; Betakova et al., 2015), to study the impact of wind farms on birds population (Agha et al., 2015) and to study the disturbance of offshore wind farm on the seascape view (e.g. Gee and Burkhard, 2010). Finally, the local scale was adopted to plan the production of biomass for RE (Bennett and Isaacs, 2014; Casado et al., 2014; Tayyebi et al., 2016; Fernandez-Campo et al., 2017). 24 out of 64 papers are concerned with the regional scale. The studies at regional scale were focused on the impact assessment on regulating ES groups, e.g. the impact of offshore wind farm on the marine ecosystems (Bergström et al., 2014), or the impact of hydropower plants on the aquatic habitat (Szabó and Kiss, 2014). Some studies were planning RET at regional scale. These were concerned with the planning of energy crops or the forests harvesting for the production of biomass. (Dockerty et al., 2012; Stoms et al., 2012; Harvolk et al., 2014; Schulze et al., 2016; Höfer et al., 2016; Pang et al., 2017).

11 out of 64 papers address the national scale and three papers both the local and the national scale. The latter publications validate the outcomes of local case studies about the social attitude towards the installation of wind farms at national level (Ladenburg, 2008; McManamay et al, 2015; Firestone et al., 2015) the former conduct e.g. a mapping of the impacts of RET at national scale or define the main criteria at national level to locate RE plants by crossing national date sets with local data (e.g. Josimovic and Crncevic, 2012; Baltas and Dervos, 2012; Kienast et al., 2017).

The two most recurrent combinations of RES and ES groups were the assessment of wind RET in relation to the regulating ES R9 "Lifecycle maintenance and habitat protection" with either the cultural ES C1 "aesthetic, heritage" (12 out of 64 papers), or the cultural ES C1 "aesthetic, heritage" (10 out of 64 papers). With 14 studies, the ES C1 "aesthetic, heritage" is, in relation to wind RET, the most considered ES, either singular or in combination with other cultural ES. In seven out of 64 studies, the ES group R9 "Lifecycle maintenance and habitat protection" was evaluated together with cultural ES, in relation to wind RET. The Annex B of this paper shows the combination of the ES themes and groups and RES per strategy of inquiry, method of inquiry and spatial scale for each paper. The table is ordered per year and reveals an increase of studies that analyze multiple and integrated RES compared to bundles of ES (Howard et al., 2013; McManamay et al., 2015; Lupp et al., 2015; Tayyebi et al., 2016; Schulze et al., 2016; Kienast et al., 2017).

The next sections will focus on objectives and which specific methods were adopted in each of the four types of approaches, namely *social attitude approach*, *impact assessment approach*, *planning approach* and *integrated planning approach*. Annex C summarizes papers per approach type and the review parameters, while the Fig. 3 below illustrates the share of papers per type of approach.

3.1.1. The social attitude approach

The objective of the studies that fall under the type of social attitude approach was to investigate what people think about RE development, what their attitude is with regard to landscape changes, and what attitude they have towards improving their surroundings through RET. Of the 64 papers, 25 belong to this category. Of those 25 papers, 17 studied what people think about wind farms development and their impact on the landscape. In two papers the wind farm development was considered combined with hydro-power development. Another five studies employed questionnaires and focus groups to study what people in general think about RET development (e.g. benefits and drawbacks of RE, visual impact of RET). None of the papers in this category used the ES framework. Table 5 summarizes the papers that fall under the type social attitude approach according to the strategy of inquiry and participatory methods.

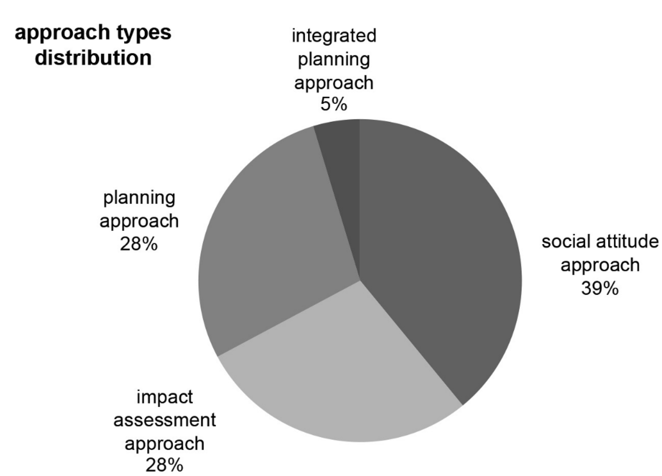

Fig. 3. Distribution of papers per approach type.

Table 5
The participatory methods used in the social attitude approach, organized per strategy of inquiry and renewable energy source.

Strategy of inquiry	RES	Participatory methods	Papers
A Quantitative	W	Opened and closed questionnaires, surveys, email surveys, interviews, aimed at the quantification of the attitude through indicators typical of the environmental economics such as WTP, House Price, or specific indicators as the number of wind turbines encountered on a daily routine	Ladenburg and Dubgaard (2007) and Ladenburg and Dahlgaard (2012)
B Qualitative	W S H RET	Opened and closed questionnaires; surveys; email surveys; interviews; group discussions, aimed at the formulation of qualitative judgments and scenarios through very diverse methods from social sciences and statistics to overcome subjectivity and safeguard the representativeness of data	Ek (2005), Kaldellis (2005), Bergmann et al. (2008), Warren and McFadyen (2010), Dimitropoulos and Kontoleon (2009), Graham et al. (2009), Fisher and Brown (2009), Frantál and Kunc (2011), Gee (2010), Graham et al. (2009), Swofford and Slattery (2010), West et al. (2010), Rygg (2012), Kontogianni et al. (2014), Batel et al. (2015), Caporale and Lucia (2015), Firestone et al. (2015), Bertsch et al. (2016), Petrova (2016), Delicado et al. (2016), Olson-Hazboun et al. (2016), Klæboe and Sundfør (2016) and Sherren et al. (2016)

3.1.2. The impact assessment approach

Of the 64 papers, 18 fall under the type of impact assessment approach. The objective of these studies was to assess the impact of specific RES/RET on environmental and landscape values. Only Gee and Burkhard (2010) worked with the ES framework. Different methods were applied, depending on the considered RES/RET. In the case of CES assessment, methods making use of landscape visualizations are used frequently (14 out of 18 papers). Visualizations were used both in expert-based and participatory methods to assess the impact of PV fields and wind farms on the landscape. The spatial scale of impact assessments does vary. Out of 11 quantitative studies, six are conducted at national/regional scales to provide general data for RE planning. The following Table 6 summarizes the papers that fall under the type of impact assessment.

3.1.3. The planning approach

18 out of 64 papers fall under the planning approach type, employing different methods. Quantitative studies (six out of 18 papers) evaluated land-use development scenarios through expert methods and datasets. The objectives were the plan of biomass production, or forest sustainable harvesting for bio-energy production. In three cases they examined the spatial distribution of the ES and their level of provision through GIS based multi-criteria analysis. The studies applied at national scale (three out of 18) defined criteria for finding the most suitable sites for biomass plantations. At regional and local scale, studies simulated through software the landscape and land-use change by introducing different cropping systems dedicated to RE production and related alternative scenarios, or planned the optimal allocation for wind turbines. Qualitative studies (three out of 18 papers) were using participatory methods for evaluating future scenarios for biomass, wind and solar RET through models and stakeholder involvement in the assessment (two papers), while a third paper was based on experts and reported on landscape design strategies to include and integrate PV into the landscape pattern.

The studies adopting a mixed strategy of inquiry (seven out of 18 papers) were exclusively adopting expert-based methods, combining qualitative and quantitative evaluations at local and regional scales. These studies employed GIS models to generate scenarios for biomass, wind and hydropower that were then elaborated by means of qualitative evaluation. The following Table 7 summarizes the papers that fall under the type planning approach.

3.1.4. The integrated planning approach

Only three out of 64 papers applied an integrated planning approach. All three used the ES framework. The key concept characterizing these studies is the land-use conflict between a set of RES and a set of ES. For each scenario, RES were combined to reach the target amount of RE which, in turn, is based on local demand. The scenario studies served to understand how to reduce trade-offs between RE generation and ES supply. The three studies adopted three different strategies of inquiry: quantitative, qualitative and mixed. The former two strategies of inquiry were conducted through expert based methods. The mixed one, on the contrary, was conducted through a participatory method. The Table 8 below summarizes the papers that fall under the type integrated planning approach, per strategy of inquiry and RET.

3.2. Spatial references and methods for the ES trade-offs in landscape planning and design

In this section we report the main results from search stage two (47 papers). results are presented per employed spatial reference system.

3.2.1. Land use and land cover (LULC) as spatial reference system

Of 47 studies, 21 adopted the LULC as spatial reference system. LULC based studies were in most cases quantitative, expert-based and applied at local scale. In the majority of the cases, regulating and provisioning ES were assessed; specifically P1 “Terrestrial plants and animals” and R6 “Atmospheric regulation”. Other frequently analyzed ES were: P5 “Biotic material” and C3 “Recreation and community activities”.

Nine out of 21 papers applied a quantitative analysis of ES per LULC type, through land-use maps and field measurements. Some of the studies calculated the economic value of multiple ES by means of costs-benefit analysis (Grêt-Regamey and Kytziab, 2007; Nelson et al., 2009; Tomscha and Gergel, 2016). To assess ES provision, the ES indicators values were obtained from public databases and literature or either directly estimated. They frequently produced land use-based scenarios for decision-making through the application of existing models or the experimentation of new models (Grêt-Regamey and Kytziab, 2007; Nelson et al., 2009; Tomscha and Gergel, 2016).

Seven out of 21 studies adopted qualitative strategies and primarily employed participatory methods asking open-ended questions, such as: what is the capacity of a specific LULC to supply ES? Or how to determine spatial trade-offs among ES? They expressed the capacity of landscape to supply services, or the level of potential spatial synergies or trade-offs among ES, using value ranges through GIS frameworks, or models and matrix approaches (Burkhard et al., 2009; Kandziora et al., 2013a,b; Jackson et al., 2013). Four studies conducted interviews or questionnaires with stakeholders to determine ES hot spots (Lamarque et al., 2011; Lavorel et al., 2011; Howard et al., 2013; Jackson et al., 2013). Six out of 21 studies adopted a mixed strategy of inquiry, either with participatory or expert based methods. These mixed method studies applied GIS models to combine quantitative data from indicators with qualitative data attributed by expert or stakeholders to LULC classes (Albert et al., 2016), or evaluated geographical patterns and gradients of ES supply at local scale (Carreño et al., 2012). One study used indicators for the ecological functioning of the ecosystems and applied a matrix approach to evaluate both demand and supply for ES in relation to the Corine LULC classes (Burkhard et al., 2012).

Among the studies adopting LULC for spatial trade-off analysis,

Table 6
The methods used in impact assessment approaches per strategy of inquiry and RES.

Strategy of inquiry	RES	Expert based methods	Participatory methods	Papers
A Quantitative	Solar	Calculating indexes on visibility, color, and fractality		Chiabrando et al. (2009, 2011) and Kapetanakis et al. (2014)
	Wind	Calculating visually affected area through GIS mapping; modeling visibility, proximity or density of wind farms; field survey to calculate the affliction caused by wind farms on habitat and fauna populations		Sibille et al. (2009), Rodrigues et al. (2010), Möller (2010), Riddington et al. (2010) and Agha et al. (2015)
	Hydropower	Field survey to calculate the affliction caused by hydropower peaking and reservoirs on habitat		Josimovic and Crncevic (2012), Szabó and Kiss (2014)
B Qualitative	Wind	Evaluating temporal extent, spatial extent, and sensitivity of animal species within each ecosystem component - use of Likert scale to evaluate the impact scores		Bergström et al. (2014)
			Surveys, questionnaires to rank and score the affliction of environmental and landscape values/ES by local residents	Ladenburg (2009) and Gee and Burkhard (2010)
C Mixed	Wind		Interviews and focus groups on landscape visual quality combined with quantitative data as distance from wind turbines, number of wind turbines, turbines height, size of wind farm; Choice Experiment (CE) for preferences in reducing wind farm disamenities combined with Willingness To Pay (WTP); spatially explicit models to assume attributes and value them through Choice Experiments (CE)	Ladenburg and Dubgaard (2009), Gee and Burkhard (2010), Meyerhoff et al. (2010), Chias and Abad (2014) and Betakova et al. (2015)

eight were including CES in the assessment. In five studies, CES were evaluated through a mixed strategy of inquiry and participatory methods with the aim to attribute cultural values to a specific or a combination of LULC.

3.2.2. Land use and land cover (LULC) plus landscape metrics

Eight out of 47 papers combined spatial reference LULC with landscape metrics. Of those eight, four were quantitative studies, expert-based, with applications at regional scale. These studies focused on the provisioning ES P1"Terrestrial plant and animals" and P5"Biotic materials" as well as the CES C1 "Aesthetic, heritage". Quantitative studies worked with software platforms including landscape metrics to advance scenarios assessment. These applications, for example GISCAME (Frank et al., 2014, 2015), were based on data obtained from regional planning authorities (LULC, planning data, digital elevation model, and management guidelines). The aim was to assess land-use changes and the impact of land management scenarios on ES provision (e.g. Grimaldi et al., 2014; Kirchner et al., 2015).

Two studies were adopting a qualitative strategy of inquiry and two a mixed strategy of inquiry. These focused on the assessment of CES and employed so-called participatory mapping of ES. This type of mapping involves surveys in which people indicate specific places at the regional scale, and attribute a value by placing dots on aerial images or other map sources. The points are then digitalised in GIS with landscape metrics in relation to LULC, such as abundance, diversity, rarity and risk. These metrics were calculated to provide values at regional scales relevant for landscape management (Bryan et al., 2010; Brown and Reed, 2012). The mapping of trade-offs resulted in the overlay of valuable points and risk points.

3.2.3. Studies adopting the landscape infrastructure

Seven out of 47 papers applied landscape infrastructure as spatial reference system. Four papers adopted a mixed strategy of inquiry, in three cases through participatory methods. Three papers adopted a qualitative strategy of inquiry and expert based methods. The studies aimed to include information on the landscape infrastructure to enhance the assessment of ES with regard to the landscape's physical and beta-structural aspects. In two papers, LULC was integrated with information on measurable landscape infrastructure features such as amount of tree lines, edge-rows etc., these were introduced as input in spatial frameworks and software like Multi-Criteria Decision Analyses for strategic spatial planning (Frank et al., 2012; Bagstad et al., 2013). Two studies adopting a mixed strategy of inquiry applied a participatory mapping process. One paper included the design of landscape scenarios in collaboration with stakeholders, these were represented by quantified measures of regulating ES supply, and CES were evaluated through landscape visualizations submitted to stakeholder qualitative judgment (Grêt-Regamey et al., 2013). In the other paper the authors orchestrated participatory mapping where stakeholders mapped preferred areas. For those, the presence of specific elements of the landscape infrastructure was measured, then a qualitative assessment of the ES supply by a Likert scale was operated (Ungaro et al., 2014).

3.2.4. Studies adopting other spatial reference system

Only two papers adopted the biophysical structure of ecosystems (BSS) as spatial reference system (Paetzold et al., 2010; Castro et al., 2014). The two studies applied respectively a qualitative strategy of inquiry applied at local scale and a mixed strategy of inquiry at regional scale. In both cases they assessed regulating ES, in particular R9 "Lifecycle maintenance and habitat protection" with provisioning ES and CES.

The remaining nine studies applied a participatory mapping. The inedited maps produced through the participatory mapping activity, which are called "social maps" (Crampton, 2001), were used as a spatial reference system. Such maps could be digital geo-referenced aerial photographs in which stakeholders could indicate the places where they

Table 7
The methods used in planning approaches per strategy of inquiry and RET.

Strategy of inquiry	RET	Expert based methods	Participatory methods	Papers
A Quantitative	Biomass	Frameworks and models elaborating land-use economic and policy based scenarios to identify synergies and trade-offs among Biomass RE production and ES (*EFISCEN*, *InVEST, GLOBIO, LANDSIM)*		Baltas and Dervos (2012), Stoms et al. (2012), Bennett and Isaacs (2014), Verkerk et al. (2014), Schulze et al. (2016), Fernandez-Campo et al. (2017) and Pang et al. (2017)
			Models elaborating scenarios panels enabling users to compare the outcome of crop change scenarios on ES	Tayyebi et al. (2016)
	Wind		Choice Experience workshop to choose between different scenarios expressing a trade-off among the increase of costs installing wind farms off-shore at specific distances and the decline of cultural ES groups	Westerberg et al. (2013)
B Qualitative	Biomass		Models elaborating land-use economic and policy based scenarios; public questionnaire survey, focus group meetings with community groups, and interviews with key NGOs, industry and local government based on bird's eye landscape visualizations	Dockerty et al. (2012) and Lupp et al. (2015)
	Solar	Landscape design strategies to include solar RET into the landscape pattern based on Capital cost of the system, Leveled Cost of Electricity (LCOE), landscape pattern and density of solar panels		Scognamiglio (2016)
C Mixed	Biomass	Models producing land cover based development scenarios to assess synergies and trade-off among Biomass RE production and regulating ES groups; economic models based on land use to assess the impact of Biomass energy crops on land use change and regulating ES groups		Harvolk et al. (2014) and Casado et al. (2014)
	Hydropower		Cost-benefit analysis of hydropower based on the overlay between buffer areas of hydropower potential and other buffer maps on ES	McManamay et al, (2015)
	Wind	Producing scenarios according to a set of criteria and based on site analysis per buffer areas for planning off-shore wind farms; Multi-Criteria Decision Making for planning wind farms; sites at regional scale based on regional expert's panels		Kim et al. (2016) and Höfer et al. (2016)
			Planning wind turbines welfare-optimal allocation through the assessment of trade-offs between production costs and landscape externalities by combining choice experiments and spatially explicit modeling	Drechsler et al. (2011)

Table 8
The methods used in integrated planning approaches per strategy of inquiry.

Strategy of inquiry	E Expert based methods	P Participatory methods	Papers
A Quantitative	Based on demand land-use scenarios and spatial trade-off assessment between RE and ES		Burgess et al. (2012)
B Qualitative	Spatial overlay of Energy Potential Maps and Landscape Services Maps and Conflict matrix between RES and ES		Kienast et al. (2017)
C Mixed		Spatio-temporal analysis framework elaborating long term visions based on land-use and stakeholder questionnaire to score threats and benefits between the ES and RET based on Likert scale	Howard et al. (2013)

benefit from ES (Fagerholm et al., 2012), or as in the case of Sinare et al. (2016) maps of social ecological patches (landscape types that correspond to terms of local use defining a combination of LULC and topography). In the latter case the amount of ES supply was evaluated in percentage per each social ecological patch, and then a matrix of ES and patches was developed to address strategies to reduce ES trade-offs and enhance synergies.

Table 9 summarizes the main findings from search stage two, indicating per spatial reference system the found methods per strategy of inquiry plus methods for integrating CES into the trade-off analysis.

4. Discussion

Our results confirmed that the introduction of an ES approach in the assessment or planning of RE generation is still at an early stage (Kienast et al., 2017). In general, the literature focuses on the relationship between the landscape and RE, but rarely in terms of relationship between RE generation and ES and their trade-offs. By interpreting parameters and values adopted by the selected studies in terms of ES groups, we learned that each RET can have peculiar trade-offs with specific groups of ES at different spatial scales. These depend on the spatial footprint interrelation with the physical and beta structure of the landscape infrastructure delivering ES. In the majority of cases, research seems to be driven by local communities issues, which are highly focused on the visual impact of RET or often by perceivable trade-offs, as this might explain why some approach types are more recurrent than others.

Local communities are more concerned with perceivable trade-offs (as the visual impact of wind farms on the landscape) than, for example, with land-use change caused by the introduction of energy crops and PV fields. Yet different groups of stakeholders are concerned about different ES implications. Farmers are more concerned with the consequences on food production of PV fields and energy crops causing land-use change. Nature conservation managers and environmental associations are concerned about the impact of off-shore wind farms on the marine habitat or the effect of hydro-power plants on the river ecosystems ecological integrity.

The objective of this paper was to report which approaches and methods can be found in literature to analyze the spatial relationship between RET and ES themes and groups, and, more particular, which spatial reference systems better describe the spatial trade-offs among ES in landscape planning and design. Then what approach categories better pursuit the planning and design of sustainable energy landscapes? The review process considered only empirical papers. The analysis of empirical papers reporting on applied approaches and methods, could safeguard the learning and the identification of knowledge gaps from case study applications. The studies were categorized in different approaches based on the research objectives and recurrent parameters values, namely: *social attitude approach*, *impact assessment approach*, *planning approach* and *integrated planning approach*. These types were conceived after the review of the parameters, yet not influencing the results within these. The aim of types was to frame results per objective in order to summarize aims and respective approaches and methods in the more operational way as possible.

A distinction among approaches must be done between those aimed at the *assessment of a case* (social attitude and impact assessment approaches) and those aimed at the *planning of a case* (planning and integrated planning approaches). The former two approaches are relevant for decision makers and the design of RE action plans and strategies at national and regional levels. Both approaches produce information on people attitude towards RET development, or specific data on RET impact assessment, that can inform the decision making process with regard to RET development action plans at national level (e.g. the Energy National Action Plan in Italy) or regional strategies (e.g. the Zeeland 2040 Regional Strategy for RE generation in the Netherlands). The latter two approaches respond to the need at regional or local level of spatially display RET development sustainable scenarios in order to apply the national or regional action plans and strategies at regional or local level.

The social attitude approach studies are those typically driven by community instances on perceivable trade-offs at local scale, as we also mentioned at the beginning of these discussions. Very few had considerations on the complexity of RET as integrated means to produce RE (Ek, 2005; Batel et al., 2015; Bertsch et al., 2016; Olson-Hazboun et al., 2016), the majority focused on the attitude towards a singular RET, lacking of reflections on the interaction among multiple RET and ES. Yet this approach proved to be relevant to steer research in the assessment of CES due to the adoption of effective participatory methods and landscape visualization tools. Studies adopting the impact assessment approach provided expert analyses for different aims, and responded to the need to assess the real impact of RET installations on specific landscape and environmental concerns. Quantitative strategies with expert based methods were recurrent at national and regional scales, while participatory methods at local scale. These studies were efficient for example, when studying the assessment of regulating ES groups as R4 “Water regulation”, R9 “Lifecycle maintenance and habitat protection”, R6 “Atmospheric regulation” and R11 “Gene pool protection” at regional scale through participatory methods. These studies seemed in line with their objectives and no relevant gaps of knowledge were detected.

The studies representing the planning approach and the integrated planning approach make use of an ES trade-off assessment, elaborating land-use scenarios through recurrent quantitative or mixed strategies of inquiry at local scale. The majority of the planning approach studies are conceived to plan energy crops in trade-off with recurrent regulating ES groups and some provisioning groups as P1 “Terrestrial plants and animals” or P4 “Potable water”, showing little ambition in planning more complex scenarios. A limited number of papers were concerned with wind, solar or hydro-power RET planning which instead are consistently assessed, in the former two approaches on assessing cases.

The integrated planning approach was promising in planning provisioning ES in trade-offs with a combination of integrated RES/RET, showing more ambition in planning more complex scenarios. However, the adopted trade-off assessment methods lack of efficient spatial reference systems and tools to assess regulating and cultural ES groups, and of considerations on how landscape design could influence a

Table 9
The findings from search stage two per spatial reference system.

	Quantitative	Qualitative	Mixed	Frequent ES groups	CES methods	Papers
LULC	Quantitative analysis of ES per LULC type through digital maps and field measurement; spatial trade-off through maps overlay	GIS frameworks, models and matrix to express the capacity of the landscape to supply services or the level of potential spatial synergy/ trade-off among ES using Likert scales; spatial trade-off through maps overlay	GIS framework or models combining quantitative data from indicators with qualitative or semi-qualitative data attributed by expert or stakeholders to LULC classes capacity to provide; ES Spatial trade-off through maps overlay	P1, P6, R5	Participatory processes to attribute cultural value to specific LULC or combination of them	Grêt-Regamey and Kytziab (2007), Nelson et al. (2009), Raudsepp-Hearne et al. (2010), Carreño et al. (2012), Lamarque et al. (2011), Lavorel et al. (2011), Jackson et al. (2013), Kandziora et al. (2013a), Howard et al. (2013), Felipe-Lucia et al. (2014), Palacios-Agundez et al. (2014), Turner et al. (2014), Cordingley et al. (2015), Dunford et al. (2015), Harmáčková and Vačkář 2015), Law et al. (2015), Albert et al. (2016), Cordingley et al. (2016), Egarter Vigl et al. (2016), Galler et al. (2016) and Tomscha and Gergel (2016)
LULC + metrics	Software platform including landscape metrics to advance scenarios assessment in MCSA	MCA framework for the qualitative assessment of regional potentials to provide ES; assessment of ES social ecological hotspots	Participatory mapping of ES and metrics calculation to give a measure of the landscape mosaic providing ES	P1, P5; C1	Participatory mapping and introduction of LULC landscape metrics in frameworks and software to assess CES	Bryan et al. (2010), Laterra et al. (2012), Brown and Reed (2012), Koschke et al. (2012), Frank et al. (2014), Grimaldi et al. (2014), Frank et al. (2015) and Kirchner et al. (2015)
Landscape infrastructure		Framework for modeling spatial correlations between the supply of ES, built on maps of ES source location, sink location, and flows or carriers as elements of the LI	Integrating LULC with the information on measurable features of the landscape as quantification of tree lines, edge-rows etc. in spatial frameworks and software	P1, R4, C3	Participatory mapping and introduction of features of the LI in frameworks and software to assess CES; landscape visualizations as tool to measure CES in future scenarios characterized by other ES supplies	Burkhard et al. (2009), Bastian et al. (2012), Frank et al. (2012), Syrbe and Walz (2012), Verweij et al. (2012), Grêt-Regamey et al. (2013), Grunewald and Bastian (2015) and Ungaro et al. (2014)
Other incl. biophysical structure			Supply and consume of ES through a participatory process per landscape type/SPUs (Service Providing Units); contingent valuation to estimate individual willingness to pay (WTP) for the preservation of ES	P1, R9		Raymond et al. (2009), Paetzold et al. (2010), Fagerholm et al. (2012), Kandziora et al. (2013b), Cárcamo et al. (2014), Castro et al. (2014), Hermann et al. (2014), Lu et al. (2014), Dawson and Martin (2015), Rodríguez-Loinaz et al. (2015), Grêt-Regamey et al. (2017) and Sinare et al. (2016)

reduction of critical trade-offs. This is due mainly to a lack of participatory processes and landscape visualizations tools with regard to CES (Burgess et al., 2012; Kienast et al., 2017) and the exclusive use of LULC as spatial reference system (Howard et al., 2013). Indeed, landscape design deals with the changing of landscape pattern and can, therefore, influence the supply and the trade-off among ES, in particular with regard to CES. As described in the introduction, considering spatial trade-offs among RE and ES only in terms of land use planning reduces the possibilities to minimize trade-off through informed landscape design principles, yet LULC cannot afford the spatial description of CES. e.g. PV panels designed along linear traditional systems of the landscape as the Dutch dams can reduce the trade-offs with the ES group P1 "Terrestrial plant and animals", but afflict the ES group C1 "Aesthetic heritage". This is the most relevant knowledge gap detected in this paper, particularly relevant with regard to CES, which are the most debated among studies due to community concerns about the visibility of wind farms and related NIMBY syndromes.

Moving towards the conclusions of this discussion, what can we learn from these approaches in order to advance the knowledge on the relationship between RE and ES and the planning and design of renewable energy landscapes? All the approach types can potentially contribute to advance the planning and design of renewable energy landscapes, the main question is whether individually or combined. If we want to build a logic prospectus of approaches we can affirm that the success is on the approaches combination and integration: the social attitude approach and the impact assessment approach are preparatory and performing in collecting data that can be used in the planning approach and in the integrated planning approach. Yet relating to the definition of sustainable energy landscapes (Stremke and van den Dobbelsteen, 2012) the integrated planning approach facilitate the sustainability of the renewable energy landscapes because it provides methods to spatially display integrated and different RE sources as available in the landscape. The social attitude approach, the impact assessment approach and the planning approach can be preparatory (collecting data or planning a specific RET) of the integrated planning approach: complexly a mixed strategy of inquiry.

Finally, we will discuss some key aspects related to the results of the second search stage; these are functional to clarify some aspects related to the use of specific spatial reference systems for the spatial description of the ES supply and its enhancement. The second search stage showed how LULC is the most adopted system to spatially describe the supply of ES besides provisioning ES and this is also valid for the studies in the integrated planning approach type. Yet, several authors in the reviewed studies state the need to include additional information on the landscape to fill the information gap of LULC based approaches, and to enable a better analysis of regulating ES or cultural ES (Frank et al., 2012; Grunewald and Bastian, 2015; Kirchner et al., 2015). For example, the landscape infrastructure networks appear relevant to determine the flows of ES and their relationships (Nassauer and Raskin, 2014; Pagella and Sinclair, 2014). The LULC can spatially define the amount of supply of certain provisioning ES such as the P1 "Terrestrial plant and animals", as these are calculated as amount per area and can inform planning. However, the LULC system is not capable to describe how some regulating ES and CES are supplied through the landscape (e.g. the R4 "Water flow regulation" in Syrbe and Walz (2012), and this is necessary to inform evidence-based landscape design strategies.

In addition to LULC, landscape metrics can give a quantitative measure of landscape patterns preferred by people when participatory mapping is applied (Bryan et al., 2010). The presence of landscape infrastructure elements considered relevant by people for the supply of specific CES, can provide information on the spatial distribution of these services (Ungaro et al., 2014). Yet the landscape infrastructure appears essential in describing provisioning and cultural ES groups provided by the landscape, and this should always be included when assessing CES either by expert or through participatory processes. Participatory mapping results a relevant tool to ask society to express their landscape preferences through participation. It allows local communities and different groups of stakeholders to define the spatial distribution of ES.

Participatory mapping combines local knowledge from stakeholders and *connoisseurs* (Arler, 2011) with GIS techniques (Brown and Reed, 2012) both to assess the actual situation and to choose between future development scenarios (Raymond et al., 2009; Plieninger et al., 2013). In particular with regard to CES, the involvement of communities in participatory methods is the most relevant aspect, because participation safeguards the citizens and stakeholders contribution in defining the spatial distribution of CES such as C1 "Aesthetic, heritage" and their level of supply. According to literature CES are a complex concept and so difficult to operationalize (Blicharska et al., 2017), yet these are a direct expression of the people living in the landscape (e.g. C4 "Recreation and community activities" ES group), this is in accordance with the European Landscape Convention (ELC, 2000). CES also depend on the way the landscape and the supported ES are managed. This interrelation can only be assessed through landscape visualizations (as in several social attitude studies) where people can perceive how the landscape will look like according to different levels in the supply of other ES. For example, an augmented supply of biofuel production can modify the land use and the appearance of the landscape. Consequently, the CES supplied by the landscape such as R3 "Recreation and community activities" can vary.

5. Conclusions

The relationship between RE and the landscape has been described as a conflict between global and local perspectives, as a trade-off between provisioning ecosystem services (Renewable Energy Ecosystem Services) and cultural ecosystem services (Van der Horst and Vermeylen, 2011). The literature review that was motivated by this observation confirmed the need to introduce the study of ecosystem services trade-offs into the spatial planning and design for energy transition, to identify potential synergies and minimize trade-offs between renewable energy and other ecosystem services.

The objective of this paper was to report which approaches and methods can be found in literature to analyze the spatial relationship between RET and ES themes and groups, and, more particular, which spatial reference systems better describe the spatial trade-offs among ES in landscape planning and design. This review found that a relatively small number of papers (all published in the last eight years) on renewable energy explicitly applied the ES framework. The three most frequently considered ecosystem services were the cultural group "aesthetic, heritage", the regulating group "lifecycle maintenance and habitat protection" and the cultural group "Recreation and community activities". About the encountered approaches and methods, the review defined four types of approaches according to the study objectives and recurrent strategies and methods: two types *assessing a case* – social attitude and impact assessment – aimed at analyzing the communities attitude towards renewable energy technologies development and collecting data on technologies impacts on the environment and the landscape. The projects that fall under the other two types *planning a case* – planning approach and integrated planning approach – applied existing data in planning simulations. The most recurrent approach type is the social attitude approach, and this must be related to the huge amount of research on the public discussions about the impact of technologies as wind farms and photovoltaic panels on our cultural landscapes.

The integrated planning approach was identified to best facilitate the planning and design of sustainable energy landscapes, because it provides methods to spatially display integrated and different renewable energy sources as available in the landscape. Nevertheless, all the approach types are relevant to advance the planning and design of renewable energy landscapes: the assessing a case approaches demonstrated relevant methods to collect data both in an expert or participatory way, while the planning a case approaches demonstrated relevant methods for planning activities. Yet a relevant knowledge gap was found in the integrated planning approach: the adopted trade-off assessment methods lack efficient spatial reference systems and tools to assess regulating and cultural ecosystem services groups, and of considerations on how landscape design could influence a reduction of critical trade-offs or even enhance synergies. Land use and land cover (the most used spatial reference system in planning related literature) are not capable of describing the landscape infrastructure networks that could properly inform landscape design principles. These should be considered as a planning tool in the integrated planning approach because different landscape design principles could reduce trade-offs and enhance synergies. This is particularly true for cultural and regulating ecosystem services.

A second search stage attempted to answer this gap of knowledge regarding the used spatial reference systems, and what we found is that the trade-off among ecosystem services and renewable energy can be examined making use of different spatial reference systems, depending on the ecosystem services that are considered in the analysis. Land use and land cover classifications enable the trade-off assessment between provisioning ecosystem services. To support the assessment of both regulating and cultural ecosystem services, a combination of land use and land cover maps with information on landscape metrics and landscape infrastructure is favorable. Cultural ecosystem services can be studied effectively with non-expert stakeholders making use of participatory mapping. The output is a series of maps illustrating cultural ecosystem services supply that can subsequently be used in spatial trade-off assessments. Participatory methods of inquiry are necessary in order to identify potential synergies and trade-offs across space and time. Through active participation, local communities can inform researchers, studying optimum scenarios for low carbon futures while, in turn, the outcome of their inquiry can inform local transition.

Future research efforts should be directed to further advancing the “integrated planning approach”, with diversified spatial reference systems, the use of participatory mapping and landscape visualizations tools for cultural ecosystem services and the elaboration of landscape design principles. The papers analyzed in this review report several methods that can be used to advance the integrated planning approach. We can then conclude that the advancement of an “integrated planning approach” is the preferred means to introduce ecosystem services assessment into spatial planning and design for sustainable energy transition. Stremke and van den Dobbelsteen (2012), among others, have argued repetitively for the consideration of ecosystem services in energy transition. The degree of sustainability of energy-related intervention in the landscape can only be examined making use of the ecosystem services framework. Eventually, this can help to mitigate conflicts between the local rights to landscape and the global need for energy transition.

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Annex A

Abbreviations, relative terms, and definitions used throughout the paper.

Abb.	Term	Definition
–	Landscape	“Landscape” means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors” (Europe, 2000, art. 1)
–	Landscape Infrastructure	The natural or constructed physical or beta- structure of the landscape delivering material or immaterial benefits and services and the recycling of energy and materials
–	Landscape Metrics	Measures expressing the landscape pattern
–	Participatory Mapping	A participatory process were stakeholders are asked to map places where they perceive to benefit from ecosystem services
RE	Renewable Energy	The energy generated from renewable sources through a particular technology
RES	Renewable Energy Sources	Renewable energy sources such as, sun, water, wind, biomass and geothermal
RET	Renewable Energy Technologies	The technologies necessary to generate energy from renewable energy sources
REES	Renewable Energy Ecosystem Services	REES are the aggregation of the Ecosystem Services provided by both biotic and abiotic renewable energies sources (Schetke et al., 2018)
EL	Energy Landscapes	Those landscapes whose infrastructure is modified by RET so it becomes a new layer of the landscape
SEL	Sustainable Energy Landscapes	“a physical environment that can evolve on the basis of locally available renewable energy sources without compromising landscape quality, biodiversity, food production and other life-supporting ecosystem services” (Stremke and van den Dobbelsteen, 2012, p. 4)

Annex B

Combination of the ecosystem services groups – renewable energy sources per strategy/method/spatial scale per study and per year. The table is ordered per year.

Year	Author(s)	ES-RET-Strategy of inquiry/Method of inquiry/Spatial scale
2005	Ek	C1R9R10R11-RET-BPL
2005	Kaldellis	C1-W-BPN
2007	Ladenbburg and Dubgaar	C1-W-APR
2009	Sibille et al.	C1-W-AER
2008	Bergamn et al.	C1R6R9-WH-BPN
2008	Ladenburg	C1-W-BPR
2010	Warren and MacFadyen	C1C3R9R11-W-BPL
2009	Chiabrando et al.	C1P1R6R9-S-AEL
2009	Dimitropoulos and Kontoleon	C1C3P1R6R9-W-BPR
2009	Fisher and Brown	C1C3R9-W-BPL
2009	Graham et al.	C1-W-BPR

2009	Ladenburg	C1-W-BPR
2009	Ladenburg and Dubgaard	C1C3R9P3-W-CPR
2010	Gee	C1C2C3R9-W-BPR
2010	Gee and Burkhard	C1C2C3C4-W-BPL
2010	Meyerhoff et al.	C1R6R9-W-CPR
2010	Möller	C1-W-AEN
2010	Riddington et al.	C3-W-AEN
2010	Rodrìgues et al.	C1C3-W-AEN
2010	Swofford and Slattery	C1R6-W-BPR
2010	West et al.	C1-RET-BPR
2011	Chiabrando et al.	C1-S-AEL
2011	Drechsler et al.	C1R6R9-W-CPR
2011	Frantál and Kunc	C1C3-W-BPL
2012	Baltas and Dervos	C1P1-WSHBIO-AEN
2012	Burgess et al.	P1P5-WSBIO-BEL
2012	Dockerty et al.	C1-BIO-BPR
2012	Drechsler et al.	C1R9-W-CPL
2012	Josomivic and Crncevic	C1R7-H-AEN
2012	Ladenburg and Dahlgaard,	C1-W-APR
2012	Rygg	C3R9-W-BPL
2012	Stoms et al.	R9-BIO-AER
2013	Howard et al.	C1C2C3C4P1P4P5R3R4R5R6R7R9-WBIO-CPL
2013	Westerberg	C1C3-W-BPN
2014	Bennet and Isaacs	R9R11-BIO-AEL
2014	Bergström et al.	R9R11-W-BER
2014	Chias et al.	C1-W-CPL
2014	Harvolk et al.	R5R6R7R8R9-BIO-CER
2014	Kapetanakis et al.	C1-S-AEL
2014	Kontogianni et al.	C1P1R9R11-W-BPR
2014	Rivas Casado et al.	P1R9R11-BIO-CEL
2014	Szabo and Kiss	R4R9-H-AER
2014	Verkerk et al.	C3P6R6R9-BIO-AEN
2015	Agha et al.	R9R11-W-AEL
2015	Batel et al.	C1C2C4-RET-BPL
2015	Betakova et al.	C1-W-CPL
2015	Caporale and de Lucia	C1R6-W-BPR
2015	Firestone et al.	C1C3-W-BPL/N
2015	Lupp et al.	C1C3P5R4R5R6R8R9-BIO-BPL
2015	McManamay et al.	C1C3P2R5R7R9R11-H-BPL/N
2016	Bertsch et al.	C1-RET-BPN
2016	Delicado et al.	C1-WS-BPL
2016	Höfer et al.	C1R5R8R9R11-W-CER
2016	Kim et al.	C1P3R9R11-W-CEL
2016	Klaeboe and Sundfor	C1-W-BPL
2016	Olson Houzbon et al.	C1-RET-BPL/N
2016	Petrova	C1C4-W-BPL
2016	Schulze et al.	P1R5R8R6-BIO-AER
2016	Scognamiglio	C1R4R5-S-BEL
2016	Sherren et al.	C1C2C3R9-H-BPL
2016	Tayyebi et al.	R2R5R6R8R9R10R11P1-BIO-APL
2017	Fernandez-Campo et al	C2C3P1P6R5R6R7-BIO-AEL
2017	Kienast et al.	C1C3P5R9P1P4-WSBIO-BPN
2017	Pang et al.	C3P6R6R9-BIO-AER

Annex C

Papers per approach type and strategy of inquiry/method of inquiry/spatial scale, indicating the considered ecosystem services groups and renewable energy sources.

SOCIAL ATTITUDE APPROACH		
APR quantitative/participatory/regional scale		
C1 W	2007	Ladenburg and Dubgaard
C1 W	2012	Ladenburg and Dahlgaard
BPL qualitative/participatory/local scale		
R9R10R11C1-RET	2005	Ek
R9R11C1C-3W	2010	Warren and MacFadyen
R9C1C3-W	2009	Fisher and Brown
C1C3-W	2011	Frantál and Kunc
R9C3-W	2012	Rygg
C1C2C4-RET	2015	Batel et al.
R9C1C2C3-H	2016	Sherren et al.
C1C4-W	2016	Petrova
C1-W	2016	Klaeboe and Sundfor
C1W-S	2016	Delicado et al.

BPN qualitative/participatory/national scale		
C1-W	2005	Kaldellis
C1-RET	2016	Bertsch et al.
BPN/L qualitative/participatory/national and local scales		
R6R9C1-WH	2008	Bergmann et al.
C1C3-W	2015	Firestone et al.
C1-RET	2016	Olson Houzbon et al.
BPR qualitative/participatory/regional scale		
C1-W	2008	Ladenburg
R6R9P1C1C3-W	2009	Dimitropoulos and Kontoleon
C1-W	2009	Graham et al.
R6C1-W	2010	Swofford and Slattery
R9C1C2C3-W	2010	Gee
C1-RET	2010	West et al.
R9R11P1C1-W	2014	Kontogianni et al.
R6C1-W	2015	Caporale and de Lucia
IMPACT ASSESSMENT APPROACH		
AEL quantitative/expert/local scale		
R6R9P1C1-S	2009	Chiabrando et al.
C1-S	2011	Chiabrando et al.
C1-S	2014	Kapetanakis et al.
R9R11-W	2015	Agha et al.
AEN quantitative/expert/national scale		
C1C3-W	2010	Rodrìgues et al.
C3-W	2010	Riddington et al.
C1-W	2010	Möller
R7C1-H	2012	Josomivic and Crncevic
AER quantitative/expert/regional scale		
C1-W	2009	Sibille et al.
R4R9-H	2014	Szabo and Kiss
BER qualitative/expert/regional scale		
R9R11-W	2014	Bergström et al.
BPL qualitative/participatory/local scale		
C1C2C3C4-W	2010	Gee and Burkhard
BPR qualitative/participatory/regional scale		
C1-W	2009	Ladenburg
CPL mixed/participatory/local scale		
C1-W	2014	Chias et al.
C1-W	2015	Betakova et al.
CPR mixed/participatory/regional scale		
R6R9C1-W	2010	Meyerhoff et al.,
R9P3C1C3-W	2009	Ladenburg and Dubgaard
R6R9C1-W	2011	Drechsler et al.
PLANNING APPROACH		
AEN quantitative/expert/national scale		
P1C1-WSHBIO	2012	Baltas and Dervos
C3P6R6R9-BIO	2014	Verkerk et al.
AER quantitative/expert/regional scale		
R9-BIO	2012	Stoms et al.
C3P6R6R9-BIO	2017	Pang et al.
AEL quantitative/expert/local scale		
R9R11-BIO	2014	Bennet and Isaacs
R5R8R6P1-BIO	2016	Schulze et al.
C2C3P1P6R5R6R7-BIO	2017	Fernandez-Campo
APL quantitative/participatory/local scale		
R2R5R6R8R9R10R11P1P7-BIO	2016	Tayyebi et al.
APN quantitative/participatory/national		
C1C3-W	2013	Westerberg
BEL qualitative/expert/local scale		
R4R5C1-S	2016	Scognamiglio
BPL qualitative/participatory/local scale		
R4R5R6R8R9P5C1C3-BIO	2015	Lupp et al.

BPN qualitative/participatory/national scale		
C1-BIO	2012	Dockerty et al.
CEL mixed/expert/local scale		
R9R11P1-BIO	2014	Rivas Casado et al.
R9R11P3C1-W	2016	Kim et al.
CER mixed/expert/regional scale		
R5R6R7R8R9-BIO	2014	Harvolk et al.
R5R8R9R11C1-W	2016	Höfer et al.
CPR mixed/participatory/regional scale		
R9C1-W	2011	Drechsler et al.
CPN/L mixed/participatory/national and local scales		
R5R7R9R11P2C1C3-H	2015	McManamay et al.
INTEGRATED PLANNING APPROACH		
BEL qualitative/expert/local scale		
P1P5-WSBIO	2012	Burgess et al.
BPN qualitative/participatory/national scale		
R9P1P4P5C1C3-WSBIO	2017	Kienast et al.
CPL mixed/participatory/local scale		
R3R4R5R6R7R9P1P4P5P7C1C2C3C4-WBIO	2013	Howard et al.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2018.12.010.

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