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Designing landscapes for sustainable outcomes – The case of advanced biofuels

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ABSTRACT

The design of socio-ecological landscapes to provide simultaneously multiple benefits has become a key concept in current sustainable development thinking and an attractive goal for policy makers. However, its application in the practice of landscape management has proved difficult. In this study, we develop an approach for practical application of landscape design to advance multifunctionality and sustainable outcomes. We combine ideas of landscape ecology with methods for collaborative decision-making to deal with the practice of designing landscapes. Our approach consists of six components including (a) definition of boundaries and scales, (b) assessment of local values and concerns, (c) knowledge development, (d) stakeholders participation, (e) collaborative decision-making and (d) monitoring. We test the approach on the case of advanced transport biofuels. These technologies have attracted attention in recent years as a means to achieve climate, energy and development goals avoiding the environmental and socio-economic risks of conventional biofuel technologies. The findings suggest that the landscape design approach has the potential to guide the planning of complex biofuel projects for sustainable outcomes improving local acceptability of potentially controversial projects.

1. Introduction

For millennia ecosystems have been modified by humans to cheaply and reliably produce desired services such as food, feed and materials such as fibre and timber (Ellis et al., 2013). The management of ecosystems has traditionally focused on sectorial approaches without concern about their multifunctional nature (Bennett et al., 2009). However, recent decades have seen the emergence of the sustainability discourse and a call to redirect research efforts to meet human-induced landscape challenges (Palmer et al., 2004; Lambin and Meyfroidt, 2011). In this context, the design of landscapes to simultaneously provide multiple benefits has become a key concept in current sustainable development thinking (Termorshuizen and Opdam, 2009; O'farrell and Anderson, 2010) and an attractive goal for policy makers.

Multifunctional landscapes are created and managed to integrate human production and landscape use into the ecological fabric of an ecosystem maintaining critical ecosystem functions, service flows and biodiversity (O'farrell and Anderson, 2010). An important concept for studying landscape multifunctionality is that of ecosystem services as the benefits that ecosystems, either natural or managed, provide to humans (Mea, 2005). Structurally integrating ecosystem services into landscape management holds important opportunities for improving sustainability and resilience (Lovell and Johnston, 2009; De Groot et al., 2010). However, the application of the scientific knowledge of ecosystem services in the practice of landscape management has proved difficult (Nassauer and Opdam, 2008; Musacchio, 2011; Clark and Nicholas, 2013).

The aim of this study was to develop and test an approach for the practical application of landscape design to advance multifunctionality and sustainable outcomes. Combining ideas of landscape ecology with methods for collaborative action, our approach deals with the practice of designing landscapes for sustainable outcomes as a complex task. As an activity, the process of landscape design has attracted increasing attention due to the shift from a governmental model in which governments are the single actors responsible for environmental management to a governance model in which a wide range of actors share that responsibility (Kooiman, 2003; Opdam et al., 2015). In landscape governance, the wide array of actors and interests at stake increases the complexity of the decision making process. In this context, reaching agreement on actions to change landscape configurations requires cooperation between actors and across governance scales (Newell et al., 2012) taking into account the features of the social system (including stakes, values and concerns) as well as the biophysical conditions (Westerink et al., 2017).

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The results of this study provide insights into the suitability and limitations of landscape design as a practical means to govern landscapes at appropriate scales (Nassaur and Opdam, 2008; Lovell and Johnston 2009; Termorshuizen and Opdam 2009; Musacchio 2011). As an instrument of landscape governance, our application of landscape design builds on ideas from place-based discourses about sustainability (see Potschin and Haines-Young, 2013). In particular, interpreting the concept of landscape as place provides the context in which problems can be framed, values understood, choices made and conflicts resolved allowing a more socially grounded management of ecosystems (Potschin and Haines-Young, 2013). The model of governance advanced by our approach is grounded on the idea of design as the ability to create 'possibility spaces' (De Landa and Ellingsen, 2008) within which desirable futures can be shaped. Therefore we see design as a value rich process centred on deliberation about goals, values, interests and outcomes (Swaffield, 2013).

We present evidence through the case of advanced transport biofuels. Transport biofuels have attracted attention in recent years for the unwanted effects that their expansion could cause to ecosystems and communities, directly or indirectly, affected by their supply chains. The biofuel case is of particular interest here because of the risk of conflict between global dynamics, aimed at an expansion of these systems to achieve climate and energy security goals, and the priorities and concerns of local communities affected by these systems. Advanced biofuel technologies, which rely on waste, residues and perennial crops cultivated on less productive land, are expected to reduce these risks (IEA, 2010). However, evidence suggests that their deployment might suffer the same problems as conventional technologies (Mohr and Raman, 2013; Batistella et al., 2015). As a case study, we selected the experience with advanced biofuels in Sardinia (Italy) where a developer initiated one of the first projects for large-scale production of cellulosic ethanol from dedicated energy crops in Europe.

In the reminder of the article, we illustrate the conceptual basis of our landscape design approach (Section 2) before we introduce the approach and its six components in Section 3. While the results of the case study are presented in Section 4, we dedicate limited space to the details of the assessment of local values and concerns (Di Lucia and Ribeiro, 2018 forthcoming), and to the co-development of knowledge (Anejionu et al., forthcoming). The findings of the study are discussed in Section 5 before the conclusions are presented.

2. Conceptual basis

2.1. Landscape design and the challenges of sustainable biofuels

The term 'landscape approach' has been used to describe a range of approaches for dealing with landscape attributes in an integrative and transdisciplinary way (Tress and Tress, 2001; Sayer et al., 2017). The approach has developed within a variety of scientific disciplines such as ecology, developmental economics, sociology and political sciences (see Arts et al., 2017). In landscape ecology, the emergence of landscape design reflects the transition from a focus on the study of the relationship between spatial pattern and ecological processes (Turner, 1989) to the inclusion of the human components of landscapes and the interactions with processes and patterns (Leitao and Ahern, 2002). In this context, landscape design has emerged as a spatially explicit process in which landscape patterns are intentionally changed to provide ecosystem services while meeting societal needs and respecting public values (Nassauer and Opdam, 2008). In this process, new landscape configurations are designed through deliberative processes about values and goals and are then tested for their functionality through scientific methods (Swaffield, 2013).

Since the release of the Millennium Ecosystem Assessment report in 2005 (Mea, 2005), the term 'ecosystem services' has become a keystone concept to link society and the environment (Costanza et al., 1997; De Groot et al., 2012). In the Mea (2005) ecosystem services are defined as "the benefits people obtain from ecosystems". The framework of ecosystem services has been debated in the scientific literature (Schröter et al., 2014) because of its predominantly anthropocentric character and lack of attention to the intrinsic value of nature (Luck et al., 2012). However, the assumption behind its widespread adoption is that by providing information about their services, ecosystems may be rightfully considered in environmental management (see Opdam et al., 2015).

While many challenges remain to structurally integrate the concept of ecosystem services into the practice of landscape design (De Groot et al., 2010), the concept of multifunctional landscapes has emerged from the literature of ecosystem services (Fry, 2001; Naveh, 2001). Here multifunctionality has been described as achieving multiple objectives, or functions, at the same time. However, promoting multifunctionality requires the understanding of complex dynamic systems (Southern et al., 2011), careful consideration of the inherent contributions of various landscape features to multiple goals (Lovell and Johnston, 2009), and the recognition of synergies and trade-offs (Freeman et al., 2015). There is agreement that this knowledge and understanding can only be developed in a transdisciplinary fashion (Nassauer and Opdam, 2008) in which scientific knowledge from a variety of disciplines is integrated with traditional and local knowledge (Tress et al., 2005).

Similarly, the design of biofuel landscapes is a process of considering context relevant principles and information (Duvenage et al., 2013) and requires knowledge about the current distribution of ecosystem services, of potential winners and losers, as well as the perceived needs and expectations of stakeholders in relation to these services (Dale et al., 2016; Dale et al., 2017). The provision of this knowledge is challenging because biofuel systems are (relatively) new and have significantly expanded (Di Lucia, 2013) involving a wide range of disciplines and stakeholders and generating unknowns and large uncertainties (Lattimore et al., 2010). A further challenge of landscape design for biofuels is the identification of appropriate spatial and temporal scales at which to examine social, economic and environmental effects (Parish et al., 2013). Due to the wide range of complex ecological and socio economic effects often operating over broad spatiotemporal scales, determining the appropriate mix of scales, from local to global, to address local concerns while reconciling these with dynamics at higher levels, is a major challenge for the practical implementation of landscape design for biofuels (Dale et al., 2016).

2.2. Landscape governance and collaboration for biofuels

Since landscapes are characterised by the connections between multitudes of socio-ecological components, their design fits well with ideas of a governance model of societal steering. Interest in landscape governance is connected to the growing number and role of private parties and citizens actively engaged in public decision making, and to the decentralization of governmental powers to lower levels of command (Beunen and Opdam, 2011). The governance model takes into account the complexity of today's society and the importance of informal institutions and actors, including interest groups and citizen organizations, who bring a variety of sometimes competing perspectives in the decision process (Kooiman, 2003; Westerink et al., 2017). Since governance requires more than one actor, collaboration could contribute to effective landscape management (Innes and Booher, 1999; Bodin et al., 2016). Collaborative modes of management and decision making have sprung up since the 80 s in reaction to technocratic modes, which characterised the 60 s and 70 s (Wondolleck and Yaffee, 2000). Collaborative modes recognise the need to ground decision making and management in good science but understand that technical factors are only one of the many considerations in decision making (Wondolleck and Yaffee, 2000).

In a meta-analytical study of the literature of collaborative governance, Ansell and Gash (2008) suggested that a number of variables affect the capacity of collaborative governance to achieve its objective, i.e. 'some degree of consensus among stakeholders'. Some of the variables identified refer to the conditions present at the outset of the exercise, while others to the collaborative process itself. Recent years have seen the application of collaborative governance also in the field of landscape planning and management. In a review of a long term project on Adaptive Collaborative Landscape Management in Australia, Duff et al. (2009) concluded that collaboration among participants is more effective in achieving sustainable outcomes than integrative action where participants join separate contributions. On a similar note are the conclusions of other studies that have explored the value of different forms of collaboration in landscape management and planning for natural pest control (Steingröver et al., 2010), biodiversity conservation (Cooke et al., 2012), land management in coastal areas (Karrasch et al., 2017), natural resource management (Davies and White, 2012), or in connection to ecosystem services (Opdam et al., 2015) and landscape services (Westerink et al., 2017). This rapidly expanding literature illustrates a shift in landscape science toward the recognition that the translation of science into landscape action requires collaborative approaches (Swaffield, 2013).

The integration of biofuels into existing environmental and socio-economic systems requires the deployment of effective processes dealing with stakeholders' diversity and interests (Dale et al., 2016). In this context, collaborative actions based on consensus among those involved in the biofuel supply chain and between them and those affected by the project hold important opportunities for the implementation of complex and potentially controversial biofuel projects (Dale et al., 2017).

2.3. On the effectiveness of landscape design

The effectiveness of a collaborative landscape design approach can be interpreted with regard to management outcomes, i.e. the ability to deliver social and environmental benefits, or process outcomes, i.e. the capacity to achieve agreement among participants. In a recent review of the literature, Reed et al. (2016) showed a surprising lack of empirical data documenting the effectiveness of landscape approaches in delivering social and environmental benefits. This appeared to be the consequence of a general lack of investments in long-term monitoring and evaluation of performance (Reed et al., 2015; Reed et al., 2016). Moreover, the intrinsic complexity, uncertainty and uniqueness of each landscape hinder efforts for standardized monitoring and evaluation of outcomes (Sayer et al., 2017). In spite of this, much of the theory and practice of the landscape approach is underpinned by the assumption that by accounting for trade-offs and exploiting synergies the approach will eventually lead to consensus among parties on desired outcomes (Sayer et al., 2013). However, there is limited evidence supporting this assumption (Sayer et al., 2015).

Aware of these issues, in this study we interpreted the effectiveness of landscape design as the capacity to advance agreement among participants, i.e. process outcomes. However, we did not limit agreement to the resolution of fundamental differences among parties, but related it also to instances of improved shared understanding of conflicts, trade-offs and future scenarios (Sayer et al., 2015). Our evaluation focused on the features of both the process and the outcomes. The process needs to ensure the timely engagement of all key stakeholders representing all interests, the availability of accurate information to all stakeholders, and the effective participation of stakeholders in decision-making, in particular, guaranteeing equal treatment (Innes and Booher, 1999; Susskind et al., 1999:32; Innes and Booher, 2010:6). Regarding the type of outcomes, ideally the process should result in tangible outcomes such as formal agreements in the form of detailed plans. However, considering the iterative nature of collaborative landscape approaches (Ansell and Gash, 2008; Westerink et al., 2017), we considered effectiveness as related to the outcomes' ability to initiate or support the collaborative cycle. Therefore, effective outcomes can consist of improved communication and dialogue among stakeholders, shared understanding of trade-offs and synergies, or intermediate outcomes such as practical actions, e.g. joint fact findings, and shared pathways forward. These achievements can feed back into the collaborative process encouraging a virtuous cycle of commitment toward a formal plan.

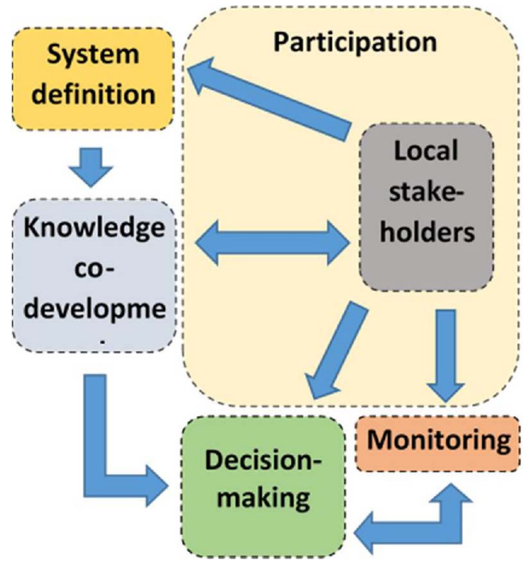

Fig. 1. Structure of the six-component landscape approach for biofuels developed in this study.

3. Landscape design for biofuels

In this section, we illustrate the landscape design approach for biofuels developed in this study. The approach entails six components (Fig. 1):

a) System definition – boundaries and spatiotemporal scales;
b) Local stakeholders – assessment of values and concerns;
c) Knowledge co-development;
d) Participation;
e) Decision making;
f) Monitoring and feedback mechanisms.

3.1. System definition – boundaries and spatiotemporal scales

The first component of the approach deals with the definition of system boundaries and spatiotemporal scales for analysis and decision making. Although landscape design can be applied to various scales, the need for concepts and effective procedures to delineate local landscapes and connect them with global and national dynamics across scales has been widely recognised (Opdam et al., 2013).

To effectively apply the landscape approach to biofuel systems, we need to interpret what local means and understand how the local is nested into the global. Our approach addresses this challenge by, firstly, interpreting the local level as the place where physical elements of the landscape interact directly with social networks of landscape managers and users (Opdam et al., 2013); and, secondly, by defining the bio-physical and socio-economic boundaries of the local system integrating the ecosystem services framework with a model of the biofuel supply chain. This approach consists of spatially locating elements of the biofuel supply chain (from feedstock production to final consumption) into the landscape. For the identification of land to be converted to biofuel feedstock, we apply a multi-criteria approach in combination with GIS techniques, as recently suggested in the literature (see e.g. Lovett et al., 2014; Parish et al., 2016; Pulighe et al., 2016). In the following step, we employ the ecosystem services framework to draw the boundaries of the system. For this process, we employ the ecosystem services emerging from the assessment of local values and concerns (Section 3.2) matching each societal concern with one or more ecosystem services. This understanding is then used to draw system boundaries compatible with the production of system knowledge (Section 3.3).

Finally, for the definition of spatiotemporal scales we find insight in ideas emerging from hierarchy theory (O'neill et al., 1989) which evolved from the need to deal with complex systems in a variety of disciplines including ecology (Wu, 1999). One of these ideas suggests that for any problem, it is advisable to consider processes developing at scales above and below the one at which most processes take place (Wu, 1999). This is to ensure that relevant patterns and processes are taken into account including drivers originating at higher or lower scales but having a potentially significant influence on the system of interest.

3.2. Local stakeholders – assessment of values and concerns

The second component of the approach addresses the need to systematically assess local values and concerns. We interpret values as 'assigned values' or "the relative importance or worth of an object to an individual or group in a given context" (Brown, 1984). It has been shown that the values people attach to places are "complex and multilayered" and sometimes involve conflicting dimensions, e.g. utilitarian versus intellectual (Clement and Cheng, 2011). These complex judgments are based on knowledge as well as emotional reactions (Bozeman, 2007:13).

In order to assess local values and concerns, we need a definition of stakeholders, an approach to identify stakeholder categories and representatives, and a method to elicit each category's perception of the project and its impacts on the landscape. Stakeholders can be broadly defined as the groups and individuals affected by or affecting a decision (Freeman, 1984:52). However, in the context of landscape design a more appropriate definition is one connecting stakeholders to landscapes through the ecosystem services framework. This line of thinking suggests that the variety of services provided by the landscape determines the number and diversity of stakeholders (Westerink et al., 2017). In our landscape design approach, stakeholders consist of providers and beneficiaries of the ecosystem services affected by the biofuel project (Dale et al., 2017). Providers include landholders, such as farmers, nature organisations and local governments, while beneficiaries are governments, civil society groups and businesses. Some providers are at the same time beneficiaries.

Since effective involvement of stakeholders affects the quality of collaborative decisions (Innes and Booher, 1999), we apply a practical method to ensure that all key categories of stakeholders are identified and involved. The method consists of an iterative process combining data collected through a review of written sources and in-person interactions with representatives of the biofuel company and local experts. The evidence is used to identify categories of key stakeholders as the groups that need to be represented at the table in order for decisions to be considered legitimate and be implementable.

The assessment seeks to elicit the values of these stakeholders by exposing their perceptions of the biofuel project and its effects on environmental and socio-economic conditions of the area. Perceptions are analysed by categorising them and quantifying their importance with the goal of ranking. We developed a simple but practical approach for quantifying the importance of each issue emerging from the data collected (Fig. 2). The results of this process are used to identify the ecosystem services for the definition of system boundaries and the co-development of knowledge and alternative scenarios.

3.3. Knowledge co-development

The next component of the approach deals with the need to provide knowledge suitable to support the design process. Our approach to knowledge development builds on the assumption that context matters (Efroymson et al., 2013; Potschin and Haines-Young, 2013). Thinking about landscape as place allows us to develop a deliberative process for knowledge development, which accounts for how different people view the landscape and value the different services it provides. In applying these ideas we interpret the production of knowledge as a process that integrates knowledge from different scientific disciplines, while including values, know-how, and expertise from non-scientific sources.

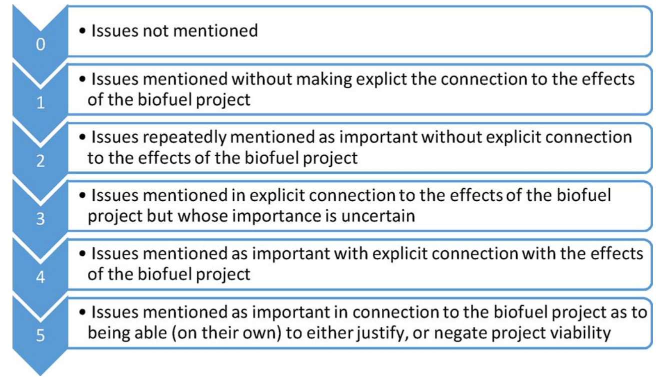

Fig. 2. Approach employed to quantify the importance of stakeholder values and concerns. Scale of importance from 0 (low) to 5 (high).

The suitability of this knowledge for landscape design should be judged based on its saliency, legitimacy and credibility. By linking science and society, landscape design strives to facilitate decisions based on knowledge that is credible (i.e., scientifically adequate), salient (i.e., relevant to the needs of decision makers) and legitimate (i.e., produced in respect of stakeholders values) (Cash et al., 2003; Nassauer and Opdam, 2008). For this, we see the use of computer models as providing important opportunities. Overall, the use of computer models is justified by the complexity of environmental and socio-economic processes interacting over space and time in socio-ecological systems, i.e. landscapes, (Dale et al., 2013; Summers et al., 2015). However, systems involving multiple sectors, issues and stakeholders, such as the case of most environmental resource management problems, require a type of modelling that is integrated and participatory (Von Korff et al., 2012). Integrated modelling brings systematically together knowledge developed across a broad range of fields and disciplines through a variety of approaches including, e.g., Systems Dynamics, Bayesian Networks, Coupled Component Models, Agent-Based Models and Knowledge-Based Models (for an overview, see Kelly et al., 2013). Participatory forms of modelling, which see the contribution of stakeholders to data collection, model selection and development, scenario development, and/or results interpretation (Voinov and Bousquet, 2010), are used to integrate local and traditional expertise within models (Renger et al., 2008; Voinov and Bousquet, 2010; Voinov et al., 2016). Although there is no optimal level of engagement, or predetermined components of participation in modelling, several approaches to participation have been suggested (see e.g. Voinov et al., 2016).

In our approach to landscape design, we apply integrative and participatory modelling. Integrative modelling is used to provide the interdisciplinary knowledge needed to address all issues considered important by stakeholders at different scales, i.e. to ensure knowledge saliency. The integrated model, including its functioning, assumptions and input data, is reviewed with stakeholders to promote knowledge legitimacy and quality. Finally, as part of knowledge co-development, we facilitate the articulation of societal preferences also through the collaborative development of alternative scenarios of land use and natural resource management. Scenarios developed with stakeholders represent their interpretation of how key effects of the biofuel project could and should be mitigated (threats), or exploited (opportunities).

The results of the model simulations feed into the decision-making process illustrated in Section 3.5.

3.4. Participation

In landscape design, participation is deemed critical since societal processes are considered essential to understanding the dynamics of landscapes as coupled human and natural systems (Opdam et al., 2013). Participation is also increasingly advocated in environmental decision making (Reed, 2008; Voinov et al., 2016) as a way to foster legitimacy and ownership of decisions (Mostert, 2003), but also greater transparency (Reed, 2008), and increased quality and durability of decisions (Fischer, 2000; Beierle, 2002). However, the design of public participation processes can be a very complex endeavour (Bryson et al., 2013). In the literature of public participation in decision making, no single ideal process design exists (Van Asselt and Rijkens-Klomp, 2002), while it remains disputed what the minimum level of public involvement should be (Irvin and Stansbury, 2004).

In our approach to landscape design, participation activities play an essential role to ensure that stakeholders are effectively involved throughout the process. In line with the idea that context matters, the participation process relies on a careful assessment of local values and concerns, and accounts for the local biophysical and techno-economic conditions (Potschin and Haines-Young, 2013). In doing that, we seek to ensure the participation of representatives of all categories of key stakeholders from an early stage of the design process ensuring that participants are equally informed and treated, and that the process has a genuine influence on decisions.

We structure the participation process into four phases of the landscape design cycle:

1) The initial engagement of stakeholders is a delicate phase in which participants are contacted seeking to enlist them in the landscape design exercise. This process provides the initial framing of the problems and critical data inputs for the definition of system boundaries. The methods applied should be based on the local context with preference for direct interaction with participants (Ostrom, 1998).
2) In knowledge development, participation of local stakeholders is necessary for developing the transdisciplinary knowledge needed by the landscape design. Although a variety of methods are available (Van Asselt and Rijkens-Klomp, 2002), we suggest here methods linking computer modelling and group exercises with stakeholders as parallel and interactive activities (Prell et al., 2007).
3) In decision-making, effective participation is a critical component for building agreement and collaboration. In this process, the positions of participants are articulated, acknowledged, discussed and used as the basis for seeking mutually agreeable solutions.
4) During the monitoring phase, stakeholder participation is required since management should be adjusted overtime to ensure that desired outcomes are achieved. Moreover, since outcomes desirability might change with regard to contextual conditions and stakeholder priorities, 'continual improvement' will require continued engagement of stakeholders (Dale et al., 2016).

3.5. Decision making

This component of the landscape design focuses on advancing agreement and collaboration among participants. However, collaboration is the most ambitious form of interaction in group decision making (Jankowski and Nyerges, 2001). Differently from communication, cooperation, or coordination, collaboration involves actors agreeing to work on the same task with a shared understanding of it creating synergy and a shared understanding of the decision (Jankowski and Nyerges, 2001).

To facilitate collaboration, we propose the application of a consensus-based decision process. In consensus-based decision making, agreement is reached meeting the interest of all stakeholders through dialogue taking into account participants' views, knowledge and understandings (Susskind et al., 1999:6; Innes, 2004). However, in most real world decision-making situations the traditional meaning of consensus as a full and unanimous agreement is almost impossible to achieve. Thus, we suggest that decisions are consensual as long as an overwhelming majority is reached after all interests have been explored and every effort has been made to satisfy each concern (Innes and Booher, 1999; Susskind et al., 1999:32; Innes and Booher, 2010:6). Regarding the level of majority required, this is determined by the type of outcomes pursued by the process. Tangible outcomes are, e.g., formal agreements, work plans or specific recommendations for moving forward. Intangible outcomes consist of, e.g., establishing a rapport, improving relationships, illuminating areas of agreement and disagreement, increasing mutual understanding about the concerns of other stakeholders, or creating opportunities to build trust.

Consensus-based decision making has been criticised for the capacity to achieve only lowest common denominator agreements on the most tractable problems (Van De Kerkhof, 2006). Although these shortcomings might be the result of poorly conducted exercises, we must be aware that the application of consensus-based decision-making should be limited to cases where some form of collaboration among actors is required, traditional approaches to decision making are ineffective, controversies and differences in values and understandings among participants are high, and there are large gaps in understanding of system functioning (Innes, 2004).

3.6. Monitoring and feedback mechanisms

To realize the full potential of landscape design there is a need to deploy effective processes to monitor the management process and its outcomes over long time periods (Sayer et al., 2017). As other forms of collaborative governance, landscape approaches entail an iterative process of negotiation, trial and adaptation (Reed et al., 2016). Here monitoring becomes necessary to adapt the management to changing conditions. However, effective monitoring requires that baselines and measurement systems are put in place (Sayer et al., 2015) and that desired outcomes are agreed and described in ways that enable measurement. New evidence emerging from monitoring activities feeds back to the decision making process to inform future decisions. This is a critical component of any adaptive management process and a basis of landscape design (Sayer et al., 2015; Dale et al., 2016). However, monitoring is also recognised as the least developed area of landscape approach application (Reed et al., 2016) due to inherent difficulties of measuring impacts and a lack of adequate investment in establishing and monitoring metrics over the long term (Sayer et al., 2017).

Monitoring and feedback mechanisms are a component of our landscape approach as illustrated in Fig. 1. Monitoring activities follow the implementation of decisions reached during the decision-making phase of the exercise. Activities consist of measurements of specific indicators to provide data suitable to evaluate progress toward desired management outcomes. Without these data progress would be indeterminable, feedback loops would fail and adaptive management would be unachievable hindering the effectives of the landscape approach (Reed et al., 2016). Stakeholders are directly involved in the process of monitoring management outcomes and, in particular, in the definition of indicators suitable to assess progress. Since 'what gets measured gets managed' (Stiglitz et al., 2010), it is of key importance that indicators are selected in line with stakeholder values and priorities. Finally, feedback mechanisms should be in place to make available to decision makers the evidence emerging from monitoring activities. The selection of appropriate mechanisms is highly dependent on the type of outcomes sought by the landscape approach and local circumstances including stakeholder priorities and budget constraints.

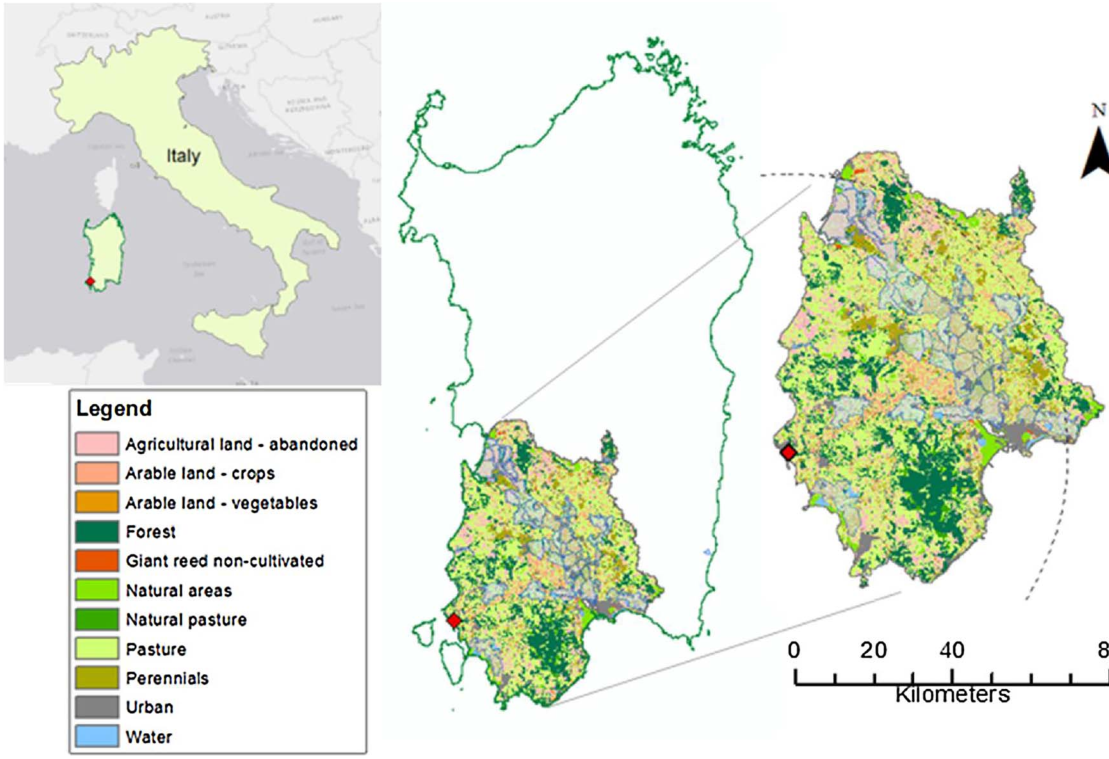

Fig. 3. Map of Sardinia and spatial extent of the landscape. Criteria applied include max distance from industrial site (75 km); previous land use (abandoned); and availability of irrigation infrastructure (blue areas). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Application of landscape design to the case of advanced biofuels in Sardinia

4.1. Case study background

In the past two decades, governments around the world have supported biofuels as key technologies to reduce carbon emissions from transportation and decrease reliance on oil imports, while contributing to economic development of rural areas. However, conventional biofuel technologies relying on sugars, starch and oil-based feedstock have shown limits in advancing these objectives. Recent studies report marginally positive energy balances and only limited GHG savings over the entire lifecycle,[1] especially when highly contested indirect emissions are accounted for (Searchinger et al., 2008; Davis et al., 2009; Chum et al., 2011; Ahlgren and Di Lucia, 2014). More worryingly, competition for fertile land induced by an expansion of biofuel production may result, either directly or indirectly, in the conversion of biodiversity rich natural areas and the release of large quantities of stored carbon (Fargione et al., 2008; Danielsen et al., 2009). These risks have fuelled an ongoing debate among the industry, environmental groups, scientists and policy makers on the opportunity to support further deployment of these technologies (Mol, 2010).

Advanced biofuels from non-food crops, waste and residues have been proposed as an important step towards more sustainable biofuels. Advanced biofuels promise improved GHG emissions savings of up to 95% against fossil fuels on a life cycle basis (Morales et al., 2015), reduced competition with food and feed production, higher material and chemical efficiencies, and lower risk of direct and indirect land use changes (IEA, 2010; Sims et al., 2010; Dale et al., 2014; Kline et al., 2017). However, the deployment of these technologies is progressing at a slow pace (IRENA, 2016) partly due to the negative public perception linked to conventional biofuels (Mohr and Raman, 2013). The inability to reconcile dynamics at global and national level with the priorities of local stakeholders can potentially result in the failure of advanced biofuel technologies upon which much of current policy discourses seem to rely.

The experience with large scale production of advanced biofuels is still very limited (IRENA, 2016). The biofuel project analysed in this study started in 2012 with the goal of setting up a first of a kind commercial scale plant for the production of cellulosic ethanol in Sardinia. The project consisted of an industrial facility to convert 400 000 t of agricultural residues and dedicated crops into 80 000 t of ethanol per year. The crop selected to provide around 45% of the feedstock was locally produced giant reed (*Arundo Donax*). Based on field trials conducted in the region, which showed that the crop is very productive with yields between 25 and 35 t DM/ha (Arca, 2016), an area between 5200 and 7200 ha was required by the project. In order to exploit synergies with existing infrastructures, the biofuel investor selected as the site for the industrial facility a brownfield located within a large and decaying industrial complex in the south-west of the Sardinian island (Grati, 2015, personal communication). In this context, the project received the endorsement of the national and regional governments for its potential contribution to a "green industrial development" of an area characterised by high levels of unemployment and environmental pollution (GOVSARD, 2012).

4.2. Results

This section illustrates the application of the landscape design approach for biofuels to the case of advanced biofuels in Sardinia.

4.2.1. System definition – boundaries and scales

For the delineation of the biophysical and socio-economic boundaries of the system to design, we localised the biofuel supply chain in the area by identifying suitable areas through multi-criteria analysis and GIS techniques. The criteria employed emerged from interaction with the biofuel company (Grati, 2015, personal communication) and

[1] A noteworthy exception is sugar cane ethanol (Rocha et al., 2014; Walter et al., 2014).

included (a) a maximum distance of 75 Km from the industrial plant; (b) no direct conversion of food crop land; (c) availability of supplementary irrigation; and (d) average size of converted plots between 2 and 3 ha. These conditions were motivated by a combination of economic concerns about the cost of transportation and the yields of giant reed, but also by the ambition to avoid conflict with local food production and ensure that farmers will not be "quitting the profession by converting all their land to giant reed" (Grati, 2015, personal communication).

In the following step we applied the ecosystem services framework to delineate the spatial scale of the system affected by the biofuel supply chain (Fig. 3). In this process, we employed two sets of inputs: the ecosystem services emerging from the assessment of local values and concerns and a list of influential factors originating at higher scales. The former set of inputs was used to ensure that the spatial boundaries of the system were compatible with the knowledge demands of stakeholders. For instance, due to the importance of questions about water resources we used the boundaries of the watershed to spatially delineate the system. This decision allowed us to model the hydrological system of the area at watershed level. With regard to the latter set of inputs, we reviewed national and EU policies in the field of climate change, renewable energy, environmental protection and agriculture to identify factors originating outside the study area but having a significant influence on the system under analysis. These factors included loss of biodiversity, expansion of renewable energy, production of food and animal feed and reduction of GHG emissions. This process allowed us to introduce in the landscape design exercise important system drivers that would be otherwise missed.

Finally, we selected the year 2011 as reference year for the implementation of the biofuel project due to the availability of critical datasets.

4.2.2. Local stakeholders – values and concerns

For the identification of key stakeholders we reviewed written sources and in particular local media outlets, and conducted six scoping interviews with local experts and representatives of the biofuel company. The evidence collected allowed us to identify ten categories of key stakeholders (Table 1). For each category, we selected a sample of organisations to be engaged in the landscape exercise. We conducted 26 in-person semi-structured interviews with representatives of all organisations with the goal of eliciting their values, concerns and knowledge of the biofuel project.

The analysis of the interviews and written sources showed that stakeholders had a limited knowledge of the biofuel project. This result was in line with the communication strategy of the biofuel company which focused on limited interaction with top officials of few key organisations (Grati, 2015, personal communication). The lack of communication emerged as a critical factor negatively affecting the perception of the biofuel project among locals. Moreover, the results of the assessment were used to identify and rank stakeholders' perceptions in order of importance. Each issue was categorised as threat or opportunity by the stakeholders engaged or, in case of written sources, based on our interpretation of the text. The results, displayed in Table 1, showed that the most important threats were the lack of water for irrigation (29), the competition with local food production (18) and the loss of biodiversity (8), while the most important opportunities were the generation of income (18) and employment (14) and the reduction of GHG emissions (7). Soil quality (19) represented a contested issue due to large differences in the knowledge and interest of different categories of stakeholders. For example, farmers and their associations were primarily concerned with the impacts on soil quality of giant reed removal at the end of the growth cycle, while the regional government and NGOs focused on the opportunity offered by giant reed cultivation for phytoremediation of polluted soils.

4.2.3. Knowledge co-development

The goal of knowledge co-development is the production of the transdisciplinary knowledge required to support landscape design. For this objective, we developed an integrative model applying a 'Coupled Component Modelling' approach in which models from different disciplines are combined to provide integrated outcomes (Kelly et al., 2013). In the analysis, we employed models existing in the literature as well as models developed specifically for the case study (Table 2). The participatory component of the modelling work relied largely on four thematic focus groups. In each event the models, their assumptions, input data, and preliminary results, were reviewed and discussed with stakeholders.

Through this process, we promoted the saliency of the knowledge by ensuring that the scope and resolution of the modelling exercise was consistent with the results of the stakeholder assessment, local circumstances, and the type of outcomes sought by landscape exercise. Legitimacy was advanced by offering stakeholders the opportunity to contribute to knowledge development through the focus groups. Finally, the credibility of the knowledge was supported by utilising (i) existing models accepted by the scientific community, (ii) ad hoc models sufficiently transparent for local experts to appreciate their functioning, (iii) data that were highly context specific, and (iv) by ensuring that model results were validated by local experts.

The integrative model was applied to analyse the current state of the area and a set of four alternative scenarios of land and natural resource management. Scenarios were designed with stakeholders and represented a 'what if' change of system conditions regarding, in particular, the deployment of the biofuel project.

1. Company scenario – In this scenario the biofuel project is implemented following the original plan of company (illustrated in

Table 1
Stakeholder perceptions of the impacts of the biofuel project on the landscape. Opportunities are displayed by arrows pointing upwards (↗); threats by arrows pointing downwards (↙). Scale of importance from 0 (low) to 5 (high) based on the method illustrated in Fig. 2.

	Water		Soil quality	Bio-diversity	Climate	Food	Feed	Energy	Employment	Income
	Quality	Availability								
Regional agricultural agency		↙2				↙4	↙4		↗3	↗2
Biofuel company		↙3	↗3	↙1	↗5	↙2			↗1	↗3
Environmental NGO	↗4	↙5	↗4		↗2	↙4		↗2		
Farmers			↙5						↗1	↗4
Farmer associations		↙1	↙4			↙1	↙1		↗1	↗4
Irrigation agencies		↙4								
Local governments		↙4		↙3		↙3			↗4	↗3
Regional government		↙5	↗3	↙4		↙4				↗3
Regional water agencies	↗4	↙5								
Workers union									↗4	
Totals	**8**	**29**	**19**	**8**	**7**	**18**	**5**	**2**	**14**	**19**

Table 2
Integrative model developed through Coupled Component Modelling approach.

Issue – Indicator	Model	Description
Water – consumption and availability in reservoirs	SWAT model [a]	Examines and simulates irrigation requirements for giant reed, and the availability of water in reservoirs
Habitat		
Quality – Unit-less value	InVEST model [b]	Examines and simulates the impact of land use change and management on habitat quality
Connectivity – number of links	Linkage Mapper model [c]	Examines and simulates landscape connectivity measured as Least Cost Path between habitat patches
Food – consumption and production	Area mass balance – Spreadsheet [d]	Examines consumption and production of food in the landscape (Data from FAO National Food Balance Sheets for Italy and SWAT model simulations)
Animal feed – consumption and production	Area mass balance – Spreadsheet [d]	Examines consumption and production of forage in the landscape (Data from official regional statistics and SWAT model simulations)
Energy – consumption and production	Area mass balance – Spreadsheet [d]	Estimates consumption and production of energy at landscape level (Data from official statistics for electricity, heat and transport)
Income – farm net cash	Area balance – Spreadsheet [d]	Estimates breakeven point at farm level and net cash farm income for all converted land
Employment – direct employment in agriculture	Area balance – Spreadsheet [d]	Estimates direct Full Time Employment (FTE) in agriculture in the landscape (local coefficients of FTE/ha for different land uses)
Climate regulation – GHG emission savings	Emissions inventory – Spreadsheet [e]	Examines GHG emissions from animal farming and energy sector including electricity, heat and transport (Data from national and regional statistics)

[a] Soil and Water Assessment Tool (Arnold et al., 1998).
[b] Natural Capital Project (Nelson et al., 2009).
[c] Mcrae and Kavanagh (2013).
[d] Models developed for this study.
[e] IPCC (2006).

Section 4.1) in which c. 6000 ha of arable land previously not used for food crop production are converted to giant reed and irrigated with water supplied by the irrigation system.

2. Recycled water scenario – To mitigate the project impacts on water availability, this scenario simulates the cultivation of c. 6000 ha of giant reed irrigated with water recycled from urban water treatment plants. The land converted to giant reed in this scenario is arable land available in a 10 km buffer area surrounding each treatment plant.
3. Polluted land scenario – Competition with food and animal feed production in the area is mitigated in this scenario by limiting conversion to giant reed of land officially classified as polluted, while water of irrigation is provided by the irrigation system.
4. Food and fuel scenario – In this scenario, a three-fold increase in the acreage of durum wheat is simulated to provide c. 30% of the local feedstock demand of the biofuel project (straw) and increase local food production (grain). The remaining 70% of the feedstock is supplied as giant reed following the Company scenario.

With the exclusion of the Company scenario, stakeholders played a central role in providing inputs, through interviews and focus groups, for identifying the overall theme and key features of each scenario. The Recycled water scenario was championed, in particular, by the regional water agencies who in recent years have piloted a number of projects to test the feasibility of utilising residential waste water for agricultural purposes (Lai 2015, personal communication). The Polluted soil scenario was proposed by many stakeholders in line with the Regional plan for treatment and reutilisation of polluted areas (GOVSARD, 2013). Finally, the Food and fuel scenario was designed following a diffused opinion among stakeholders who stressed the need to revert the decreasing production of food in the area. Durum wheat was selected by the researchers because it could provide both food (grain) and biofuel feedstock (straw).

4.2.4. Participation

As part of the landscape design exercise, we deployed a set of participatory activities building on the results of the assessment of local values and concerns, and accounting for the socio-cultural context of the area. In particular, the traditional low level of trust and collaboration among actors in the agricultural sector of the region created challenges. These challenges were carefully considered when planning participation activities. The participation process we devised covered three phases:

- Initial engagement through in-person interviews – This process sought to establish the basis for building trust while ensuring further participation in the exercise. Within each key category of stakeholders, we identified one or several representatives. The sampling methods applied was snowball sampling and other forms of peer-to-peer referral (Atkinson and Flint, 2001). The core of the engagement was a set of 26 in-person interviews lasting between 30 and 90 min each. The exercise confirmed the importance of in-person interactions to ensure effective engagement. Other forms of interaction tested in the project such as emails did not produce satisfactory results since representatives tended to “forget” or “neglect” this type of approach.
- Knowledge co-development via focus groups – The aim of this process was to allow the integration of local knowledge with scientific knowledge through participatory modelling. Specific activities deployed for this purpose consisted of four focus groups (Scott, 2011) each dedicated to a specific cross-cutting theme including hydrology, land use, farm management and agriculture, and natural habitats. Four to six experts participated in each event. Participants were selected for their technical competences and experiences with the specific theme, as well as their ability to commit to a few meetings. During the events, the group reviewed the functioning of the models, including assumptions, input data, and preliminary results, and provided comments with regard to the communication of model results to stakeholders.
- Decision making via participatory process – Most of the work of building agreement for collaborative actions was accomplished during a decision making event. We organized a one-day meeting involving 16 people in representation of all key categories of stakeholders. The purpose of the event, agreed upon by all the participants, was to identify ways forward for the biofuel project that were acceptable to all participants. The event was led by a local professional facilitator.

4.2.5. Decision-making

The decision making process aimed to identify a pathway forward for the biofuel project that was acceptable to all participants. During the event, the landscape design team presented the knowledge co-produced

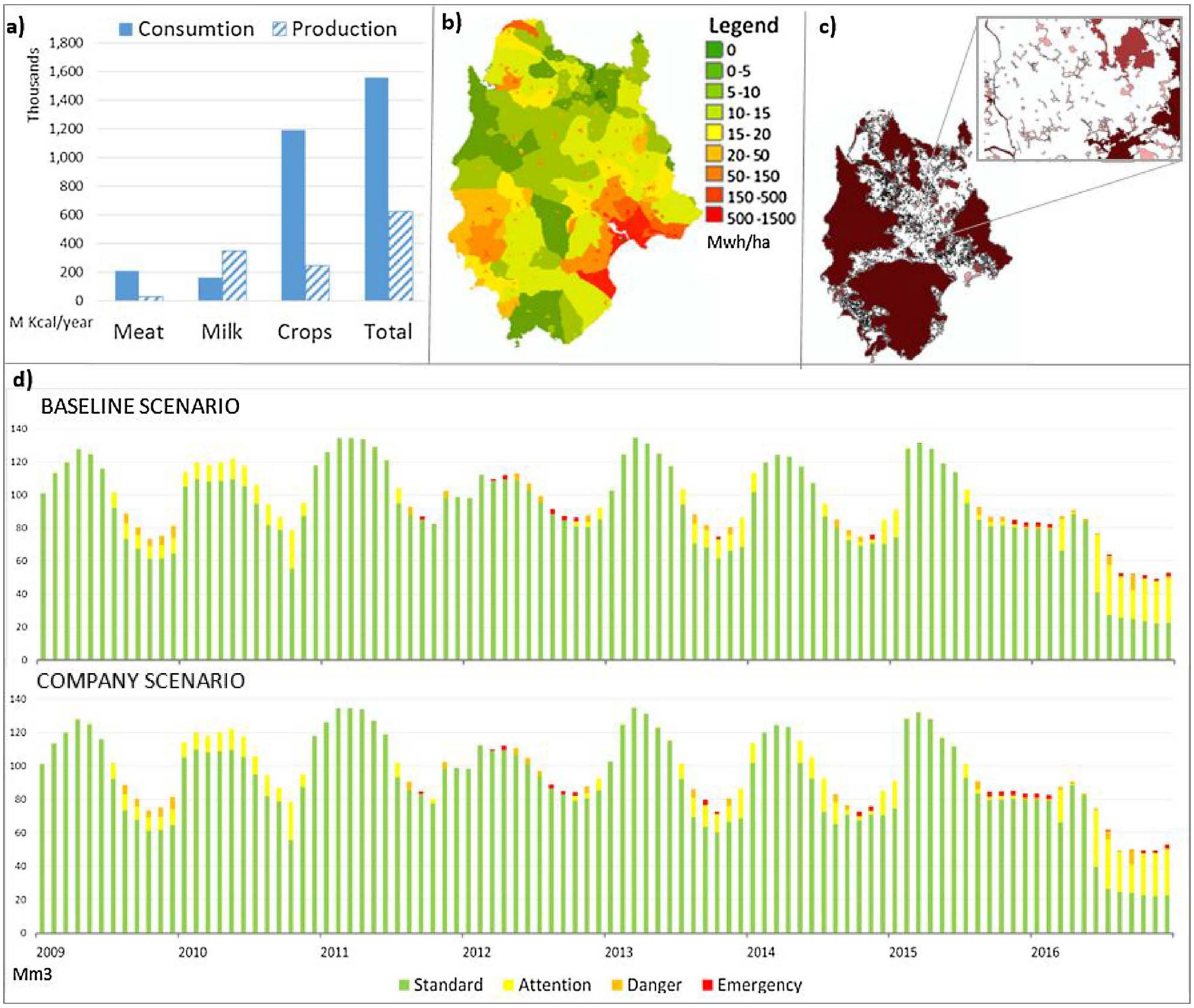

Fig. 4. Sample of maps and figures employed to communicate the results of the modelling exercise.
Food mass balance showing food consumption and production (Million Kcal) in the area with reference to the Baseline;
a) Map of *energy consumption* of the Baseline showing consumption of electricity, heat and transport fuels (Mwh) per hectare/year;.
b) Map of *habitat connectivity* of the Company scenario displaying linkages between habitat patches – darker patches show more linkages.
c) *Water availability* as volumes of water stored and state of reservoirs[2] in the Baseline and Company scenario.

providing participants with a shared understanding of the system and its dynamics. Systemic knowledge of the biofuel project and its impacts on the landscape was presented in the form of maps and figures (see examples in Fig. 4).

The modelling results were used by stakeholders to structure the discussion of the biofuel project. Supported by the facilitator who, in particular, ensured that participants had equal opportunity to contribute and that discussions did not diverge from the object of the meeting, participants articulated their position regarding each scenario. The summary provided by Table 3 was employed. Regarding water availability, the results of the SWAT model suggested that, although the irrigation of giant reed could require up to 33 Mm^3 a year from the regional water system, it might not generate significant changes to the status of the reservoirs in the watershed. This result is due to the hydrological system of the region being highly managed through a network of artificial canals and conducts (GOVSARD, 2015) meaning that a large share of the irrigation water utilized in the watershed and around half of that used to irrigate giant reed could be transfers from the rest of the island. Moreover, the results (Table 3) showed that in the Company scenario the project could consume between 2 and 5.1% of the water stored in the reservoirs in each irrigation season (May–November). While these consumption levels match the water requirements of the Polluted land and Food and fuel scenarios, the Recycled water scenario showed no impact on water reservoirs since all irrigation water for giant reed could be supplied in the form of recycle water.

In addition, stakeholders discussed project's impacts on biodiversity, climate regulation, food, feed and energy production, and generation of employment and income. With regard to biodiversity, the models simulated positive impacts on habitat quality and connectivity. These results did not raise concerns among participants with the exception of representatives of the environmental NGO with regard to habitat fragmentation. Similarly, the group dedicated limited attention to impacts on climate regulation which were simulated in terms of GHG emissions savings from the substitution of gasoline and coal for power production with ethanol and lignin respectively. Impacts on local production of food and animal feed were sensitive issues. The model estimated minor negative impacts on food production, with the exception of the Food and fuel scenario, and a moderate reduction of animal feed

[2] The status of reservoirs was estimated employing the results of the SWAT model and the methodology developed by the Regional drought alarm system (GOVSARD, 2017).

Table 3
Results of the analysis of alternative scenarios, normalized values in comparison to Baseline. Arrows direction refers to the quality of net change (↗ positive and ↙ negative). *It refers only to areas affected by direct land conversion to giant reed or durum wheat.

Category	Indicator	Scenarios			
		Company	Recycled water	Polluted land	Food & fuel
Water	Used as share of stored	↙ 2.0–5.1	↗ 0	↙ 2.1–5.3	↙ 1.8–4.5
Biodiversity	Habitat quality	↗ 2.5	↗ 4.1	↗ 4.5	↗ 1.2
	Habitat connectivity	↗ 20.9	↗ 0.7	↗ 1.2	↗ 56.2
	Habitat fragmentation	↙ 35.0	↗ −2.0	↗ − 1.2	↙ 27.2
Climate	GHG emissions	↗ −3.0	↗ −3.0	↗ −3.0	↗ −3.0
Products	Food	↙ −0.4	↙ −0.8	↙ −0.6	↗ 36.0
	Animal feed	↙ −7.4	↙ −5.0	↙ −4.3	↙ −8.6
	Energy	↗ 0.6	↗ 0.6	↗ 0.6	↗ 0.6
Employment	Jobs in agricultural sector	↗ 0.8	↗ 1.7	↗ 1.6	↗ 3.4
Income	Farm net cash*	↗ 74.0	↗ 75.0	↗ 71.0	↙ −195.0

production caused by the targeted expansion of giant reed on grazing land. Concerns regarding food and feed appeared motivated by the strong agricultural vocation of the area and the increasing reliance on imports, estimated at 60% for food and 53% for animal feed in 2011. Another set of issues that dominated the discussions focused on employment and income creation. On the one hand, participants were somehow disappointed at the limited overall benefits for the area. On the other hand, through dialogue they were able to put into perspective the biofuel project, which would directly affect only a minor area (c. 6000 ha) of the total agricultural land in the area (c. 400 000 ha).

Following the discussion of the modelling results, each participant was asked to present her/his position by illustrating major strengths and weaknesses of each scenario. Through this process the facilitator engaged all participants in the development of a common pathway. The pathway represented a shared view supported by all participants and combined elements of all the scenarios with the exception of the Food and Fuel scenario. There was overwhelming agreement on the importance of utilising recycled water to mitigate impacts on water resources and exploiting marginal lands (such as polluted soils) to limit competition with animal production. The development of the common pathway relied largely on the scenarios simulated. Participants did not challenge the evidence presented but used it to support their positions. Additional considerations, not covered in the modelling exercise, emerged during the meeting. For instance, representatives of the biofuel company, regional agricultural agency, farmers and their associations, and the irrigation agency stressed the fair distribution of revenues among all actors involved in the supply chain as a critical requirement to ensure the acceptability of the biofuel project. Moreover, participants identified critical challenges of the common pathway including the cost of irrigation systems for distributing recycled water, the lack of public subsidies for giant reed in Sardinia, and concerns over the removal of the crop at the end of the growth cycle that could be "expensive and environmentally damaging".

4.2.6. Monitoring and feedback mechanisms

The common pathway that emerged from the decision-making event provided the basis for a number of actions to be undertaken by stakeholders in the following months. These next steps included an evaluation of the agronomic suitability of local land resources for energy crop production, an assessment of the availability of recycled water from small scale waste water treatment plants, and an expansion of giant reed field trials to evaluate rain-fed management opportunities. The participants of the decision making event considered this set of activities necessary in order to move from agreement on a common pathway to a detailed implementable plan for the biofuel project. Once implemented, the detailed plan would ideally be accompanied for a number of years by the monitoring of management outcomes to allow the adaptation of the plan to changing conditions. However, the landscape design exercise ended shortly after the decision making event due to a sudden change in the industrial strategy of the biofuel company.

5. Discussion and conclusions

The practice of designing multifunctional landscapes for human well-being maintaining critical ecosystem functions is still in its infancy (Opdam et al., 2013). To gain insights of the effectiveness and limitations of landscape design, we tested it on the case of advanced transport biofuels in Sardinia, Italy. When evaluated for the capacity to advance agreement among participants, i.e. process outcomes, we observe that the approach was suitable to engage representatives of all categories of key stakeholders from an early phase of the project. Representatives had the opportunity to contribute to the framing of the problem(s) and the development of the knowledge for decision making, and to effectively participate to the decision making process. However, equal treatment of stakeholders was a challenge. The concern that powerful stakeholders can dominate the process and control the outcomes is a real risk. We largely equalized power around the table with appropriate management of dialogue and by sharing knowledge, while power outside the exercise was untouched. Regarding 'process outcomes', we observe that the approach was not able to produce a formal agreement among participants. However, it achieved an intermediate outcome in the form of a common pathway and a set of practical actions potentially suitable to lead to agreement on a formal plan. However, we were not able to test this last component of the approach due to a sudden change in circumstances.

However, we observe that the approach initiated a virtuous cycle. At the beginning of the exercise, key stakeholders contested the biofuel project due to a variety of issues, in particular, connected to a lack of communication from the biofuel company. This lack allowed the emergence of poorly founded expectations among stakeholders. Groups of stakeholders with vested interests, sometimes intentionally, fuelled a controversy relying on partial knowledge of the project and on preconceived positions. Through the landscape design exercise, participants improved their knowledge of the biofuel project and consequently their perception of the potential effects, even though important concerns remained.

Another contribution of the landscape design approach was the provision of systemic knowledge about the potential effects of the project in the area. The availability of this type of knowledge has been considered essential in previous studies to be able to deal with trade-offs and synergies between the supply of energy and the provision of other ecosystem services (Dale et al., 2013; Opdam et al., 2015; Dale et al., 2016; Dale et al., 2017). Through integrated and participatory modelling, our approach provided stakeholders with the knowledge needed to develop a constructive dialogue. This knowledge was sufficiently credible, legitimate and salient to support the adoption of a set of practical actions. Participatory modelling allowed the articulation of stakeholders' preferences thereby improving the quality of the modelling tools and building trust regarding tools and outputs.

The landscape design process allowed the biofuel company to identify weaknesses of their original plan and changes required to ensure local buy-in. Achieving local acceptability is a significant benefit of the application of the approach to potentially controversial biofuel projects. We agree with Dale et al. (2016) when they suggest that more bioenergy projects might be implemented successfully, if pre-emptive landscape design processes were employed to identify and address concerns before they became problems. This lesson has implications both for conventional as well as advanced biofuel technologies. Investors should not expect local communities to support the deployment of advanced technologies solely because these outperform conventional technologies on a number of parameters. Attention should be dedicated to ways to reconcile local concerns and priorities with drivers at higher levels that support the diffusion of advanced technologies.

Beyond the case of biofuels, we see clear opportunities to employ landscape design as a process for deploying supply chains that improve ecological and social benefits, while containing production costs. The approach has the potential to become a tool to turn large projects into means to increase multifunctionality in line with societal values and concerns. However, in spite of these opportunities, there are still practical challenges. These include the need to model and measure supply and demand of ecosystem services in different situations where local baseline data may be missing and also the need for a wide range of skills and competences within the landscape design team. Landscape design is a time consuming and labour intensive approach to land and natural resource management (Cowling et al., 2008). Yet, there are opportunities for streamlining some of the activities, especially those related to knowledge development through modelling. For instance, we encourage the development of a generic model for integrated assessment of ecosystem services and biodiversity that can be (a) easily communicated to local stakeholders without specialist knowledge; (b) effectively customized to match local conditions and concerns; and (c) applied utilizing data locally available.

Another type of challenges, widely discussed in the literature (Cash and Moser, 2000; De Groot et al., 2010), refers to the mismatch between landscape boundaries and those of institutions normally used for planning and managing land and natural resources. Insights gained from this study suggest that administrative and institutional boundaries need to be taken into consideration when defining system boundaries. However, by adding an additional layer to the process of system definition, we risk to further increase the complexity of the modelling exercise and impose additional compromises on scientific accuracy to improve knowledge saliency. This challenge falls within a much wider discussion on the limits of disciplinary, reductionist approaches to the study of complex socio-ecological systems (Mebratu, 1998). Our study contributes to this discussion by providing evidence in favour of interdisciplinary, whole system approaches for synthesis and integration that challenge conventional norms of scientific research (Nassauer and Opdam, 2008).

In conclusion, this study shows that landscape design has the potential to guide the planning of complex and controversial biofuel projects toward sustainable outcomes. As a means for landscape governance the approach can become an effective tool to deploy advanced transport biofuels that deliver on their promises. However, the practical application of landscape-based planning still presents challenges to be addressed before it can make a sensible contribution to sustainable management of land and natural resources. This study provides some initial evidence from the field of transport biofuels, but application to a wider range of empirical cases will be essential to improve effectiveness and support further adoption.

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