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Advanced analysis of spatial multi-functionality to determine regional potentials for renewable energies

Ulrike Wissen, Adrienne Grêt-Regamey

(Dr. Ulrike Wissen, ETH Zurich, IRL Institute for Spatial and Landscape Planning, PLUS Planning of Landscape and Urban Systems, Wolfgang-Pauli-Strasse 15, HIL H 52.2, CH-8093 Zurich, wissen@nsl.ethz.ch)
(Prof. Dr. Adrienne Grêt-Regamey, ETH Zurich, IRL Institute for Spatial and Landscape Planning, PLUS Planning of Landscape and Urban Systems, Wolfgang-Pauli-Strasse 15, HIL H 51.4, CH-8093 Zurich, gret@nsl.ethz.ch)

1 ABSTRACT

The integration of new structural elements into our environment contributes to ongoing changes in landscape and urban systems coming along with a loss of natural resources and many heritage values, and dramatic consequences for human livelihoods and biodiversity. Particularly pressing challenges of climate change and depletion of oil increase the pressure on the development of renewable energy systems (RES). A good understanding of the implications of a rapid expansion of such infrastructures on the environment is needed. Effective goals and management plans for future regional and landscape development with RES, securing the provision of vital ecosystem goods and services are however missing. As very diverse and interconnected issues including the value of landscape and ecosystem functions are impacted, a cross-sectoral examination has to take place. We present a concept to take into account this landscape multi-functionality to determine regional potentials for a diverse mix of renewable energy schemes as basis for a pro-active regional development.

2 INTRODUCTION

2.1 Renewable energy exploitation – a new challenge for landscape development

Worldwide actions are taken by industrialized countries for reducing greenhouse gas (GHG) emissions to an average of 5 % against 1990 levels over the five-year period 2008-2012 according to the targets of the Kyoto Protocol (UNFCCC 2009). The Alpine countries could cover their energy needs by the use of renewable energy with wind power schemes, photovoltaic systems, hydropower plants, as well as wood and biomass energy production plants, and even exceed the Kyoto-goals (Hahn and Rauzi 2008). According to the 'Road Map Renewable Energies Switzerland' - a study that sketches the possible development of renewable energy power capacity assuming that the technically and economically usable resources are utilized - the renewable energy supply could be doubled till 2050 in Switzerland (Berg and Real 2006). However, the authors point out that the limitation is the implementation and thus the societal accepted potential that has to be determined. Whilst the general technical-economical potential for installing renewable energy systems (RES) in Switzerland is reasonably known (Berg and Real 2006), the environmentally sound and societal accepted potential has not yet been identified leading to protests and constraints when it comes to actual implementation of the required infrastructure.

The pressure to use more renewable energies to mitigate climate change brings new challenges for landscape planning. A massive expansion of these new infrastructures will modify landscape functions and the goods and services they provide to people. On one side, these landscape changes can be supportive of the production of ecosystem goods and services and biodiversity. The management of agricultural areas for biomass production, for example, can lead to an increase in biodiversity and a more diverse rural economy. These land-use changes can however on the other side also cause negative impacts on habitats and particular native species (Thornley 2006). Solar energy technologies can affect the visual landscape aesthetic (Tsoutsos 2005). The use of water power changes the water quantity with impacts on aquatic and terrestrial ecosystems and can also cause visual intrusion (Tsoutsos 2007). Wind power plants have high impact on the view of a landscape (Wolsink 2007), triggering the fear of residents with regard to effects of noise, leading to falling house prices (Szarka 2006).

A formulation of effective goals for future landscape development with the use of renewable energies is required in order to ensure sustainable management of a multi-functional landscape that supports the wellbeing of people (Kienast et al. 2009; Rodewald 2008). However, a general difficulty in defining these guidelines comes along with the heterogeneity of landscapes with different forms of land use and divergent requirements on the landscape services. There is not one cultural landscape but there are traditional-, leisure-, transport-, industrial-, and city-landscapes to name only a few. Thus, sustainable landscape development needs strategies and concepts that are regionally differentiated and in agreement with the landscape character (Camenzind 2008). Due to the absence of concepts and methods to evaluate the impacts of the new infrastructures on landscape functions and the goods and services they provide, it is not known yet how the new energy systems can be integrated into the landscape in order to sustain the identification of the people with their cultural landscape, to preserve the ecosystem processes, and at the same time to address economical requirements related to energy production (Peters and Graumann 2006).

Multiple analyses of the general spatial potential for the individual RES have been carried out. Only a combination of various RES will however be successful in order to achieve a robust energy supply (Berg and Real 2006).

Furthermore, a tendency to top-down, technocratic planning approaches in the implementation of renewable energy technology can be noticed. This has been determined as one major obstacle to successful implementation, causing very slow development of renewable production capacity in many countries. Rather open, democratic decision-making is necessary, that takes into account multiple views and thus allows for learning and creating perceived fairness (Higgs et al. 2008, Szarka 2006, Wolsink 2007). Developing normative scenarios (reflecting preferences of stakeholders) based on potential ecological, economic, social, or cultural effects that suggest new landscape patterns as hypotheses for their functional potential might be useful. Thus, societal values with regard to the environment are translated into testable models of possible future landscapes that can be valuable instruments for informing decision-making processes on landscape development (Nassauer and Corry 2004).

2.2 Landscape multi-functionality and ecosystem services

Ecosystem services (ES) are defined as “the benefits people obtain from ecosystems” such as goods, e.g., food, water, or timber, as well as services, e.g., climate regulation, pollination, nutrient cycling, or recreation options and aesthetic benefits (MEA 2005). Using them in an unsustainable way (e.g., clear-cutting of forests) destroys these ES (e.g. water retention) at the expense of human welfare (e.g. human lives are at risk of heavy flooding events). The undervaluation of benefits from ES leads to external costs that mostly overweigh the gains of market benefits from ecosystem conversion. Accelerated changes in land use and accompanied degradation and depletion of ES supply make the costs perceivable leading to increased awareness; however, potentially too late to restore the respective ES to its required condition. Therefore, there is increased demand to integrate ES into the analysis in ecological and economical terms as a basis for better informed, pro-active decisions on trade-offs between different land use options that sustain human well-being (Costanza et al. 1997; Daily 2000; de Groot 2006; Farber et al. 2002; Grêt-Regamey et al. 2008). Many landscapes provide multiple functions based on these ES and allow for different combinations of land uses. For identifying possible threats on services by specific land use changes and capable trade-offs between various land use options (e.g., nature protection, agriculture, settlement development) and ES goals, the benefits provided by ES should be weighted. This weighting of criteria is hard to define (Chan et al. 2006; de Groot 2006; Farber et al. 2002; Kienast et al. 2009).

First, the flow of services is poorly characterized on local or regional scales so that there is a lack of data on many values of ES (Chan et al. 2006). Meyer et al. (2008: 187) argue that “an ES approach does not require economic valuation of all services supplied by an ecosystem, rather it is critical that the wide range of values is at least identified. Quantification can certainly be helpful but we argue is not a prerequisite for using an ES approach”. The integration of both quantitative and qualitative factors into multi-criteria decision analysis is required (Higgs et al. 2008).

Second, the needs of stakeholders influence the value of ecosystem services (Chen et al. 2009). Chan et al. (2006) call for an analysis that is based on demand and supply. Resulting spatial mismatches between supply and demand help priorising ES goals suitable for aligning spatial explicit development goals. Third, since ecosystem processes are highly inter-linked the identification of thresholds and the trade-offs of ES should be based on an analysis that is made under complex system conditions (Boumans et al., 2002; de Groot 2006; Ghazoul 2007). Integrating qualitative participatory techniques with GIS-based models is useful for incorporating the complexities of the spatial dimensions involved (local, regional, national, global), and the views of stakeholders.

Fourth, it is known that stakeholders' preferences for ES can change over time. A reasonable overall number of criteria to be assessed by stakeholders has to be figured out that should be included into the assessment (Park et al. 2004), and the impact of temporal change and changing framework conditions can be assessed using spatial scenarios which help to think in alternatives (Chan et al. 2006; Farber et al. 2002; Ghazoul 2007).

2.3 Participatory landscape planning

Landscapes functions are valued differently by various stakeholders, e.g. planners, foresters, farmers, tourists, and those seeking for recreation, leading to conflicting interests and contrary opinions on landscape values. Especially in the decision-making process on the implementation of renewable energy, misunderstandings of attitudes are the rule and makes planning a complicated matter (Wolsink 2007). Therefore, peoples' knowledge, experience and wishes should be included in the planning of actions, thus raising the acceptability of measures, and strengthen the collective responsibility for landscape development (Coaffee and Healey 2003; Luz 2000; v. Haaren 2002).

Comprehensive participative landscape development should be based on a broad, common understanding of aesthetical, emotional, ecological, and economical qualities of the landscape. For this purpose, the values, perceptions, and preferences of stakeholders with internal, external, or intermediate views, e.g. of new residents, should be considered (Backhaus et al. 2007; Luz 2000; Rodewald 2008; Selman 2004; Szarka 2006; Wolsink 2007). Expert knowledge should not be neglected because otherwise aspects subordinated to local interests might be excluded (Rodewald 2008). De Groot (2006) states that a more effective and structured communication of the outcomes of a multi-criteria analysis to stakeholders is crucial for collaborative planning.

In the context of participative landscape development planning, GIS-based virtual landscapes have proved to be the media that support a common concept development (Hehl-Lange and Lange 2005; Oppermann 2008; Wissen 2009). Declining costs for hard- and software, enhanced availability of GIS data, increasing amount of people with technical expertise in 3D visualization, and increasing knowledge on the role of the 3D visualization instruments in planning processes make the use of GIS-based 3D landscape visualizations more and more attractive (Lange and Hehl-Lange 2006).

For long time, research was dealing with the question of the necessary level of detail in the images and their resulting degree of creating the impression of realism. Recently, a shift can be noticed to research questions focusing on the adequate representation of the information in 3D visualizations corresponding to the target audience, the task supported by 3D visualizations (e.g. scenic beauty assessment; acceptability judgment; assessment of biodiversity etc.), and the planning phase they are used in. 3D visualizations as planning tools with specific qualities, design styles, and clearly defined potential fields of application are being focus of investigations (Paar 2006; Williams et al. 2007; Wissen 2009). Particularly the need to integrate spatial indicators into the visualization has been acknowledged by several research groups (Brooks and Whalley 2008; Hehl-Lange 2001; Higgs et al. 2008; Sang et al. 2008; Wissen et al. 2008).

2.4 Requirements for advanced analysis of spatial potentials for RES

Available planning instruments on national, cantonal and regional level are not effective enough to ensure concurrently an efficient and sustainable integration of RES into the landscape. Suitable locations have to be detected and communicated for implementation of political goals, e.g., the optimal integration of solar energy systems into the designated building and agricultural zones (RPG, Art. 18c). Evaluation and balancing costs and benefits of renewable energy production and of the provision of ecosystem and landscape services needs a sound basis showing the landscape's resources and potentials. In this way, clear priorities for spatially differentiated landscape development paths can be identified. Thereby, the entire energy policy has to be considered in order to develop rather comprehensive solutions than sectoral proposals for single RES (BFE 2007). Overall, there is a lack of studies that show how a mix of RES can be integrated into the landscape based on balancing the values of ES and further relevant socio-economic indicators thus demonstrating the limits within which a sustainable use of renewable energy is possible.

Participatory approaches can help demonstrate different alternatives of possible future landscape development, thus raising awareness for the limited sectoral views. Communication instruments such as 3D landscape visualizations are viable tools to enhance these participatory scenario studies and the evaluation of landscape aspects. However, it is not yet known, how the ecosystem service values can be integrated into the visualization of possible future landscapes including renewable energy infrastructures in order to use these instruments for more comprehensive assessments and to achieve more meaningful dialogues between stakeholders.

Summing up, research on the analysis of spatial potentials for RES is required which (i) considers the spatial potential for a mix of the different RES, (ii) shows different possible alternatives of exploiting the maximum capacity, (iii) specifically focuses on the quantitative analysis and balancing of the systems' technicaleconomical requirements and values of ES, (iv) integrates the relevant stakeholder knowledge and values into the evaluation, and (v) provides methods and instruments for utilizing the broad range of spatial

indicators on different spatial scales in participative spatial planning processes.

In this project, we present a concept for developing a land use model to assess spatial development potentials for a mix of RES. The assessment is based on optimizing the integration of the mix of RES into the landscape by considering economic, social, ecosystem, and landscape services[1] potentially affected by the renewable energy use. A combined modeling and visualization approach is proposed that offers the possibility to integrate stakeholder valuations into the decision-making process.

3 CONCEPT FOR DETERMINING REGIONAL POTENTIALS FOR RENEWABLE ENERGIES

Fig. 1 presents an overview of the workflow. The research will be divided into 3 phases: (1) Development of the RES-mix assessment model, (2) calculation of location potentials for RES, and (3) generalization of the model, which are described in more details in the following.

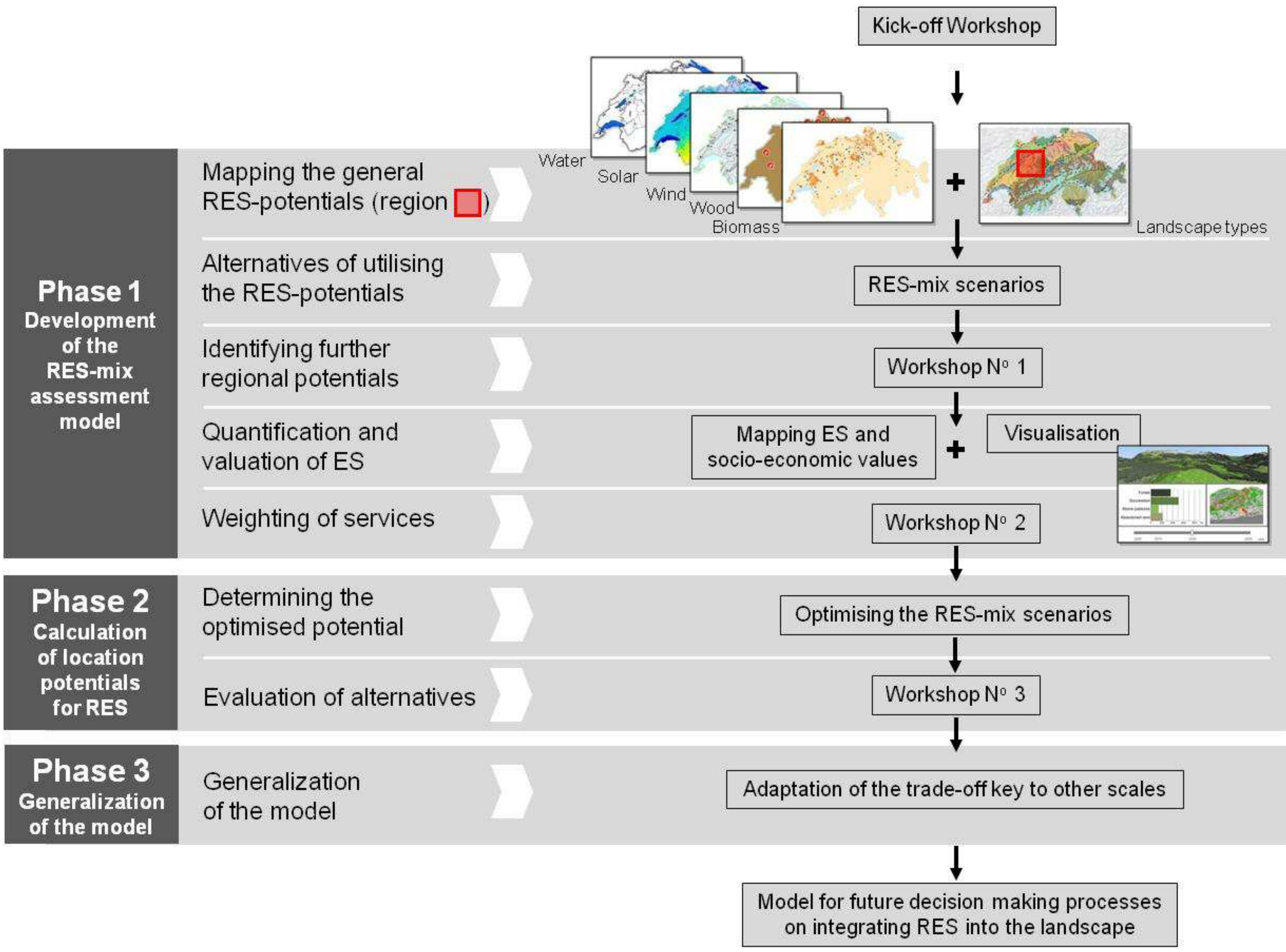

Fig. 1: Overview of the workflow (RES = Renewable Energy Systems; ES = Ecosystem Services)

Phase 1: Development of a RES-mix assessment model

[1] In the following, „ecosystem services (ES)" will be used for „ecosystem and landscape services".

This phase aims at developing an assessment model based on a set of physical and economic indicators that allow for analyzing costs and benefits of land use change scenarios with RES. The work process includes five steps: (1) Mapping the maximum spatial capacity for renewable energy exploitation in the case study area based on existing criteria and approaches as well as available analyses of spatial RES capacities set up for Switzerland; (2) Developing regional RES development scenarios, which exploit the maximum regional capacity for RE use; (3) Identifying relevant ES and their importance for the region in a workshop with stakeholders confronted with the RES-mix scenarios in form of maps, 3D visualizations and basic socioeconomic indicators; (4) Quantifying ES using GIS-based process models. Exemplary ES reflecting the benefits and threats in the context of RE use are listed in Tab. 1.

ES Categories	ES	Benefits and their valuation
Provisioning functions	Forest products (timber, energy wood)	Timber value of living trees which has a potential market value. The value depends on the density of dominant forest species of an area and their relevant market price.
	Agricultural products	Value of food produced in the area which has a potential market value.
Regulation functions	Erosion regulation	Possibility of an area to maintain the soil quality and reduce the risk of soil erosion. The value reflects the erosion mitigation contribution of vegetation.
	Water regulation	Hydrologic services of an area such as mitigation of flood damage, measurable by water quantity (Brauman et al. 2007).
Supporting functions	Habitat	Ability of an area to support biodiversity. The value is identified by habitat quality indicators, e.g., fragmentation index (Jaeger et al. 2007), Shannon's diversity index (Béné and Doyen 2008), etc.
Cultural and amenity functions	Recreation and tourism	Amount of natural and semi-natural habitat as well as accessibility of the area; proximity to population centers.
		Potential of an area for enjoyment of recreational and cultural amenities like wildlife and bird watching, water sports, aesthetic appreciation and spiritual and social services.

Tab. 1: Exemplary ES relevant in the context of RE use, their benefits and possible valuation. The ES are assigned to four categories according to the Millennium Ecosystem Assessment (MEA 2005)

For the valuation, food, timber and wood for energy are directly assessed in monetary units according to the market price for these goods. The quantification of services such as landscape aesthetics and inspiration, cultural heritage and others require different approaches such as discrete choice experiments using 3D visualizations.

The final step of the first phase is (5) Presenting the results of the quantification and valuation of ES to the stakeholders in a workshop, where they are asked to weight the services based on their value system with regard to the environment. GIS-based 3D landscape visualizations will be used to support the communication process.

Phase 2: Optimized calculation of potentials

The second phase aims at identifying optimal locations for RES based on ecological, economic, and social services of the case study area. A trade-off key is developed that integrates the stakeholder preferences into the simulation and thus allows for modelling optimal location potentials for RES using a multi-criteria optimization approach. The weighting of ES is included into the optimization model to enable the user to obtain several optimized trade-offs. The results of this analysis are spatially explicit maps of land use change combinations that differ by the amount and allocation of RES according to the balancing of values.

In a workshop, the societal accepted regional potential for RES is assessed by showing stakeholders alternative landscape development paths with RES.

Phase 3: Generalization of the model

In order to make the model applicable to other scales, the trade-off key is adapted to the requested scale of analysis. A selection of criteria is carried out that can be analyzed in a coarser raster than the regional level, and the optimization model is adapted to the new dataset. The adapted trade-off key is tested at multiregional and national levels in order to detect "hot" or "cool" spots for RE exploitation in Switzerland.

4 CONCLUSION

The project deals with the challenge of identifying optimal locations for new infrastructures such as RES in order to minimize impact on ES. It is basic groundwork with respect to approaches for multi-criteria assessments of spatial potentials for various land uses utilizing an iterative modeling process. In particular, we seek to strengthen the consideration of demand and supply of ecosystem services in the negotiation process on land use change due to infrastructure development in order to provide a better, more comprehensible decision basis. It offers an integrative method in landscape assessment and spatial scenario building by linking spatially explicit multi-criteria assessment with optimization modeling techniques. Using the capacity of GIS-based 3D landscape visualizations as tools for qualitative assessment of landscape change and linking them with quantitative indicators provides new powerful means for integrated spatial scenario assessments.

On the international level the results might contribute to implementations of the European Landscape Convention, the Europe-wide concept centering on the quality of landscape protection, management and planning. Our proposed framework to quantify the benefits of natural resources as basis for developing and evaluating strategies is consistent with the aims of the Council of Europe (2000): Applying approaches to observing and interpreting landscapes, which view the territory as a whole, include and combine several approaches, and incorporate social and economic aspects. It aims at enhancing methods and instruments for participative processes on sustainable landscape development in which the indirect costs are no longer neglected (Szarka 2006).

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