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Creating a spatial multi-criteria decision support system for energy related integrated environmental impact assessment

Thomas Wanderer [1], Stefan Herle

German Aerospace Center (DLR), Institute of Technical Thermodynamics, Systems Analysis and Technology Assessment, Wankelstr. 5, 70563 Stuttgart, Germany

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ABSTRACT

By their spatially very distributed nature, profitability and impacts of renewable energy resources are highly correlated with the geographic locations of power plant deployments. A web-based Spatial Decision Support System (SDSS) based on a Multi-Criteria Decision Analysis (MCDA) approach has been implemented for identifying preferable locations for solar power plants based on user preferences. The designated areas found serve for the input scenario development for a subsequent integrated Environmental Impact Assessment.

The capabilities of the SDSS service get showcased for Concentrated Solar Power (CSP) plants in the region of Andalusia, Spain. The resulting spatial patterns of possible power plant sites are an important input to the procedural chain of assessing impacts of renewable energies in an integrated effort. The applied methodology and the implemented SDSS are applicable for other renewable technologies as well.

Introduction

Renewable energies had a predominantly environmentally-friendly image in the past, but with a recent rise of share in the energy production their positive or negative impacts get greater and thus become subject of more detailed research. The 7th Framework Programme project (2009-2013) EnerGEO[2] undertakes the effort to assess those impacts by coupling several models and input services into a Platform for Integrated Assessment (PIA).

Parts of this effort are scenario developments for energy use in the future based on usage assumptions and geographic patterns. Whilst usage scenarios are primarily driven by socioeconomic factors, the latter ones depend on the spatially distributed nature of renewable energy resources amongst other geophysical conditions. Taking a look for instance at solar energy — availability of radiation, proximity to infrastructure, land use and cooling opportunities in the case of Concentrated Solar Power (CSP) are exemplary factors influencing the profitability of this resources' exploitation and the impact on its local environment. The kinds of spatial decision problems arising from this context are usually dealt with by Spatial Decision Support Systems (SDSS) and Geographic Information Systems (GIS).

The GIS-based SDSS tool described in this paper helps with developing spatial development scenarios for larger solar power plants by integrating accepted spatial Multi-Criteria Decision Analysis (MCDA) methods to facilitate well-founded siting decisions. The siting patterns together with demand scenarios can be further used for future impact assessments.

To allow integration with the overall project architecture and workflow of the PIA, the SDSS tool has been implemented in a service-oriented architecture (SOA) using common Web standards. Two different graphical user-interfaces provide access to non-expert and advanced users and demonstrate how GIS-based SDSS are able contribute to a modern integrated impact assessment workflow. The methodology of this tool is not restricted to a certain type of renewable technologies and provides a sound basis for integrating further capabilities.

Methodology

The procedure from theoretically available renewable energy potentials to distinguishing the preferable power plant location patterns is influenced by a multitude of different physical, economic or social criteria with many of them being of spatial nature. MCDA therefore is an adequate approach to identify different spatial renewable energy deployment regions — each representing the most plausible (optimum) location pattern for a chosen set of scenario preferences.

GIS-based MCDA

The developed MCDA approach manages heterogeneous and unrelated criteria for assessing relevant and optimal locations of solar plants. MCDA is a well-known methodology for this kind of problems and in connection with spatial data, GIS multi-criteria modelling techniques have already been used for a variety of similar decision problems in transportation, forestry, resources planning or other fields. For example, in 1991 Carver used the MCDA technique

E-mail addresses: thomas.wanderer@dlr.de (T. Wanderer), stefan.herle@rwth-aachen.de (S. Herle).
[1] Tel.: +49 711 6862 778.
[2] EnerGEO, European Commission FP7, http://www.energeo-project.eu.

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of Weighted Linear Combination (WLC) that assigns weights for each criterion and sums these to an overall score for searching suitable locations for nuclear waste disposal in Great Britain (Carver, 1991). Malczewski (2006) and lately Ferretti (2011) offer a profound overview about literature dealing with GIS-based MCDA. Recently published studies prove the applicability of this methodology for finding suitable sites and evaluating the potential of locations for solar power plants. Janke (2010) uses the WLC approach to aggregate various data like solar potentials, landcover, population density and the distance to transmission lines. In the resulting suitability map of Colorado, an overall score is assigned to each pixel representing exactly one alternative of the decision problem. To reduce uncertainties in the weighting of the criteria, Kengpol (2012) utilises a fuzzy Analytic Hierarchy Process (AHP) approach to find the most suitable sites for solar plants in Thailand. Other studies use Ordered Weighted Averaging (OWA) (e.g. Charabi and Gastli (2011)) or Data-Envelope-Analysis with Principle Component Analysis (e.g. Azadeh et al (2008)).

Certain MCDA techniques have already been incorporated into GIS software implementing modules and scripts like in IDRISI or ESRI's ArcGIS (Lidouh et al, 2011). Web-based SDSS have also been developed in the last decade. One example is the CommonGIS application, a rich-client WebGIS which also integrates decision support by incorporating a MCDA module (Andrienko et al, 2003). However, spatial MCDA techniques implemented as Web services using common standards could not be found in the literature.

Spatial decision making (SDM) usually involves multiple criteria with geographic location information of the available alternatives. As a consequence, many MCDA methods have also been adapted for these kinds of problems. Spatial MCDA requires capabilities of both MCDA tools and Geographic Information Systems (GIS). Consequently, the framework for solving spatial decision problems can be described as GIS-based MCDA (Malczewski, 1999). This framework describes a general procedure with different consecutive steps including identifying relevant criteria, standardising criteria values, expressing preferences and specifying the decision rule to aggregate the criteria value to a one-dimensional score.

Standardisation of criteria values

Since the criteria are measured on different scales, the standardisation of the values is a necessary step in order to aggregate to a single suitability value for each alternative. Further, all criteria should be transformed in a positively correlated way in respect to the suitability. Several standardisation techniques have been developed like the linear scale transformation or probabilistic approaches (Malczewski, 1999). The proposed tool supports the standardisation via fuzzy set membership functions because they are easy to understand and provide the user a variety of possible ways to model the suitability of the corresponding criterion. The user is able to alter the transition between unsuitable values and most suitable values for each criterion (Eastman, 2006). Four different transitions are available — namely linear, sigmoidal, jshaped and user defined curves. Whilst linear, sigmoidal and the j-shaped curve can take an increasing, decreasing or symmetric shape, the user defined transition is controlled by a freely chosen finite number of control points. The choice which of the functions should be applied depends on the relationship between the criterion and the decision set as well as on the information and knowledge available to the decision maker. Linear or sigmoidal functions are sufficient in the most cases according to Eastman (2006).

Criterion weighting

The criteria vary in their importance for the SDM process according to decision makers' preferences. Information about the relevance of each criterion is an essential input in order to make recommendations (Drobne and Lisec, 2009). Usually, the preferences are expressed by assigning a weight to each of the criteria. In this way, the weight vector $w = (w_1, w_2, \ldots, w_j, \ldots, w_n)$ for which holds $\sum w_j = 1$ describes the preferred structure for n criteria. A variety of techniques for the derivation of that vector exists. In the implemented tool the user can chose out of the following three methods for specifying the personal preferences:

- Ranking method: The user is asked to sort the criteria in descending order of importance. Subsequently, the weight vector can be computed by different mathematical techniques.

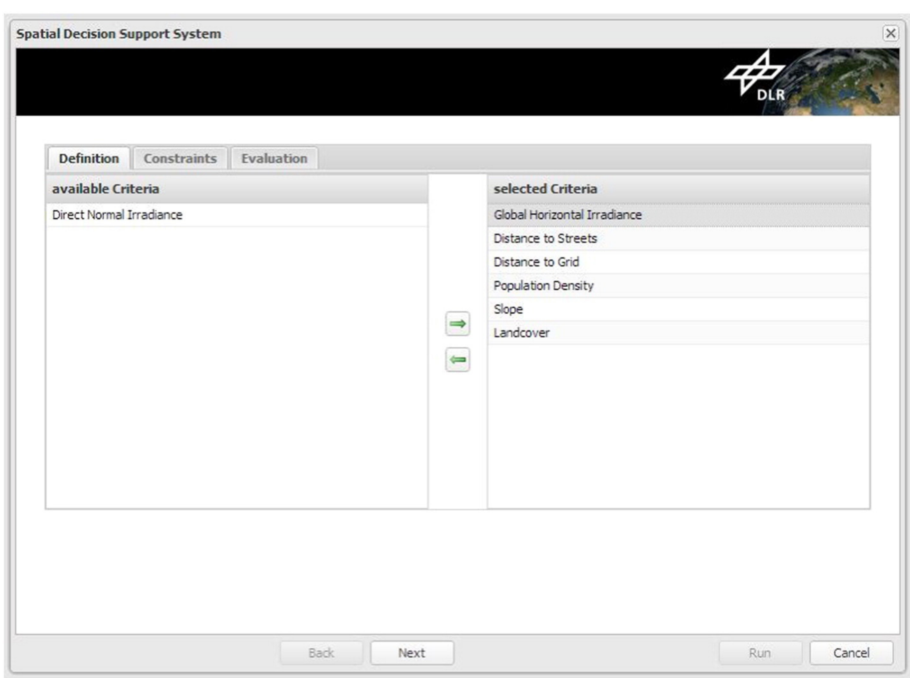

Fig. 1. Criteria selection.

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