Environmental Impact Assessment Review 66 (2017) 86–98

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Mapping environmental sensitivity: A systematic online approach to support environmental assessment and planning

Ainhoa González Del Campo

School of Geography, University College Dublin, Dublin, Ireland

ARTICLE INFO

Keywords:
Baseline environment
Sensitivity
Strategic environmental assessment
Spatial analysis
Online geoprocessing

ABSTRACT

Environmental sensitivity analysis provides a framework for systematically and objectively determining the potential for significant environmental impacts. The higher the natural or acquired sensitivity of the receiving environment, the less capable it is to cope with human-induced change. Given that sensitivity is context- and spatially-specific, Geographic Information Systems have been applied to develop an operational Webtool to analyse it. The Webtool enables a rapid and replicable spatial examination of environmental sensitivities and potential for land-use conflicts that supports Strategic Environmental Assessment and, ultimately, informed planning and decision-making. The novelty is on the provision of an online geoprocessing Widget that enables creation of context-specific maps. Pilot testing the Webtool in land-use and renewable energy planning through stakeholder engagement has validated its applicability. Stakeholders confirmed that it enables replicating and, in some cases, improving in-house SEA mapping processes while saving time and effort. However, its full reliance on publicly available spatial datasets renders completeness and resolution issues. The Webtool provides a critical starting-point for sectoral planning discussions and for developing plan/programme alternatives that avoid or minimise potentially incompatible or unsustainable zonings, while promoting consistency and transparency in impact assessment.

1. Introduction

Environmental sensitivity or vulnerability considerations are critical in natural resource management, particularly in the analysis of interactions between society and ecosystems. In the context of the legislative requirements for impact assessment, the terms are often interchangeably referred to when describing susceptible natural resources (e.g. protected habitats, water bodies) that could be significantly affected (e.g. disturbed, degraded) by anthropogenic stressors associated with the implementation of a plan, programme or project. For simplicity, this paper adopts the term sensitivity from here on. Despite its common use, no universal definition exists for environmental sensitivity, and there is no consensus on how it can be best applied to all assessments (Füssel, 2007; Gallopín, 2006; Pavlickova and Vyskupova, 2015). Various aspects and components of the receiving environment and, indeed, of the concept of sensitivity are emphasised in impact assessment literature. Some point to the specific attributes of an ecological system that render it more or less susceptible to hazard (González et al., 2011a; Toro et al., 2012; Yoo et al., 2014), also viewed as the internal or intrinsic risk factor of a system (Skondras et al., 2011); while others place the onus on the propensity of a system to suffer harm from external stresses (Iosjpe and Liland, 2012; Kasperson et al., 1995). A number of definitions bring receptor susceptibility and resilience together, noting that sensitivity is the degree to which a system is able/unable to cope with adverse effects (Adger, 2006; Carpenter et al., 2001; IPCC, 2001).

In the overall goal of achieving sustainability, sensitivity analysis should aim at the early identification of intrinsic risks affecting environmental resource protection/conservation. Although not a requirement under either the Strategic Environmental Assessment (SEA – EC, 2001) or the amended Environmental Impact Assessment (EIA – EC, 2014) Directives, environmental sensitivity analysis enables further insight into the baseline environment to the purely technical factoring of characteristics. It also presents a framework for systematically determining the potential for significant impacts. Indeed, the EIA Directive warns about the potential for significant effects when proposing developments in *environmentally sensitive* locations (Aretano et al., 2015, article 28), and the SEA Directive refers to the *vulnerability* of the area likely to be affected when identifying and characterising potential impacts (EC, 2001, Annex II, 2). It has been argued that impact assessments that account for sensitivity are generally less subjective than those that do not (Kværner et al., 2006). Therefore, environmental sensitivity analysis can serve as an empirical and more objective critical foundation for sectoral planning discussions, and support evidence-

E-mail address: ainhoa.gonzalez@ucd.ie.

http://dx.doi.org/10.1016/j.eiar.2017.06.010
Received 6 March 2017; Received in revised form 7 June 2017; Accepted 28 June 2017

based impact assessment and environmental planning.

This paper presents an online tool developed to systematically examine environmental sensitivity within a SEA framework (AIRO, 2016). The novelty of the Environmental Sensitivity Mapping (ESM) Webtool relies on the centralisation of SEA-relevant data and, more importantly, on the instant generation of plan/programme-specific sensitivity maps. The paper unfolds by first discussing how environmental sensitivity can be measured (Section 2), which sets the framework for the methodological assumptions presented in Section 3. The results describe pragmatic considerations associated with the testing of the Webtool, as well as the feedback obtained from the stakeholders engaged in the case studies (Section 4). An examination of the opportunities, limitations and lessons learnt from its practical application is undertaken before the conclusions are drawn and possible directions for further investigation are highlighted.

2. Measuring environmental sensitivity

As Adger (2006) notes, there are three generic ways for conceptualising and measuring sensitivity: a) analysing a system's or region's characteristics that make it susceptible to change - i.e. starting-point (e.g. González et al., 2011a); b) analysing resulting impacts - i.e. focusing on the end-point (e.g. Antunes et al., 2001); and c) analysing exposure, sensitivity and adaptive capacity - i.e. system approach that addresses interactions between all components (e.g. Yoo et al., 2014). Given common data and resource limitations, the majority of analysis tend to focus on either the starting- or end-points, as the system's interactions and adaptive capacity are complex and often difficult to measure.

In the context of SEA and EIA, environmental sensitivity analysis should aim, at least, at identifying areas that have higher risk of being susceptible to adverse change (i.e. starting-point or baseline environment). This can be achieved by examining the capacity of a given biophysical factor or set of factors to absorb anthropogenic change and remain in the same state (Adger, 2006; Cavan and Kingston, 2012; Carpenter et al., 2001; González et al., 2011a; Toro et al., 2012). The higher the natural or acquired sensitivity of an environment or factor, the less resilient it is - i.e. the less capable to cope with human-induced change. For example, a water body with a naturally sensitive species (such as the protected freshwater pearl mussel), or with acquired sensitivity as a result of pollution, would be less capable to absorb additional adverse biochemical changes without environmental consequences. In practical terms, environmental sensitivity can be associated to: a) quality status of a given biophysical factor (as per above, the poorer the water quality, the higher the acquired sensitivity); b) presence of a protected species or designation (e.g. biodiversity conservation areas would be naturally susceptible to change); or c) risk (e.g. flood risk areas or contaminated lands would be unable to support development without remedial action). Current legislative measures for environmental protection and risk avoidance facilitate harmonising sensitivity on the basis of the above considerations. The lower the environmental quality or the greater the risk or degree of protection assigned to a natural resource or area, the greater the sensitivity and the potential for land-use conflicts. Where such statutory measures are not available or applicable, as it is currently the case for landscape considerations, expert and/or stakeholder value judgments may be applied to determine sensitivity (Hegmann and Yarranton, 2011).

It is widely acknowledged that the evaluation of impacts has a subjective dimension associated with the varying values, knowledge and perceptions of those involved in the process (González et al., 2011b; Hegmann and Yarranton, 2011; Lawrence, 2007; Toro et al., 2012). This also holds true in sensitivity analysis. Experts may have a knowledge-led bias when determining degrees of susceptibility (e.g. ecologists considering biodiversity areas as most sensitive or hydrologists prioritising sensitivity of water features). Similarly, sensitivity determinations through public consultation (a mandatory requirement in both plan-making and SEA under the Aarhus Convention and Directive 2003/35/EC on public participation - EC, 2003) are likely to be shaped by awareness levels and/or personal values or concerns (Cox, 2013). Nevertheless, stakeholder and public involvement contributes to dissemination of environmental knowledge and improved stewardship, and decision-making is based on a wider evidence- and experience-base (Dietz and Stern, 2008; Gupta, 2008). Adger (2006) argues that sensitivity analysis must reflect social values and contexts in order to capture differentiations in local sensitivity perceptions, and thus contribute to the experience-base. This is commonly done by incorporating value judgments on significance/importance (González et al., 2011a; Hegmann and Yarranton, 2011).

Sensitivity is context-, time- and spatially-specific, as susceptible environmental features and their significance differ across regions over time (Brooks et al., 2005; González et al., 2011a; Tran et al., 2010; Wang et al., 2008). Geographic Information Systems (GIS) can therefore provide a robust platform for participative and spatially-explicit environmental sensitivity analysis. Impact assessment methodologies are increasingly moving towards greater use of spatial data and GIS (Atkinson and Canter, 2011; González, 2012). More importantly, they growingly include environmental sensitivity analysis (e.g. Cavan and Kingston, 2012; Kværner et al., 2006; Marull et al., 2007; Pavlickova and Vyskupova, 2015; Toro et al., 2012; Wang et al., 2008) and attempt to determine the potential for cumulative effects (e.g. Antunes et al., 2001; Atkinson and Canter, 2011; Geneletti et al., 2007; González et al., 2011a; Skondras et al., 2011). The ESM Webtool presented in this paper builds on this growing practice for examining accumulated relative sensitivity of the receiving environment. The simultaneous occurrence of multiple sensitive factors (such as poor water quality, presence of a red list species and a high amenity landscape) in one location will render the environment more sensitive to change than if only one of those factors were present, as a result of accumulated sensitivity. Therefore, the relative environmental sensitivity of an area at a given point in time can be considered to directly relate to the number of relevant sensitive factors that overlap at that location (Antunes et al., 2001; González et al., 2011a; Marull et al., 2007). This can help determine the likelihood of multiple natural resources being adversely affected by an individual or several anthropogenic actions at that location.

Environmental sensitivity should provide early warning for potential land-use conflicts, and identify the location and extent of likely adverse effects in order to inform planning and decision-making. Much of the international literature examines sensitivity of a single environmental theme (e.g. climate change - O'Brien et al., 2004; ecosystems – Metzger et al., 2006; landscape - Pavlickova and Vyskupova, 2015; marine environment - Iosjpe and Liland, 2012; soil - Valle Junior et al., 2014), or assess it in the context of potential conflicts deriving from the implementation of specific sectoral plans/programmes/projects (e.g. agriculture - Luers, 2005; mining – Liao et al., 2013; recreation - Tomczyk, 2011; renewable energy – Watson and Hudson, 2015; or rural development – Li et al., 2006). This is also the case in existing publicly available online tools which specifically map sensitivity to oil spills, aggregate extraction or wind farms, for example. The variety of multi-criteria algorithms and applied criteria in peer-reviewed and grey literature demonstrates that no standardised approach to sensitivity analysis exists. Nevertheless, multi-criteria assessment and GIS are commonly integrated for the combined spatial analysis of multiple environmental considerations through aggregation methods. Yet holistic approaches applicable to a range of environmental themes or sectors are rather limited (e.g. Chrysoulakis et al., 2013; Geneletti et al., 2007; González et al., 2011a; Marull et al., 2007). Moreover, published approaches are generally research-oriented and have seldom translated into practice – possibly because they are data intensive and require specialised input (e.g. modeling). More efforts are needed to link research to live projects, by means of transparent and easily transferable methods, to enhance the impact generated from the results (Riddlesden et al., 2012).

The novel ESM Webtool presented in this paper addresses some of the caveats identified above. As further described and discussed in the sections that follow, it provides additional insight on the baseline environment by enabling an examination of the intrinsic capacity of the receiving environment to absorb change, while accounting for objective and subjective values when spatially assessing environmental sensitivity. It captures multiple environmental themes and has the potential to be applicable to a wide range of sectoral plans and programmes within the framework of SEA. Nevertheless, testing its application in sectoral case studies has revealed a number of issues and limitations that remain to be addressed as discussed below.

3. Methods: Developing and testing an environmental sensitivity mapping Webtool

Environmental sensitivity mapping is often applied in SEA processes in the Republic of Ireland (Ireland hereon) – perhaps as a result of existing guidance (EPA, 2009, 2015) and/or as a result of the perceived practical benefits of its application (EPA, 2016a). To promote wider implementation, a GIS-based ESM Webtool, which includes a bespoke Widget to calculate relative environmental sensitivity 'on-the-fly', has been developed in consultation with stakeholders (EPA, 2016a) as illustrated in Fig. 1 (AIRO, 2016). The main purpose of the ESM Webtool is to support real-life SEAs and enhance consistency and transparency across assessments, while overcoming some current technical barriers and knowledge gaps (e.g. lack of centralised access to SEA-relevant datasets and technical skills). The Webtool is to provide an operational framework that assists practitioners (e.g. local authority planners, consultants) in undertaking SEA by enabling a systematic, participative and rapid spatial examination of environmental sensitivities and potential for land-use conflicts that ultimately supports informed decision-making. The Webtool has been tested by stakeholders in a number of sectoral case studies, two of which are examined in this paper.

3.1. Webtool and Widget

Supporting and facilitating SEA starts with access to up-to-date relevant information. The ESM Webtool centralises over 70 spatial datasets for viewing and querying (Table 1). The spatial datasets included in the Webtool were selected by the project team on the basis of their SEA-relevance and public accessibility. Some datasets, despite being highly relevant to SEA (such as the record of protected structures, nature reserves or flood risk areas) could not be included in the Webtool as they are currently not publicly available. All the included environmental datasets can be interrogated – i.e. the end-user can turn on/off datasets for their individual or combined visualisation and print out, as well as click on a given area to obtain information on its main characteristics (e.g. description, typology and status of environmental factors at that location) (Fig. 2).

The Webtool contains a novel geoprocessing tool or Widget that enables 'on-the-fly' context-specific sensitivity analysis (i.e. contextualised to the issues of a given plan/programme). A subset of the datasets included in the Webtool is brought into the Widget on the basis of their relevance to sensitivity analysis.

The Widget is based on a multi-criteria weighted linear combination algorithm that avoids normalisation (González et al., 2011a). Therefore, the overall sensitivity of an area relates directly to the number of sensitive factors overlapping at that location – each multiplied, where applicable, by the relative importance (i.e. weight) assigned to it. It follows common multi-criteria approaches to impact assessment,

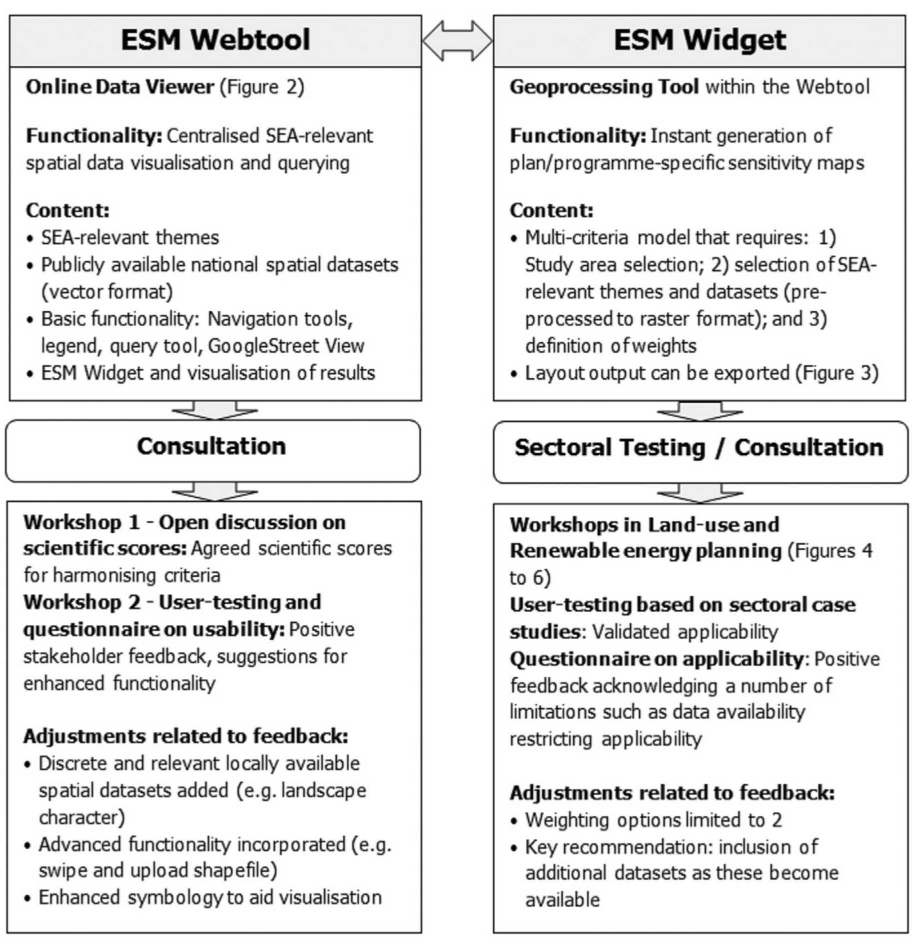

Fig. 1. General steps in the development and testing of the Environmental Sensitivity Mapping (ESM) Webtool and Widget.

Table 1
Datasets available in the Widget for environmental sensitivity mapping and their assigned scientific scores. Note that the Webtool viewer contains additional datasets for viewing and querying.

Widget criteria and agreed scientific scores, where 1 = Low, 2 = Moderate, 3 = High		Scientific score basis (all scores were subject to consultation)
Population and human health		
WFD RPA Ground drinking water	3	Statutory: Protection priority
WFD RPA Lakes drinking water	3	Statutory: Protection priority
WFD RPA River drinking water	3	Statutory: Protection priority
Biodiversity, flora and fauna		
Ancient woodlands		Value judgment: Protection priority
Ancient woodland	3	
Possible ancient woodland	3	
Long-established woodland	2	
Article 17 habitats	3	Statutory: Legal protection and indicator of environmental quality
Coastal habitats (Saltmarshes)	2	Statutory: Protection priority and environmental quality
Forest Inventory and planning system		Value judgment: Environmental quality
Deciduous	2	
Coniferous	1	
Margaritifera sensitive areas		Statutory: Legal protection and indicator of environmental quality
Catchments of SAC populations	3	
Catchments of other extant populations	3	
Catchments with previous records but current status unknown	2	
Natural heritage areas	3	Statutory: Legal protection
Proposed natural heritage areas	2	Statutory: Protection priority
Salmonid rivers	3	Statutory: Legal protection
Special areas of conservation (SACs)	3	Statutory: Legal protection
Special protection areas (SPAs)	3	Statutory: Legal protection
Woodland habitats	2	Value judgment: Environmental quality
Water		
Aquifer vulnerability		Value judgment: Environmental quality
High/extreme/rock near surface	3	
Moderate	2	
Low/Water	1	
Aquifer categorisation		Value judgment: Environmental quality
Pure limestones that are designated as karst aquifers	3	
Pure limestones that are not designated as karstic aquifers, impure limestones and precambrian marbles	2	
Non-carbonate rocks	3	
Groundwater source protection areas	3	Statutory: Protection priority
RPA Nutrient sensitive areas (Lakes)	3	Statutory: Protection priority
RPA Nutrient sensitive areas (Rivers)	3	Statutory: Protection priority
RPA Recreational waters (Lakes)	3	Statutory: Protection priority
RPA Recreational waters (Coastal/Rivers)	3	Statutory: Protection priority
RPA Water dependant habitats (SAC)	3	Statutory: Protection priority
RPA Water dependant habitats (SPA)	3	Statutory: Protection priority
Wetlands	2	Statutory: Protection priority
WFD Groundwater status		Statutory: Environmental quality
Good	1	
Poor	2	
WFD Lake status		Statutory: Environmental quality
High	2	
Pass/good/moderate	1	
Poor/bad	2	
WFD River status		Statutory: Environmental quality
High	2	
Pass/good/moderate	1	
Poor/bad	2	
Soils and geology		
Geoparks and geosites	3	Statutory: International importance
Outcrops	2	Value judgment: Protection priority
Peatlands	2	Statutory: Protection priority
Well drained soils	2	Value judgment: Environmental quality
Poorly drained soils	2	Value judgment: Environmental quality
Air and climatic factors		
Air zones		Value judgment: Environmental quality
Dublin/cork/cities	11	
Rural areas		
Coal restricted areas		Value judgment: Environmental quality
Restricted	11	
Unrestricted		
Historical flood extents	3	Statutory: Risk status
Cultural heritage		
National inventory of architectural heritage	2	Statutory: Protection priority
Record of monuments and places	3	Statutory: Legal protection

assuming that environmental sensitivity and, hence, the potential for significant environmental impacts are dependent, among other things, on the spatial distribution of the effects and of the affected natural resources. Potentially affected environmental factors and their relative importance are context-specific due to varying local conditions and perceptions (Wang et al., 2008), and to the specificities of planning hierarchies and sectors (González et al., 2011a). The Widget undertakes an aggregated analysis of context-specific spatial datasets or criteria that illustrate not only the location and spatial correlation of environmental features on the landscape but also their baseline status (e.g. environmental quality indicators) and the importance ascribed to them by stakeholders/the public at a given point in time. The Widget can be repeatedly applied, varying the criteria and weights brought into the analysis as appropriate, to examine how different considerations and (changing) importance values may alter the relative sensitivity of the receiving environment.

The SEA-relevant spatial datasets in the ESM Webtool are incorporated in vector format (providing detailed resolution of discrete point, line or polygon features) and can be viewed and queried by the end-users as such. However, to enable map algebra in order to combine overlaying datasets for calculating aggregated sensitivity, vector datasets are converted to raster format. Furthermore, to facilitate an aggregated and comparable representation of biophysical criteria, the relative sensitivities of each dataset need to be harmonised (Antunes et al., 2001; González et al., 2011b; Wang et al., 2008; Yoo et al., 2014). Harmonisation of indicator values enables combination of multiple criteria into a single sensitivity index. The overall degree of sensitivity of an area can be obtained through aggregation of harmonised individual indicator values occurring in that area. To achieve this, the raster datasets were harmonised by reclassifying them according to the agreed scientific scores as detailed below. Such raster datasets are only used for environmental sensitivity calculations; they are automatically called upon when selecting the environmental criteria and weights in the Widget. A raster resolution or pixel size of 100 m × 100 m has been adopted for ESM Widget calculations and outputs. This cell size preserves sufficient detail for SEA as it reasonably represents environmental and land-use processes and patterns at the landscape scale (Antunes et al., 2001; Geneletti et al., 2007; González et al., 2011a; Marull et al., 2007). To facilitate comparability of results, a consistent sensitivity index is applied (Fig. 3).

3.2. Applying the Widget

The Widget prompts the end-user to select a study area and, subsequently, SEA themes and criteria (i.e. spatial datasets) that address plan/programme considerations (Fig. 2 and Table 1). The criteria have embedded the consented scientific scores. The selection of themes and criteria should be informed, and contextualised to the planning hierarchy and sector for a meaningful and focused assessment (Jones et al., 2005; Therivel, 2004). For example, in the context of a renewable energy plan, population and human health, biodiversity, flora and fauna,

Fig. 2. Screenshot of the Environmental Sensitivity Mapping (ESM) Webtool illustrating environmental themes, associated datasets/criteria and weight selection options.

and landscape themes could be prioritised in the assessment.

The Widget also promotes public participation. It enables inputting subjective values that capture stakeholder and/or public concerns by means of significance weights applied to each environmental theme selected. As per selection of environmental criteria, weights can be established by the end-user but, ideally, they should be consented among stakeholder during SEA scoping and public consultation (as the Widget enables the incorporation of a single weight per environmental theme). Alternative weighting scales were presented and discussed with stakeholders. For simplicity and user-friendliness, it was agreed the provision of two weighting options: 1 to maintain the scientific scores as they are; and 2 to emphasise the significance of a given theme in comparison to other/s included in the analysis. Stakeholders felt that this “emphasis” was sufficient to highlight relevant considerations as the weight doubles the scientific scores of environmental criteria within the selected theme, intensifying the overall sensitivity of the related areas. Once the environmental themes, criteria and weights are defined, the Webtool generates “tailored” environmental sensitivity maps for the sectoral plan or programme under assessment (Fig. 3).

3.3. Consultation

The development of the ESM Webtool and Widget was subject to extensive stakeholder consultation (EPA, 2016a). Two workshops were held engaging 43 practitioners, researchers and governmental representatives involved in SEA and environmental planning (referred to as stakeholders from hereon for simplicity). They were identified and invited to participate on the basis of their expertise and roles, which ranged from undertaking SEAs and preparing sectoral plans and strategies, to gathering and/or creating SEA-relevant spatial datasets, and to reviewing SEA environmental reports to inform decision-making. A range of experts across the various SEA-relevant themes took part in these workshops (e.g. biodiversity officers, hydrologists, planners, etc.).

The objective of the first workshop was to harmonise the relative degrees of sensitivity (technically referred to as ‘scientific scores’ from hereon) of the environmental spatial datasets. Preliminary scientific scores for each dataset included in the Widget were put forward by the project team to the workshop participants. These preliminary scores were initially based on statutory measures of quality, protection and risk that capture the baseline status, translating these to relative sensitivities on a scale of 1 – meaning low, to 3 – high (Table 1). The applied harmonisation rules assume that the lower the quality status, the bigger the associated risk, or the greater the level of protection assigned to the environmental criterion, the greater its sensitivity and the higher the scientific score assigned to it. Stakeholders were asked to revise these preliminary scores and provide expert input for their adjustment. The revised scores were revisited at the second workshop and agreed (for further detail see González, 2017). This second workshop also provided the stakeholders an opportunity to apply and review the pilot ESM Webtool, and stakeholder feedback contributed to its betterment. The revised version was then tested during two sectoral workshops, engaging 28 stakeholders – some of which were present in the initial two workshops. The objective of the sectoral workshops was to test the applicability of both the visualisation and information capabilities of the ESM Webtool and the reliability and usefulness of environmental sensitivity maps produced through the application of the Widget in a number of case studies. Feedback was sought from participants on the meaningfulness of the produced maps and on their capacity to provide additional insights that may be useful in the SEA and planning processes.

3.4. Sectoral case studies

The ESM Webtool was tested during two sectoral workshops relating to hypothetical scenarios for the land-use planning and renewable energy sectors. These sectors were selected on the basis of current SEA practice; approximately 75% of SEAs undertaken in Ireland relate to land-use and 5% to energy planning (EPA, 2016b). The mapped outputs of the workshops were subsequently contrasted to real-life SEAs to ascertain their validity and reliability.

For land-use planning, one scenario prioritised natural and cultural heritage protection while the other promoted residential and industrial development. In renewable energy planning, the first scenario aimed at achieving electricity targets through wind only, while the second scenario also contemplated solar energy and biomass. On the basis of these sets of scenarios, workshop participants were prompted to scope analysis criteria and create environmental sensitivity maps for counties Clare and Kildare, in the South-West and East of Ireland respectively. These counties were chosen due to their recent preparation of a county development plan and wind energy strategy (AIRO, 2014; CCC, 2015).

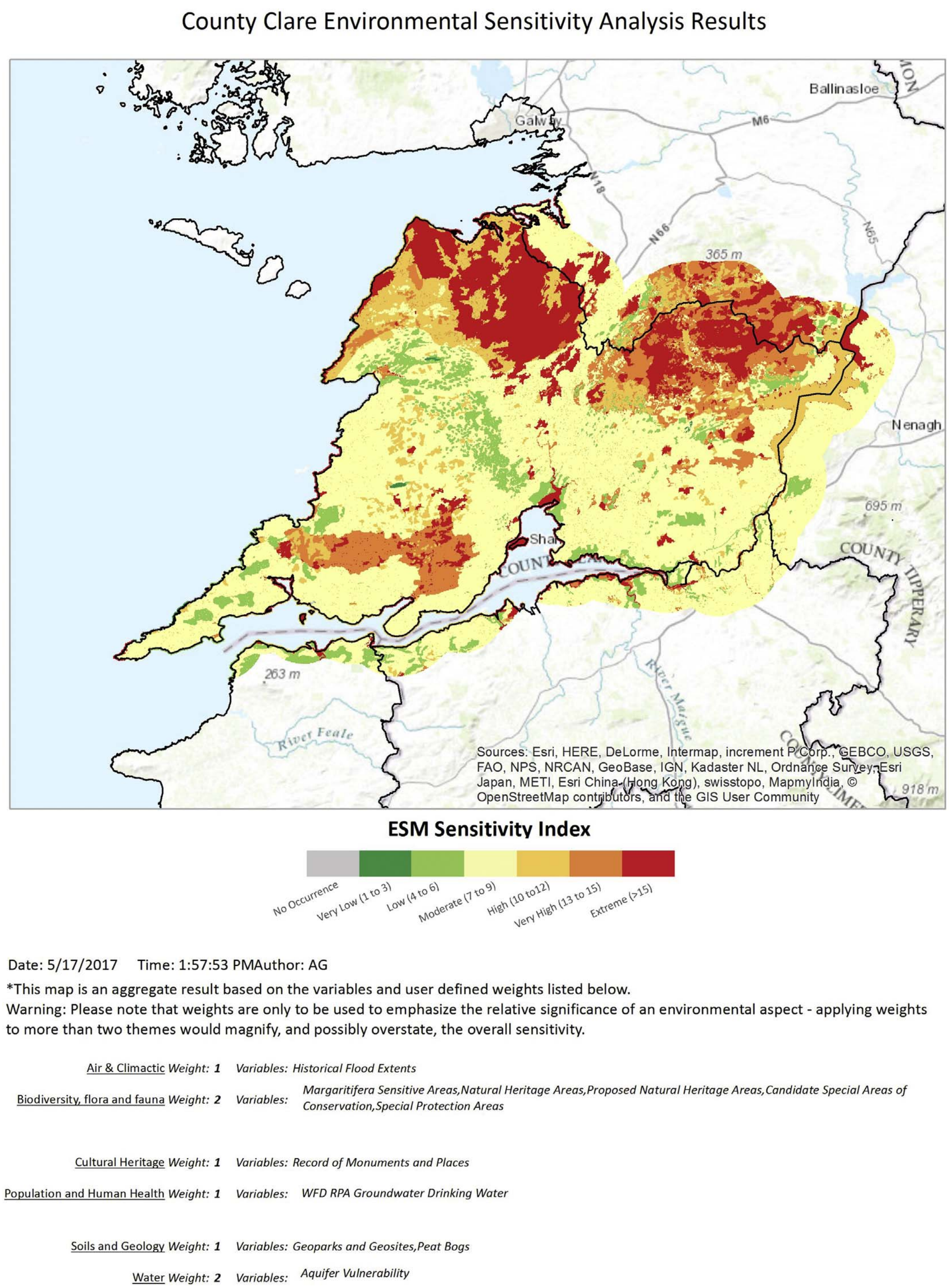

Fig. 3. Typical Environmental Sensitivity Mapping (ESM) Widget output.

4. Results

4.1. Agreeing criteria and scientific scores for the Widget

Certain datasets in the Webtool, such as administrative boundaries or water management units, do not represent sensitivity and, therefore, were not included in the Widget. Other datasets, such as soil classification, could not be directly translated into relative sensitivity scores during the consultation workshops and proxies, such as soil permeability, were developed.

All preliminary scientific scores assigned by the project team on the basis of statutory measures of quality, protection and risk were subject to debate but the large majority were retained throughout consultation (González, 2017). In some thematic areas (e.g. biodiversity) wide agreement was reached, mainly due to existing statutory protection measures (Table 1). In other areas, such as population or material assets, divergences in value judgments resulted in no definite scores being assigned to certain criteria. Stakeholders highlighted that the significance of these spatial datasets is sector-specific (e.g. it may be a good or a bad thing that population is high/low or goes up/down in the study area, and the sensitivity of waste treatment plants should be graded by capacity for certain assessments). Discussion led to agree that population and material assets are not representative of environmental sensitivity as such and, therefore, these criteria were also omitted from the Widget.

4.2. Feedback on the applicability of the Webtool and Widget

Stakeholders commended the added value of the Webtool, noting that access to multiple datasets in a single platform is an excellent resource to support SEA processes. Others pointed to the fact that no GIS expertise is needed to apply it and produce context-specific environmental sensitivity maps that, as noted by a practitioner, are "robust and useful (…) to identify areas where development would need to be carefully considered and sensitively planned". The large majority of gathered responses (95%) indicated that the output maps meaningfully highlight potential sensitivities, providing a good visual overview of different degrees of sensitivity at a strategic level and, in this way, they improve understanding on suitable/exclusion areas for development. A representative from the Environmental Protection Agency noted that "the index enables creating comparable results and easier to analyse outputs". Nevertheless, a number of participants (23%) observed that knowledge of the area may be required to appropriately interpret the outputs. Moreover, the majority of stakeholders (53%) referred to the influence of available datasets on the applicability of the Widget as well as to the effects of their level of detail/scale on the validity of outputs. Inclusion of additional datasets (such as landscape sensitivity, scenic views, ecological corridors, etc.) was recommended, as well as additional datasets as these become available in order to continue to develop the Webtool and provide a fully comprehensive set of criteria.

4.3. Analytical results from the land-use planning case study

During the preparation of the draft SEA for the Clare County Development Plan (CCC, 2015), an environmental sensitivity analysis was undertaken following national guidance (EPA, 2009, 2015). Clare County Council applied the datasets and weights presented in Table 2 resulting on the sensitivity map in Fig. 4. This map shows the range and concentration of physical environmental factors that require consideration in identifying locations for potential future growth. Noteworthy are the areas to the North and North-East of the county which include ecological designations, heritage landscapes and aquifer vulnerability. Interestingly, the SEA of the County Development Plan also notes the sensitivity of the Southern lands, along the Shannon Estuary (CCC, 2015). It is observed that the flood plains and heritage landscapes, among other considerations, make these lands sensitive to development – yet the mapped outputs do not capture such issues (Fig. 4, top).

The environmental sensitivity considerations for the assessment of Clare County Development Plan were mirrored at the ESM workshop in so far as possible (i.e. certain datasets are not available in the Webtool, such as nature reserves, and the level of detail in others differs - for example, flood risk zones are not publicly available at national level so historical flood events are used as a proxy in the Widget). The results are comparable as both maps capture the overall sensitivity of the Northern lands - and, in some cases, specific pockets of high sensitivity correlate (Fig. 4).

A further sensitivity map was created to include all the datasets proposed in the workshop land-use scenario that prioritised natural and cultural heritage protection for county Clare (Fig. 5). This entailed appending the following datasets and scientific scores to those listed in Table 2: habitats protected under Article 17 of the Habitats Directive (EC, 1992) with a scientific score of 3; freshwater pearl mussel sensitive areas where catchments of protected populations have a scientific score of 3, and catchments with previous records but current status unknown are given a score of 2; sensitive landcover (such as ancient woodlands, natural grassland, beaches, saltmarshes, peatlands and water bodies) as well as 100 m buffer areas around rivers, lakes and cultural heritage features, all with scientific scores of 3. The mapped output (Fig. 5) was perceived by workshop participants, in particular by Clare County Council's environmental officer, to more appropriately capture environmental sensitivities. It identifies, among other areas, the highly sensitive zones along the coast and the Shannon estuary, acknowledged in the SEA Environmental Report but not captured in the associated map (Fig. 4, top).

4.4. Analytical results from the wind energy strategy case study

The planning team at Kildare County Council undertook a strategic spatial examination of suitable areas for wind energy development (AIRO, 2014). In that process, spatial datasets were aggregated to identify planning and environmental constraints to development. In doing so, a number of criteria were assigned very high scores to automatically rank them as extremely sensitive, rendering the associated areas deliberately unsuitable for wind energy development (Table 2 and Fig. 6).

During the ESM workshop, a number of maps were produced by participants to explore the suitability for wind, solar and biomass projects. There were differences in the criteria and assigned scores adopted by the County Council and those applied at the workshop (e.g. scenic value landscapes or Record of Protected Structures). Despite the expected evident differences in the distribution and degree of sensitivity resulting from the differing assessment parameters, the maps are consistent in the identification of most suitable lands (i.e. cutaway peatlands with low constraints/sensitivity) to the North-West of the county (Fig. 6).

5. Discussion: Added value, limitations and lessons learnt

Workshop participants consider the Webtool to be a good resource to support SEA by pulling together a range of environmental variables and datasets that have not been easily accessible previously, and by providing quick mapping outputs relevant to the assessment process. In Ireland, like in many other European Member States, environmental and planning datasets are provided by disparate sources through various online platforms (e.g. GeoHive, National Biodiversity Data Centre, Marine Irish Digital Atlas, Heritage Viewer, etc.) and, in some cases, are retained in-house constraining their ready access. The Webtool pulls them together and provides an operational Widget that rapidly generates context-specific sensitivity mapping outputs to support SEA.

The advantages of applying spatial data and GIS to environmental assessment have been extensively acknowledged in literature, including transparency, objectivity and enhanced information delivery (e.g. Atkinson and Canter, 2011; González, 2012; Marull et al., 2007; Vanderhaegen and Muro, 2005). In light of these benefits, research has repeatedly attempted to develop GIS-based multi-criteria methods and decision-support systems for environmental assessment and planning. However, in practice, applying exploratory GIS solutions seems to be hindered by a lack of 'know-how' or by data requirements (Riddlesden et al., 2012). The Webtool bridges this gap by providing a pragmatic operational platform that requires little technical skills and no data input. Moreover, it reduces resource and time requirements. Based on anecdotal experience, preparation and aggregation of data for the creation of environmental sensitivity maps can take a number of specialised person/days; the Webtool enables intuitive creation of such maps in a matter of minutes.

Pilot testing through the sectoral workshops verified that the Webtool could enable recreating in-house SEA mapping if current data availability limitations can be overcome. As noted by an environmental officer "the ESM output compares well and may actually be better than the process undertaken [in-house]". The ESM Webtool is fully reliant on publicly accessible spatial datasets and, as a result, completeness and resolution remain issues. It is acknowledged that data availability and quality issues affect spatial assessment outputs (González, 2012; Cavan and Kingston, 2012). Therefore, addressing current data gaps resulting from availability and accessibility constraints, and tackling scale and

Table 2
Environmental criteria and associated scientific scores included in the case studies.

In-house sensitivity criteria	Score	Sectoral testing of the Webtool
Clare County Development Plan		
Real-life: Fig. 4 Top Map		Sectoral testing: Fig. 4 bottom map
Aquifer vulnerability		Dataset available but a different set of scientific scores applied in the Webtool as per stakeholder feedback: Rock near surface = 3; Extreme = 3; High = 3; Moderate = 2; and Low = 1.
Rock near surface	5	
Extreme	4	
High	3	
Moderate	2	
Low	1	
Ecological designations		All datasets are available and included with the same set of scientific scores.
Special areas of conservation	3	
Special protection areas	3	
Natural heritage areas	3	
Proposed natural heritage areas	2	
Flooding		Historical flood events are only available in the Webtool. A scientific score of 3 is assigned to this proxy dataset.
Flood risk zone A	3	
Flood risk zone B	2	
Groundwater status		Dataset available but different scientific scores applied as per stakeholder feedback: Good = 1; and Poor = 2.
Good	4	
Poor	2	
Landscape heritage	3	Not available in the Webtool but landscapes designated as sensitive in the County Development Plan included as a proxy with a scientific score of 3.
Nature Reserves	3	Excluded from the analysis as the dataset is not available in the Webtool.
River water body status		Dataset available but a different set of scientific scores applied as per stakeholder feedback: High = 2; Good = 1; Moderate = 1; and Poor = 2.
High	5	
Good	4	
Moderate	3	
Poor	2	
Source protection areas	3	Dataset available and included with the same scientific score.
Wetland habitats	3	Dataset excluded from the analysis as it is not available in the Webtool.
Kildare Wind Energy Strategy		
Real-life: Fig. 6 Left Map		Sectoral testing: Fig. 6 Right Map
Cultural heritage		Datasets for protected structures and architectural conservation areas were excluded as they are currently not available in the Webtool. The dataset for monuments and places is available but was included with the maximum scientific score of 3.
Architectural conservation areas (200 m buffer)	7	
Record of monuments and places (100 m buffer)	7	
Record of protected structures	7	
Dwellings/urban areas	7	Dataset available but included with the maximum scientific score of 3.
500 m buffer		
Ecological designations		All datasets are available but were included with a scientific score of 3, except for Proposed Natural Heritage Areas that were assigned a score of 2 by the consulted stakeholders.
Special areas of conservation	1	
Special protection areas	1	
Natural heritage areas	1	
Proposed natural heritage areas	1	
Land cover		Datasets available but included with a scientific score of 3; except for forestry areas which were assigned the same scientific score of 1.
Beaches, dunes, saltmarshes, inland marshes, water bodies	1	
Forestry	1	
Landscape heritage		The specific landscape datasets are not available in the Webtool (as they are collated at county level only), so the proxy Areas of Outstanding Natural Beauty was included with a score of 3.
Areas of high amenity and high scenic value landscapes	7	
Medium scenic value landscapes	1	
Designated scenic views/prospects	1	
200 m buffer around the Garden Survey and major Demesnes)	7	
Landslide sensitivity		Dataset available and included with the same scientific score.
Slope > 15% and > 4% in peatland areas	1	
Rivers and lakes		Dataset available but included with the maximum scientific score of 3.
100 m buffer	7	
Transport corridors		Datasets available but included with a 100 m buffer for all transport corridors and the maximum scientific score of 3.
200 m buffer from motorways and major roads	7	
100 m buffer from regional roads and railway lines	7	
Waters		Datasets available but included with a scientific score of 3.
Catchment with *M. margaritifera* (Freshwater pearl mussel)	1	
Salmonid waters	1	
Wind speed		Dataset available but included with the maximum scientific score of 3.
< 7 m/s at 75 m hub height	7	

quality limitations in the datasets included in the Webtool is warranted for a fully comprehensive and detailed sensitivity analysis. The ESM outputs can be easily refined as existing data improve and as additional relevant data become available. The inclusion of existing local authority datasets, for example, would readily enhance the comprehensiveness of the Webtool, Widget and resulting sensitivity analysis.

The reliability of the sensitivity index depends not only on data availability and quality, but also on the parameters selected for inclusion in the analysis, as corroborated by Marull et al. (2007). The availability of more data for certain SEA themes in the Webtool (e.g. large number of water-related spatial datasets due to the Water Framework Directive requirements) is likely to tilt the balance of

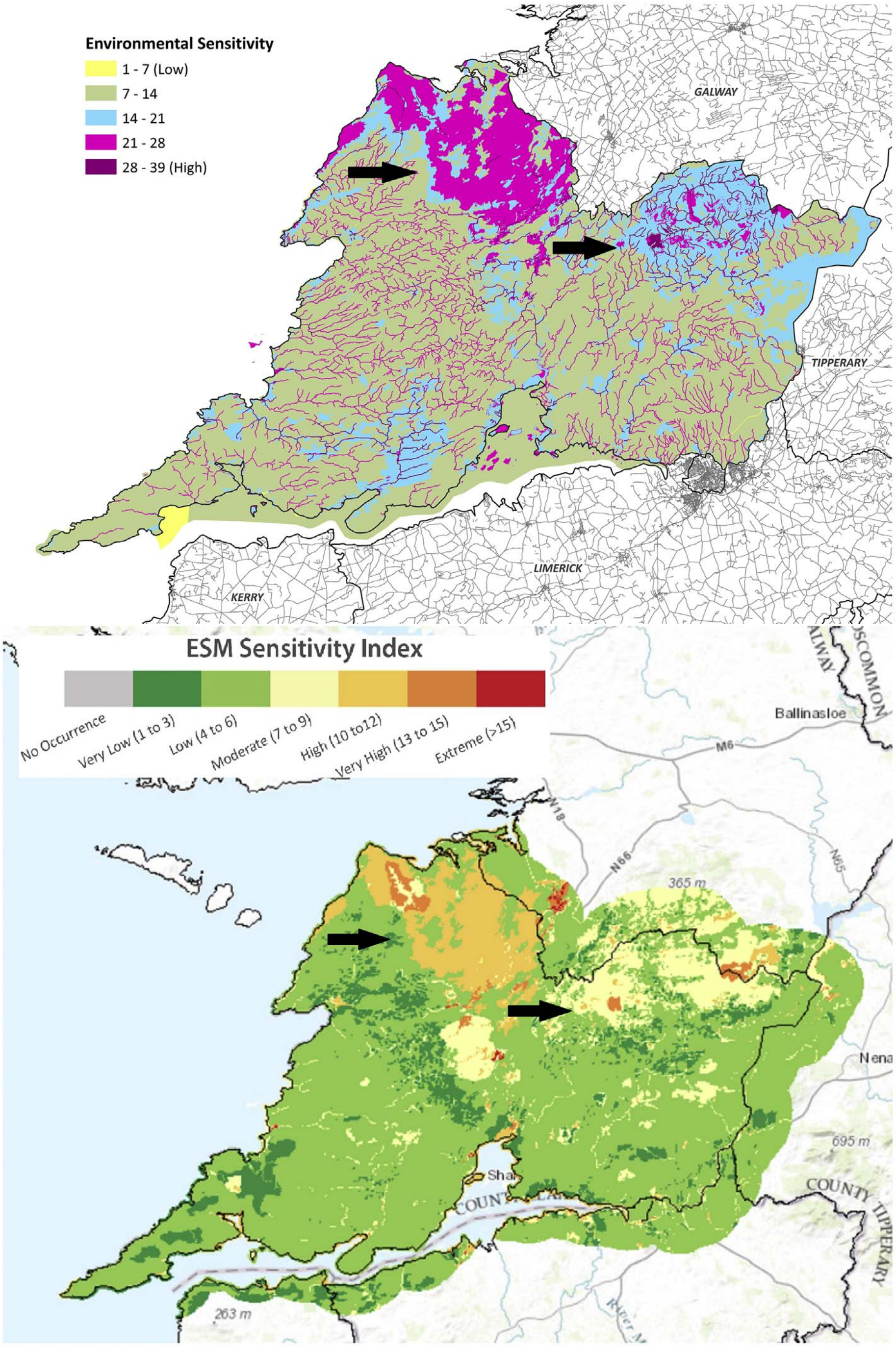

Fig. 4. Environmental sensitivity for land-use planning of county Clare. In-house datasets and analysis criteria (top - Source: Draft Clare County Development 2017–2023 Plan Strategic Environmental Assessment Report (CCC, 2015)) and mirrored using the Webtool, the outputs comprising a 10 km buffer zone around the administrative boundary (bottom).

environmental sensitivity towards a given theme if all criteria were selected. This has implications for the assessment outputs but can be addressed by ensuring that a sensible number of criteria are included within the relevant themes to avoid unintended bias. Similarly, various data combinations could generate relatively high sensitivity indices for certain areas where a single sensitivity criterion may be present (e.g. for a woodland area when simultaneously selecting ancient woodlands, the forest inventory, and Special Protection Areas and habitats pertaining woodlands protected under the Habitats Directive – EC, 1992). Nevertheless, this may be a desired output if the accumulated sensitivity (e.g. due to multiple environmental quality and protection measures) of the area is to be highlighted. The Webtool provides the flexibility to run the geoprocessing Widget under different criteria, as many times as desired/necessary, and examine the effects of incorporated variations. The above criteria selection considerations are addressed in the online user manual; any remaining difficulties affecting meaningful application of the Webtool and Widget could be easily tackled through training.

Scientific scores determine the intrinsic susceptibility of each environmental criterion and are the basis by which datasets are aggregated for the sensitivity analysis. In the Webtool, they range from 1 (low - e.g. coniferous forests) to 3 (high - e.g. ancient woodlands) and have been defined for each dataset in consultation with stakeholders (EPA, 2016a). Engaging a different set of actors may have resulted in a different set of scores. Efforts were made to engage a range of experts for each environmental theme (e.g. a National Parks and Wildlife Service divisional ecologist, local authority heritage officers, and ecologists from BirdWatch and private consultancies participated in the biodiversity theme) and wide or full agreement was reached on the assigned scores. Reaching consensus was important given their fixed nature (i.e. they cannot be modified by the user). Nevertheless, it is acknowledged

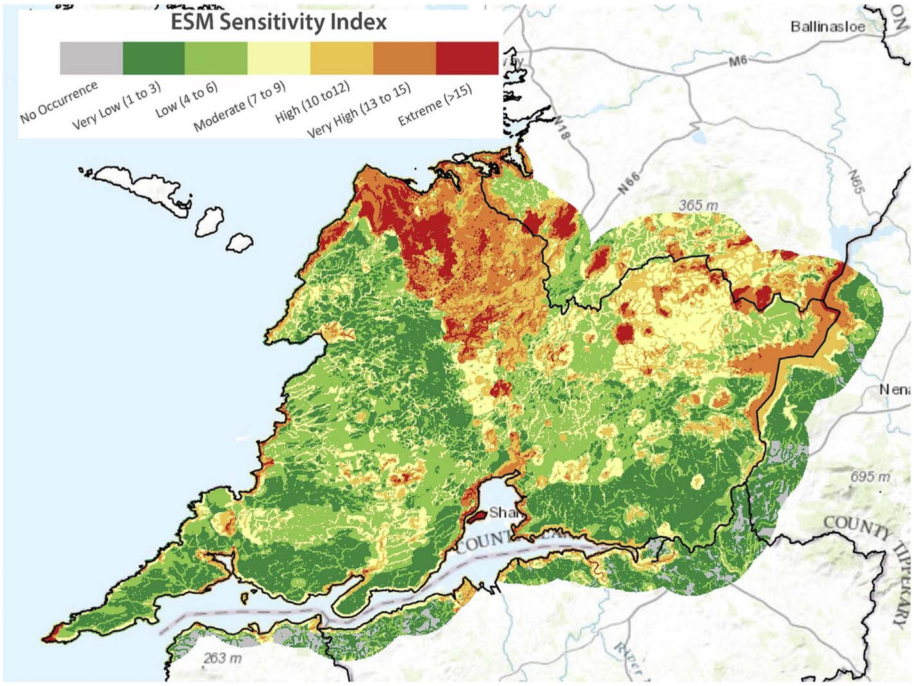

Fig. 5. Environmental sensitivity for land-use planning of county Clare using the Environmental Sensitivity Mapping workshop land-use planning scenario. The Webtool outputs comprise a 10 km buffer zone around the administrative boundary.

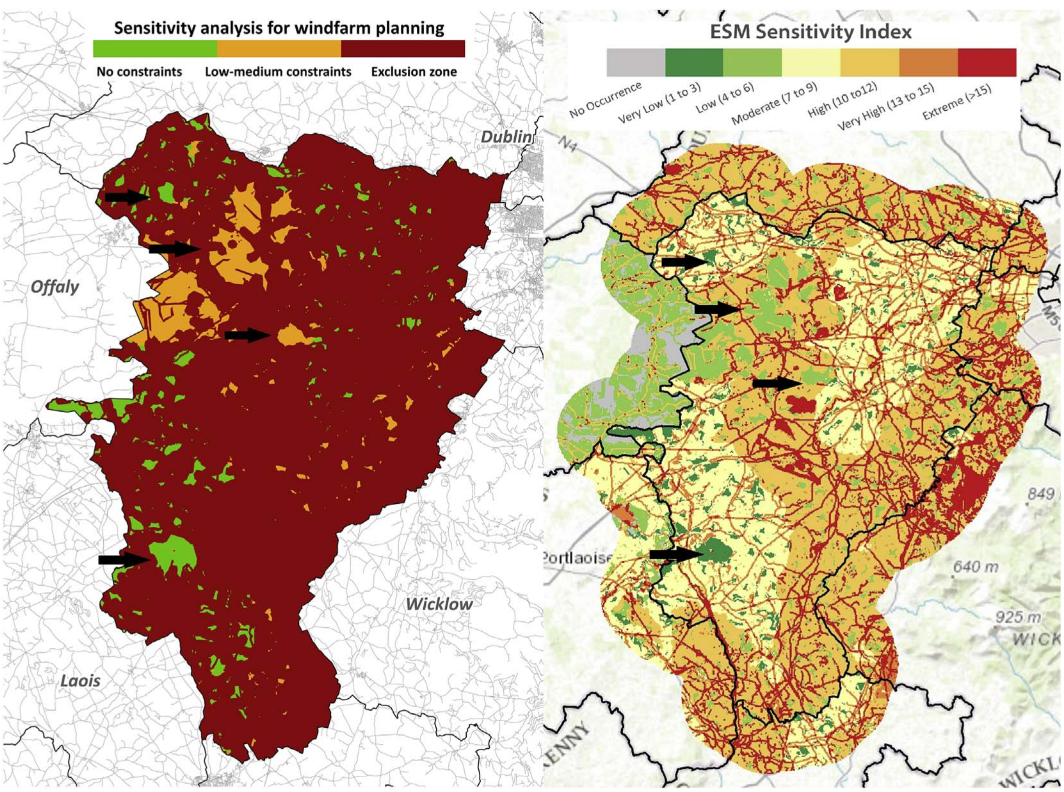

Fig. 6. Environmental sensitivity analysis for wind energy planning in county Kildare – prepared by the All Ireland Research Observatory (AIRO) for the County Council (left), and mirrored using the Webtool which comprises a 10 km buffer zone around the administrative boundary (right).

that the perception of individuals involved and their agendas significantly influence value judgments (González et al., 2011b; Lawrence, 2007; Toro et al., 2012). Therefore, further consultation is warranted to ascertain the range and validity of the scientific scores.

It has been argued that sensitivity analysis increases objectivity of assessments (Kværner et al., 2006; Marull et al., 2007). Yet, subjectivity needs to be incorporated in the form of selection criteria and significance weights to ensure a focused assessment (Jones et al., 2005; Therivel, 2004), one which addresses context-specific considerations and local perceptions (Adger, 2006). The inclusion of significance weights not only contributes to stakeholder engagement, it also facilitates the creation of context-specific maps that capture differing degrees of concern associated with different planning alternatives. However, where different public/stakeholders groups are consulted, variations in the importance assigned to each environmental theme could result in diverging maps for a single assessment. Weights should be used in an informed manner (e.g. rationally defined in consultation with experts involved in the preparation and assessment of the plan/programme) to emphasise the significance of a given theme while deliberating personal and professional bias. While acknowledging possible variations in the resulting maps, the objective of this approach is to ensure that key issues/concerns are captured in the assessment and that public/stakeholder values are factored in. Interpretation of the mapped outputs must have due regard to the selected environmental themes and criteria, as well as to the assigned weights which are all recorded in the map layout (Fig. 3). The Webtool currently prevents assigning weights for full exclusion (as in the case of the Kildare Wind Energy Strategy sensitivity analysis). This was perceived by some of the stakeholders as a benefit (i.e. impeding the immediate creation of 'no-go' areas), and by others as a limitation (i.e. as this prevents to heighten the sensitivity of certain areas and natural resources). The effects that significance weights may have on the overall sensitivity index need careful consideration, as such weights may emphasise/magnify a less sensitive environmental criteria and thus dilute highly sensitive criteria. In order to address this, an evaluation of the effect that stakeholder perceptions and related weights may have on the ESM outputs, that is on the resulting sensitivities across a region, is recommended (Chen et al., 2010; Geneletti, 2010).

The sensitivity maps provide a meaningful backdrop against which proposed sectoral planning alternatives can be assessed. The ESM index provides a composite illustration of the accumulated sensitivity, facilitating the spatial examination of the potential for adverse cumulative effects. By assuming that the overall relative environmental sensitivity of a given area at a given point in time directly relates to: a) the overlapping number of environmental criteria at that location; b) their conservation/quality/risk status as defined by legislation or expert knowledge; and c) their significance as perceived by end-users/stakeholders, the index ensures that context-specific considerations, statutory requirements and public values are all factored in. It brings together qualitative and quantitative spatial information, and objective and subjective values in a meaningful way, and all parameters are transparently computed. Although the aggregated index may, in principle, result in individual environmental criteria being obscured, the ESM Webtool permits identifying and querying all criteria co-occurring at a given location, and in this way enables scrutinising all underlying sensitivities. Moreover, these and their weights are identified in the print out map (Fig. 3).

To be useful to planners, data and indices must be reliable at the scale required for decision-making (Partidário, 2007). Workshop participants considered that the Webtool provides appropriate resolution and detail for SEA. It provides a quantitative cartographic index that combines relevant spatial data and expert knowledge through GIS geoprocessing techniques to support planning and decision-making. The outputs are not intended to identify no-go areas or provide green light to development. All vector datasets have been converted to 100 m × 100 m resolution raster files to facilitate geoprocessing; this loss of local level detail impedes fully representative consideration of issues at local level and, indeed, for EIA. The output maps aim to highlight the relative environmental sensitivity of different areas at a strategic level. Given its strategic nature and acknowledging the limitations discussed above, they are to be used to provide early warning, inform on the potential for land-use conflicts and cumulative effects, and in this way, promote evidence-based planning. It is within this basis that the Webtool and Widget can play a significant role in informing SEA.

The Webtool focuses on the baseline environment (i.e. starting point). It has been observed that "how?", "why?" and "to what?" the system is susceptible need to be examined for a comprehensive sensitivity analysis (Aretano et al., 2015). The Webtool permits exploring why environmental criteria are susceptible by interrogating the attributes associated to each dataset. Contextualising the selection of environmental criteria to the scope of the plan/programme permits strategically addressing to what they are susceptible, but further development of the Webtool is necessary to address "how?" and work towards a system-approach when assessing sensitivity.

6. Conclusion and future directions

The implementation of simple, systematic, replicable and time- and resource-efficient methods to support the various SEA stages, such as the ESM presented in this paper, can be seen as key in providing the foundations for consistency and transparency in impact assessment practice. The ESM Webtool provides an operational framework that spatially defines sensitive features and lands, thus providing a critical basis for SEA-related sectoral planning discussions and for developing alternatives that avoid or minimise potentially incompatible or unsustainable zonings. Such a standardised foundational analysis of the receiving environment's capacity to absorb development, and hence impact, can provide an objective account of the baseline environment, as well as additional insight on susceptibility and resilience. Moreover, the involvement of stakeholders in defining criteria and scores in the Widget can be considered itself a component of the SEA process as it enables tailoring criteria and value judgments to the planning hierarchy and sectoral characteristics of the plan/programme under assessment. The novelty however is on the provision of an online geoprocessing Widget that enables 'on-the-fly' creation of context-specific maps that capture the relative sensitivity of the plan area subject to SEA. It has been developed through GIS using simple mathematical language that can be understood by planners and decision-makers. The pilot tests validate the applicability of the Webtool and the validity of the outputs. Stakeholders welcomed the provision of an intuitive and interactive mapping system, commended the consolidated data portal, the robustness of the geoprocessing tool and the usability of the sensitivity maps. Nevertheless, further efforts are needed to gather and centralise datasets, and address current data gaps and scale/quality limitations.

The Webtool could be enhanced by including additional datasets as these become available. Moreover, datasets for Northern Ireland could also be incorporated to account for potential transboundary sensitivities, as well as offshore datasets to support SEAs of plans and programmes related to the marine environment. While the current phase of the Webtool is best applied to the screening, scoping and baseline stages of SEA (i.e. the analytical starting-point), it also provides a robust basis for informing the later stages (e.g. impact assessment and mitigation). Additional geoprocessing tools can be incorporated to further enhance its potential and capabilities. For example, a systematic approach has been recently developed to examine spatially accumulated anthropogenic actions and effects (Lally, 2016), which can contribute towards adopting a system-approach when measuring sensitivity. In all cases, provision of additional geoprocessing tools in the Webtool needs to be done within a framework of flexibility to accommodate sectoral assessment requirements and context-specific considerations.

Given the current lack of systematic approaches that translate to practice, the ESM Webtool and Widget present a pragmatic and easily applied method, and a first-step towards consistency in SEA-related environmental sensitivity analysis practice in Ireland and, perhaps, beyond. It not only enables context-specific selection and aggregation of environmental variables and their relative sensitivity, but also facilitates public and stakeholder participation, and enhances assessment transparency and comparability. Environmental assessors, land-use planners, decision-makers, lobby groups and the general public can all access the Webtool and systematically explore the environmental features and attributes that may make an area inherently susceptible or resilient to changes from plan/programme implementation.

Acknowledgments

This work was supported by the Environmental Protection Agency, under grant number 2013-B-FS-4. The author is grateful to Justin

Gleeson, Eoghan McCarthy and Katie Goodwin who have been invaluable in the development of the Webtool and Widget. The author would also like to extent her gratitude to the project Steering Committee and to all the consulted stakeholders for participating in the project and for their insightful feedback.

References

Adger, W.N., 2006. Vulnerability. Glob. Environ. Chang. 16 (3), 268–281. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.006.

AIRO, 2014. Development of Wind Strategy Baseline Maps for Kildare County Council. Unpublished Report. All Ireland Research Observatory, Ireland.

AIRO, 2016. Environmental Sensitivity Mapping. All Ireland Research Observatory, Ireland (Retrieved from). http://airomaps.nuim.ie/id/ESM_GP/.

Antunes, P., Santos, R., Jordão, L., 2001. The application of geographical information systems to determine environmental impact significance. Environ. Impact Assess. Rev. 21, 511–535. http://dx.doi.org/10.1016/S0195-9255(01)00090-7.

Aretano, R., Semeraro, T., Petrosillo, I., De Marco, A., Pasimeni, M.R., Zurlini, G., 2015. Mapping ecological vulnerability to fire for effective conservation management of natural protected areas. Ecol. Model. 295, 163–175. http://dx.doi.org/10.1016/j.ecolmodel.2014.09.017.

Atkinson, S., Canter, L., 2011. Assessing the cumulative effects of projects using geographic information systems. Environ. Impact Assess. Rev. 31, 457–464. http://dx.doi.org/10.1016/j.eiar.2011.01.008.

Brooks, N., Adger, W.N., Kelly, P.M., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Glob. Environ. Chang. 15, 151–162. http://dx.doi.org/10.1016/j.gloenvcha.2004.12.006.

Carpenter, S.R., Walker, B.H., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765–781. Retrieved from. -. http://eprints.icrisat.ac.in/4240/1/Ecosystems_4_8_765%E2%80%93781_2001.pdf.

Cavan, G., Kingston, R., 2012. Development of a climate change risk and vulnerability assessment tool for urban areas. Int. J. Disaster Resilience Built Environ. 3 (3), 253–269. http://dx.doi.org/10.1108/17595901211263648.

CCC, 2015. Draft Clare County Development Plan 2017–2023 – Strategic Environmental Assessment - Environmental Report. Clare County Council, Ireland Retrieved from. http://www.clarecoco.ie/planning/publications/draft-clare-county-development-plan-2017-2023-volume-10b-i-strategic-environmental-assessment-environmental-report-21917.pdf.

Chen, Y., Yu, J., Khan, S., 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environ. Model. Softw. 25 (12), 1582–1591. http://dx.doi.org/10.1016/j.envsoft.2010.06.001.

Chrysoulakis, N., Lopes, M., San José, R., Grimmond, C.S.B., Jones, M.B., Magliulo, V., Klostermann, J.E., Synnefa, A., Mitraka, Z., Castro, E.A., González, A., Vogt, R., Vesala, T., Spano, D., Pigeon, G., Freer-Smith, P., Staszewski, T., Hodges, N., Mills, G., Cartalis, C., 2013. Sustainable urban metabolism as a link between bio-physical sciences and urban planning: the BRIDGE project. Landsc. Urban Plan. 112, 100–117. http://dx.doi.org/10.1016/j.landurbplan.2012.12.005.

Cox, R., 2013. Environmental Communication and the Public Sphere. SAGE, Canada, Thousand Oaks.

Dietz, T., Stern, P.C. (Eds.), 2008. Public Participation in Environmental Assessment and Decision Making. The National Academies Press, Washington.

EC, 1992. Council directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. European Communities. European Commission. Off. J. Eur. Union L206. 22.7.1992. Retrieved from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=EN.

EC, 2001. Directive 2001/42/EC, of 27th June, on the assessment of the effects of certain plans and programmes on the environment. European commission. Off. J. Eur. Union L197/30. 21.7.2001. Retrieved from. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0042&from=EN.

EC, 2003. Directive 2003/35/EC of the European parliament and of the council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice council directives 85/337/EEC and 96/61/EC. European commission. Off. J. Eur. Union L156. 25/06/2003. Retrieved from. http://eur-lex.europa.eu/resource.html?uri=cellar:4a80a6c9-cdb3-4e27-a721-d5df1a0535bc.0004.02/DOC_1&format=PDF.

EC, 2014. Directive 2014/52/EU of the European parliament and of the council, of 16 April 2014, amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment. European commission. Off. J. Eur. Union L124/1. 25.4.2014. Retrieved from. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0052&from=EN.

EPA, 2009. GISEA Manual: Current Practice and Potential on the Application of Geographic Information Systems as a Support Tool in Strategic Environmental Assessment of Irish Land-use Plans. Environmental Protection Agency, Ireland.

EPA, 2015. GISEA Manual: Improving the Evidence Base in SEA. Environmental Protection Agency, Ireland Retrieved from: https://www.epa.ie/pubs/advice/ea/GISEA%20Manual%20Updated%202015.pdf.

EPA, 2016a. Stakeholder and Sectoral Workshops: Consultation Outcomes. National Environmental Sensitivity Mapping Tool. Unpublished report. Environmental Protection Agency, Ireland.

EPA, 2016b. SEA Statistics. Environmental Protection Agency, Ireland Retrieved from. http://www.epa.ie/monitoringassessment/assessment/sea/statistics/.

Füssel, H., 2007. Vulnerability: a generally applicable conceptual framework for climate change research. Glob. Environ. Chang. 17, 155–167. http://dx.doi.org/10.1016/j.gloenvcha.2006.05.002.

Gallopín, G., 2006. Linkages between vulnerability, resilience, and adaptive capacity. Glob. Environ. Chang. 16, 293–303. http://dx.doi.org/10.1016/j.gloenvcha.2006.02.004.

Geneletti, D., 2010. Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites. Waste Manag. 30 (2), 328–337. http://dx.doi.org/10.1016/j.wasman.2009.09.039.

Geneletti, D., Bagli, S., Napolitano, P., Pistocchi, A., 2007. Spatial decision support for strategic environmental assessment of land-use plans. A case study in southern Italy. Environ. Impact Assess. Rev. 27, 408–423. http://dx.doi.org/10.1016/j.eiar.2007.02.005.

González, A., 2012. GIS in environmental assessment: a review of current issues and future needs. J. Environ. Assess. Pol. Manag. 14, 1250007. http://dx.doi.org/10.1142/S146433321250007X. (23 pages).

González, A., 2017. A conceptualisation framework for building consensus on environmental sensitivity. J. Environ. Manag. 200, 114–122. http://dx.doi.org/10.1016/j.jenvman.2017.05.061.

González, A., Donelly, A., Jones, M., Klostermann, J., Groot, A., Breil, M., 2011b. Community of practice approach to developing urban sustainability indicators. J. Environ. Assess. Pol. Manag. 13 (4), 591–617. http://dx.doi.org/10.1142/S1464333211004024.

González, A., Gilmer, A., Foley, R., Sweeney, J., Fry, J., 2011a. Applying geographic information systems to support strategic environmental assessment: Opportunities and limitations in the context of Irish land-use plans. Environ. Impact Assess. Rev. 31 (3), 368–381. http://dx.doi.org/10.1016/j.eiar.2010.12.001.

Gupta, A., 2008. Transparency under scrutiny: information disclosure in global environmental governance. Glob. Environ. Polit. 8 (2), 1–7. http://dx.doi.org/10.1162/glep.2008.8.2.1.

Hegmann, G., Yarranton, G.A., 2011. Alchemy to reason: effective use of cumulative effects assessment in resource management. Environ. Impact Assess. Rev. 31, 484–490. http://dx.doi.org/10.1016/j.eiar.2011.01.011.

Iosjpe, M., Liland, A., 2012. Evaluation of environmental sensitivity of the marine regions. J. Environ. Radioact. 108, 2–8. http://dx.doi.org/10.1016/j.jenvrad.2011.08.001.

IPCC, 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge Retrieved from: http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg2/index.htm.

Jones, C., Baker, M., Carter, J., Jay, S., Short, M., Wood, C., 2005. Evaluating the SEA of Land-Use Plans. In: Jones, C., Baker, M., Carter, J., Jay, S., Short, M., Wood, C. (Eds.), Strategic Environmental Assessment and Land-Use Planning - An International Evaluation. Earthscan, London, pp. 28–43.

Kasperson, J.X., Kasperson, R.E., Turner, B.L., 1995. Regions at Risk: Comparisons of Threatened Environments. United Nations University Press, New York.

Kværner, J., Swensen, G., Erikstad, L., 2006. Assessing environmental vulnerability in EIA - the content and context of the vulnerability concept in an alternative approach to standard EIA procedure. Environ. Impact Assess. Rev. 26, 511–527. http://dx.doi.org/10.1016/j.eiar.2006.01.003.

Lally, A., 2016. Developing GIS Approaches to Cumulative Effects Assessment. Unpublished MSc Dissertation. Trinity College Dublin, Ireland.

Lawrence, D.P., 2007. Impact significance determination - pushing the boundaries. Environ. Impact Assess. Rev. 27, 770–788. http://dx.doi.org/10.1016/j.eiar.2007.02.010.

Li, A., Wang, A., Liang, S., Zhou, W., 2006. Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS: a case study in the upper reaches of Minjiang River, China. Ecol. Model. 192 (1-2), 175–187. http://dx.doi.org/10.1016/j.ecolmodel.2005.07.005.

Liao, X., Li, W., Hou, J., 2013. Application of GIS based ecological vulnerability evaluation in environmental impact assessment of master plan of coal mining area. Procedia Environ Sci 18, 271–276. http://dx.doi.org/10.1016/j.proenv.2013.04.035.

Luers, A.L., 2005. The surface of vulnerability: an analytical framework for examining environmental change. Glob. Environ. Chang. 15, 214–223. http://dx.doi.org/10.1016/j.gloenvcha.2005.04.003.

Marull, J., Pino, J., Mallarach, J.M., Cordobilla, M.J., 2007. A land suitability index for strategic environmental assessment in metropolitan areas. Landsc. Urban Plan. 81, 200–212. http://dx.doi.org/10.1016/j.landurbplan.2006.11.005.

Metzger, M.J., Rounsevell, M.D.A., Acosta-Michlik, L., Leemans, R., Schröter, D., 2006. The vulnerability of ecosystem services to land-use change. Agric. Ecosyst. Environ. 114 (1), 69–85. http://dx.doi.org/10.1016/j.agee.2005.11.025.

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., West, J., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. Glob. Environ. Chang. 14 (4), 303–313. http://dx.doi.org/10.1016/j.gloenvcha.2004.01.001.

Partidário, M.R., 2007. Scales and associated data – what is enough for SEA needs? Environ. Impact Assess. Rev. 27 (5), 460–478. http://dx.doi.org/10.1016/j.eiar.2007.02.004.

Pavlickova, K., Vyskupova, M., 2015. A method proposal for cumulative environmental impact assessment based on the landscape vulnerability evaluation. Environ. Impact Assess. Rev. 50, 74–84. http://dx.doi.org/10.1016/j.eiar.2014.08.011.

Riddlesden, D., Singleton, A.D., Fischer, T.B., 2012. A survey of the use of geographic information systems in English local authority impact assessments. J. Environ. Assess. Pol. Manag. 14, 1250006. http://dx.doi.org/10.1142/S1464333212500068. (14 pages).

Skondras, N.S., Karavitis, C.A., Gkotsis, I.I., Scott, P.G.B., Kalyd, U.L., Alexandris, S.G., 2011. Application and assessment of the environmental vulnerability index in Greece.

Ecol. Indic. 11, 1699–1706. http://dx.doi.org/10.1016/j.ecolind.2011.04.010.
Therivel, R., 2004. Strategic Environmental Assessment in Action. Earthscan, London.
Tomczyk, A.M., 2011. A GIS assessment and modelling of environmental sensitivity of recreational trails: the case of Gorce National Park, Poland. Appl. Geogr. 31 (1), 339–351. http://dx.doi.org/10.1016/j.apgeog.2010.07.006.
Toro, J., Duarte, O., Requena, I., Zamorano, M., 2012. Determining vulnerability importance in environmental impact assessment - the case of Colombia. Environ. Impact Assess. Rev. 32, 107–117. http://dx.doi.org/10.1016/j.eiar.2011.06.005.
Tran, L.T., O'Neill, R.V., Smith, E.R., 2010. Spatial pattern of environmental vulnerability in the Mid-Atlantic region, USA. Appl. Geogr. 30 (2), 191–202. http://dx.doi.org/10.1016/j.apgeog.2009.05.003.
Valle Junior, R.F., Varandas, S.G.P., Sanches Fernandes, L.F., Pacheco, F.A.L., 2014. Environmental land-use conflicts: a threat to soil conservation. Land Use Policy 41, 172–185. http://dx.doi.org/10.1016/j.landusepol.2014.05.012.
Vanderhaegen, M., Muro, E., 2005. Contribution of a European spatial data infrastructure to the effectiveness of EIA and SEA studies. Environ. Assess. Rev. 25 (2), 123–142. http://dx.doi.org/10.1016/j.eiar.2004.06.011.
Wang, X.D., Zhong, X.H., Liu, S.Z., Liu, J.G., Wan, Z.Y., Li, M.H., 2008. Regional assessment of environmental vulnerability in the Tibetan Plateau: development and application of a new method. J. Arid Environ. 72, 1929–1939. http://dx.doi.org/10.1016/j.jaridenv.2008.06.005.
Watson, J.J.W., Hudson, M.D., 2015. Regional scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation. Landsc. Urban Plan. 138, 20–31. http://dx.doi.org/10.1016/j.landurbplan.2015.02.001.
Yoo, G., Kim, R.A., Hadi, S., 2014. A methodology to assess environmental vulnerability in a coastal city: application to Jakarta, Indonesia. Ocean Coast. Manag. 102(A), 169–177. http://dx.doi.org/10.1016/j.ocecoaman.2014.09.018.