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Introducing a group spatial decision support system for use in strategic environmental assessment of onshore wind farm development in Mexico

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ABSTRACT

In this paper we introduce a method for potential use in strategic environmental assessment (SEA) which integrates knowledge and tools of Collective Intelligence, Complexity Theory and Geoprospective, via the implementation of a technological Group-Spatial Decision Support System (GSDSS), usable for scenario building for infrastructure project planning. It operates on the basis of interdisciplinary consensus of a multidisciplinary group of experts, without strict dependency on a spatial analysis based on a single cognitive stance, using existing historical data. The method is used in a study case on planning of onshore wind energy in Mexico, which has been developed through a collaborative Geoweb application, and is functioning in a distributed and asynchronous real-time way, so-called Geospatial System of Collective Intelligence (SIGIC). The significance of this research lies in demonstrating the feasibility of a collective intelligence analysis aimed at proposing spatial locations in an energy transition context within an SEA framework.

1. Introduction

Strategic Environmental Assessment (SEA) can be described as a decision support instrument for the formulation of sustainable spatial and other sectors' policies, plans and programmes (PPP), aiming to ensure an appropriate consideration of the environment (Fischer, 2003). In Mexico, it has neither taken any definite shape nor is it fully integrated into legislation, yet. The Secretary responsible for the environment in Mexico (SEMARNAP from 1994 to 1999; SEMARNAT from 2000 to present) has recognised the limitations of project Environmental Impact Assessment (EIA) for over fifteen years, and has considered SEA for policies, plans and programmes as a complementary instrument, which functions as a preventive mechanism for sustainable development. Under a federal initiative during the 1994–2000 administration, the Secretary of the Environment and Natural Resources stressed the importance of taking firm steps for the development and adoption of SEA. Potential areas of application were considered and the urgent need for Mexico to create a suitable SEA approach was acknowledged, taking into account international experience in the field (SEMARNAP, 2000).

It was suggested that it might be difficult to design a unique model of SEA, because of, amongst other things, the complexities of the dynamic processes of decision making. Nevertheless, while recognising this challenge, it is also deemed essential that progress be made in this area through an approach that overcomes limitations of the current method of analysis and project-based EIA.

Mexico has been using practices and approaches which resemble SEA, but which have been too random in application to enable change. However, some efforts have been made to improve practices, including the development and introduction of central government initiatives, proposals for amendments to relevant laws, and the initiation of pilot projects by governmental bodies. Examples include:

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- Environmental Impact Assessment: achievements and challenges for sustainable development 1995–2000 (SEMARNAP, 2000).
- Towards sustainable development: progress, challenges and opportunities (SEMARNAT, 2006).
- SEA of the Works Programme of the Electricity Sector in the Northeast Region for the Selection of Sites and Trajectories (CFE, 2009).
- Political-technical document to define and present SEA as a new tool for environmental management in Mexico (DGIRA, 2010).
- Potential benefits of SEA in the development planning in Mexico. Case study: The National Infrastructure Programme 2007–2012 (Ahumada et al., 2011).
- Environmental Sustainability, from concept to practice: an opportunity for the implementation of SEA in Mexico (Ahumada et al., 2012).
- Draft decree that reforms the General Law of Ecological Balance and Environmental Protection (Cámara de Diputados, 2016).

However, despite the brief mentioning of SEA in the recent Law of Energy Transition (SEGOB, 2015), a structured approach to SEA and an overall methodological framework are still missing.

Various authors have endorsed formalisation of SEA in Mexico. For instance, Luján Alvarez et al., (2004) suggested that strategic evaluation should be considered as a fundamental action in sustainable development programmes, aimed at assessing the changes that have to be made in order to achieve such development. In his context, Palerm (2005) discussed how SEA could be an effective tool to implement sustainable development and support the environmental integration discourse of the Mexican Government. Bravo et al. (2007) proposed the use of SEA as a tool to foster cross-cutting coordination between the different competent authorities in order to formulate, apply, evaluate and follow up on ecological and territorial regulations. Furthermore, Montañez-Cartaxo (2014) reported on the activities carried out to include SEA into the state-owned electric utility of Mexico as known as CFE. This was connected with the aim of promoting the incorporation of sustainability into the decision-making process of the company. Finally, Tejeda et al., (2014) called for a need to upgrade Environmental Assessment laws and methodologies in order to insert SEA in the country's legal and institutional frameworks.

The reasons for implementing SEA are based on which benefits are thought to result from its application. A range of benefits are said to result from SEA, including the support of PPP processes and an environmentally sound and sustainable development. Moreover, SEA allows for a more systematic and effective consideration of wider environmental impacts and alternatives at higher tiers of decision-making. In this sense, the rationale for applying SEA is connected with current shortcomings of PPP making (Fischer, 2003).

We believe that Environmental Assessment research needs to be extended to include methodologies and supporting tools to achieve an explicit inclusion of environmental objectives into national regulatory frameworks. SEA research has considered diverse aspects, including:

- The consideration of cumulative effects assessment (CEA) as an integral part of environmental assessment at both, project and more strategic levels (Therivel and Ross, 2007);
- The introduction of resilience thinking into SEA which may also help to provide new, structured ways of dealing with the uncertainty and complexity inherent in planning processes and to incorporate ecosystem services in development proposals and assessments (Fundingsland Tetlow and Hanusch, 2012);
- The strategic advocacy role in SEA for sustainability (Partidario, 2015);
- The call for more evidence-based, empirical research along with research on legal and specific methodological aspects (Fischer and Noble, 2015);
- The development of a more strategic approach to SEA - one that helps facilitate strategic innovations in PPP formulation and drives transitions in governance and decision-making processes (Noble and Nwanekezie, 2017).

1.1. Renewable energy development in Mexico

Technological and social evolution towards an economy based on alternatives to fossil fuels has become an issue of great importance worldwide. We are witnessing what could be called an energy generation revolution with regards to both, non-renewable and renewable sources (Koeppel and Fischer, 2013). Mexico, like other newly industrialised nations, is steadily expanding its renewable energy capacity and building new facilities to meet its renewable energy goals. For instance, we currently observe a steady deployment of wind energy on a wide-scale around the world. Nevertheless, and despite its significant potential to reduce greenhouse gas emissions (GHG) by displacing fossil fuel-based electricity generation, wind energy has the potential to produce some detrimental impacts on the environment and on human activities and well-being. Therefore, these potential concerns need to be taken into account to ensure a balanced view of wind energy, especially if wind energy is to expand on a large scale (IPCC, 2011).

Pang et al. (2014) pointed out that since both, climate change and biodiversity loss are seen as highest priority issues, there is a need for an integrated approach to assessment, which can consider both, energy needs and environmental impacts. In this context, SEA represents a window of opportunity, providing for a tried and tested approach, which can play a key role in helping to achieve more environmentally sustainable practices and processes for a sustainability transformation.

1.2. Wind energy in Mexico

Mexico is a privileged place for the generation of wind energy as its geography provides for numerous areas with high potential for the development of this form of electricity. Furthermore, the country's energy sector is in a period of profound change, catalysed by the comprehensive Energy Reform the government has enacted in 2013 (IEA, 2016). Various regulatory frameworks have promoted the implementation of these reforms and driven the recent evolution of renewable energy policy. A key policy is the Law for the Use of Renewable Energy and Financing the Energy transition (LAERFTE). This law has been adopted to comply with signed international agreements on GHG emissions reduction and establishes a set of non-fossil fuel generation goals of 35% for 2024, 40% for 2035, and 50% for 2050.

LAERFTE was also meant to define and regulate the use of renewable energy mainly for power generation. It mandated the Secretary of Energy (SENER) to develop a National Renewable Energy Inventory to provide reliable information on renewable energy resources in Mexico. It established a set of instruments like the Special Programme for the Use of Renewable Energy, an Energy Transition Strategy and a Fund for the Energy Transition and Sustainable Energy Use (IRENA, 2015). Based on the results reported on in the National Renewable Energy Inventory (INERE), it is clear that the Mexican power system largely relies on conventional energy sources (SENER, 2014a). Fossil fuel power generation capacity dominates the system with some 70.18% (41,240 MW) of total

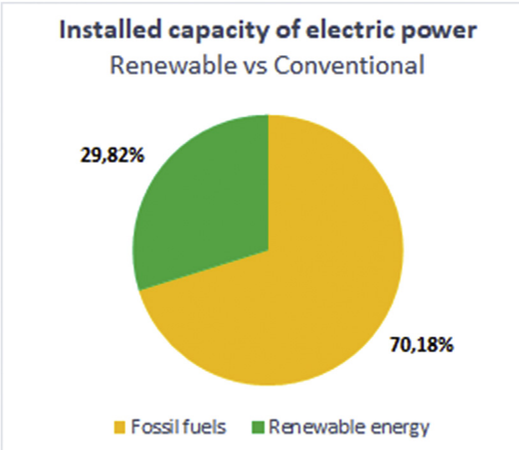

Fig. 1. Installed capacity of electric power in Mexico.

installed capacity. Yet renewable power already has a capacity share of 29.82% (17, 519 MW). This includes hydropower (70.95% or around 12.43 GW), wind (18.23% or 3.19 GW), geothermal (5.25% or 920 MW), biomass (4.87% or 863 MW) and solar PV (0.7% or 123 MW), (see Figs. 1 and 2).

Mexico has many regions with a steady wind supply appropriate for high capacity factor wind farms (SENER, 2014b). In 2017, the country had 36 wind farms, which together had an installed capacity of 3193.10 MW (which is still less than a tenth of Germany's). These plants are located in the states of Oaxaca, Baja California, Quintana Roo, Tamaulipas, San Luis Potosí, Sonora, Chiapas, Jalisco, Nuevo León and Puebla. Fig. 3 shows the location of wind power plants installed in the country. All wind farms in the country, including installed capacities, are listed in Appendix A. In addition, according to a study on wind potential in Mexico conducted by the multinational company PwC in collaboration with the Mexican Wind Energy Association (AMDEE), the country has a wind potential greater than 50 GW (i.e., about 17 times the capacity currently installed) with plant capacity factors above 20%. The Institute of Electrical Research (IIE) carried out studies obtaining similar results (CFE, 2014). Estimation is based on the assumption that only 10% of the total area with potential is usable for the installation of wind farms. This is due to orographic, environmental and social as well as technical and economic feasibility factors (SENER, 2012).

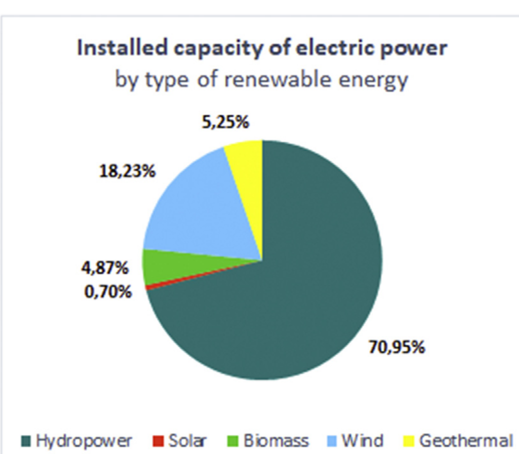

Fig. 2. Installed capacity of renewable energy in Mexico.

1.3. Rationale for the research study underlying this paper

Given the right mix of policies, Mexico has the potential to support large-scale investment in renewables that can help diversify its energy supply. Increased renewable energy use would set the country on a path towards significantly reducing its GHG emissions (IRENA, 2015). Furthermore, accelerating Mexico's uptake of renewable energy could substantially benefit its population and environment, resulting from lower harm to health and reduced CO_2 emissions. However, to gain such benefits, policy changes in spatial and environmental planning are required, since this is at the heart for ensuring that transmission, expansion and grid integration can accommodate the full range of renewable power technologies.

This paper reports on a research project on establishing sites suitable for the development of wind energy. In this context, a specialised technique is put forward that allows for a more comprehensive consideration and reduction of various impacts. SEA for onshore wind energy in Mexico is used to demonstrate that it is possible to implement spatially-explicit analytical supporting tools that foster the integration of SEA into the country's legislation.

2. Method

Our method is structured along interrelated phases of cyclical interactive, flexible and adaptive processes. This is outlined in Fig. 4, indicating the main strategic steps to undertake a participatory spatial analysis (right-hand side of the diagram). It also shows the possible integration into an SEA process (left-hand side), namely at the stages of *Identification & Assessment of Reasonable Alternatives* and *Evaluation & Impact Forecasting*. The framework follows the United Nations guidelines on mainstreaming sustainability into policymaking (UNEP, 2009). Our method responds to the need for more effective reasoning in decision-making (Fischer, 2007) by proactively developing possible *spatial* development options in a participatory manner and enabling the assessment of impacts of these options.

The participatory element is enabled through the use of surveys that are an integral aspect of the implemented geocollaborative application named Geospatial System of Collective Intelligence[1] (SIGIC after its acronym in Spanish; Castillo Rosas et al., 2015a) which in essence operates as a group-based spatial decision support system (GSDSS).

Following Hendriks and Vriens (2000), GSDSS -or SGDSS- are conceived as group extensions to spatial decision support systems (SDSS) and geographic information systems (GIS) by exploring the sources of complexity in spatial decision situations, i.e. the GSDSS is perceived as a tool that enables the stakeholders involved to collectively deal with spatial complexity.

Additionally, for the purposes of this paper we understand that SDSS is “the computer-based system that combines conventional data, spatially-referenced data and information, and decision logic as a tool for assisting a human decision-maker” (Crossland, 2008), and, as has been noted by this author, an SDSS does not actually make a decision, but instead assists the human decision-maker in reviewing and analysing data and presenting processed information in a user-friendly format.

Surveys with experts, stakeholders and the public are based on interviews, questionnaires and emails. Expert opinions on possible effects are frequently considered in SEA through surveys,

[1] The term Collective Intelligence for the purposes of this work is understood as “the capacity of human collectives to engage in intellectual cooperation in order to create, innovate and invent” (Lévy, 2010).

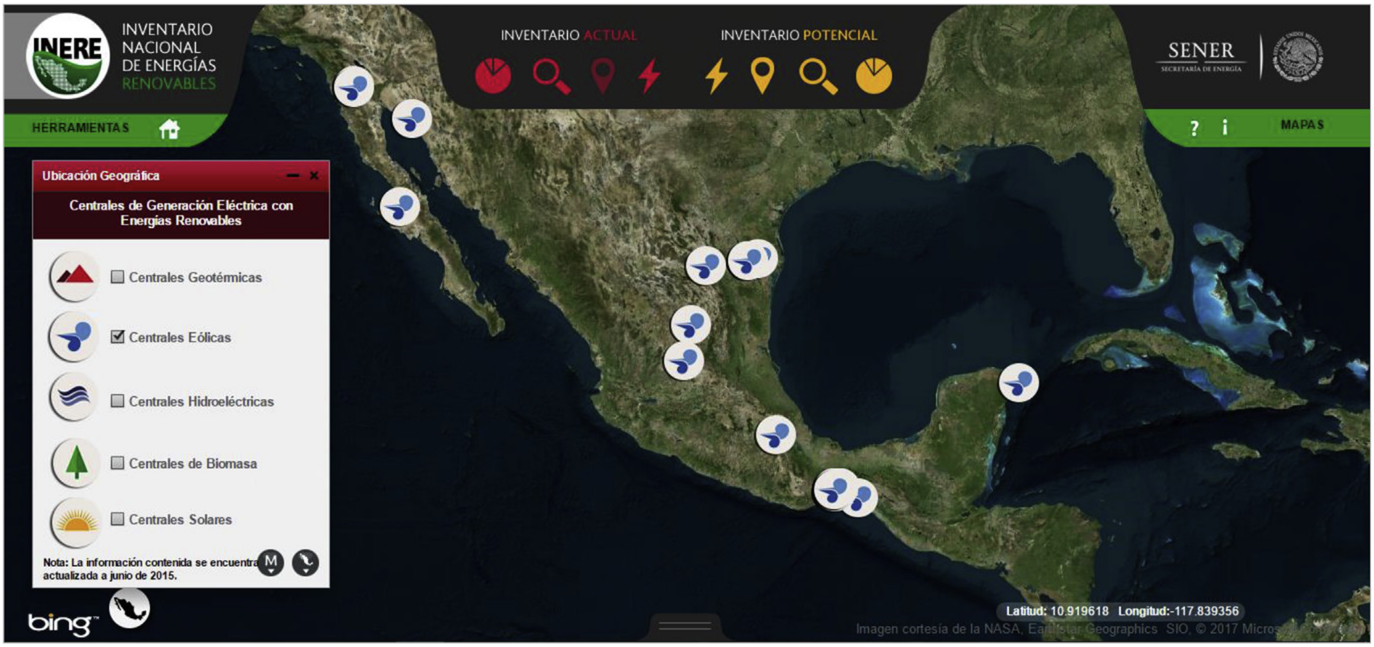

Fig. 3. Main locations of wind farms in Mexico.
Source: SENER (2014a).

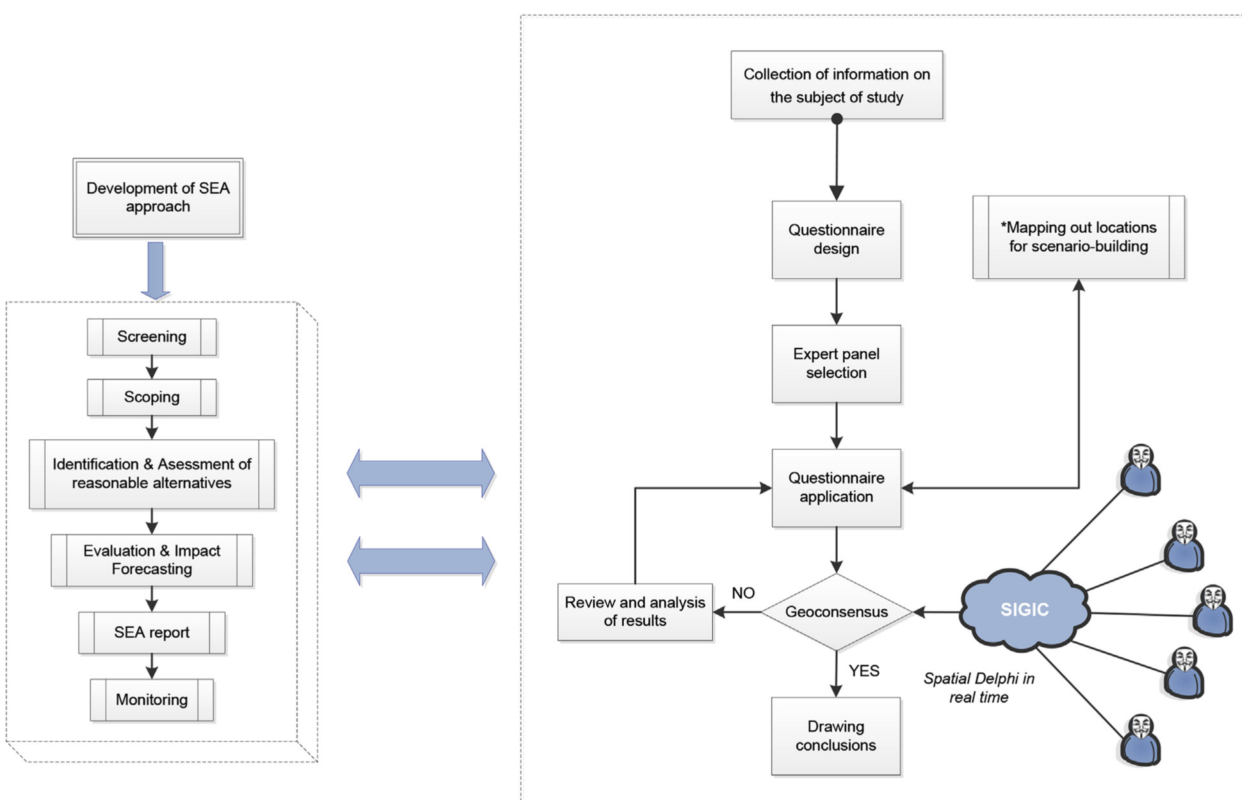

Fig. 4. GSDSS-based SEA methodological framework.
Source: own elaboration.

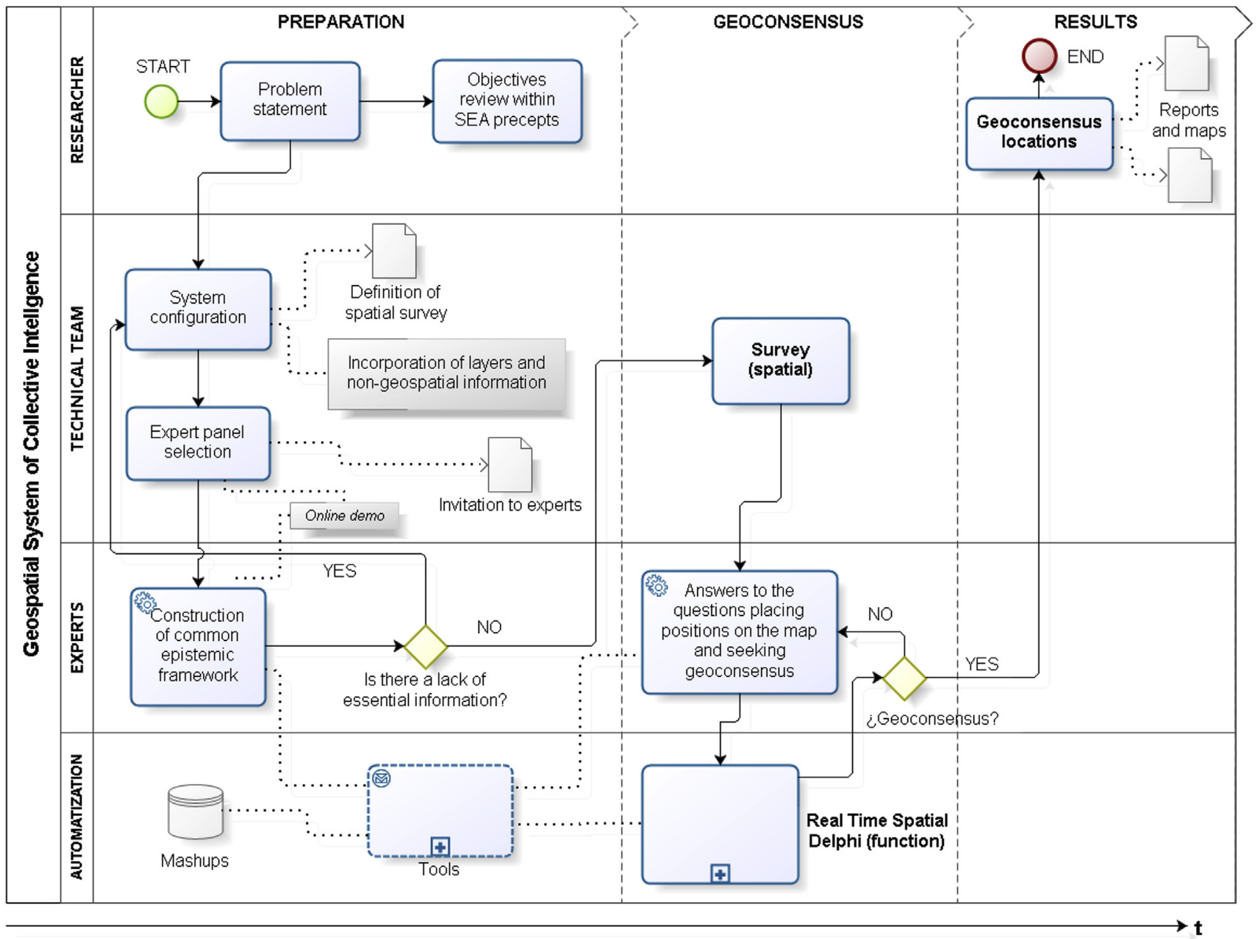

Fig. 5. Scheme of the methodological process.
Source: Adapted from Castillo-Rosas et al. (2017).

particularly in situations that are complex and where the assessment has to be conducted at low cost. Furthermore, expert surveys may be helpful for achieving a better understanding of possible future development, particularly in situations that are marked by a high degree of uncertainty. Surveys with stakeholders allow for the identification of different interests in decision making processes. Following Gorsevski et al. (2013) this collaborative tool was designed to provide interactive mapping and spatial analysis capabilities for enhancing group decision making.

It was also expected to assist the participants to collectively frame and address tasks that require exploration of spatial attributes and alternatives and visualisation of geographical data, setting a systematic group communication through provided mechanisms for exploring alternatives and building consensus from group preferences. The usefulness of our proposed GSDSS-based SEA framework, covering a cluster of features and technology components, was empirically tested for site location and strategic sustainability planning of new onshore wind energy developments. Further details on the specific process are provided below.

[2] For the purpose of replication of experimentation and other related concerns, it is noted that the sequential order shown here does not necessarily have to be strictly followed. Some activities can be performed in parallel according to specific needs and opportunities.

2.1. *Step-by-step description of the process*

Fig. 5[2] illustrates the overall methodological approach to the participatory spatial analysis. This shows three main phases (preparation, geo-consensus, and results), along with four cardinal participation elements (researcher, technical team, experts, and automations). Finally, basic tasks and processes, as well as logical sequence flow and main interconnections between all of them are shown.

2.1.1. *Preparation*

a. The process begins with a definition of the decision problem (in our case the location of onshore wind farm development in Mexico).
b. The objectives of the analysis are reviewed in accordance with the SEA and the Collective Spatial Analysis paradigm (Castillo Rosas et al., 2015b).
c. A spatial survey is designed and information layers (base maps and special maps) are proposed.
d. The first stage of the system configuration and adaptation of the interface is undertaken, consisting of the registration of the questionnaire in the database as well as the integration of geospatial information, and other information of a general nature.

Table 1
Final list of confirmed participants.

Confirmed Participants	
United Nations Environment Programme (UNEP - Mexico)	Mexico's Representative Officer
Secretariat of Environment and Natural Resources (SEMARNAT)	Deputy Director of Spatial Analysis and Support to Decision Making
Secretariat of Energy (SENER)	Directorate of Renewable Energy
National Institute of Ecology and Climate Change (INECC)	Coordination of Climate Change and Low Carbon Development
National Institute of Ecology and Climate Change (INECC)	Chief of Financial Schemes
Mexican Association of Wind Energy (AMDEE)	Executive Management
Mexican Centre for Innovation in Wind Energy (CEMIE-Eólico)	Technical Specialist
Centre for Services in Energy and Sustainability (ENESUS)	Directorate General
Autonomous University of Ciudad Juarez	Department of Civil and Environmental Engineering
Environmental Consulting (Natura Medio Ambiente)	Technical Specialist
*Greenpeace Mexico *(declined its participation)*	Executive Office

e. A selection of the people is necessary, which in our case consists of a panel of experts. This should be made following the *IAIA Public Participation Best Practice Principles* (Enserink et al., 2006), adopting the ‘participation by consultation’ typology proposed by Hughes (1998), and considering the stakeholder categories and types observed in Vivek et al. (2007).
f. Subsequently, users/experts accepting to participate (second stage of the system configuration) were registered. They should be informed about the implementation period and the mechanics of the exercise, providing them with all the necessary information in the form of instructions and tutorials[3] as well as system login credentials.

As our consultation was to be held with experts and not with laymen, *technical participation* was used. Thirteen candidates (all based in Mexico) from different target groups were invited, including representatives from government institutions, private industry, intergovernmental organisations, the consulting sector, NGOs and academia. All of them were knowledgeable about the geographical area of study. The expert panel is shown in Table 1.

2.1.2. Geoconsensus

a. This step essentially represents the beginning of the participatory exercise. Having reached this point, the survey is conducted employing the *Real Time Spatial Delphi*[4] technique (Di Zio et al., 2016), collecting answers to the questions and placing positions on the map looking for geo-consensuses, i.e. a convergence of opinions in a geospatial context. “Convergence of opinions” is understood here as a structured process in which individual thoughts on issues under discussion can lead to shared conclusions (Di Zio and Pacinelli, 2011). As proposed by the inventors of the Real Time Spatial Delphi, during the process a number of convergence measures of spatial opinions can be used. These include quantitative indices of the evolving consensus among the participants, referring to each question. The simplest indicator is the percentage of the area of the current circle in respect to the initial one. When this percentage is low (close to zero), the current circle is small compared to the surface of the initial one, therefore indicating a high geoconsensus.
b. The members of the multidisciplinary team ought to share an epistemic framework and agree on the analysis of a common problem, which does not mean having an omni-comprehensive common theory on the problem (García, 2006). Geoconsensus depends on many factors, and even if it is desirable as a result of the method, when it is not reached other types of results emerge from the analysis, according to the logic of the Delphi method (Dalkey and Helmer, 1963).
c. Members of the panel are informed about the objective of the exercise and are encouraged to seek a convergence of views by placing points inside the circles. However, this is not imposed as a preconception or condition to perform the exercise. The consensus is an element of particular concern in this research, but it is not the ultimate goal of the implementation of the experimental phase. The expert is free to place the point outside the circle, thus reducing the degree of geoconsensus, but he/she is also invited to provide an explanation of the choice. In the end, for each question, convergence can be reached or not. In the former, the solution to the problem is the portion of territory delimited by the final circle, while in the latter the written arguments represent a ‘value’ result of the survey. The lack of geoconsensus means that the area of interest presents critical issues, and the arguments of the experts are used to deepen the research problem.

2.1.3. Results

Thanks to the system features, in particular the real-time mode, results were obtained during the course of experimentation. This process was synthesized and complemented with the production of reports, including maps and statistics regarding the evolution of the exercise, pointing out the identified areas, as appropriate.

2.2. Conducting the exercise

2.2.1. Initial considerations

1) Access to the platform for the participant experts was made possible through http://www.sigic.net, using their login credentials.
2) Cartographic information (i.e. map layers) was added that was considered to help the experts to visualise and to understand the geographic space which is the object of the study. This way the opinions and proposals of site locations had a solid scientific basis. The special selection of map layers for spatial support was composed from an inventory of wind energy (existing and potential), wind speed, wind power density, protected natural areas, regions with high concentrations of indigenous people,

[3] One-to-one online demonstrations of the archetype were optionally offered to the panel members. Through this interaction with those who accepted, they were asked about the consideration of additional information for its incorporation.

[4] The Spatial Delphi is based, like the classical Delphi, on the judgments made by experts, and it is useful in the consultations for decision and/or forecast purposes, provided that they concern matters of spatial location. The basis for the questionnaire is a map, on which each expert provides answer(s) on one or more opinion-points, i.e., locations that, according to their opinion, are best for a specific purpose (Di Zio and Pacinelli, 2011). The Real Time Spatial Delphi is its real time version (Di Zio et al., 2016).

Ramsar sites, archaeological sites, national power grid, and zoning of the country.

These layers of information for analysis were integrated from diverse sources of information, including National Inventory of Renewable Energies (INERE), National Institute of Statistic and Geography (INEGI), National Institute of Anthropology and History (INAH), International Renewable Energy Agency (IRENA), Google Maps, Google Earth and OpenStreetMap Foundation.

3) In addition, a *File section*[5] (non-georeferenced information) was made available, where the members of the panel could find documentation intended to support when thinking about their opinions.

2.2.2. Responding to the survey

1) Unlike a common survey, here the answers to the questions are considered as *spatial opinions/answers.* That is, the participant would have to answer each question by placing a location on the representation of the territory under study, which he or she thinks is most appropriate.[6] To do so, each member of the panel had to select the *Opinion* button of the question to be answered; then, adding a brief comment that would guide others regarding his or her choice. It was important for the participants to consider that they were part of a multidisciplinary and anonymous group. This means that members had different professional and academic backgrounds, and nobody was aware of the identities of the other members. In addition, it was pointed out that neither too extensive nor too complex answers were sought, but concrete reflections that could be expressed and understood in a relatively small number of statements.
2) The questions of the survey were displayed on the *Expert consultation* panel. The buttons for answering such questions were presented with different coloured icons for each of them. The same colour corresponded to the mark of an expressed opinion on the map.
3) The interactive map also showed a circle for each question in the colour corresponding to the icons of the buttons. This circle indicated the area of *convergence of opinions*[7] (agreement, consensus or rather geoconsensus) among the experts. The smaller the circle, the larger the agreement and vice versa.
4) The experts were not allowed to see the spatial opinions of the other members of the panel (due to aspects of anonymity, distinctive feature of the Delphi Method), but they were able to observe the *circles*[8] mentioned in the previous paragraph. This indicates the area which is containing 50% of the opinion points of the group as a whole. From a Delphi perspective, a circle represents the feedback (in real time) on which the experts (re) modulate their opinions.

   On the *Geoconsensus* toolbar, the users were able to activate and deactivate the visualisation of the geoconsensus circles. They were told that, at first, and before starting to answer the survey by placing their marks on the map, they could deactivate the display. Then, once they had started, they could re-activate the visualisation of these circles; so, they would be able to observe (in real time) the system performance and the evolution of the emerging geo-consensus. This system allows the creation and visualisation of a dynamic and real-time geo-consensus. Additionally, the participants would be able to read the rationales of all the members of the panel through the *Arguments* button of each question.
5) In the *Arguments*[9] window the experts were able to find the updated justifications of each expert who answered the survey, always anonymously. They could also see in a green rectangle those comments that are within the areas of convergence of opinions. On the other hand, the comments that support the opinions outside this area were represented by the red rectangles. The user icon corresponds to the response of the active users. Finally, they were able to show or hide the corresponding text messages by clicking on the icon located to the left, flagged with the symbol '+'. It is worth noting that, following the rationale of the Real Time Delphi (Gordon and Pease, 2006) each participant was free to answer the same questions (giving both points and arguments) as many times as he/she wanted. This is an important feature of the process which allowed the panel, through the change of the spatial opinions (in the light of the continuous feedbacks), to reach a geoconsensus.

The brief survey that integrated the exercise was composed of the questions introduced in Box 1.

3. Outcomes

The experimental exercise was carried out during two phases over 55 calendar days; allowing access to the SIGIC platform from November 14th to December 9th, 2016, and from January 9th to February 7th, 2017 (excluding the Christmas holiday period). From the list of 11 experts who had confirmed their participation, at the end 9 contributed to the collective spatial analysis answering the survey fully or partially (see Table 2).

Table 3 provides an overview of the degree of participation of experts in the spatial survey, in which the *percentage in relation to the total* refers to the proportion of participants who answered each question with respect to the total number of experts who agreed to participate in the survey (11), just as the *percentage of real participation* is given by the number of experts who answered each question in relation to the nine experts who actually participated in the survey. As a result, it was possible to obtain a final participation average of 71% and an average level of -real- participation of 86.7%.

Fig. 6 shows the display of the arguments' windows as well as the geoconsensus indicator. As previously mentioned, it is green if the point was positioned inside the circle of convergence (indicating consensus) or red if the point was located outside (indicating

[5] By the same token, in this section (during the completion of the survey) they were also able to upload digital documents such as pictures, provisions, applicable laws, papers, etc., which they would consider relevant to support their arguments besides being useful to other participants, thus stimulating the discussion and providing a positive feedback.

[6] In other words, following the principles of the spatial version of the Delphi Method, through the survey the experts were asked to indicate points that represent the most suitable locations for either goods or places where a future event will likely take place directly on a digital map. The experts could also provide the documents justifying their choices. The result of these iterations is a map with a set of geo-referenced opinion-points (Di Zio and Pacinelli, 2011), each with geographic coordinates (e.g., latitude and longitude).

[7] As noted by Di Zio and Pacinelli (2011) "in the classical Delphi, the convergence is governed by the interquartile range, which contains 50% of the respondents. In the Spatial Delphi, these guidelines are kept, but rather than an interval containing 50% of opinions, an area is used".

[8] "Assuming isotropy and thus excluding non-random directions, the first possible geometric shape in a two-dimensional space is the circle, i.e., we are interested in finding a circle that contains 50% of all opinion-points" (Di Zio and Pacinelli, 2011).

[9] Please note that the respondents could change their answers as many times as they wanted, nevertheless, they should be aware that every change would invalidate the previous answer. Consequently, only the latest changes in each question have been considered because each participant can only provide one answer per question (Castillo-Rosas et al., 2017).

Box 1
Exercise questionnaire.

Questionnaire

Taking into account the current conditions and the layers displayed on the platform, please place your opinion with a point on the map, the following:

What do you consider to be the most suitable sites/areas for the development of new -onshore- wind power facilities in terms of sustainability?

1. For the Northern region of the country.
2. For the Central region of the country.
3. For the Southern region of the country.
4. From the tested areas -shown on the screen-with the potential for electricity generation through wind power, please choose an area which you consider of highest priority and strategic relevance for wind energy development in the country.
5. In relation to the previous question, and taking into consideration possible cumulative effects, please choose an area where you deem that there will be a greater environmental degradation as a result of the construction of such wind-generated energy complexes.

Table 2
Final participation of panel members.

Participation Report					
Expert	Question 1	Question 2	Question 3	Question 4	Question 5
1					
2	✓	✓	✓	✓	✓
3			✓	✓	✓
4	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	
6	✓	✓	✓	✓	✓
7					
8			✓	✓	
9	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓
11	✓	✓	✓	✓	✓

Table 3
Participation of experts regarding each question.

Question number	Experts	% in relation to the total	% of actual participation
1	7	64	78
2	7	64	78
3	9	82	100
4	9	82	100
5	7	64	78

dissent). Moreover, the various circles generated by the system can be observed, whose colours match each of the questions in the survey; blue circle for question number one, yellow circle for question number two, green circle for question number three, pink circle for question number four and red circle for question number five.

In the following map (Fig. 7), through the activation of different layers of information and using the zoom function, the complexity that characterises the Mexican territory is visualised: large areas with significant potential for the use of wind energy, but also large areas of land with high concentrations of indigenous peoples and important geographic spaces where it is important to preserve biodiversity as well as cultural or historical values. The south of Mexico, for example, while considered one of the areas with the highest wind energy potential in the country, is also one of the most complex to address regarding the social and ecological dimensions of sustainability (as is indicated by the bright red colour).

The two figures below (8 and 9) show a geographical representation of the history of geo-consensus which has evolved over time with modified and new opinions emerging. From Fig. 8 the spatio-temporal evolution of the geo-consensus for each of the survey questions can be seen, and from Fig. 9 the view for a specific question is visualised.[10]. For instance, here the green circle shows the area that would be considered most appropriate for the development of new onshore wind power facilities for the southern region of the country, in addition to the dimension of that circle with respect to the beginning and end of the exercise.

Fig. 10 provides a different perspective of the geographical results of the appraisal of wind energy site location. It is assumed that through the opinion-points and the interaction that has taken place, it was possible to identify certain areas that might be useful for sustainable spatial planning and environmental assessment of wind energy at the strategic level. As an example, in this image the colours on the map indicate that several layers of information (base maps and special maps) have been activated and overlap; amongst them wind speed, protected natural areas, Ramsar sites and regions with high concentrations of indigenous people can be visualised. This aimed at assisting in the exploration of spatial attributes and the possible interlinkages between the different geographic data.

To summarise the above, based on Fig. 11, it is possible to observe the result of data processing performed by the system, where the areas shown correspond to the final circles (one per question), which represent the convergence achieved. Note that, in terms of the size of the country and the zoning considered, the dimensions of the geo-consensuses in questions 2, 3 and 5 show well defined areas (small final circles), but not the extension of the geo-consensuses corresponding to questions 1 and 4 (large final circles). This might be due to the complexity that is attempted to address, either the relative to the territory in question, or perhaps the one regarding the proposed problem itself (or both).

Complementing the aforementioned, Fig. 12 shows the evolution in the geo-consensus for each of the questions. The X-axis represents time (number of days from the start of the survey) and the Y-axis shows the diameter of the circle of convergence. It is thus possible to see three important aspects: 1) convergence, 2) stability, and 3) the speed of the convergence.

From these time series, we can see that for questions 2, 3 and 5 there was a good geoconsensus. The sizes of the final circles are, respectively, equal to 14%, 1% and 5% of the initial (bigger) circles, meaning that the circles reduced a lot during the exercise. An interpolation curve helped to see the speed and the magnitude of the convergence, observing the distance between the horizontal axis and the curve at the end of the survey. For questions 1 and 4, the percentage of the area of the final circles in respect to the initial ones is high (respectively 22% and 20%), confirming a lack of geoconsensus.

The time series also show some other interesting findings, for example, the stability of the responses of the panel. The curves, in all cases, become almost horizontal and this means that at the end of the survey the opinions of the experts stabilized: continuing

[10] This information can only be viewed by the system administrator.

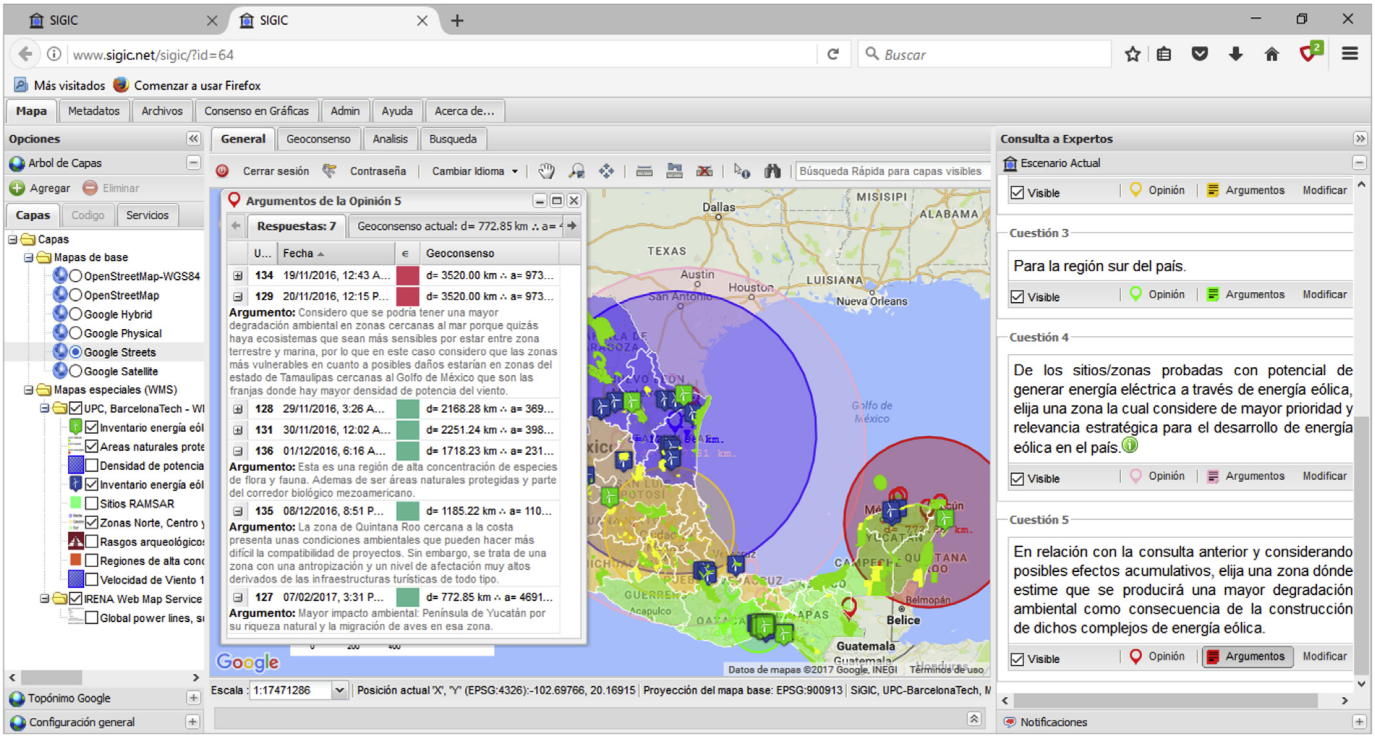

Fig. 6. Display of the arguments given by the experts.

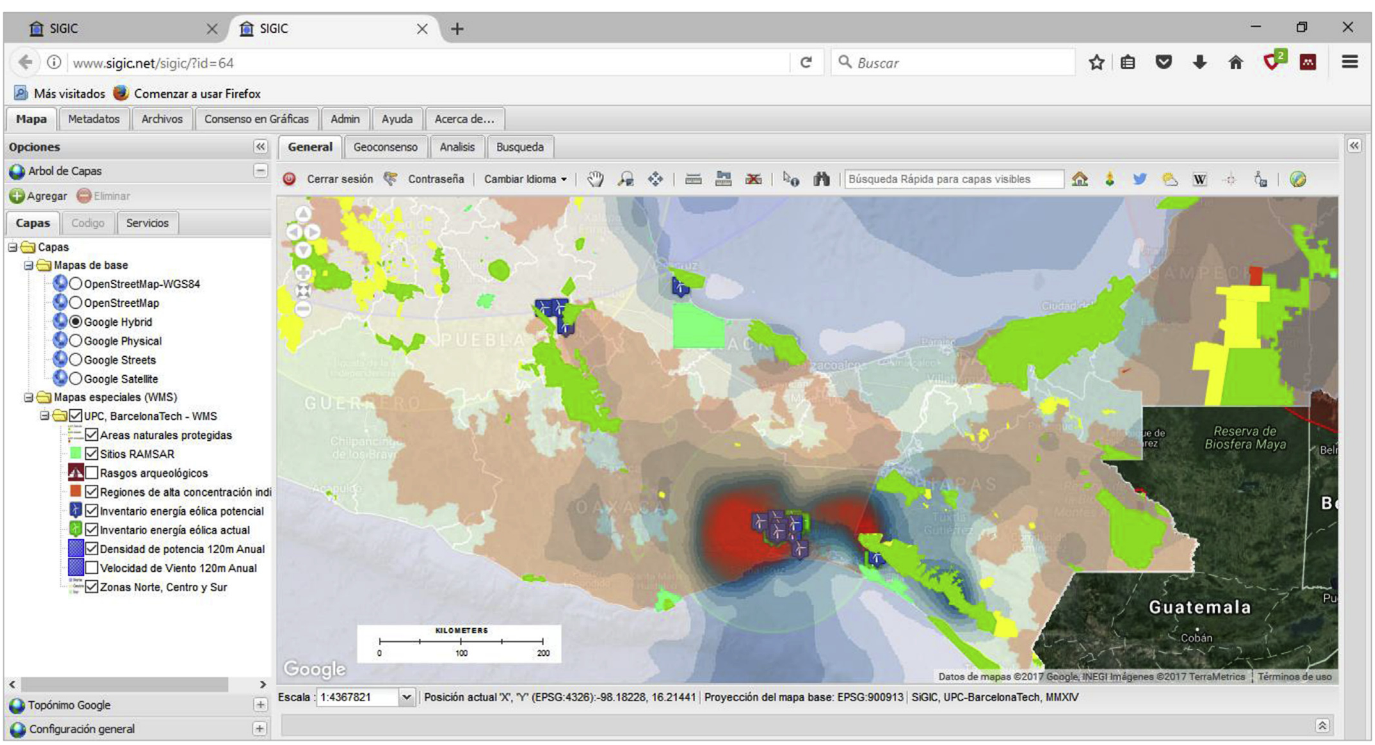

Fig. 7. Deployment of existing and potential wind energy development within a complex territory.

beyond would not lead to new results. In Delphi-like research, this is very important as it provides an indication as to when to stop the survey.

Finally, the time series also shows the speed of convergence. The charts show that for questions 3, 4 and 5 experts rapidly reached a final solution (regardless of the degree of consensus) because the

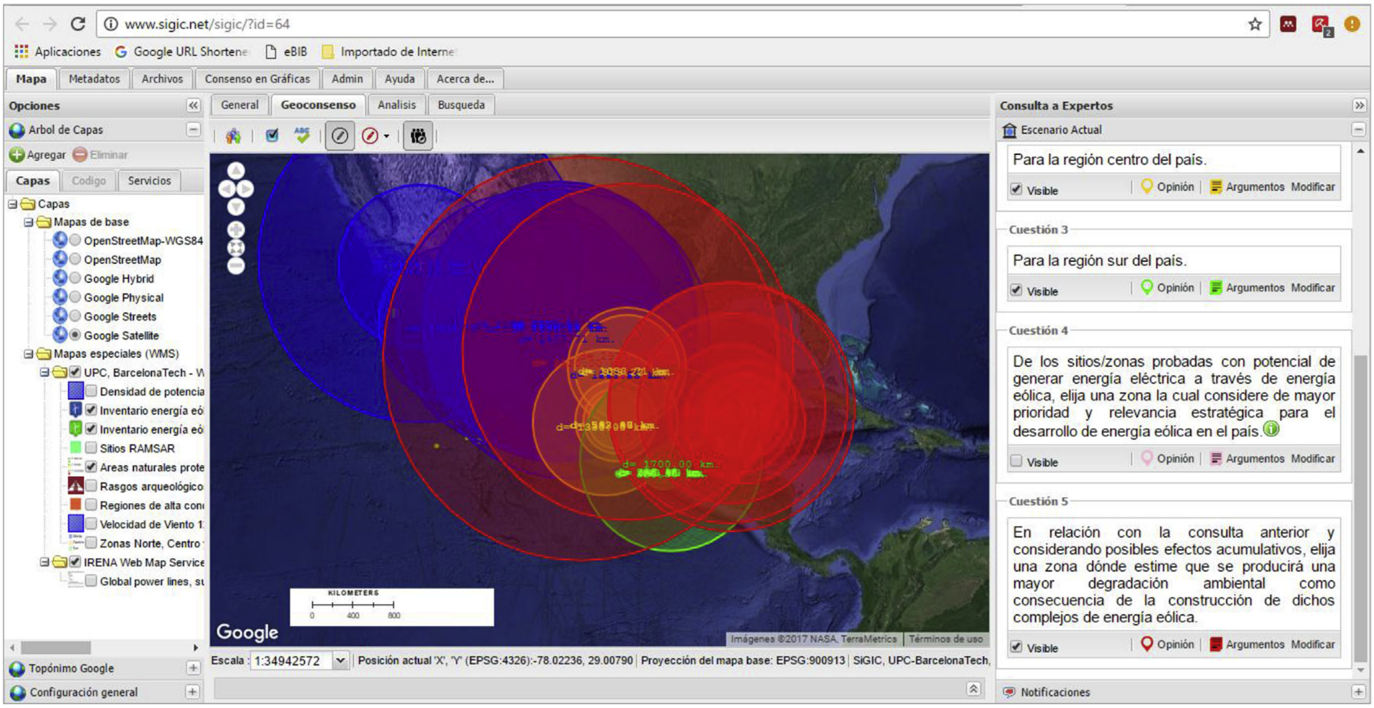

Fig. 8. Evolution of geoconsensus regarding each question.

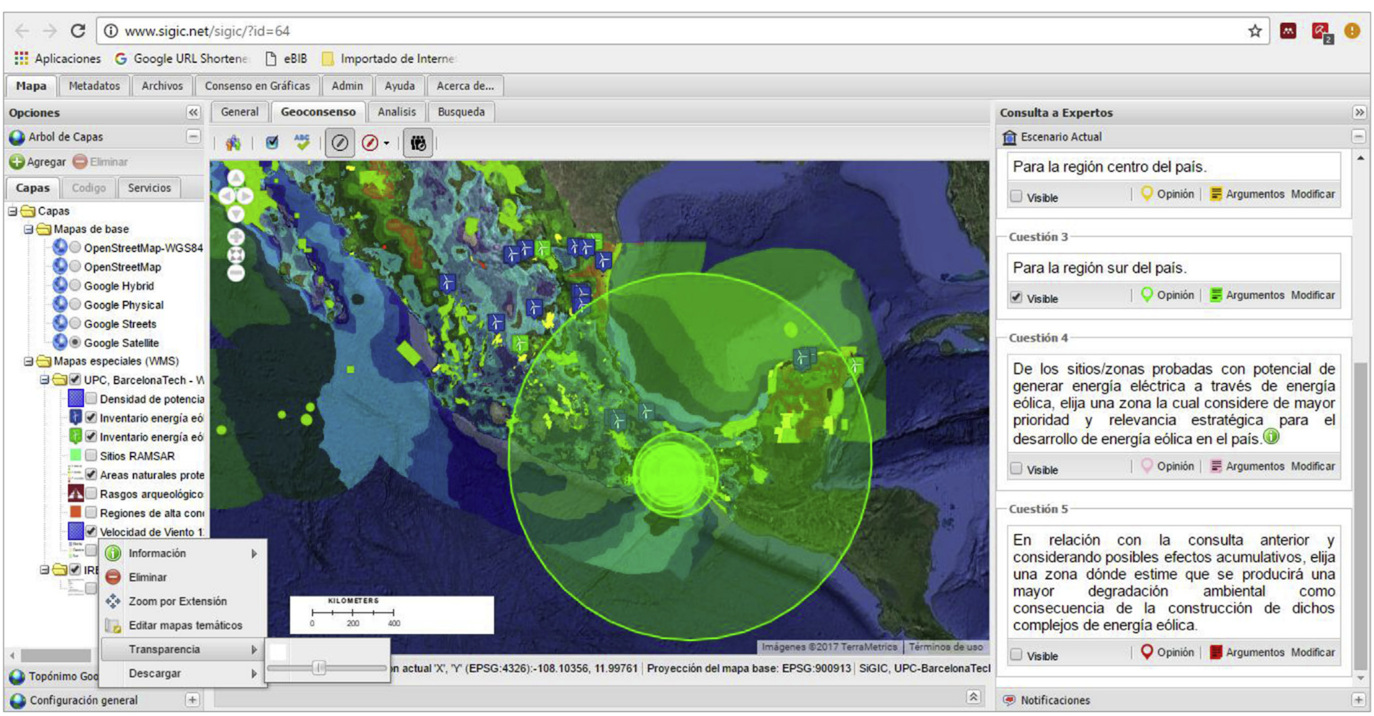

Fig. 9. Geoconsensus history for a specific question.

curves decrease fast toward the horizontal asymptote. On the contrary, in questions 1 and 2 the reduction of the size of the circles were slower, which means that the experts took longer for reaching an agreement.

For questions 3 and 5 therefore there was a quick achievement of geoconsensus, while for question 2 the formation of the geo-consensus was slow and gradual. For question 1 there was an immediate resistance to consensus. Finally, for question 4, after a very short phase in the first days of the survey where consensus grew rapidly, it stopped settling on a fairly large circle.

By calculating the R-square of the interpolated curve we also have a measure of the smoothness of the process of convergence which represents, in some way, how much debate there was among the participants before arriving at a shared solution. For questions 1

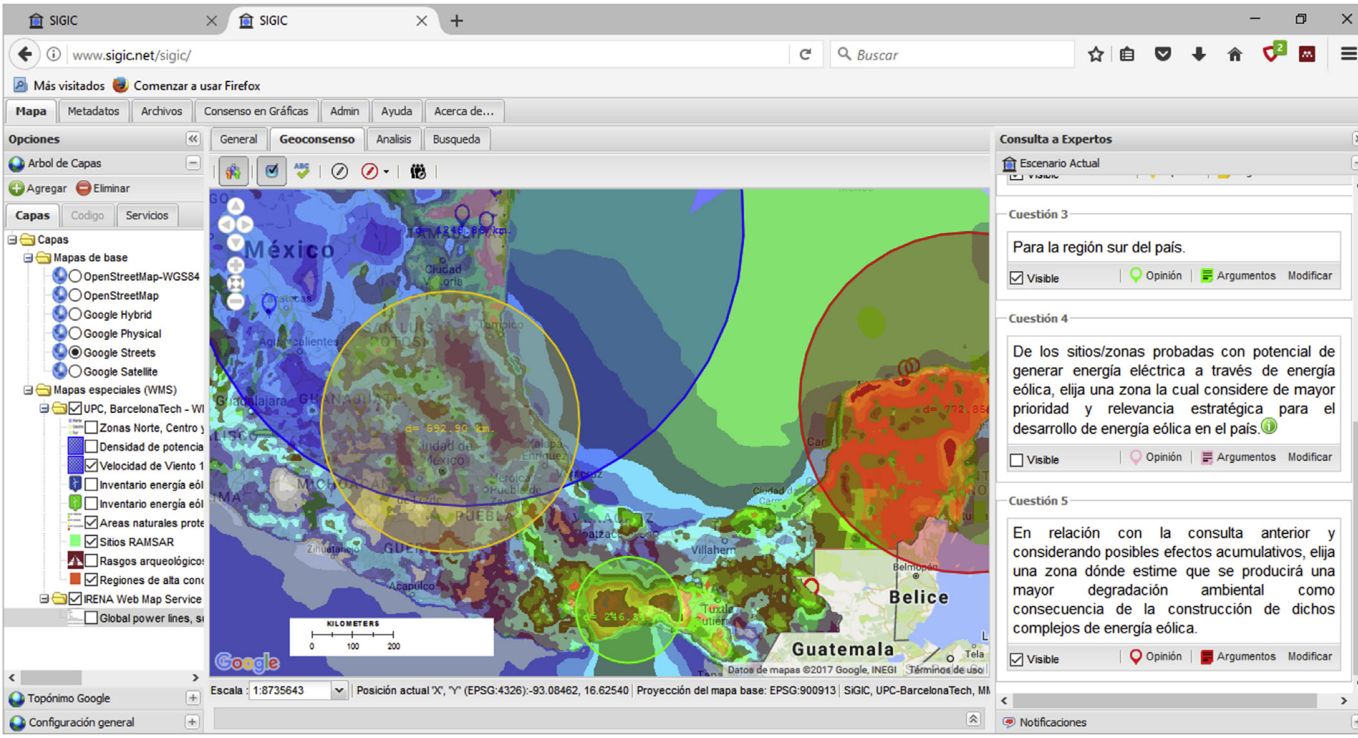

Fig. 10. Geographical results of the appraisal of wind energy site location.

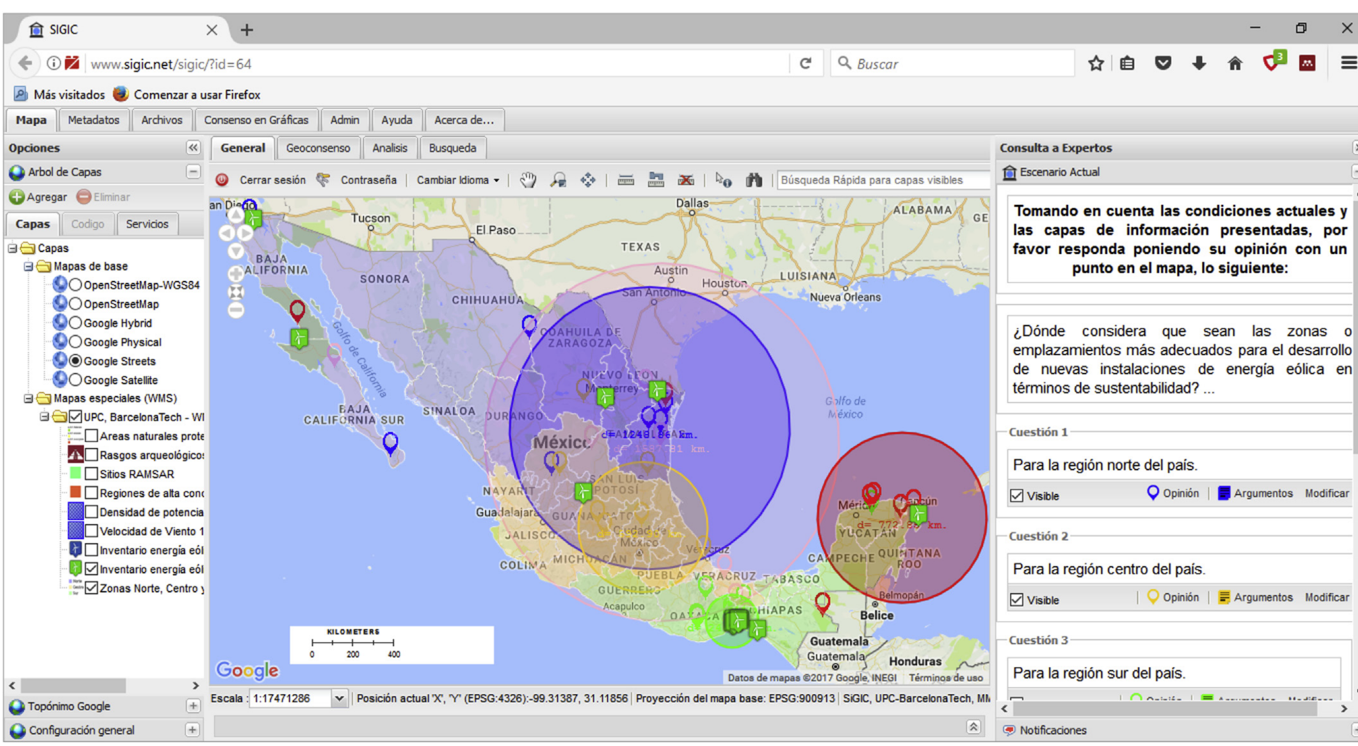

Fig. 11. Final status of circles of convergence and opinion-points.

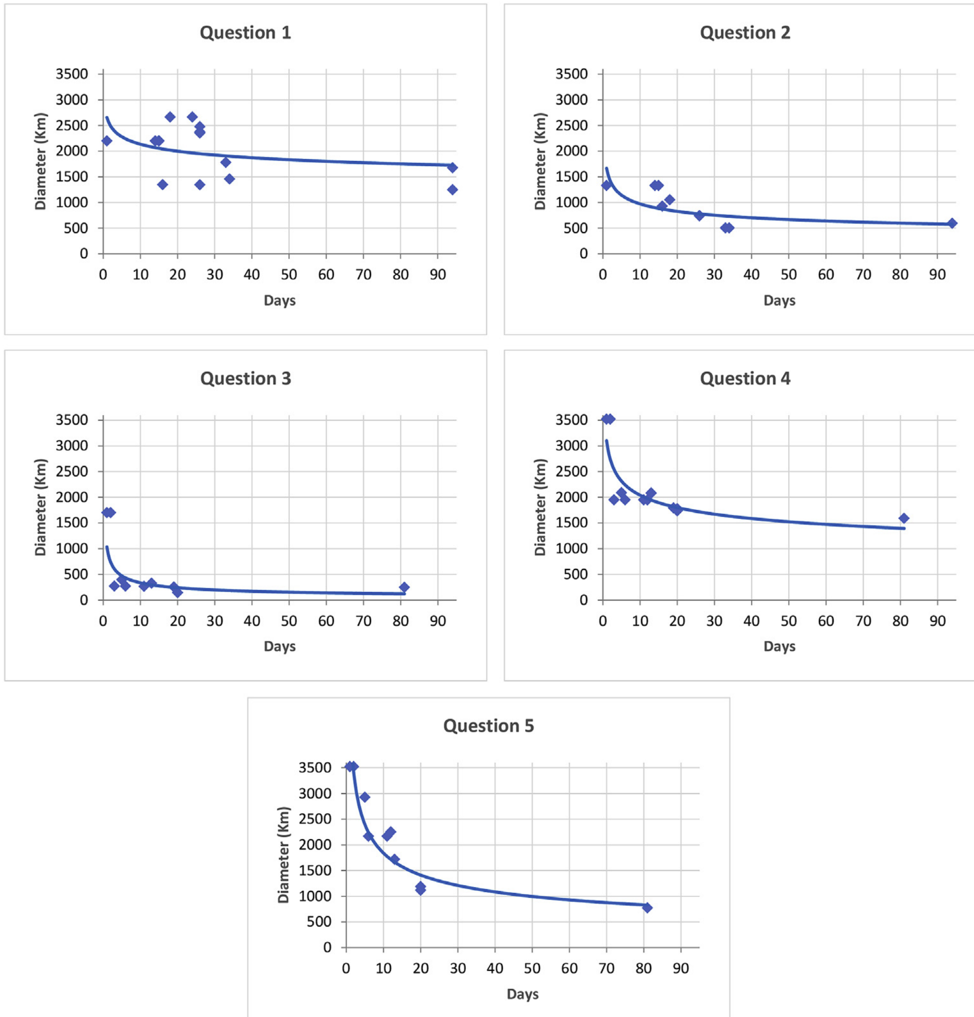

Fig. 12. Spatio-temporal evolution of the circles of geo-consensuses.

and 2 the values of R-square are very low (0.13 and 0.49) meaning that the "discussion" inside the panel was extensive. For question 3 the R-square is 0.57, an intermediate value. Conversely, for questions 4 and 5 high values are observed (0.72 and 0.87, respectively). This means that the experts have followed a regular and smooth process of reaching the final solution, i.e. without major dispute

4. Discussion

A methodological approach has been developed which integrates the essential principles of SEA, combining it with a technological tool of collective intelligence as support for decision-making in the context of spatial planning of renewable energies in Mexico. This tailor-made approach aims to provide valuable strategic information to enable environmental interests to be properly taken into account in decision-making of wind energy, playing a fundamental role in the refinement of national spatial planning, but also offering a holistic perspective that can help to make renewable energy development more sustainable, participative, open and transparent.

SEA aims at allowing for environmental considerations and project objectives to be considered early on and handled as inherent elements of planning for prevention rather than providing opportunities for mitigation and reaction (Sayre, 2009 following Eccleston). Instead of the established practice of designing for mitigation over avoidance, with SEA the impetus becomes prevention before mitigation (Sayre, 2009 building on Fischer, 2007). SEA represents an instrument which is preceding but not replacing EIA (Orea, 2007).

Our approach aims at better addressing analytical methods in SEA in order to foresee and assess environmental effects at the strategic level. In this sense, it is directed at innovating SEA by promoting the use of an appropriate spatially-explicit and (semi) quantitative approach, which has been based on advances in relevant disciplines (e.g., Complexity Theory, Technology Forecasting, Geographic Information Science, Geoprospective, in this case), and the increasing availability of data and technology (Geneletti, 2015).

Current models used for spatial analysis and environmental assessment (involving GIS applications, concepts and criteria of collaborative planning, evaluation of alternatives, public participation and spatial analysis) do not underpin the spatial decision-making process on the basis of consensus or convergence of views. We therefore suggest that our approach is pioneering, since it is the first time that an application of the Real-Time Spatial Delphi (RTSD) is performed through the Geospatial System of Collective Intelligence from a SEA perspective in an energy context.

Convergence of views was not achieved in all questions of the survey. As was indicated in the previous section, for three questions

(No. 2, No. 3 and No. 5) a reasonable level of consensus was observed amongst the participants, with two (No. 1 and No.4) not leading to consensus. That is to say, at the end of the experimental exercise it was feasible to identify -a convergence of views about- the most suitable areas for the development of new onshore wind power facilities for the Central and Southern regions of the country (questions number two and three), as well as in an area where a greater environmental degradation as a result of the construction is thought to occur (question number five). On the other hand, the most suitable area for the development of wind energy in the Northern region could not be easily distinguished (question number one). Likewise, a consensus was not reached when proposing an area considered of highest priority and strategic relevance for wind energy development in the country (question number four).

For those questions where consensus was not reached, reasons might be connected with the territorial extension under analysis. It is thus likely that even though the territory was zoned into three main regions, the geographical space was still too large. Secondly, and correlated with the previous consideration; the great wealth of wind resources observed throughout much of the national territory (north, centre and south of the country) turn the various regions into zones with numerous candidate states competing for the development of wind power infrastructure.

Nonetheless, it is important to recall that in any Delphi [survey] the lack of consensus must not be interpreted as a failure of the exercise. It means that the problem must be deepened. Moreover, we also suggest that in Delphi studies, as is expressed by various authors (Scheibe et al., 1975; von der Gracht, 2012), the absence of consensus is, from the viewpoint of data interpretation, as important as the presence of it. In the same way the importance of the opinions collected throughout the exercise is emphasised (Di Zio et al., 2016). This means that in the areas affected by questions 1 and 4, the circles represent the delimitation of the territories in which the research must be deepened. Thus, in three cases the result is the geoconsensus (recommendation for site location), while in the other two the result is the delimitation of an area in which any decision regarding the site location of onshore wind energy must be established with caution.

In practical terms, one of the key challenges was to form a committed group of participants with different visions that could interact in an environment of anonymity, with an interdisciplinary disposition and a shared goal. There was a selection process which ran over several months (which in turn became a scheduling problem). There were also invitations to potential candidates from which no response was ever obtained. With regards to the experts who finally agreed to participate, not all of them provided rapid confirmations. Thus, regular contacts, persuasion, and motivational work was necessary, where not only the initial presentation of the project was considered, but also an ongoing process of emailing and phone calls. Furthermore, one-to-one online demonstrations of the platform had to be provided for those members who accepted this type of support.

With respect to the development of the collective spatial analysis, it was stressed in the research conducted by Castillo Rosas (2016) that a major problem detected is related to a basic component of the system i.e. the human factor. This is one of the main distinctive features for our data processing. Not all people are willing to collaborate without receiving a direct benefit in return (apart from a citation and public acknowledgement). This was later noticed during the development of the exercise. There were days of complete inactivity and there were experts who accessed the platform only once. Some of them, despite having had formally accepted to collaborate in the analysis, never provided their answers (in fact, one of them openly gave up his participation). In most cases, these issues are uncontrollable (Castillo Rosas, 2016).

5. Conclusions

The research project underlying this paper was conducted with the purpose of developing a context-specific method for SEA, using a geo-collaborative platform for supporting spatial decision-making with regards to the site location of onshore wind farm development in Mexico. To that end, tasks included the implementation of a WEB-GSDSS application based on the Real Time Spatial Delphi (RTSD) method. Its GIS interface was designed and specifically adapted for the study case. This method is an archetype which is based on a SDSS and can contribute, together with other elements, to the choice of suitable locations/options.

The central function of a RTSD is to enable and promote study and reflection amongst participants in order to reach a geo-consensus -or spatial consensus- with regards to locations of e.g. infrastructure development in a defined territory. This should lead to a better understanding of possible and suitable future development and represents an important advantage over standard Spatial Analysis, especially in those situations where there is little data to perform geo-processing, and/or in circumstances that are marked by uncertainty and non-linearity.

The importance of our work lies in the ability of the proposed approach to address some shortcomings of spatial planning as observed by e.g. Nelson (2015). In particular, our approach can help in addressing a lack of transparency and an absence of exploring alternative choices of action. Our tool supports striking a balance between different sustainability aspects by providing stakeholders with an opportunity to express their specific points of view in an interactive web-based exercise.

The method was tested with input from experts in Mexico and the results are presented in this paper. Strengths of the method (some inherited from the Real Time Spatial Delphi (Di Zio et al., 2016);) are found to include:

- It provides an opportunity to share expertise and to benefit from local knowledge and different perspectives;
- It allows the participation of different actors in the analysis, and does not limit them to just being data providers;
- Simultaneous computation and delivery of participant responses is possible;
- Any type of supporting material can be included;
- Experts are not forced to respond a fixed number of times and at defined time intervals;
- Respondents are not compelled to complete the entire questionnaire in one working session;
- It is easy and fast in responding (simply locating points on a WebGIS interface);
- The interpretation of the results is simple and does not require statistical processing;
- The scale and extent of the map are modifiable in real time;
- The expert can instantly consult a number of different supporting GIS map layers;

The most important challenges identified are:

- Being clear about how the proposed method adds value to SEA;
- Overcoming resistance from those practitioners familiar with traditional GIS, and other routine methods used in environmental assessment;
- Possible misunderstanding of the proposed method for spatial development options, especially amongst those with an extensive experience in Multiple-Criteria Decision Analysis (the classic comparison of alternatives carried out in multi-criteria evaluations is not considered in the proposed application);

- Preparation of the survey and configuration of the system interface which requires a comprehensive study and collection of data, project management skills as well as specific coding knowledge, which makes the preparatory phase rather difficult;
- Emergence of possible prejudices about the ease of use of the system;
- Success or failure depends essentially on the commitment, professionalism, knowledge and availability of participants;
- The problem of drop-out, although lower than in conventional Delphi surveys;
- Overcoming resistance and disbelief in adopting this type of method which is based on a subjective basis.

Based on the results, the following key insights are gained:

1. Through a novel geotechnical web application, members of a multidisciplinary panel of experts based in Mexico, with little or no technical expertise in geographic information science and with little or no knowledge of decision support systems were able to interact from their different perspectives, experiences and interests, proposing the most suitable locations for the development of wind energy facilities, under an interdisciplinary consensus approach, and taking into account environmental and sustainability issues.
2. Following the above, it was not achievable to come up with a clear consensus area, which is considered to be of the highest priority and strategic relevance for wind energy development in the country.
3. In relation to the previous question, and taking into consideration possible cumulative effects, it was possible to choose areas that are deemed to have lower sensitivity to environmental degradation caused by the construction of wind farms.
4. It is feasible to conduct an analysis of collective intelligence aimed at reaching a convergence of opinions relative to spatial locations in an energy transition context. This is remarkable in terms of new implications for the processes of environmental assessment, land-use management, strategic planning, and policy development.

Although consensus is advocated, the degree of complexity this entails has been recognised. What the exercise seeks to achieve is balance and counteracting polarisation in decision-making. Whilst in the collective intelligence analysis a consensus was sought, the building of it was not forced, like in Delphi-like exercises. What was achieved was a convergence of opinions of the participants.

The results presented in this paper support the claim that the level of consideration given to sustainable development concerns of strategic documents such as policies, plans and programmes, should be raised. Furthermore, support for more transparent strategic decision-making can be provided, delivering relevant and reliable information for those involved.

The proposed approach openly envisages a shift in focus under a philosophy of strategic thinking, and a coherent, consistent, transparent and sustainable management of environmental impacts. There are various ways to tackle problems and questions posed by sustainable development. One of the most relevant instruments in this context is environmental assessment, consisting of SEA and EIA.

We suggest that a comprehensive SEA system can lay the foundations for a review not only of the environmental system, but also of the economic, social and geopolitical models of development. This will enable consideration of alternative solutions that may be more prospective in nature, e.g., boosting and consolidating certain productive sectors as key drivers of regional and national economies, including renewable energy. A deep decabornisation of the power system may thus be encouraged as well as a greater independence from the traditional exploitation of energy sources such as oil, gas and coal. In the same way, leading to the gradual transition -yet accelerated and sustained- towards renewable energy.

Among the most substantial shortcomings of project-level EIA are a reactive approach to development proposals revolving around measures for mitigating negative environmental impacts as well as a failure to consider cumulative impact of projects. SEA aims at preventing or anticipating negative impacts and at proactively enhancing positive developments (Fischer, 2007). This can be supported by the method proposed in this paper

We believe that our method leads to different results from other more conventional GIS based approaches, that can be said to lack perspective (following Hendriks and Vriens, 2000). The difference between GIS and SDSS is that GIS looks at data and SDSS looks at problem situations (Cooke, 1992; Crossland, 2008). Furthermore, our approach tackles the necessity of addressing the group component in spatial decision-making, recognising the fact that spatial analysis conducted by isolated individuals is insufficient to cover the entire domain of the problem posed. Hence, the proposed method introduces a collaborative element through a GSDSS (characterized as an SDSS-plus) which enables dealing with the complexity of spatial problems, placing special attention to complexity.

At present, flexible systems developed through open source tools that allow shared graphic environments and networked access to spatial databases, which also promote the exploration of alternative solutions and consensus building are hard to come by. Traditional methods based on GIS and well-known multi-criteria evaluation (MCE) systems do not support all forms of complexity. However, the GSDSS does. The idea is that if decision-makers are offered suitable methods, they may be enabled to find new ways of dealing with problems. The approach presented here can therefore be a turning point to establish new research goals and objectives regarding support for spatial decision-making through SEA and a Collective Spatial Analysis.

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Appendix A. Existing inventory of wind farms in Mexico (SENER, 2014a).

State	Municipality	Items	Installed capacity (MW)
Oaxaca	El Espinal	31	26,35
Oaxaca	Juchitán de Zaragoza	68	102
Oaxaca	Santo Domingo	68	102
Oaxaca	Juchitán de Zaragoza	68	102
Baja California	Mulegé	1	0,6
Oaxaca	Juchitán de Zaragoza	104	84,2
Quintana Roo	Benito Juárez	1	1,5
Tamaulipas	Reynosa	36	54
Oaxaca	Unión Hidalgo	69	90
Oaxaca	Juchitán de Zaragoza	152	137,5

(*continued*)

State	Municipality	Items	Installed capacity (MW)
San Luis Potosí	Charcas	100	200
Oaxaca	Ixtaltepec	120	67,5
Baja California	Tecate	52	156
Sonora	Puerto Peñasco	1	2
Oaxaca	Santo Domingo	51	102
Oaxaca	Ixtaltepec	34	102
Oaxaca	Santo Domingo	121	102,85
Oaxaca	Juchitán De Zaragoza	124	164
Oaxaca	Santo Domingo Ingenio	80	160
Chiapas	Arriaga	16	32
Oaxaca	Juchitán de Zaragoza	35	70
Oaxaca	Juchitán de Zaragoza	37	74
Jalisco	Ojuelos de Jalisco	28	50,4
Nuevo León	Santa Catarina	8	22
Oaxaca	El Espinal	35	70
Oaxaca	Juchitán de Zaragoza	300	250,5
Oaxaca	Ixtaltepec	60	80
Oaxaca	Juchitán de Zaragoza	252	234
Oaxaca	Juchitán de Zaragoza	3	0,3
Baja California	Mexicali	5	10
Oaxaca	Juchitán de Zaragoza	82	101,9
Oaxaca	Santo domingo Ingenio	33	49,5
Puebla	Palmar del Bravo	33	66
Oaxaca	El Espinal	37	74
Nuevo León	General Bravo	84	126
Nuevo León	General Bravo	47	126

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