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**Abstract**

In this paper we develop 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 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).

**Introduction**

Strategic Environmental Assessment (SEA) has neither taken definite shape nor is it fully integrated into Mexican legislation yet, and it could be argued that at present it does not really exist in Mexico. The Secretary responsible for the environment (SEMARNAP from 1994-1999; SEMARNAT from 2000 to present) has recognised the limitations of project Environmental Impact Assessment (EIA) for more than ten years, and has considered SEA for policies, plans and programmes (PPP) as a complementary instrument, which functions as a preventive mechanism for sustainable development. Under a federal administration 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.

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 recognizing this challenge, it was 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 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:

* 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, Espejel, & Arámburo, 2011).
* Environmental Sustainability, from concept to practice: an opportunity for the implementation of SEA in Mexico (Ahumada, Pelayo, & Arano, 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, Olivas García & Magaña Magaña (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, Alfaro, & Medellín (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.

**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 & 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, Mörtberg & Brown (2014) point out that, since both, climate change and biodiversity are increasingly seen as being of the highest priority, 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.

**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 also 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, 2014b). Fossil fuel power generation capacity dominates the system with some 70.18% (41,240 MW) of total 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 Figures 1 and 2).

**Figure 1** Installed capacity of electric power in Mexico

**Figure 2** Installed capacity of renewable energy in Mexico

Mexico has many regions with a steady wind supply appropriate for high capacity factor wind farms (SENER, 2014a). In 2017, the country had 36 wind farms, which together had an installed capacity of 3,193.10 MW (i.e. 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. Figure 3 shows a schematic depiction of the location of wind power plants installed in the country. All wind farms in the country, including installed capacities, are presented 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).

*Source:* SENER (2014b)

**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 CO2 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. In order to provide support for the new architecture of the wind sector, this paper reports on a research exercise 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.

**Methods**

Our methods are structured along interrelated phases of cyclical interactive, flexible and adaptive processes. This is outlined in Figure 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 (SIGIC after its acronym in Spanish) which in essence operates as a group-based spatial decision support system (GSDSS). Following Hendriks & 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.

*Source:* own elaboration.

**Figure 4** GSDSS-basedSEA methodological framework

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

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

Figure 5[[1]](#footnote-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.

*Source:* Adapted from Castillo-Rosas et al. (2017).

**Figure 5** Scheme of the methodological process

**Preparation**

1. The process begins with a definition of the decision problem (in our case the location of wind energy in Mexico).
2. The objectives of the analysis are reviewed in accordance with the SEA and Collective Spatial Analysis.
3. A spatial survey is designed and information layers (base maps and special maps) are proposed.
4. 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.
5. 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, Connor, & Croal, 2006), adopting the ‘participation by consultation’ typology proposed by Hughes (1998), and considering the stakeholder categories and types observed in Vivek et al. (2007).

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 finally composed is shown in Table 1.

|  |
| --- |
| **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 |

**Table 1** Final list of confirmed participants

1. Subsequently, users/experts accepting to participate (second stage of the system configuration) are 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[[2]](#footnote-3) as well as system login credentials.

**Geoconsensus**

1. This step essentially represents the beginning of the participatory exercise. Having reached this point, the survey is conducted employing the *Real Time Spatial Delphi*[[3]](#footnote-4) technique (Di Zio, Castillo Rosas, & Lamelza, 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 & Pacinelli, 2011).
2. 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). Geo-consensus building does not represent in any way a mandatory requirement or a dominating factor within the proposed analysis, according to the logic of the Delphi method (Dalkey & Helmer, 1963).
3. Members of the panel are informed about the objective of the exercise and encouraged to seek a possible convergence of opinions. 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 survey should be completed according to the procedure described in the following results section of this paper.

**Results of research study**

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.

**Conducting the exercise**

***Initial considerations***

1. The access to the platform was made possible through the web address http://www.sigic.net, using 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, 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[[4]](#footnote-5)* (non-georeferenced information) was made available, where the members of the panel could find documentation intended to support when thinking about their opinions.

***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[[5]](#footnote-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[[6]](#footnote-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[[7]](#footnote-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, the 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 recommended 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 visualization 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.

1. In the *Arguments[[8]](#footnote-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 & 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.

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| **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. |

**Box 1** Exercise questionnaire

**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 definite 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).

|  |
| --- |
| **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 2** Final participation of panel members

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%.

|  |  |  |  |
| --- | --- | --- | --- |
| **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 |

**Table 3** Participation of experts regarding each question

Figure 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 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-consensuses which has evolved over time with modified and new opinions emerging. From Figure 8 the spatio-temporal evolution of the geo-consensus for each of the survey questions can be seen, and from Figure 9 the view for a specific question is visualised.[[9]](#footnote-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.

Figure 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 overlapped; 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 Figure 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, Figure 12 shows the evolution in the geo-consensus for each of the questions, calculated based on the panel's opinions. The X-axes represents time and the Y-axes diameter of the circle, both starting from 0. In order to be able to compare, it is important that the maximum value of Y is always the same for all diagrams. It is thus possible to see: 1) the convergence 2) the stability 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 size 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 curve, in all cases, become almost horizontal and this means that at the end of the survey the opinions of the experts were stabilized: continuing beyond would not lead to new results. In Delphi-like research, this is very important as it provides for a criterion 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 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 spent more time reaching an agreement

For questions 3 and 5 therefore there was a quick achievement of geoconsensus, while for question 2 the formation of the geoconsensus 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 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

**Figure 12** Spatio-temporal evolution of the circles of geo-consensuses

**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 an 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 it is deemed to occur a greater environmental degradation as a result of the construction of such wind-generated energy complexes (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).

In the case of the 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, Skutsch, & Schofer, 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, it should be noted that 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).

It would be useful to underline here that these problems are not a feature of our study, but rather they are typical of surveys making use of experts.

**Conclusions**

The research project underlying this paper was conducted to develop an artefact consisting of the proposal of a context-specific SEA approach integrated with a geo-collaborative platform for supporting spatial decision-making regarding the site location of onshore wind energy in Mexico. To that end, the main tasks covered the implementation of a WEB-GSDSS application based on the Real Time Spatial Delphi (RTSD) method. Its GIS interface was designed and especially adapted for the study case. The tool presented here is an archetype which is based on a SDSS and can contribute, together with other elements, to the choice of most suitable locations/options.

The central function of the RTSD enables and promotes study and reflection amongst participants in order to reach a geoconsensus -or spatial consensus- regarding locations of the infrastructure under consideration in a defined territory, thus achieving a better understanding of possible and suitable future development. This represents an important advantage over the 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 nonlinearity.

Amongst the strengths of the delivered archetype, subsequently the most important are emphasised; noting that some of them have been inherited from the Real Time Spatial Delphi (Di Zio et al., 2016):

* It provides an opportunity to share expertise and to benefit from local knowledge and fresh 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 present 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 constraints identified are:

* Difficulty in understanding how the proposed scheme can improve what has been done so far in SEA, and how it can benefit the environmental assessment process;
* Likely signs of resistance from those practitioners familiar with traditional GIS, and usual methods used for environmental assessment;
* Possible misunderstanding about the proposed approach 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);
* The preparation of the survey and the configuration of the system interface 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;
* The success or failure in the application of the archetype depends essentially on the commitment, professionalism, knowledge and availability of the participants;
* The problem of drop-out is still present, although lower than in the conventional Delphi survey;
* There is some resistance and disbelief in adopting this type of technology with a subjective basis.

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

1. Through a novel geotechnical web application, the members of a multidisciplinary panel of experts based in Mexico, with little or no technical expertise in geographic information science and the use 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 environment 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 (plausible explanations were discussed in the previous section).
3. In relation to the previous question, and taking into consideration possible cumulative effects, it was possible to choose an area where it is deemed that a greater environmental degradation will be caused as a result of the construction of such wind-generated energy complexes.
4. Disregarding these outcomes and the interpretation of consensus areas, the findings of this research, and more concretely those related to the experimental component of it, demonstrate that 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 counteract polarisation in decision-making. Whilst in the collective intelligence analysis a consensus was sought, the building of it was not forced, like in any Delphi-like exercise. What was observed was a convergence of opinions of the participants.

Having responded to the questions that gave rise to this research, the following contributions should be highlighted:

1. Proposal of a GSDSS-based SEA approach with practical focus to improve the understanding and future formalisation of SEA in Mexico.
2. Application of the Real-Time Spatial Delphi method in a new spatial planning context.
3. Promotion of a structured sustainability impact management framework useful for the transition process towards renewable energy.
4. Implementation of an open and transparent stakeholder engagement and publication consultation exercise in line with international SEA principles.
5. Collaboration in the development of a technological application of Collective Intelligence for the geospatial analysis from an interdisciplinary perspective.

This results presented in this paper support the claim that the level of **consideration given to sustainable development concerns** on strategic documents such as policies, plans and programmes, should be raised, identifying and proposing affected areas in the context of the Mexican wind energy transition that may arise as a result of the implementation of these instruments and its alternative approaches. Furthermore, it aimed at providing support for more transparent strategic decision-making, delivering relevant and reliable information for those involved in timely and effective PPP making.

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 sustained over time through the SEA. Accordingly, it can be stated that there are interesting proposals to face the dilemma and the questions posed by sustainable development. One of the most relevant perhaps, SEA, includes a number of important measures that can be taken to address the challenge at its root, which goes beyond the traditional concept of EIA of projects.

Finally, 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 model of a nation and those regions where it is carried out. This in turn will enable achievement of other solutions that may be more prospective in nature, e.g., boosting and consolidating certain productive sectors as key drivers of regional and national economies, i.e., renewable energy, and in parallel promoting a deep decabornisation of the power system as well as a greater independence from the traditional exploitation of energy sources such as oil, gas and nuclear. In the same way, leading to the gradual transition -yet accelerated and sustained- towards renewable energy, and the ultimate goal of sustainable development.

***Thomas’s question:***

***Are our results in line with what could have been expected even if our method hadn’t been applied?***

I believe they would lead to different results. Following I can try to explain some reasons.

if we would had not applied our method, but instead another more conventional GIS based approach, there would have been a lack of perspective (following Hendriks & Vriens, 2000). The difference in perspective between GIS and SDSS can be explained as follows: GIS looks at data and SDSS look at problem situations (Cooke, 1992; Crossland et al., 1995). 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 the collaborative element through a GSDSS (characterized as an SDSS-plus) which is conceived as a tool that enables dealing with the complexity of the spatial problem, placing special attention to the social complexity embedded in the situation under analysis.

On the other hand, at present, it is difficult to find flexible systems developed through open source tools that allow shared graphic environments and networked access to spatial databases (like the one used here), which also promote the exploration of alternative solutions and consensus building. 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 the appropriate tools to see that there are alternative ways of conceiving the problem, new light may be shed on how to deal with these problems (and it is highly likely that such light will lead to different results). The approach presented here can be therefore be a starting point to establish new research goals and objectives regarding support for spatial decision-making through a Collective Spatial Analysis.

1. 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. [↑](#footnote-ref-2)
2. 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. [↑](#footnote-ref-3)
3. 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 & Pacinelli, 2011). The Real Time Spatial Delphi is its real time version (Di Zio et al., 2016). [↑](#footnote-ref-4)
4. 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. [↑](#footnote-ref-5)
5. 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 & Pacinelli, 2011), each with geographic coordinates (e.g., latitude and longitude). [↑](#footnote-ref-6)
6. As noted by Di Zio & 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”. [↑](#footnote-ref-7)
7. “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 & Pacinelli, 2011). [↑](#footnote-ref-8)
8. 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). [↑](#footnote-ref-9)
9. This information can only be viewed by the system administrator. [↑](#footnote-ref-10)