Design and Implementation of an Environmental Decision Support System: tools, attributes and challenges

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Abstract

This paper presents the approach and findings related to the implementation of an Environmental Decision Support System (EDSS), designed to assist the Moroccan national decision makers, in particular, in their evaluation of the state of the environment, and in their approach to sustainable development and environmental policymaking. We describe the background of the environmental situation in Morocco and the need that drives the development of an EDSS. The EDSS offers a number of salient features and attributes that help with framing the decision making process, ranging from the management and monitoring of indicators, modelling of environmental problems using a knowledge-based approach, uncertainty handling using fuzzy logic, dissemination of information with the society, as well as stakeholder involvement. The description of these features is linked to the main system components and tools. We also discuss some of the major challenges we faced during the different project phases in spite of the recognized importance of the EDSS for environmental management and evaluation at the highest levels. We discuss the perhaps most problematic set of challenges, namely elicitation of the requirements, scarcity of data and knowledge, and failure to define clear criteria to frame the selection of relevant indicators.

1. Background

Morocco is a mountainous country, vulnerable to both marine and Saharan influences. The increase in population has conducted to an increase of the gross domestic product (GDP), which stressed by deficient resource management, has led to the degradation of the environment. The annual cost of environmental damage has been estimated at nearly 4.8% of Morocco's GDP (World Bank, 2002). Morocco is a country that lacks natural resources, especially arable land and water. During the last years, intensive agricultural production, uncontrolled irrigation schemes, industrialization, and urbanization have made the country subject to enormous problems. The country has suffered from severe air and water pollution, soil erosion, and environmental health degradation. The country is also subject to impacts of global climate change. Forest ecosystems and biodiversity are threatened by deforestation. Emissions of greenhouse gases increase, and access to safe drinking water in rural areas is still below expectations. As for liquid sanitation, it remains a problem. Water resources quality can be altered by uncontrolled sewage or siltation of reservoirs; and coastal waters suffer sometimes from oil pollution; and despite the construction of social housing, some citizens still live in unhealthy places [1].

The main approach adopted by Morocco to achieve the targets of sustainable development (SD) is environmental. One of the initiatives that support the Moroccan strategy for sustainable development is the establishment in 2010 of a National Charter for the Environment and Sustainable Development CNEDD [2] which constitutes a positive and constructive action. Its aim is to: 1) consider the preservation of the environment and sustainable development as a national priority, 2) to disseminate awareness among citizens, all managers, whether public enterprises or

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private, government, local authorities and elected officials of the need to preserve the environment and to take it into account in the economic and social projects. It is a collective involvement. The National Charter for Environment and Sustainable Development is considered the first initiative of its kind in Africa and the first in the Arab World. The charter is guiding environmental policymaking and laws on natural resources and sustainability. The charter led to the integration of sustainable development principles into sectorial strategies, the implementation of the Strategy for Improvement of the Environment (MANE) and the National Initiative for Human Development (INDH), as well as the formulation of concrete and operational proposals like the National Strategy for Environmental Protection (SNPE) and the National Strategy for Sustainable Development (SNDD).

Another initiative is the Moroccan National Environmental Observatory (ONEM) that aims at improving knowledge related to the Moroccan environmental system and performing a deep analysis of interactions environment-development. In this perspective, ONEM's approach is based on a number of fundamental principles: 1) to collect, analyze and disseminate information; 2) to produce statistics and indicators on sustainable development; 3) to develop a network of decision makers in terms of environmental monitoring; 4) to contribute to the definition of public policies in terms of sustainable development; 5) and to publish reports on the environmental situation.

As can be felt from the different abovementioned Sustainable Development initiatives, and given the scale of the environmental problems in Morocco, the need for an integrated Environmental Decision Support System (EDSS) [3-6] for monitoring the environment is critical to effective evaluation, management, and follow-up. Such system should also support decision making for regional environmental protection in order to reconcile economic demands and social needs with the capacity of the environment to sustain human and other life. Incorporating economic, social and environmental data is necessary to achieve the targets of 'Sustainable Development'. This approach should help clarifying the socio-economic causes of environmental degradation and their impacts. Furthermore, the adoption of one of the best practices in environmental modeling, namely the technical model Driving Force - Pressure - State - Impact - Response (DPSIR) [7] should assist in gaining insight into environmental problems.

In order to bring science to decision makers and help in structuring the activities of the decision making process, the EDSS should integrate a set of tools such as, a database on ecological and socio-economic indicators along with their historical data, Geographic Information Systems, Multiple Attribute Decision Making methods (MADM), simulations and tools for knowledge acquisition and modeling.

All these needs have been developed in an EDSS designed to assist the Moroccan national decision makers in particular in their evaluation of the state of the environment and in their approach to sustainable development and environmental policymaking. The detailed architecture and the different design decisions and technology choices of the EDSS have been discussed in [8]. The EDSS building block architecture gives a number of evident attributes like the ability to scale up, flexibility and simplicity of process reusability and duplication when there is a need to. The modular design allows the EDSS to follow the need to build complex environmental services to be offered at different scales and open to a wide audience ranging from NGOs, experts, decision makers and citizens. The system allows composing different functionalities to higher level entities thus allowing creation of different deployment scenarios possibly distributed at different administrative regional and national levels.

2. The major EDSS attributes

The EDSS offers a number of salient features and attributes that help with framing the decision making process. It allows:

1) the definition, management and monitoring of indicators and historical data,
2) the modelling of environmental problems using the DPSIR framework that brings ecological indicators as well as socio-economic drivers and pressures into the same picture,
3) it also incorporates possible responses to environmental issues and gives support to evaluation of relevant policy alternatives,
4) it uses a knowledge-based approach and leverages heuristic expert knowledge in order to analyze the DPSIR causal links,
5) it supports uncertainty handling using fuzzy logic,
6) it promotes communication with the society using a GIS Web Mapping service and a mobile application, and
7) it supports stakeholder involvement through scenario development and evaluation.

2.1. An integrated and generic approach

The framework employed to guide the selection of indicators was initiated within the DPSIR model. The goal of using DPSIR in the EDSS is to guarantee that scoping goes beyond sectorial interests and limited problem perceptions, focusing on finding the balance between socio-economic needs and the protection of ecosystems, which is an essential perquisite for achieving the targets of sustainable development. During this phase, sufficient understanding about the functioning of the studied ecosystem of any environmental issue should be gained, including the identification of relevant indicators and cause-effect links between them.

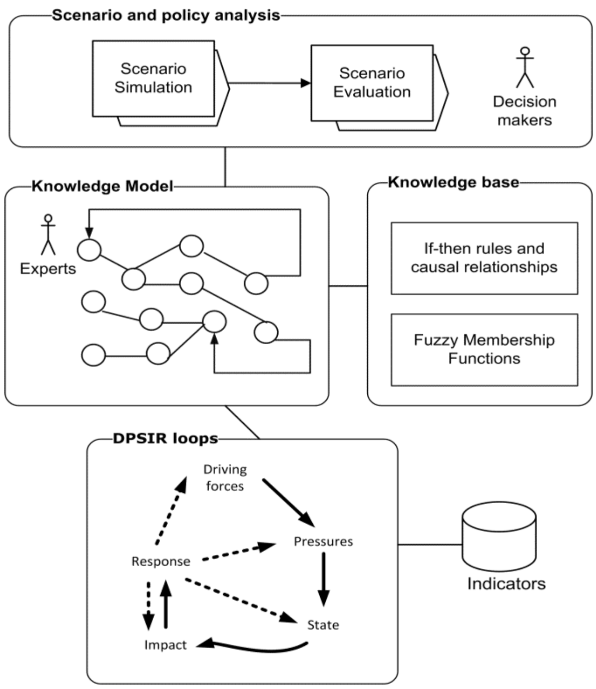

Figure 1: The different components of the knowledge-based model

The strength of the generic and integrated decision support approach was proven by two case studies, traditionally belonging to two different areas of expertise. Namely, the EDSS was used to analyze river water quality which allowed the identification of key pressures on water quality in the Bouregreg-Chaouia basin. Hereafter we provide details of a second example that includes a case study to evaluate key policy options that can mitigate air pollution impacts on the public health in big cities.

Assessing air pollution impacts on health or evaluating the different policy options to mitigate the impact of air pollution on health is a complex process that brings together socio-economic aspects as well as ecological indicators in an attempt to understand and control the pressures that drive the ecosystem changes. A knowledge-based model, based on Fuzzy Cognitive Maps (FCMs) [9] and Rule-based Inference systems, was chosen to be utilized to perform an integrated evaluation of the air pollution issue because of the nature of the application. The model is made of nodes that represent the different air pollution pressures like emissions of sulfur dioxide; impacts like health risks induced by respiratory and cardiovascular complications; and responses or remedies like the introduction of clean fuels, industrial pollution control or creating low emission zones. The model supports also representation of complex cause-effect relationships between the different indicators in the form of fuzzy inference systems that dynamically determine the influence induced by one indicator on another. An inference algorithm was outlined to process acquired data against the knowledge base and answer questions, evaluate a range of possible scenarios or predict output under consideration of human perceptions, uncertainty and complex cause and effect factors. The different components of the model are summarized in Figure 1.

The developed DPSIR loop related to air pollution with the different causality links between indicators is illustrated in Figure 2. Qualitative descriptions of some of the considered indicators are shown in Table 1. A sample set of if-then rules describing the causality links between the different concepts are shown in Table 2. The DPSIR-based cognitive map and the rules were elaborated in consultation with environmental experts.

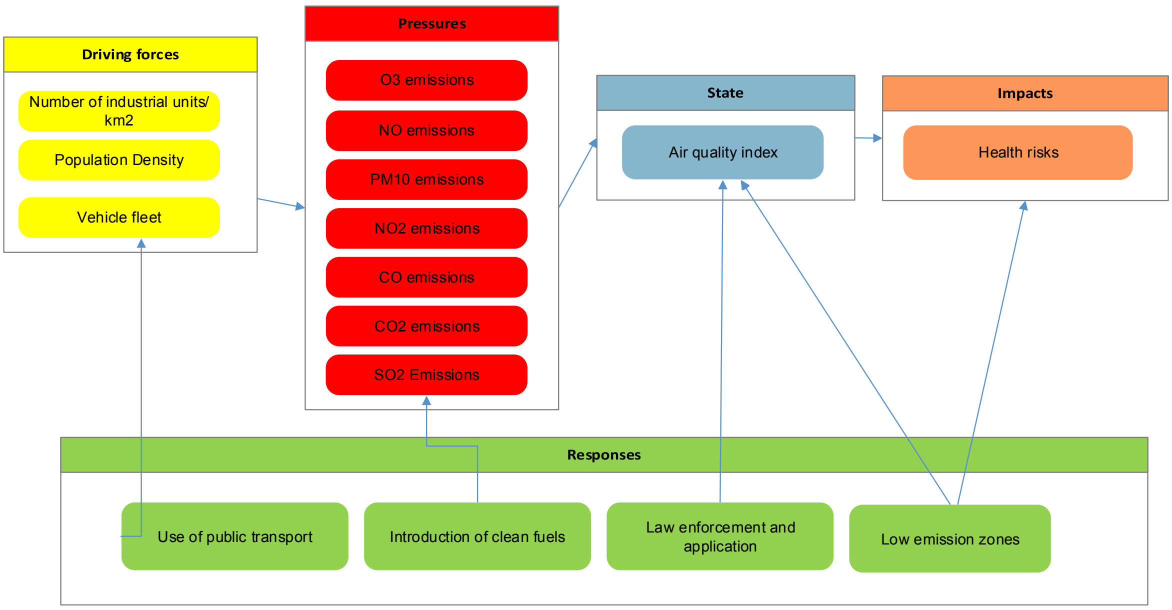

Figure 2: The DPSIR loop for the air pollution issue

The knowledge-based approach, leveraging expert knowledge, seems to be very helpful to managers and stakeholders, because it brings together data and expert heuristics in an attempt to tackle decision making, planning and policy formulation.

2.2. Collaborative data collection and exchange through a web portal

The environmental management functions are mainly based on the access to complete and quality data, enabling the information system to carry out its tasks. However, there are different providers of environmental information in Morocco. This is generated by a variety of public and private institutions like ministries, hydraulic basin agencies and urban agencies. Therefore, a network of regional stakeholders and partners has been established to ensure dynamic sharing and exchange on historical data and to guarantee an efficient and regular data collection in order to feed and update the regional information system.

Stakeholders and partners actively contribute in the production of environmental information, through a web portal for the upward transmission and circulation of the information to the Department of the Environment (DE) without further moderation. The web portal was designed and built as a Rich Internet Application so as to provide state of the art user experience and ubiquitous access to the environmental information stored in the EDSS. The backend was built according to the Model-View-Controller design pattern leveraging standard frameworks.

2.3. Dissemination of information in a participatory approach

Public participation and the right to have access to environmental information were instructed by the Moroccan Environmental Charter. This makes environmental information sharing an important element of the environmental decision support system.

A dynamic GIS web mapping application was used as an inexpensive means for publishing environmental data and sharing it with a wide audience of users. By maximizing the use of the Internet for sharing, information accessibility is significantly improved compared to conventional paper distribution of maps. Users can query the database of indicators and choose layers of statistics in different geographical divisions that are cross-referenced to point to ESRI Shapefiles.

An Android mobile application was developed to allow users collect air quality status in their location, using the convenience of a mobile device. The application makes it easy for people with respiratory complications to determine when extra caution is advisable or when they should limit the outdoor activities. The user implication in environmental matters is also encouraged with an option to report air quality violations, like smoking vehicles or any evidence of hazardous waste.

Indicator threshold values	SO_2 emissions (ug/m^3)	Industrial units ($number/km^2$)	Health risks (%)
Low	0 - 159	<3	0-1
Average	160 - 249	4-5	1-3
High	250- 349	>5	3-100
Very high	350- 549		

Table 1: Sample indicator threshold values used in the air pollution DPSIR loop

2.4. Uncertainty handling using fuzzy logic

In modeling environmental problems, experts often fail to provide a clear knowledge because of the lack of common standards and hence ecological systems would be described with knowledge that is ambiguous or imprecise to a certain extent. Uncertainty defies the reliability of the obtained results' effectiveness in the decision making process. To deal with ambiguities and uncertainties, Fuzzy logic, which was first introduced by Zadeh [10] was very convenient in conciliating observations due to using multiple experts which is a desired feature in running FCM sessions, whether in describing indicator threshold values or the cause-effect relationships between them. Fuzzy logic allowed us to develop a natural language system that makes use of linguistic variables, where the universe of discourse of an indicator is divided into a number of fuzzy sets with a linguistic description attributed to each one. The same set of linguistic terms was used to describe the relationships between input indicators and outputs using fuzzy if-then rules. In spite of the underlying knowledge acquisition complexity when fuzzy logic is used, it allowed us, besides the handling of uncertainty, to establish a more natural user interface since results can be communicated in numerical formats or in natural language terms. Another advantage is the ability to combine individuals' knowledge and beliefs in an easy and meaningful way. The result of the aggregation of individual's FCMs is sometimes referred to as a "social cognitive map"; it is perceived as a representation of shared knowledge and has been used in a wide spectrum of applications and scientific fields in order to support decision making processes. The aggregation of expert knowledge helps in gaining a more comprehensive understanding and reaching consensus among experts about complex systems [11].

Fuzzy Rules
Link : Pressures transport -> Air quality
IF Transport emissions is low THEN influence ON Air quality is low IF Transport emissions is medium THEN influence ON Air quality is high IF Transport emissions is high THEN influence ON Air quality is very high IF Transport emissions is very high THEN influence ON Air quality is very high
Link : Air quality -> Health impact
IF Air quality is good THEN influence ON Health is low IF Air quality is medium THEN influence ON Health is medium IF Air quality is poor THEN influence ON Health is very high IF Air quality is very poor THEN influence ON Health is very high
Link : Clean fuels -> SO2 emissions
IF Clean fuel introduction is low THEN influence ON SO2 is low IF Clean fuel introduction is medium THEN influence ON SO2 is low IF Clean fuel introduction is high THEN influence ON SO2 is medium IF Clean fuel introduction is very high THEN influence ON SO2 is medium

Table 2: Sample rules built to model the causality links in the air pollution DPSIR loop

2.5. Stakeholder involvement

In collaboration with the Regional Environmental and Sustainable Development Observatory (OREDD) and the Environment Department (DE), we conducted a pilot deployment in the region of Meknès-Tafilalt by capitalizing on a previous work that resulted in the identification of key sustainable development indicators and the establishment of a network of regional partners and stakeholders for data collection and monitoring. The project was conducted to allow local authorities to have an overview on the state of the environment in the region of Meknès-Tafilalt, to know the consequences of the population on ecosystems and have an action plan that aims to improve the environmental situation while remaining in articulation with programs and projects and taking into account the institutional arrangements and financial support measures. The project is organized around four main missions: 1) establishment of a network of regional partners for data collection, 2) establishment of a database of environmental indicators in use in the region, 3) integrated assessment of the environment and development of the regional report on the state of the environment, and 4) proposition of action plans for the protection and restoration of the regional environment.

An iterative and incremental approach was adopted, conducted in a collaborative spirit with some amount of formality. The idea was to generate a quality product while taking into account the changing needs. Potential areas of environmental concern along with the set of indicators to be used were identified by performing a close study through a number of consultations and discussions with specialized environmentalists.

3. Challenges faced

In spite of the recognized importance of the EDSS in environmental management and evaluation, there have been a number of challenges that we faced during the different project phases. We discuss the perhaps most problematic set of challenges: elicitation of needs, scarcity of data and knowledge, and failure to define a set of criteria to frame the selection of relevant indicators.

3.1. Elicitation of the needs and communication with end users

One of the challenges we faced and also discussed in [12], is that the requirements, initially, were not clearly detailed or even understood by the end users themselves. What complicates the problem further is that the EDSS project was funded by DE, but subcontracted by private consulting companies and implemented by academic researchers independently of the originally intended end users, which created a problematic communication setting for the EDSS developers. To mitigate somehow the problem, we adopted an approach that is iterative, adaptive and interactive. We built a number of prototypes that served initially to validate the requirements and provide suggestions, however the process was very costly and time consuming.

3.2. Data and knowledge quality

Applying the DPSIR framework to an environmental issue should be strengthened by a solid knowledge base; the result highly depends on quality data and knowledge availability. Unfortunately, in the EDSS, the DPSIR is usually applied in the early stages of any project, because this is where it seems the most effective. However, this step is performed independently on the data collection process. The main effort deployed in designing the DPSIR loops was spent on retrieving data from different partners separately, but little effort was spent on data transformation and integration from different sources to match, for example, the *Impact* indicators with the *State* or *Pressures* constituting a single DPSIR loop. Moreover, in an integrated evaluation approach, availability of knowledge in the different areas of the DPSIR model cannot be assumed. Learning trends and knowledge extraction was quite hard too because of scarcity of data. For example, in the pilot region of Meknès-Tafilalt, we noted that 85% of indicators have no history, and that only 10% of indicators contribute to the available data with a filling percentage lower than 40%, which means that there is missing data for many indicators and for many periods. Another factor that contributes to the problem is the underlying acquisition cost of non free data. This situation has pushed DE to put pressure on the different stakeholders in order to maintain the level of interest and funds required to collect the necessary data.

3.3. Environmental data and indicator framework

Given the complexity and the interlacing nature of environmental issues, the list of indicators to be used in the integrated environmental evaluation has not been finalized as yet up to today. The project failed to handle the actual complexity of environmental issues because of the lack of scientific consistency and the failure in defining and adopting a clear framework or criteria for choosing the indicators that best describe a specific ecological problem. It is felt that a procedure for environmental indicator selection should be adopted. The procedure should have clear criteria and also present a method to evaluate the indicators against the chosen criteria. The set of indicators need to capture the complexities of an ecosystem but yet be simple, easily monitored and measured. They should also be relevant to the policy life cycle and help decision makers take informed decisions. The result of this process should then be used as a baseline for data collection and environmental monitoring.

4. Conclusion

In this paper we described the background, tools, attributes and challenges of an EDSS developed to support the Moroccan national strategy for environmental protection and sustainable development. One of the major assets of the EDSS is that it was designed and deployed within a framework that includes stakeholder participation and expert knowledge. This linkage was maintained within the frame of a national project conducted by the Moroccan Environment Department. Applying the DPSIR framework by integrating ecological indicators and socio-economic indicators is very important in an integrated evaluation of the environmental situation and in reaching the targets of sustainable development. However, it remains very challenging to mobilize enough expertise pertaining to inter-related domains of a given environmental issue. The knowledge-based approach was proposed to clearly define the network of causal links between indicators and in associating the qualitative and quantitative data, which are all necessary activities in the modeling process but lacking in the DPSIR framework.

It can be concluded that, in EDSS development, it is of a tremendous importance to define a formal and transparent framework, with clear criteria for selecting and assessing the set of considered indicators in order to obtain the ones that are very representative of a specific ecological problem, and yet can be easily monitored and measured. It is also very important that the EDSS developers, not only focus on functionality, but should also engage in elaborate usability and user oriented process models in order to ensure correct elicitation of the end user needs and their involvement in the different stages of the project.

References

[1] International Institute for Sustainable Development, "Morocco Case Study: Analysis of National Strategies for Sustainable Development," International Institute for Sustainable Development, 2004.

[2] Ministry of Energy Mines Water and Environment, "Morocco's National Charter for Environment and Sustainable Development," in *Green Compass Research*, 2010.

[3] R. Mayer-Föll, A. Keitel, C. Hofmann, G. Lukács , M. Briesen, and A. Otterstätter, "Integrated Analysis and Reporting of Environmental Data Through Cooperation and Technical Innovations – Despite Organisational Changes, Increasing Requirements and Decreasing Budgets," *Informatics for Environmental Protection - Networking Environmental Information,* 2005.

[4] W. G. Booty, D. C. L. Lam, I. W. S. Wong, and P. Siconolfi, "Design and implementation of an environmental decision support system," *Environmental Modelling & Software,* vol. 16, pp. 453-458, 7// 2001.

[5] h. Vögele, M. Klenke, F. Kruse, and S. Groschupf, "A New and Flexible Architecture for the German Environmental Information Network," *Informatics for Environmental Protection - Networking Environmental Information*, 2005.

[6] U. Madari, "Supporting Strategic Decision Making on Climate Change Through Environmental Information Systems: The Case of ENVIS," 2012.

[7] P. B. P. Gabrielsen, "Environmental indicators: typology and use in reporting.," Copenhagen: EEA 2003.

[8] T. R. A Mourhir, M Karim, "A Decision Support System for the Environment: Application to Morocco," *J. Int. Environmental Application & Science*, vol. 9, pp. 10-23, 2014.

[9] B. Kosko, "Fuzzy Cognitive Maps," *International Journal of Man-Machine Studies*, vol. 24, pp. 65-75 1986.

[10] L. A. Zadeh, "Fuzzy sets," *Inform. Control, vol.8*, pp. 338–353, 1965.

[11] S. A. Gray, E. Zanre, and S. R. J. Gray, "Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs," in *Fuzzy Cognitive Maps for Applied Sciences and Engineering*. vol. 54, E. I. Papageorgiou, Ed., ed: Springer Berlin Heidelberg, 2014, pp. 29-48.

[12] B. S. McIntosh, J. C. Ascough Ii, M. Twery, J. Chew, A. Elmahdi, D. Haase, *et al.*, "Environmental decision support systems (EDSS) development – Challenges and best practices," *Environmental Modelling & Software*, vol. 26, pp. 1389-1402, 12// 2011.