COmmunity-based Management of
EnviromenTal challenges in Latin America

D1.2: "Locally-adapted Prospective Analysis Techniques to Social-Ecological-Systems"

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Executive summary

The successful management of environmental challenges depends on several internal and external factors, but the communities that base their livelihood and interact daily with ecosystems can play an important role in sustainable management. However, they often lack skills and locally adapted tools for such management. The local lack of understanding on SES dynamics, their interactions with broader social, economic and institutional settings and the effects of management practices may pose significant barriers to sustainable management.

COMET-LA searches to improve this situation through a better understanding of these dynamics, interactions and effects. It is a research project for the benefit of the Civil Society Organizations (CSOs) aiming to identify sustainable governance models for the management of environmental challenges. The COMET-LA project emerges as a result of the collaboration of 11 partners and several local and regional stakeholders. The working method is based on the use of participatory techniques and a learning arena where scientific and local knowledge are shared and integrated. This way, it not only fosters the participation, but also the involvement of the local communities in the project, which leads to a higher level of appropriateness of the outcomes to their needs.

The project is developed around 3 Case Studies (CSs) in Colombia, Mexico and Argentina, each one analyzing environmental challenges in specific Social-Ecological Systems (SESs); water and biodiversity management is analyzed in 2 Communitarian Councils of Black Communities in the Colombian Pacific, forest management in a community of the Mexican Sierra of Oaxaca, and marine and coastal areas management in the Argentinean Bahia Blanca Estuary and adjacent coasts.

After a comprehensive characterization of the SESs based on 132 variables (see COMET-LA Deliverable 1.1: Locally-adapted tools for the Characterization of Social-Ecological Systems), the second phase of the project have been dedicated to select the most important variables and drivers in the dynamics of the SES. Capturing and condensing the knowledge of SES users on the central environmental challenges they face without omitting its inherent complexity, is a rather difficult but essential step for a common understanding that drives the planning and development of sustainable management options. In addition, it is a necessary step for building future scenarios, which constitutes the last phase of the project.

This report summarizes the results of Task 1.2: Adaptation of Prospective Analysis Frameworks to local conditions (included in COMET-LA WP1) and presents the methodological preparations to deliver a locally-adapted framework for identifying the role played by the different variables in the current and potential functioning of the SESs according to the perceptions of the local communities that base their livelihoods on them.

The framework proposed by COMET-LA, is based on the second step of the foresight methodology *la prospective*: Prospective Structural Analysis (PSA) (Godet 1986, 1994, Godet et al. 2004). This technique analyzes the relationships of influence/dependence between the main variables in a system as perceived by the stakeholders and classifies them. PSA starts by selecting the most relevant variables describing the dynamics of a system and consecutively gathers the direct influences between them. Afterwards it calculates the indirect interrelationships highlighting the invisible structure of interactions among the system's elements and establishes hierarchies among them. In addition, PSA permits differentiating clusters and nets of interrelated variables and thusly evaluate the role of each element of the system. It shows how the stakeholders see their territory and what they consider to be restrictions, opportunities and potentialities for change; it draws a dynamic image of the perceptions by local actors (Delgado-Serrano et al. 2010).

However, PSA has been conceived for use with experts that are generally highly trained and on sectors that possess substantial means (strategic regional or corporate planning) (Bradfield et al. 2005), so the methodology in its original form is not suitable for use at the local level, particularly with local communities. So, when planning to use PSA in SESs and working with local communities, a thorough adaptation to the local level is in order. All the proposed adaptations were conceived and applied in close collaboration with the beneficiary communities within the framework of COMET-LA. This way, the community members not only have the results of the PSA exercise, but also master the techniques and can eventually use and apply them in the future.

The adapted PSA method has been tested in the 3 COMET-LA CSs. The diversity of situations and characteristics in them has led to use different approaches for taking into account the local environmental differences and dissimilar complex social interactions and to which fine-tune the proposed framework to the particularities of each CS. The results of its application can be consulted in deliverable 2.2: Stakeholder vision on problems and drivers related to environmental challenges in Colombia CS; deliverable 3.2: Stakeholder vision on problems and drivers related to environmental challenges in Mexico; and deliverable 4.2: Stakeholder vision on problems and drivers related to environmental challenges in Argentina CS), all of them available at http://comet-la.eu/index.php/en/publications.html.

The adaptations proposed for improving the synchrony between the framework used to characterize the SESs, the PSA technique and the local context of community-based natural resource management, are mainly situated in the fields of stakeholder selection, concept translation to lay language, and adapting facilitation techniques and workshop organization to the local level. The methodology thusly has been adapted to the oral and visual cultural dynamics of the local communities. The close collaboration with the community members allowed them not only to have the results of the PSA exercise, but also to understand and be trained in the techniques.

The report thus includes a full description of the theoretical basis of *la prospective*, of the mathematical procedures for applying PSA, as well as practical guidelines for conceiving a PSA exercise well-adapted to the local level. Indeed, tips and hints are given for optimizing participation of local stakeholders by giving the locals a central position, including a maximum of social diversity in the analysis, making the exercise comprehensible for lay-people, and sharing the results with the beneficiaries. Suggestions are made to build the community's capacities in SES analysis and key variable identification so they can appropriate and repeat the exercise.

Through the group effort during this stage of the project, the basis laid for the creation of a learning arena where stakeholders can share knowledge and negotiate optimal policies for reaching an inclusive, sustainable and profitable management of the SES, is further extended and intensified. The direct outcome of the PSA is a thorough and harmonized knowledge of (the stakeholders' vision on) the most relevant variables in the SES, and more precisely, the role played by these variables in the SES current dynamics and potential future evolution, and on which drivers are considered the most potent in triggering or blocking changes.

In addition, the local communities have participated in the adaptations and have been trained in the fundamentals of the techniques and can accordingly use and apply them in the future, with the support of the CSOs and research institutions. This way they own these tools for evaluating the impact of their own actions on their SES, and can monitor and assess the actions of other policy and management levels linked with the key drivers. It gives them active ownership of the knowledge.

As a conclusion, it can be stated that with the results of phases 1 and 2, a locally-adapted methodology for characterizing SESs and gaining a deeper understanding on them through the identification of the key drivers and variables and the roles each of them play in the system, is designed. Furthermore, the participatory basis of the methodology guarantees high levels of ownership and locally-rooted results, in combination with a strong integration within the local governance systems. This is a solid step towards sustainable natural resource management, and will be further reinforced during the next step of COMET-LA, Task 1.3: Adaptation of Scenario Building Frameworks to local conditions.

Finally, COMET-LA presents an important methodological innovation in the adaptation of prospective tools to identify the drivers in the SESs dynamics and also in the methodological learning to be used and mastered at the local level. The information included in this report can guide and facilitate the process of developing similar analysis in other SESs.

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COMET-LA	COmmunity-based Management of EnviromenTal challenges in Latin America
CS	Case study
CSOs	Civil Society Organizations
DoW	Description of Work
ISM	Interpretive Structural Modelling
LIPSOR	Laboratory for Investigation in Prospective Strategy and Organization
MACTOR	*Méthode d'analyse des jeux d'acteurs*, or Analysis Method of Actor Interplay
MDI	Matrix of Direct Influence
MII	Matrix of Indirect Influences
MICMAC	*Matrice d'Impacts Croisés Multiplication Appliqués à un Classement*, or Crossed Impact Matrix Multiplication Applied to a Ranking
MPDI	Matrix of Potential Direct Influence
MPII	Matrix of Potential Indirect Influences
MULTIPOL	*MULTIcritère et POLitique*, or Multicriteria and Politics
PCA	Principal Component Analysis
PSA	Prospective Structural Analysis
SES	Social-Ecological System
SMIC PROB-EXPERT	*Systèmes et Matrices d'Impacts Croisés Probabilistes*, or Systems and Matrices of Probabilistic Crossed Impacts

"Ignoranti, quem portum petat, nullus suus ventus est"
(If one does not know to which port one is sailing, no wind is favourable)
Cordoba's philosopher Seneca the Younger (4 BC – A.D. 65)

1 Introduction

The successful management of natural resources requires recognition that they are part of complex and highly dynamic social-ecological systems (SES) that evolve, often in unexpected or non-linear ways, according to the human and natural interventions they receive (Nelson et al. 2007). Natural ecosystems and human societies cannot be considered separately, but as linked in SES (Anderies et al. 2004). Environment and natural resources condition and simultaneously are conditioned by the actions exerted by the population. As stated by Berkes & Folke (1998) "resource management" is "people management".

However, tools and approaches for such people management are poorly developed. Understanding and predicting appropriate management responses at local level is made more difficult by: 1) incomplete knowledge of SES and their dynamics; 2) limited information availability (or access being prohibitively expensive or time consuming); 3) specificities of each SES that make the information nontransferable from one to another; and 4) uncertainties in modeling and in the response of ecosystems to environmental changes and human interventions (Parrott et al. 2012, Homsy and Warner 2013, Visman 2014, Coe et al. 2014).

The direct and indirect impacts on SESs depend on several internal and external factors, but the communities that base their livelihood and interact daily with ecosystems can play an important role in the sustainable management of natural resources. They base their use and management on local institutions, traditional practices and knowledge systems that are not necessarily sustainable. The local lack of understanding SES dynamics, their interactions with broader social, economic and institutional settings and the effects of management practices may pose significant barriers to sustainable management.

COMET-LA searches to improve this situation through a better understanding of these dynamics, interactions and effects. The project call answers to the proposition that *"given access to and control of their own resources, local community members can create and enforce original rules that lead to successful and sustainable economic governance models".* So it calls for *"partnerships between civil society and research organizations with a view to identify and analyze locally owned and developed solutions put in place to prevent and resolve tensions arising from a necessary new repartition and use of natural resources, including ecosystem services, due to environmental and climate changes".* Therefore, it is a project including intense collaboration with Civil Society Organizations (CSOs) and local communities.

The expected impact is described as *"enhancing the understanding and knowledge of local sustainable economic governance models of natural resources, and supporting the identification* *and implementation of means of resolving local tensions arising from new repartition and use of natural resources".*

In this scenario, COMET-LA's overall objective is *"to identify sustainable governance models for the management of environmental challenges"*, using participatory techniques and building a learning arena where scientific and local knowledge are shared and integrated. This working method fosters not only the participation, but also the involvement of the local communities in the project and the appropriateness of the outcomes to their needs, and guides scientists by targeting their research, thusly providing local communities and managers with understandable and useful information to support decision-making processes, and with sustainable community-based models in which local perceptions are integrated.

To reach the abovementioned objective, a three-phased method is proposed and tested in the 3 COMET-LA Case Studies (CSs), which have been chosen to be representative of the most important current environmental challenges. Namely, water and biodiversity management is analysed in the Councils of Black Communities of Bajo Calima and Alto y Medio Dagua in the Colombian Pacific, forest management in the community of Santiago de Comaltepec at the Mexican Sierra of Oaxaca and marine and coastal area management in the Argentinean Bahia Blanca Estuary and the Monte Hermoso-Pehuén Co beach area. Each CS aims to identify sustainable governance models focused on these challenges.

Figure 1. CS Colombia: water and biodiversity management

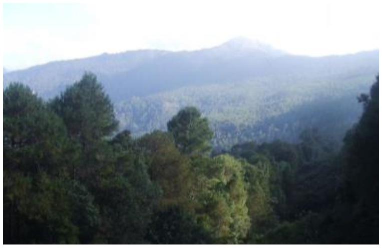


Figure 2. CS Mexico: forest management

Figure 3. CS Argentina: marine and coastal area management

The first phase has been a thorough characterization of the Social-Ecological Systems (SESs) through a locally-adapted version of the Ostrom framework (described in Deliverable 1.1, *Adaptation of Social-Ecological System Characterization Frameworks to local conditions*[1] *and* Delgado-Serrano et al., 2013). However, this comprehensive characterization (132 variables) makes planning and decision taking very challenging. Hence, the second phase of the research has focused on adapting participatory tools that select the most relevant variables defining the SES dynamics and highlight the role they play or can play. The results of this second phase will then feed into the last phase: building future scenarios for the SESs and proposing adapted management actions for promoting sustainability, applying locally adapted techniques (as part of Task 1.3, *Adaptation of Scenario Building Frameworks to local conditions*[2]*).*

[1] See deliverable 1.1 on http://comet-la.eu/index.php/en/publications.html.
[2] The results of task 3 will be gathered in the future deliverable 1.3.

This report summarizes in 8 chapters the results of Task 1.2: *Adaptation of Prospective Analysis Frameworks to local conditions*. It presents the work developed for delivering a locally-adapted methodology and tools using prospective analysis techniques in the analysis of SESs. The tool used, PSA, analyses the participants' views on a system through an iterative participatory process, and structures the results through mathematical operations in a readily usable form for better understanding; it apprehends the participants' mental model of the system's present and future drivers. The results have been tested in the three different CSs.

The outcomes of the application of this locally-adapted key factor identification methodology are described per CS in deliverables D2.2 and D2.3 (for the Colombia CS); D3.2 and D3.3 (for the Mexico CS) and D4.2 and D4.3 (for the Argentina CS) elaborated respectively by the Colombian, Mexican and Argentinean teams. All these deliverables are available at http://comet-la.eu/index.php/en/publications.html.

This deliverable, D1.2, presents a detailed description of prospective methods, a review of the most adapted tools for use at the community level, the difficulties encountered during their use and their subsequent adaptation for the 3 CSs. The most suitable tools and techniques, and the advantages and difficulties found in their use are highlighted. A draft of the present report has been presented at the 3rd Workshops and Stakeholder Fora in the 3 countries and the comments, suggestions and views of stakeholders have been included.

The first step in adapting the Prospective Analysis techniques has been a thorough literature review on prospective methods and foresight, and how they have been used in different disciplines and sectors. This review has provided an understanding of the techniques and the main points to focus on when defining a locally-adapted working method for prospective analysis in SESs. Chapter 2 provides a summary of the results.

Chapter 3 describes the particular foresight technique found as the most interesting for COMET-LA objectives: *la prospective.* It is in particular the second step of *la prospective,* PSA, which has been used to identify the role played by the key variables in complex systems, and is thus suitable for executing the second phase of the COMET-LA project. This technique permits to analyse complex systems, using participatory techniques and operationalizing subjective data through mathematical analysis. The final outcome is a dynamic image of the perceptions by local actors on the SES, differentiating clusters and nets of interrelated variables and thusly evaluate the (subjective) actual and future role of each element of the system (Delgado-Serrano et al. 2010). The review of other modelling frameworks that could be used to analyse complex systems confirmed that PSA is the most adapted to COMET-LA objectives, even if some improvements are proposed to update the technique and adapt it to working with SESs at the local level. The results of this analysis are presented in chapter 4, and PSA is fully explained in chapter 5.

PSA strongly depends on the tools for collecting data and reaching consensus on that data amongst the stakeholders. The participatory methods for use in this context have been reviewed in chapter 6. With the theoretical basis of the technique explained and mastered over the previous sections, chapter 7 presents the main contribution of this task: adapting

PSA for use at the local level, in the context of natural resource management. Special attention is given to the insertion of the technique in the global COMET-LA process.

The conclusions highlight the methodological learning process, the utility of the tools to be applied in SES and at the local level, the encountered problems, the necessary adaptations and the solutions put into practice.

Finally, Annex I enlightens the history of foresight, Annex II gives a full explanation of the 5 phases of *la prospective* technique, as a complement to chapter 3. Annex III expounds on the technicalities of ISM, another technique for identifying key drivers in a system, as a complement to chapter 4. And Annex IV describes in full detail how the Matrix of Indirect Influences (MII) is calculated (an important step in the application of PSA), as a complement to section 5.3.

The approach is rather innovative, since only very partial references of using PSA for the analysis of SES can be found in the literature, and none adapting it to be used at the local level. COMET-LA presents an important methodological innovation in the adaptation of prospective tools to identify the drivers in the SESs dynamics and also in the methodological learning to be used and mastered at the local level.

2 Prospective Methods

The proper analysis of complex systems, such as SESs, requires specific methods answering to a myriad of conditions. Prospective and foresight techniques have shown that they can be up to the task. This chapter expands on the specific requirements for SES analysis techniques, specifically for the identification of key drivers and their role in the SES. It continues by documenting how prospective and foresight techniques contain promising aspects, and what the advantages and disadvantages of their application are in the context of COMET-LA.

Indeed, SESs are very complex, adaptive systems, composed of multiple subsystems and internal variables within these subsystems that interact in different ways, and are under constant change. The ecological and social aspects of the system are interpreted as highly interconnected. Understanding how these complex systems work as a whole requires knowledge on each of the key variables and how they are inter-related. Thus, the techniques used should allow complexity be harnessed and dissected, but not reduced.

In addition, COMET-LA's project concept is based on the development of a learning arena to share local and scientific knowledge. The method proposed for this second phase of the project should be participatory and allow these interactions and exchange.

So, when selecting an analysis method several attributes that fit the objectives of COMET-LA have been considered:

- Dealing with complexity and uncertainty;
- Showing the system's trends and the potential changes over time (potential futures);
- Being participatory of nature, encouraging the implication and empowerment of local stakeholders and the interactions between local people and scientists;

- Recognizing the interactions and mutual influences among SES components;
- With options to be adapted and used at the local level;
- Linked with previous and next phases of COMET-LA.

An important family of techniques made for dealing with complexity and uncertainty by exploring possible futures, are prospective and foresight techniques, which have been reviewed. Foresight can be defined as *"a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilizing joint actions"* (European Union 2013), or shorter: studying possible futures for preparing today's decisions. Modern day foresight techniques have developed from three different schools: the intuitive logics school (USA), the probabilistic modified trends school (USA), and *la prospective* (France) (Bradfield et al. 2005) (for a completer history of foresight, see Annex I). The latter has been chosen for this research.

Different reasons justify the choice of using *la prospective* for the analysis of the drivers in SESs. The three schools of foresight techniques each have a different approach, and can be located on a scale from the rather qualitative/narrative approach (*the intuitive logics school*), up to the quantitative approach (*the probabilistic modified trends school*). *La prospective* can be situated in the middle of the scale, being quantitative and qualitative of nature (Bradfield et al. 2005, Rialland and Wold 2009). Also, the foresight team in both the intuitive-logics and *la prospective* schools are mainly composed of internal participants, with the support of some external experts in the case of *la prospective*, contrary to the probabilistic modified-trend school, where the team is solely composed of external experts. And the identification of the main driving forces in the studied system happens purely on intuition (brainstorming, discussion, etc.) in the intuitive-logics school, by analyzing data obtained in interviews and focus groups through structural analysis in *la prospective*, and by fitting curves to historical time series or expert judgment in the probabilistic modified-trend school.

Table 1. Comparison of the different schools.

	Intuitive logics	***La prospective***	**Probabilistic modified trends**
Approach	Qualitative/narrative	Quantitative and qualitative	Quantitative
Team composition	Internal participants, external optional	Internal participants, external optional	External experts
Identification of the main drivers	By intuition	By structural analysis	By trend extrapolation

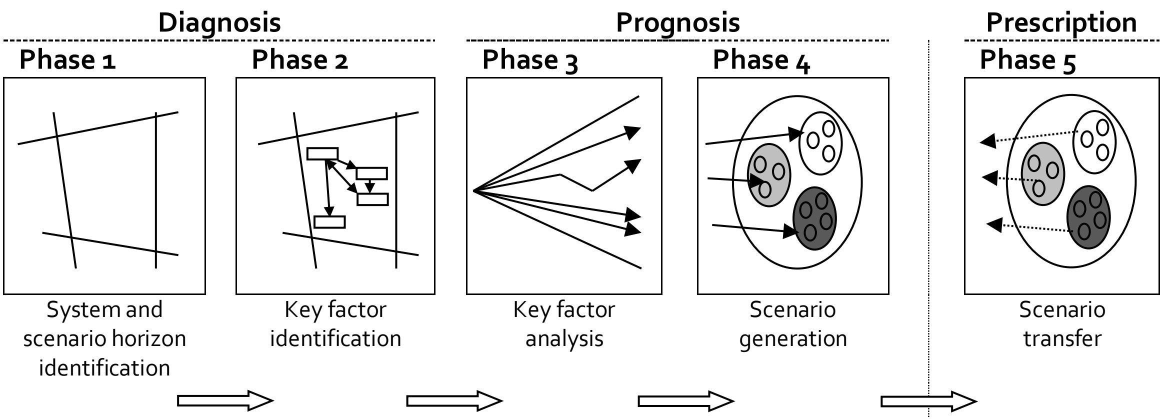
Source: Bradfield et al. 2005; Rialland & Wold 2009

As all three schools belong to the family of prospective and foresight techniques, they are all adequate for dealing with complexity and uncertainty through the exploration of potential futures. But *la prospective* is better adapted to working with local communities, due to its particular nature: no data series are needed (reliable historical data on SES functioning is frequently absent or rare), the data is obtained from the local community and not solely from external experts, and the structural analysis of the data obtained during the participatory processes adds the credibility of mathematical analysis. Furthermore, the participatory process help creating a common vision of the SES and its future options, contributing to the social learning at the community level. In brief, *la prospective* describes and studies in a structured manner the community's vision on the system and the process originated at the local level faces the participants to analyze the role they can play in shaping the future. Therefore, this foresight toolbox will be described in-depth in chapter 3.

2.1 Structure of a foresight exercise

Independent from the school, the scenario techniques follow the same general pattern and typically go through 3 steps (diagnosis, prognosis and prescription (European Union 2013)) over 5 phases (Wollenberg et al. 2000, De Jouvenel 2000, Kosow and Gassner 2008).

Figure 4. The general scenario process in five phases.



Source: Adapted from Kosow & Gassner (2008) and European Union (2013)

These five steps are briefly discussed, but it is not in the scope of this document to explain all available techniques per step. Kosow and Gassner (2008) give a detailed explanation of each step and the available foresight techniques in their manual: *"Methods of Future and Scenario Analysis"*.

1. *System and scenario horizon identification:* The first step in any foresight exercise is defining the system and its limits. What is the issue at stake? What is the problem to be dealt with? And of equal importance: What is to be left out? A lot of time can be spared over the next steps if the non-essential subjects are peeled away. The time boundaries of the foresight exercise (until when do we look?) are also defined in this step.
2. *Key factor identification:* During this step, the key factors or 'descriptors' are worked out. Key factors are those elements, variables, parameters, trends, developments and events that will receive central attention in the rest of the foresight exercise.
3. *Key factor analysis:* Key factor analysis is the first step where the future is studied, as each individual key factor is analysed and the possible future salient characteristics for each one are described. Each key factor funnels open into the future, so to speak. This

step always contains creative and intuitive aspects, independently of the chosen foresight method, as creativity and intuition are essential for imagining the various future developments of each key factor.

4. *Scenario generation:* From all possible combinations of future states of the key factors, some plausible scenarios are chosen or selected. The different foresight methods strongly differ in this step, as methods exist for doing so from narrative, literary procedures to formalized, mathematical techniques. Usually, some 4 to 6 scenarios are chosen and described. Frequently they contain the next types of scenarios: 'business as usual', 'many new actions', 'worst case scenario' or 'best case scenario'. Sometimes, the different scenario types are based on ethical choices, like: 'market first', 'policy first', 'security first' or 'sustainability first'.
5. *Scenario transfer:* Although the scenario has been generated, so the scenario building or foresight exercise in the narrower sense has finished, usually a last step is added in the process: scenario transfer or prescription. This step involves a description of the further application and/or processing of the previously generated scenarios and leads frequently to decisions on what should be done.

3 La prospective

As mentioned, '*la prospective*' or strategic foresight is a technique for studying the long-term political and social future. The literal translation of the name of the technique '*la prospective*' into English, 'prospective', does not contain the philosophy behind it (Durance 2004), that is why Godet (2006) chose the more correct translation of 'strategic scenario building', and Coates, Durance, and Godet (2010) improved it to 'strategic foresight'. As this document also mentions other forms of foresight, the term *la prospective* will be kept without translation for the sake of avoiding confusion.

The technique rests on the philosophical concept that the future is different from the past and is not imposed, but can be modeled and built. There is not a '*predetermined temporal continuity*', but it can be constructed: "*The future is not forecasted, rather it is prepared*" (from the French philosopher Maurice Blondel, 1883, quoted in Godet 2010a).

The technique explores and develops feasible futures. It departs from the current state of a system and uses the most important factors and the influence relationships among them to predict and envisage possible versions of the future. So, it permits describing the present situation as well as drawing possible future scenarios.

La prospective was initially designed for supporting public institutions in investigating the possibilities of regional development, i.e. *regional foresight* (De Jouvenel and Roque 1994, Kelly et al. 2004, Godet 2006, Casas and Talavera 2008, de Figueiredo Porto et al. 2010, Stratigea and Papadopoulou 2013), where the collective experiences of the participating citizens of the studied regions allow them to overcome the past and envision a common direction for the future (Godet et al. 2008).

Godet et al. (2008) strongly suggest using this tool for gathering the desires and expectations of the citizens in the studied region. The participation of a large number of local stakeholders is one of the principal goals of regional strategic foresight and leads to better and more legitimate public decisions. These collective experiences also allow the citizens of the studied region to analyze different options for the future.

The use of scenario techniques like strategic foresight also has important advantages in the private sector, i.e. *corporate foresight* (Lafourcade and Chapuy 2000, Benassouli and Monti 2005, Godet et al. 2008, Godet and Durance 2009, Chapuy and Gros 2010), where it can contribute strongly to the strategic management of, the communication in a firm, the coordination of the business objectives and the creation of the ability to cope with change and adopt alternative perspectives (Durance 2004, Day and Schoemaker 2005, Rohrbeck and Schwarz 2013).

Even if the techniques have been extensively applied, due to their strategic nature, many of the company prospective exercises are only used by executive managers and kept confidential. Therefore, not many references can be found in the literature, and probably its use in the private sector is underestimated.

Finally, *la prospective*, or parts of it, have also served as inspiration for the development of similar or even very different techniques, such as new methodologies for scenario building (Bell and Coudert 2005), the Grumbach method for strategic management of companies and institutions, strongly inspired on *la prospective* (Leal Afanador et al. 2011) or PACT (Pro-Active Conciliation Tool) for analyzing stakeholders' inter-relations (Jésus 2001). However, no use of the techniques for the analysis of SESs has been found in the literature.

3.1 Main steps in *la prospective*

The structure of Godet's model of *la prospective* is quite similar to the general structure of foresight techniques as described in 2.1. For each step, specific software programs have been developed by LIPSOR (Laboratory for Investigation in Prospective Strategy and Organization).

The proposed steps are (Godet 2013):

1. Posing the problem well and to choose the method with the "Strategic Prospective Workshops"
2. Identifying key questions for the future, thanks to structural analysis with the "MICMAC[3] Method" (this is later called PSA or Prospective Structural Analysis)
3. Analyzing the interplay of actors with the "MACTOR[4] Method"
4. Exploring the field of possibilities with the morphological analysis of the "MORPHOL Method"

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[3] MICMAC is the acronym for the French *Matrice d'Impacts Croisés Multiplication Appliqués à un Classement*, or Crossed Impact Matrix Multiplication Applied to a Ranking.
[4] MACTOR is the acronym for the French *Méthode d'analyse des jeux d'acteurs*, or Analysis Method of Actor Interplay.

5. Identifying the most likely scenarios as well as the various risks of rupture with "SMIC PROB-EXPERT[5] Method"
6. Identifying and evaluate strategic options with the "MULTIPOL[6] Method"

An additional advantage of the method to be used in COMET-LA and other community-based initiatives is that all the software can be freely downloaded on: http://en.laprospective.fr/ .

For the objectives of COMET-LA's second phase: delivering a locally-adapted framework for identifying the role played by the different variables in the current and potential functioning of the ecosystem according to the perceptions of the local communities, only the second step is relevant. Thus, it is the one explained in-depth in chapter 4, which describes the method to identify key factors through Prospective Structural Analysis (PSA). However, a detailed description of all the steps of *la prospective* can be found in Annex II.

4 Methods to identify key factors in complex systems

The selection of the second step of *la prospective*, PSA, for identifying key variables in complex systems came after a thorough literature review performed for exploring the compatibility of similar techniques with the COMET-LA objectives. Techniques like Principal Component Analysis (PCA), Interpretive Structural Modelling (ISM) and Prospective Structural Analysis (PSA) have been explored and its usefulness to identify key factors in a complex system analyzed.

The use of PCA for identifying the main drivers and, if possible, comparing with the outcomes from PSA was considered. PCA (Pearson 1901) is a multivariate method for statistical analysis to describe big quantities of data by a lesser number of components through the identification of new, linearly uncorrelated variables that contain the highest possible variance within the data cloud. This principle is called dimension reduction, as the variance of the data is captured by fewer dimensions each apprehending more variance than the dimensions before applying PCA.

However, neither the PCA method nor its results align with the COMET-LA objective. It is not an adequate technique as it needs large data sets from measurements or questionnaires and high-level calculations, which both fall out of the scope of the project. The other two techniques and its potential applications are described below.

4.1 Interpretive Structural Modelling (ISM)

Interpretive Structural Modelling (ISM) is a technique developed in the 70's (Lin and Yeh 2013). It helps in identifying the inter-relationships among variables. It is a suitable modelling technique for analysing the influence of one variable on other variables (Agarwal et al. 2007) and thusly identifying its importance in the system.

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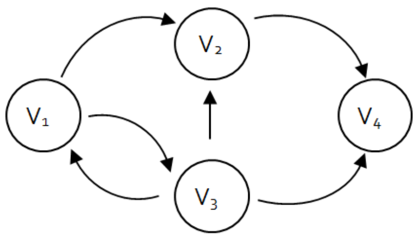
[5] SMIC PROB-EXPERT is the acronym for the French *Systèmes et Matrices d'Impacts Croisés Probabilistes*, or Systems and Matrices of Probabilistic Crossed Impacts.
[6] MULTIPOL is the acronym for the French *MULTIcritère et POLitique*, or Multicriteria and Politics.

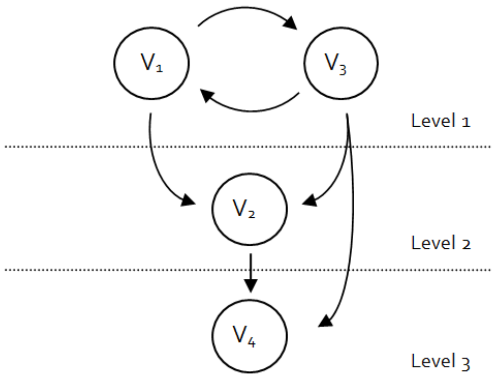
The starting point is a binary incidence matrix, containing all relations between the different variables. The outcome of the process is a hierarchy graph, ordering the variables in clusters from dependence powers to driving powers (Malone 1975). In short, it changes a digraph as shown in Figure 5 in one shown as in Figure 6.

Figure 5. Digraph representation of the system.



Source: Own elaboration.

Figure 6. Hierarchy graph representation of the system described above.



Source: Own elaboration.

For doing so, the system is translated into a binary incidence matrix, an *n x n* matrix with the *n* variables as both line and column headings, and:

$$a_{ij} = \begin{cases} 1, & if\ a\ direct\ infuence\ exists\ from\ variable\ \mathrm{i}\ to\ variable\ \mathrm{j} \\ 0, & otherwise \end{cases}$$

This matrix is then transformed to a reachability matrix, which is defined as a binary matrix where a_{ij} equals:

$$a'_{ij} = \begin{cases} 1, & if\ a\ path\ can\ be\ traced\ from\ Vi\ to\ Vj\ over\ intermediate\ variables \\ 0, & otherwise \end{cases}$$

Which is done adding an identity matrix (an *n x n* matrix comprised of zero's, but with ones on the first diagonal ($a_{ii} = 1$)) and raising the resulting matrix to successive powers (using Boolean algebra, i.e.:$1 + 1 = 1; 1 + 0 = 1; 1 \times 1 = 1\ ;\ 1 \times 0 = 0$). This new matrix holds the next values:

$$a'_{ij} = \begin{cases} 1, & if\ a\ direct\ or\ indirect\ infuence\ exists\ from\ variable\ \mathrm{i}\ to\ variable\ \mathrm{j} \\ 0, & otherwise \end{cases}$$

On the basis of that second matrix, the variables are grouped in clusters of mutually influencing variables. Through rearranging the reachability matrix with this new data on clusters, the hierarchy graph is obtained. A complete explanation of this procedure, using the example in the above figures, is given in Annex III.

ISM has some features that can be of interest to identify key factors in a system, like (Attri et al. 2013):

- The process is systematic and all possible pair wise relations are considered;
- No knowledge of the underlying process is required of the participants; they simply must possess enough understanding of the object of analysis to be able to respond to the series of relational questions asked by the facilitator of the workshop;
- It enhances the quality of interdisciplinary and interpersonal communication within the context of the problem situation by focusing the attention of the participants on one specific question at a time;
- It serves as a learning tool by forcing participants to develop a deeper understanding of the meaning and significance of a specified element list and relation;
- It permits action or policy analysis by assisting participants in identifying particular areas for policy action, which offer advantages or leverage in pursuing specified objectives.

But also disadvantages, like:

- Complex systems are difficult to analyse. Indeed, when the number of variables and relationships between variables increase, the complexity of the ISM methodology increases (Attri et al. 2013);
- Clusters of variables (variables that influence one another and form a loop) are analyzed as if they were one single variable (Lin and Yeh 2013). So, for ISM to be applicable to SES analysis, only the most influential variables and relationships should be taken into account. This lowers substantially the quality of the analysis;
- Only binary relationships are allowed. ISM only has a binary scale for describing relationships between variables, and thus cannot take the interplay of variables at different intensities into account.

4.2 Prospective Structural Analysis (PSA)

Prospective Structural Analysis, or PSA, is *la prospective*'s technique for the key factor identification. It relies upon a process of deliberations, carried out in participatory workshops where stakeholders agree on what the main variables at stake are and how they influence each other. It describes the system combining these variables in a matrix and classifying them according to their degree of influence and dependency within the system. The conclusions of these workshops represent an abstraction of (the working group's perception of) the studied system. Through a mathematical analysis of that matrix, it identifies the most influential variables and those most influenced, but also calculates an indirect influence matrix that reveals the hidden influences among variables.

These results and the previous data gathering stimulate discussions and generate ideas among the group members, leading to a higher understanding of the system's dynamics, a common vision on the future of the studied system and the necessary actions to reach it (Gavigan and Scapolo 2001, Godet 2006): it leads to a *"socially-organized learning process"* (Gertler and Wolfe 2004). Indeed, PSA stimulates imagination, reduces incoherence, creates a common language, structures collective thinking and allows its appropriation (Godet 2010a). Consequently, it helps understanding the studied systems as social constructions, where the debate and interpretations of local stakeholders on variables, influences, potentialities and incentives for change are fundamental.

Due to the participatory nature of the method, these results are subjective and highly dependent on the participants. But, that is not necessarily a problem. Indeed, the results as well as the input data (list of variables and matrix) inform as much about the manner in which reality is perceived by the working group and therefore about the group itself, as about the system under observation (Godet 2013). The results are thus not a reality but a means of looking at reality.

Among the advantages of PSA to give answer to COMET-LA objectives can be mentioned: It is systematic, does not require knowledge of the underlying process by the participants, enhances interdisciplinary and interpersonal communication, improves deeper understanding of the studied system, and permits action or policy analysis. Furthermore, PSA can manage systems with several dozens of variables, analyses variables that are part of clusters separately, and allows describing the strength of a relationship, as well as potential influences. So, PSA:

- Permits to analyze complex systems, including eventual subsystems and networks/loops of variables;
- Can deal with a big number of variables (80-100);
- Locates the interrelationships among these variables, including the hidden, indirect ones;
- Helps identifying the variables driving changes in a system;
- Shows the system possible trends and changes through time.
- Relies upon a process of deliberations, carried out through participatory workshops where stakeholders agree on what the main variables at stake are and how they influence each other;
- Stimulates and structures a collective reflection process to construct the stakeholders' vision on the SES's future and to highlight the necessary actions for reaching it (Gavigan and Scapolo 2001, Godet 2006).

The literature on PSA cites two relevant limits, namely its subjective basis and its rather small proportion of new insights (Godet 2013). Indeed, PSA is based upon the participatory identification of variables and influences in the first two phases of the method, which makes it very dependent on the facilitator and the (identification of) participants (Arcade et al. 1992). Consequently, the outcomes have a rather subjective basis. And most of the results, around 80%, are very logic and intuitive (Arcade et al. 1992, Godet 1994), only the remaining 20% are new insights.

But both of these mentioned limits are of little negative impact in COMET-LA, as the subjective basis is exactly what the project is meant to investigate: local knowledge comes from communities that interact daily with the ecosystems over long periods, so they own very relevant knowledge on its dynamics and associated management practices (Berkes et al. 2000, Fabricius and Koch 2004). In addition, PSA allows the stakeholders to reflect on the knowledge they possess and use it for a better understanding of the mental model of the system and for reflecting on the future of their SES. Also, the free software and the absence of sophisticated measures allow the community using this technique, to repeat the process and independently collect and analyze the information and feed the results into the decision-making process.

The 20% of new insights are the main added value of the analysis. Indeed, PSA is used for studying and improving the understanding of the system within the community, and should be managed accordingly.

Thus, PSA combines the advantages of ISM, with solutions for its disadvantages that position it as a better tool to be used in SES analysis. Furthermore, the results can be linked with the third phase of COMET-LA: '*Building locally-tailored scenarios for future changes and challenges*'. These reasons show that PSA is the most adequate technique. A detailed description of the method and its steps follow.

5 Prospective Structural Analysis, a full description

Prospective Structural Analysis (PSA), as mentioned, has as purpose to help identifying the principal key variables in a system or sector, based on strategic prospective workshops, taking into account the relationships of influence and dependence among the variables.

Key factor identification through the use of PSA has been used frequently outside of the general framework of *la prospective*, even out of the context of foresight (Ambrosio-Albalá et al. 2009, Khurana and Jain 2010, Ludovico De Almeida and Caldas De Moraes 2013, Elmsalmi and Hachicha 2013). Notwithstanding a thorough literature review, no traces have been found of applying PSA for the analysis of community-based natural resource management (CBNRM), and only one reference in identifying key variables within a SES with PSA (Bragança dos Santos 2012) but not in the context of CBNRM.

PSA is applied through 3 phases (Godet 2013): (1) listing the variables; (2) describing the relationships between variables; and (3) identifying the key variables through the analysis of the matrix of direct influences and the matrix of indirect influences. Phases 1 and 2 are applied in the context of strategic prospective workshops. Phase 3 can be done using the MICMAC software or using alternatives. Hereafter, a short description of these 3 phases, of the interpretation of the results from the process, and of the possible pieces of software for analyzing the data is given.

5.1 Phase 1: Listing the variables

Any system can be divided in its different components, which influence or depend on others. Understanding these interactions will help understanding the system as a whole. A logical first step in PSA is compiling a list of these components.

The list of variables is constructed with the data obtained from the strategic prospective workshops and can be enriched with information from interviews with representatives of actors in the system (Godet et al. 2004). The number of variables to be collected is not fixed, but should be limited to the more influential, as the work load for the next step increases exponentially with the number of variables. This list should normally not go beyond 80 variables (Arcade et al. 1992, Godet et al. 2004), which would already generate 6320 questions in the next step (see 5.2 below).

Each variable must be clearly defined, characterized and understood by all the participants. A detailed explanation of variables is indispensable for constructing a common basis and fomenting discussion. This shared understanding of each variable will condition the following phases of the analysis.

For easy reading, let *n* be the number of identified variables over the next sections.

5.2 Phase 2: Describing the relationships between variables

Once the final list of variables has been composed and agreed upon and the definitions of each variable are clearly understood, a cross-impact analysis is carried out to assess whether and to what extent the variables influence each other. Thus, an $n \times n$ matrix is constructed, containing all variables as headings to the columns as well as the rows. The workshop participants state which influence each row-variable has on the column-variable. The result of this step is the Matrix of Direct Influence (MDI).

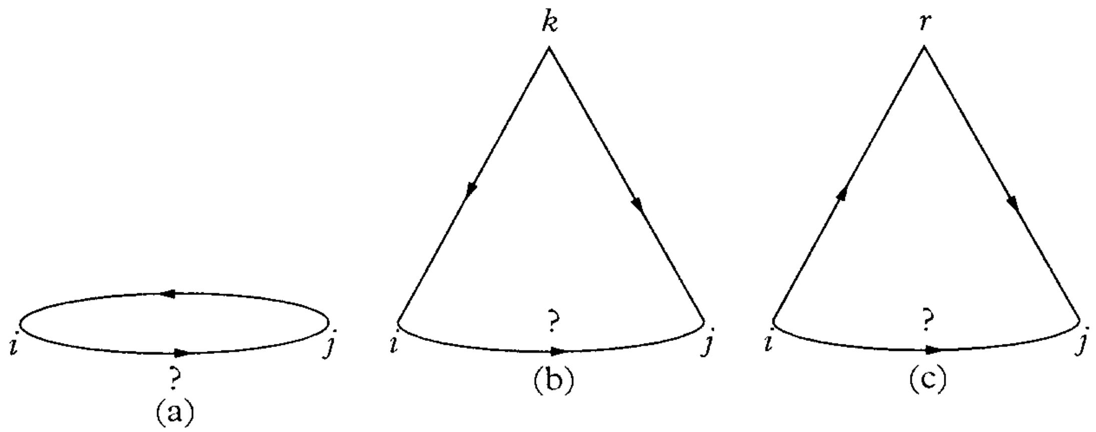
The MDI is a $n \times n$ matrix in which each a_{ij} cell of the matrix represents the direct influence variable *i* (*i* being the row number) has on variable *j* (*j* being the column number). The relationships are indicated by 0 (no relationship), 1, 2, 3 (weak to strong direct influence) and *p* (potential direct influence). The *p*-value or potential direct influence has not been defined clearly in the consulted literature. The only definition is: *"possible relationships which have not yet appeared, but whose development is incipient"* (Godet 1994).

These five categories are simple, and the *p*-value allows including future relationships, too. But on the minus side it considers as potential not only what is incipient, but also what is doubtful or disputed (Godet 1994). When more time is at disposal for PSA, the different kinds of relationships (both current and potential) can be taken into account (e.g. conditional, causal, technical, institutional, psycho-social, etc.), but for the sake of 'keeping it simple', the categories in this research have been limited to the five previously mentioned.

As the influence of a variable on itself is difficult to interpret, the values of the diagonal m_{ij} is set to zero. So, the question "How does variable *i* influence variable *j*?" is posed *n x (n-1)* times. When filling the matrix, it is essential to ask the next 3 questions for each cell, in order to avoid including indirect influences as direct ones (see Figure 7):

a) Does *i* influence *j* directly, or would it rather be *j* influencing *i*?
b) Does *i* influence *j* directly, or is there a third variable *k* influencing both?
c) Does *i* influence *j* directly, or is the influence rather indirect, passing through a third variable *r*?

Figure 7. Essential questions when filling the matrix.



Source: Godet 1994.

In a hypothetical exercise, 4 principal variables have been identified, V_1-V_4. The $(4 \times 3 = 12)$ questions have been answered and the MDI has been filled as shown in Figure 8. For example, a_{12} has '3' as value, indicating that V_1 has a very strong direct influence on V_2.

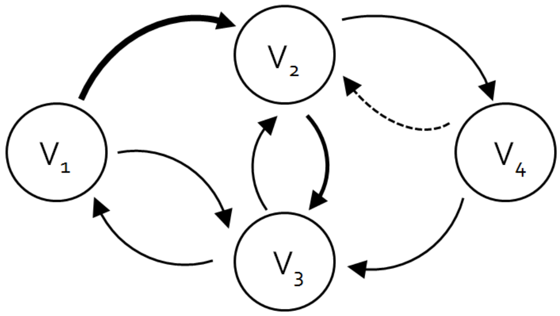
Figure 8. An example of a MDI.

$$\begin{array}{c} \\ V_1 \\ V_2 \\ V_3 \\ V_4 \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_2 & V_3 & V_4 \end{array} \\ \begin{bmatrix} 0 & 3 & 1 & 0 \\ 0 & 0 & 2 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & p & 1 & 0 \end{bmatrix} \end{array}$$

Source: Own elaboration.

The system shown in Figure 8 can be represented by a digraph for better understanding (see Figure 9). The strength of the influences are represented by the thickness of the lines, the potential influence is represented by a dotted line.

Figure 9. Digraph representation of the system described above.



Source: Own elaboration.

The influences only have a direction (from *i* to *j*) and a value (P, 1, 2 or 3), but no sign (positive/negative) is introduced in the matrix, as this would make the next analysis impossible. However, to know if the influence is positive or negative is key to understand the system functioning and the role played by the variables. It will also have a critical role in the interpreting result phase. Thus, the discussions in this phase should be recorded, in order to be used in the final analysis.

In real systems only about 15 to 30% (Godet et al. 2004, Godet and Durance 2009) of the cells of the MDI matrix have values different from 0. If more than 30-35% of the matrix is filled, indirect relationships probably have been included as direct relationships (Ambrosio-Albalá 2007). In that case, the analysis of indirect relationships will be less pertinent (Godet 1994).

PSA is a tool for collective structuring of ideas. Thus, this matrix should be the result of group discussion and cannot be filled partially by different groups, as it would contain results that are partial or make no sense (Godet et al. 2004).

5.3 Phase 3: Identifying the key variables

Once the MDI is complete, the direct and indirect relationships among variables are analyzed. The direct method estimates the overall direct influence and direct dependence of a variable in the system directly from the MDI. However, the method also analyses the influence exerted and the dependence received of a variable through other variables of the system. Thus, the significance of a variable for the system does not only depend on its direct influences but also on the indirect relations.

The relationships that were identified as potential during phase 2, indicate "*possible relationships which have not yet appeared, but whose development is incipient"* (Godet 1994). Therefore, the direct and indirect identification of key variables are done twice: once setting all *p*-values to zero for analyzing the actual system and once setting all *p*-values to three for analyzing the potential change the system will undergo when these potential relations become real.

The first round results in the two matrices with all direct and indirect influences, MDI and MII, and the second round in the two matrices with the potential relationships included, MPDI and

MPII ('P' stands for 'Potential'). The procedure is explained for the MDI and MII, the procedure for the MPDI and MPII is identical, but logically with all *p*-values replaced by zero (MDI, MII) or three (MPDI, MPII), respectively.

The comparison of these matrices and derivatives (see 0) becomes interesting if an approximate time horizon can be associated with each one (Godet 1994):

- The direct classification is the result of the short- to medium-term interplay of relationships; it often corresponds to less than a decade;
- Indirect classification integrates chain reactions which take longer to come into action, so the time horizon is rather situated on the medium- to long-term;
- Potential classification goes even further as it takes into account those relationships that haven't emerged yet but could influence the system in a further away future, so the time horizon is situated on the very long-term.

After this step, the key variables within the system, both through direct and indirect influences, are identified.

5.3.1 *Direct identification of key variables*

The direct influence of any given variable *k* (I_k) is the sum of the values of row *k* in the MDI, as is the direct dependence of variable *k* (D_k) the sum of the values in column *k*:

$$I_k = \sum_{j=1}^{n} m_{kj} \, (k = 1, 2, \dots, n)$$

$$D_k = \sum_{i=1}^{n} m_{ik} \, (k = 1, 2, \dots, n)$$

This new numeric information about the variables can be used for ranking them according to their influence or dependence. Both rankings serve as a first indicator of the importance of each variable in the system (Collacorta et al. 2012). Figure 10 shows the results when applying this to the hypothetical example of Figure 8, having replaced the potential value '*p*' by zero.

Figure 10. The MDI of the example with influence and dependence values and rankings.

$$\begin{array}{c|cccc|c} & V_1 & V_2 & V_3 & V_4 & I_k \\ \hline V_1 & 0 & 3 & 1 & 0 & 4 \\ V_2 & 0 & 0 & 2 & 1 & 3 \\ V_3 & 1 & 1 & 0 & 0 & 2 \\ V_4 & 0 & 0 & 1 & 0 & 1 \\ \hline D_k & 1 & 4 & 4 & 1 & \end{array}$$

Rankings

I_k	D_k
V_1	V_2, V_3
V_2	V_1, V_4
V_3	
V_4	

Source: Own elaboration.

5.3.2 Indirect identification of key variables

A variable can also have an indirect influence on another one, through a third variable (e.g. Figure 9: V_1 has influence on V_4 through V_2 and V_3). This influence becomes visual after some calculations.

When raising the MDI to the second, third, fourth or higher power, the indirect influence (I'_k) and the indirect dependence (D'_k) of a variable *k* changes, as well as its place in the overall ranking of influence and dependence.

$$MII = (MDI)^p = \prod_{n=1}^{p}(MDI) = \underset{p\ times}{(MDI) * (MDI) * \ldots * (MDI)}$$

Indeed, when raising MDI to the second power, indirect influences between two variables over one other variable are calculated, when raising MDI to the third power, the indirect influences over two other variables are visualized, and so on. From a given power ahead, the overall ranking of influence and dependence of a variable *k* remains constant; 7 or 8 is an usual power that guarantees ranking convergence (Duperrin and Godet 1973 cited in Collacorta et al. 2012) for systems with a high number of variables. This 'stable' final matrix is labeled as the Indirect Influences Matrix (MII).

In the example, stability is reached at the 5^{th} power, as the rankings do not change at the 6^{th} power. This MDI^5 is then called MII and is given in Figure 11. See Annex II for a detailed description of these calculations.

Figure 11. The MII of the example with influence and dependence values and rankings.

$$\begin{array}{c|cccc|c} & V_1 & V_2 & V_3 & V_4 & I'_k \\ \hline V_1 & 25 & 43 & 63 & 24 & 155 \\ V_2 & 17 & 35 & 31 & 9 & 92 \\ V_3 & 12 & 33 & 42 & 16 & 103 \\ V_4 & 7 & 16 & 12 & 3 & 38 \\ \hline D'_k & 61 & 127 & 148 & 52 & \end{array}$$

Rankings

I'_k	D'_k
V_1	V_3
V_3	V_2
V_2	V_1
V_4	V_4

Source: Own elaboration.

5.4 Tools for interpreting the results

Apart from the two matrices with all direct and indirect influences, MDI and MII, and the two matrices with the potential relationships included, MPDI and MPII ('P' stands for 'Potential'), Godet's technique foresees other tools for interpreting the results, like:

- The ranking of variables according to influence and the displacement map between the direct and indirect classifications;
- The influence/dependence map;
- The influence graph.

5.4.1 *Ranking of variables according to influence*

Using the MDI, MII, MPDI and MPII as a base, the sums of the rows and columns can be calculated. The totals per row indicate the influence of each variable on the whole system (level of (in)direct influence), and the totals per column indicate the degree of dependence of each variable (level of (in)direct dependence). Using these sums, a ranking of the influence and dependence of the variables in the system can be constructed for the four different matrices.

The respective position of each variable in all four of the previously mentioned rankings can be used for evaluating the importance of each variable for the system in each time horizon (MDI for the short- to medium-term; MII for the long-term; MPDI and MPII on the very long-term). By comparing these classifications, it becomes possible to evaluate which variables will be important on the short term, and which on the longer term (see Table 2).

Table 2. Comparing the rankings of direct and indirect influence of a ficticious example in a displacement graph.

Rank	Ranking of Direct Influence	Ranking of Indirect Influence
1	Deforestation	Research
2	Public institutions	Deforestation
...	...	...
8	Traditions	Public institutions
...	...	...
11	Research	Illegal loging
12	Illegal logging	Traditions

Source: Own elaboration.

5.4.2 *Influence/dependence map*

After the PSA calculations, all the variables are defined by a (in)direct influence and (in)direct dependence, which allows plotting them on an influence/dependence chart. Depending on the place the variable has on this chart, it plays a different function within the system: there are the influent and the dependant variables, each on an opposite side of the influence/dependence spectrum; the ones that are at the same time influential and influenceable; the completely independent ones; and those whose impact is hard to define. The influence/dependence map is a tool that can help detecting those active variables.

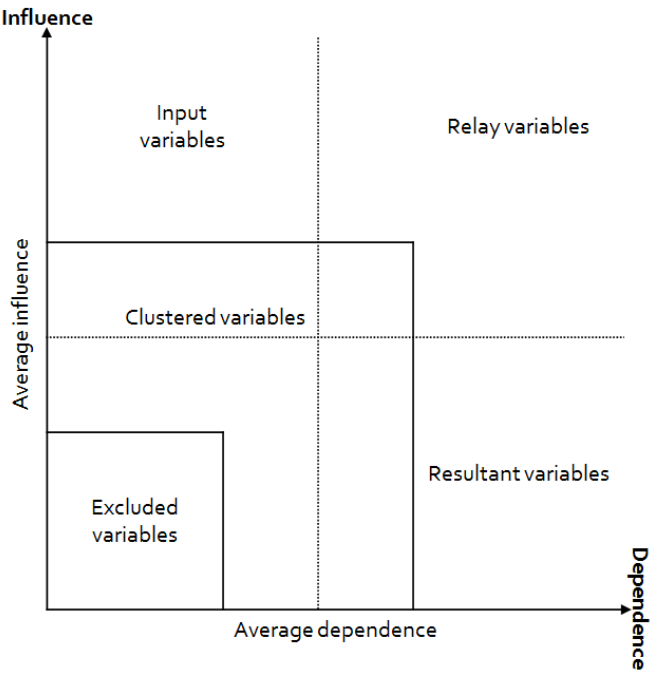
These clusters can be defined following two logics: the input-output logic and the strategic logic. In the input-output logic, the input elements condition the evolution of the system and the output ones mark the direction of the changes. Five different clusters can be determined (Godet 1994, Godet et al. 2004) (see Figure 12, the horizontal and vertical lines represent the averages):

- Input or influent variables - Highly influential but independent variables, conditioning the rest of the system;
- Relay variables - Influential and dependent at the same time. Thus unstable, since any action on these variables will have repercussions on other variables,

which will on its turn feed back to them, amplifying or defusing the initial impulse;

- Resultant or depending variables - Not influential but dependant, conditioned by the influences applied by the input and relay variables;
- Excluded variables - Neither influential nor dependant, thus without impact on the short term. These variables can be excluded from the analysis without creating too big disturbances;
- Clustered variables - Not sufficiently influential or dependent for including in the previous clusters. Their impact cannot be evaluated easily, but they cannot be excluded of the analysis.

Figure 12. Different types of variables on the map with axes influence and dependence.



Source: Adapted from Godet (Godet 1994, Godet et al. 2004)

The system concept behind this input-output classification, is that of a quite simple system, comprised of an independent input (the input variables), a tangle of effects (relay and clustered variables) leading to an output (resultant variables). The excluded variables are those that remain on the side, having no or little influence on the system.

Another logic can be applied when evaluating the role of the variables in the system: the strategic logic evaluates the role of the variables according to their positions relative to the diagonals. The first diagonal (full line in Figure 13) separates the entries from the exits in the system (Astigarraga n.d.):

- Determinant variables - Strong influence and low dependency variables that determine the functioning of the system. The upper left part holds these entry variables;
- Regulating variables – Medium influence and dependency. Situated close to the diagonal and participate in the normal functioning of the system;
- Exit variables - Little influential but very dependent. They indicate the results of the system's functioning. The lower right part holds them.

The strategic value (S_k) of a variable can be defined as the sum of its influence and dependence in the system, as it comprises the importance of its influence and the possibility to act on the variable (Astigarraga n.d.).

$$S_k = I_k + D_k$$

The first diagonal (full diagonal in Figure 13) can thus be defined as the *strategic diagonal*. The combination of influence and dependence in the variables located close to it, originates that acting on them causes effects on the evolution of the rest. These variables have the capacity to multiply effects. This leverage effect gives them a strategic value. The capacity to multiply effects increases with their distance from the origin of the plane. Thus, the farther a variable is located from the origin, the more strategic it is. This strategic diagonal offers a plastic vision on the strategic challenges of the system.

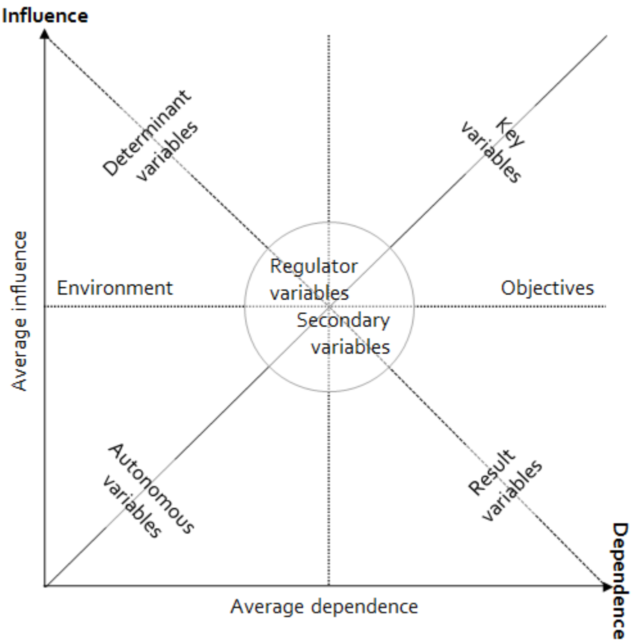
The second diagonal (dashed line in Figure 13) separates in this logic the variables with a less-than-average strategic value (S_k) from those with a more-than-average strategic value, if the diagonal is constructed through the intersection between the vertical and horizontal lines, representing the respective averages.

Combining both criteria, another classification system can be constructed (see Figure 13) and 8 different clusters can be distinguished:

- Determinant variables: These variables have a high incidence of the dynamics of the system, but other variables have little influence on them. Thus, the actions of other variables on them will not transmit to the system;
- Environment: These variables have medium influence on the system, and other variables have little influence on them;
- Objectives: These are the goals of the system, as the rest of elements have a high influence on them, but they also have some influence on the system;
- Result variables: These variables have a low influence on the system but are very influenced by it. They are considered descriptive indicators of the system’s evolution;

- Key variables: These variables are considered to have a high influence on the system's dynamics, and the rest of the variables of the system have a high influence on them. They are also the most unstable;
- Regulator variables: These variables have medium dependence and influence on the system, but they can act as lever;
- Secondary variables: These variables have a low to medium influence on the system, and the system has a medium influence on them. Secondary and regulator variables are called the 'squad variables' of the system;
- Autonomous variables: These have a low impact on the system and the system has a low influence on them.

Figure 13. Clustering of variables according to their influence and dependence.

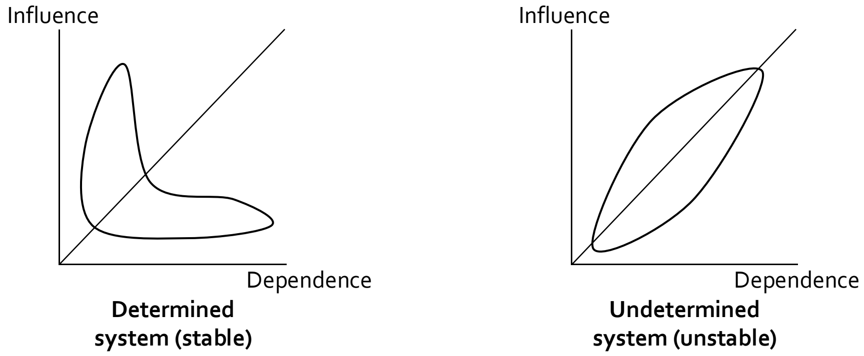


Source: Adapted from (Ambrosio-Albalá et al. 2009)

Depending on the role a variable plays in the system, an intervention on that variable can have an overall multiplier effect or no effect at all. Indeed, when intervening on a result variable, the effort is probably lost, but when concentrating efforts on variables with a more active role in the system, the effects can be multiplied through that variable's direct and indirect influences.

An additional reflection from the influence-dependence map arises from the analysis of the distribution of the variables in the chart. The form of the system in this map is an indication of the stability of the system (Arcade et al. 1992). If the variables are grouped around the first diagonal, the system can be classified as unstable, but if the variables are rather ordered in an L-shape, the system is stable (see Figure 14).

Figure 14. Shape of the system.



Source: Adapted from (Arcade et al. 1992, Godet 1994)

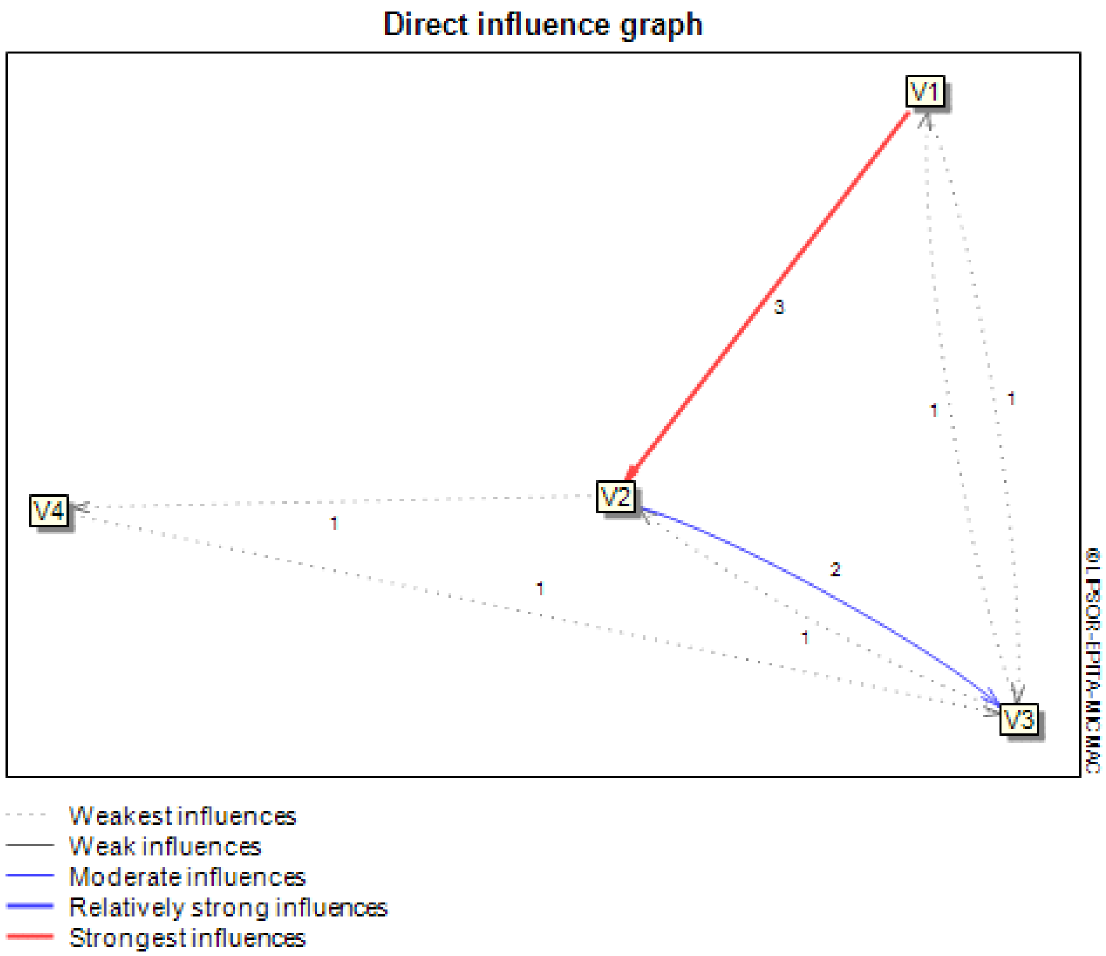
Indeed, the first system contains only input/output and excluded variables, which makes it straightforward and rather predictable (Arcade et al. 1992). This stability can be an advantage if the system is sustainable and no change is needed, if not it can be very hard to change it from within the system (the input variables cannot be influenced from within the system, but might from outside). The second system is made of variables that are influential and dependent at the same time, which makes the system less predictable and more unstable, as any action on one variable has repercussions on all the others and in turn on the original variable (Godet 1994). However, this instability creates opportunities to change the system from within, and make it evolve to another, wanted state.

5.4.3 Influence graph

The influences between variables can be shown on an influence graph, linking the variables with arrows, indicating both strength and direction of the influence relation. MICMAC allows limiting the visible relationships to only a certain percentage of the most important ones, so the graph becomes more readable.

In Figure 15, the direct influence graph of the example has been constructed with MICMAC. As it is a small system, 100% of the influences are given; in bigger systems, only the most important fraction would be made visible to ease its reading.

Figure 15. The direct influence graph of the example.



Source: MICMAC outcome of own example.

5.5 Validation workshop

Once the 3 phases of PSA are finished and the results are interpreted, it is essential to present the conclusions and validate them with the original participants of the strategic prospective workshops of phases 1 and 2 of PSA. The eventual remarks of the workgroup should be taken into account for correcting the conclusions. Special attention should go to analyzing and interpreting the counter-intuitive results.

The final version, validated with the workshop, can then serve for the next steps of the overarching methodology.

5.6 Some limits of MICMAC

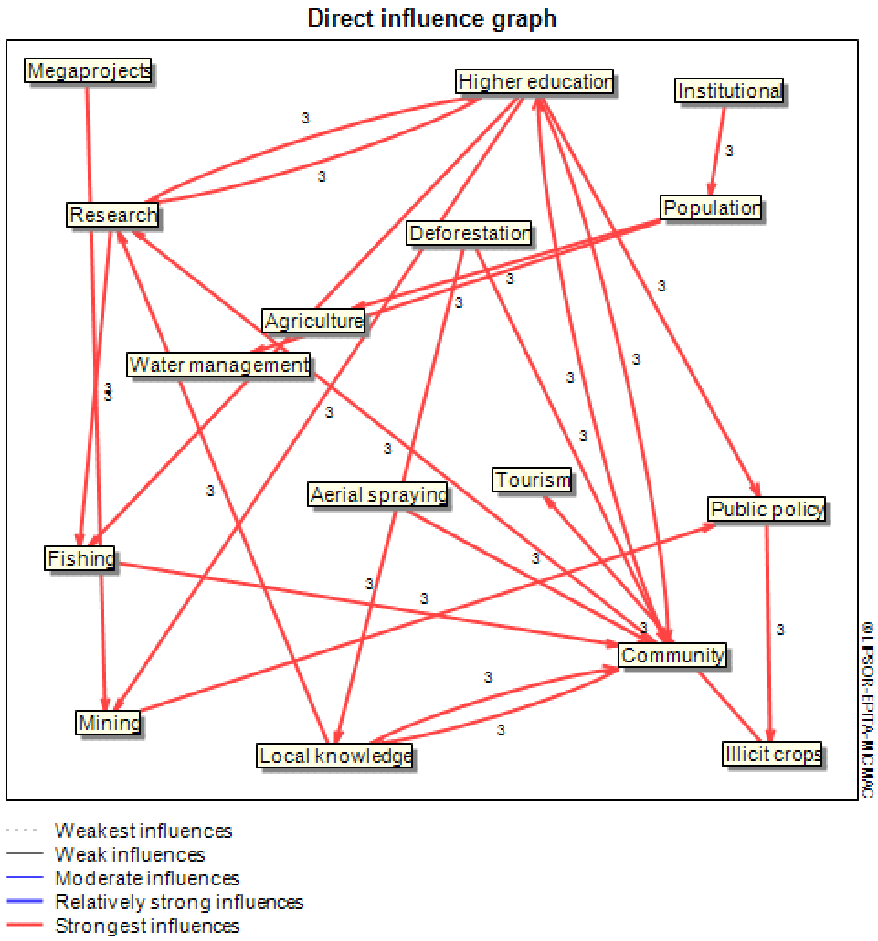
As mentioned, MICMAC is interesting free software to apply PSA. The program works in a very straightforward, intuitive way, and is capable of calculating all that is needed for proper data analysis in PSA. Calculating the MII and MPII are fully automatic, as are building the rankings of variables, and drawing both the influence/dependence map and influence graph.

Indeed, MICMAC is a strong tool for PSA, but the last version has been written in 2003/04 (source: 'About' menu in MICMAC) and is quite rigid and outdated. This lack of updates limits strongly the possibilities of data manipulation within the software. This is especially detrimental to the usefulness of the influence graphs and the program's compatibility with other pieces of software.

Indeed, it seems that in the influence graphs, the variables have a random place within the image which cannot be changed, and the filters only remove a certain percentage of the least important data, and do not remove full categories. This makes it difficult to interpret correctly the graph.

Figure 16 shows a fictitious example of such an influence graph. It is hard to see that Institutional/Population/Agriculture/Water management is a separate network, and it is hard to believe that the 5% strongest ties include all ties of strength 3. Both problems make a correct interpretation of the graph very challenging.

Figure 16. Fictitious example of an influence graph of the 5% strongest ties as provided by a MICMAC analysis.

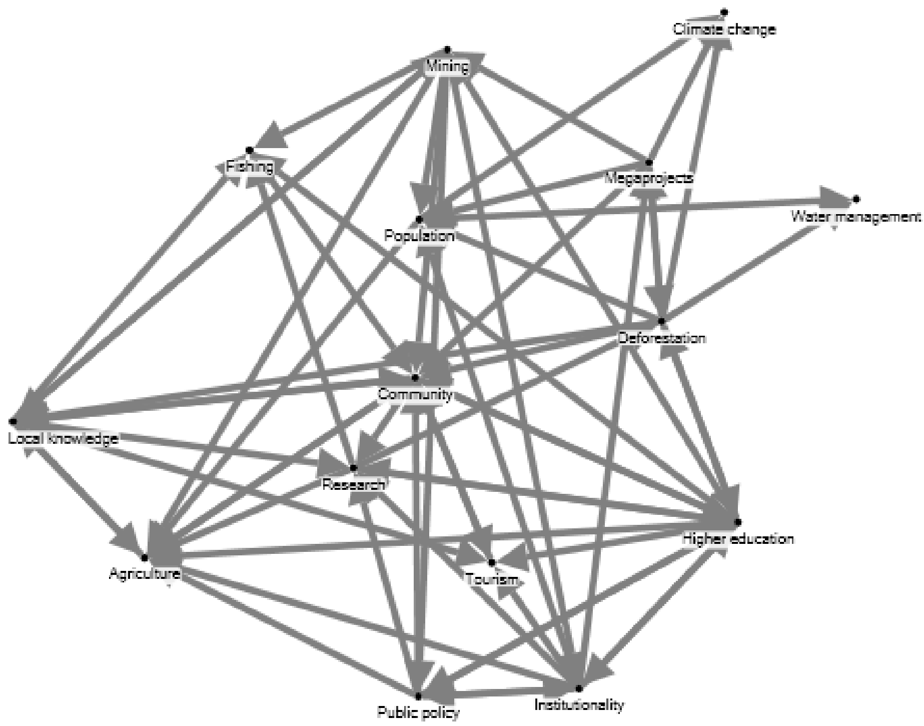


Source: Own elaboration based on MICMAC outcomes.

Luckily, this can be easily circumvented by the use of other programs for the display and analysis of network graphs. Most of PSA can be performed using traditional spreadsheet applications, like Excel or the open source alternative Calc. The process is less automatic, as each step has to be entered manually, but the user has total control over the process and has thus less the feeling to be working with a 'black box', like MICMAC.

Matrix multiplications can be done using the array formula MMULT in both Excel and Calc, and the ranking exercise is easily done using the filter function. For both the influence/dependence graph and influence graph, an add-on should be downloaded for the spreadsheet applications, as those graphs are not foreseen in the basic functions of those programs. 'XY Chart Labeler[7]' is one example of an add-on that allows labeling the points of a XY scatter plot in Excel, and makes the construction of an influence/dependence graph possible. NodeXL[8] is an example of an add-on that allows visualizing networks within Excel, and makes the construction of an influence graph possible, without the inconveniences of MICMAC (see section 5.6 above). Figure 17 shows an influence graph constructed with NodeXL, based upon the same fictitious system as Figure 16. Remark that many class 3 influences are shown that were hidden in Figure 16, and the previously identified separate network Institutional/Population/Agriculture/Water management isn't really a separate network.

Figure 17. The influence graph of a ficticious example made with NodeXL, only influences of class 3 are shown.



Source: Own elaboration based on Excel/NodeXL outcomes.

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[7] Download XY chart labeler on http://www.appspro.com/Utilities/ChartLabeler.htm
[8] Download NodeXL on http://nodexl.codeplex.com/

Other alternatives also exist. Some software is specialized in specific parts of the PSA methodology and could allow extra analysis, but has not been tested. Mainly the programs written in the field of Graph Theory and Network Analysis could add extra information to the analysis of the influence graph. Some programs worth mentioning are: Pajek, Gephi and UCINET[9].

6 Participatory techniques for PSA

PSA is a data collection and analysis technique, based on participatory workshops and basic mathematical operations. The latter has been explained in the previous section, but the participatory workshops need some clarifying.

When using *la prospective* for a participatory foresight exercise, the first step is to carefully design who should participate in the workshops. This step is crucial for the own nature of the method, where the outcomes rely on the views of the participants, and thus, they depend on their honest and complete participation (Arcade et al. 1992). To help in this stage, stakeholder-mapping techniques can be used[10].

Internal specialists and key stakeholders in the analysed field, sector or territory should attend the workshops, as it is essential for the ownership of the results by the participants. It is essential not subcontracting this phase (Godet et al. 2004, Godet 2013), although calling on external advisors is not excluded.

Once they are selected and they agree to take part, strategic prospective workshops are organized. During these workshops, participants become familiar with the tools for identifying and hierarchizing the main drivers for the future. The group will not only receive training in the techniques, but also produce ideas on how to define the problem.

These workshops should last 2-4 hours and people can work in subgroups of 8-10 persons. Two regulatory principles or guidelines lead the organization of the workshops (Godet et al. 2004):

- Permit full freedom of speech to all speakers, including individual time for thought in silence and writing feedback of all ideas;
- Channel the participants' production (especially through a strict time management and above all through systematic recourse to techniques like classification of ideas, prioritization, etc.).

The process should be guided by facilitators with good expertise in leading interactive workshops and preferably experience in leading strategic prospective workshops (Arcade et al. 1992). They should be neutral, not add content to the discussions but structure, and

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[9] See respectively pajek.imfm.si; gephi.org and sites.google.com/site/ucinetsoftware/home
[10] COMET-LA proposes a method to develop a stakeholder mapping that can be consulted and downloaded in its Deliverable 1.1 (http://comet-la.eu/index.php/en/publications.html).

proactively include everyone in the process. In fact, the facilitator is the guardian of the regulatory principles mentioned above.

A multitude of participatory techniques exists for helping the facilitator reaching the goals of the workshops. It is impossible to treat them all in this document, as each facilitator creates his/her own style and uses his/her own methods, based on well-established techniques. As example, two frequently used techniques, brainstorming and mindmapping, are briefly explained to indicate the general direction of these methods. Other participatory creativity and idea structuring techniques are World Cafés, focus groups, expert panels, etc. but for the sake of simplicity, only these two are discussed here.

Brainstorming is a method of eliciting ideas without judgement or filtering. It is often used in the early stages of future workshops and in many other contexts. It involves encouraging wild and unconstrained suggestions and listing ideas as they emerge. This technique has the following basic components:

- Generating as many creative solutions as possible to tackle a problem;
- Setting time limits;
- Listing every idea presented without comment or evaluation - deferring the judgment of ideas improves the volume of participant input and consequently the value and encourage creativity;
- Not scoring ideas, but considering equal value to all opinions;
- Subsequently, grouping ideas to reduce redundancy, allow for related ideas to be brought together;
- Evaluating or assign priorities to the ideas.

Mindmapping is a technique for structuring the ideas that surge from participatory group sessions, like brainstorming (European Union 2013). In the most basic form, a central theme is written in the middle of a sheet of paper, and the group adds branches of ideas around this central theme. It allows a group's ideas to be charted in logical groupings fairly quickly, even when ideas are given in a non-sequential manner.

Strategic prospective workshops were finally chosen because they are easy to set up, as little time (1-2 days) and little materials (flip charts, pens and post-it notes) are needed. Their purpose is immersing the participants in prospective thinking in service of strategic action. After these workshops, the participants will be able to indicate the priorities and objectives, the planning and method for continuing the exercise of *la prospective* (Godet 2013). Apart of these outcomes, the group discussions as such are the real main result: "*The goal is a pretext, almost an excuse, for the group effort, shared experience and ties created among the participants*" (Durance 2004).

7 Adaptations of PSA to work at the local level

The previous chapters conclude on the usefulness of PSA for dealing with the second phase of COMET-LA and reaching the project's objectives. They also present a detailed description of the theoretical and practical bases of the method. As stated, the technique's normal field of work has been strategic planning within the public and corporate sectors. Thus, the use of PSA on SESs within local communities has required significant adaptations that can be considered as one major innovation developed by the COMET-LA project.

The next sections present the methodological learning derived of the adaptations of the technique to be used at the local level and making the tools more understandable and usable for the communities, following the COMET-LA objective of developing a learning arena. Every step in the process of PSA has been adapted and applied in close collaboration with the beneficiary communities. Thus, the community members not only have the results of the PSA exercise, but also master the techniques and can consequently use and apply them whenever they need in the future, with the support of the CSOs and research institutions for data analysis.

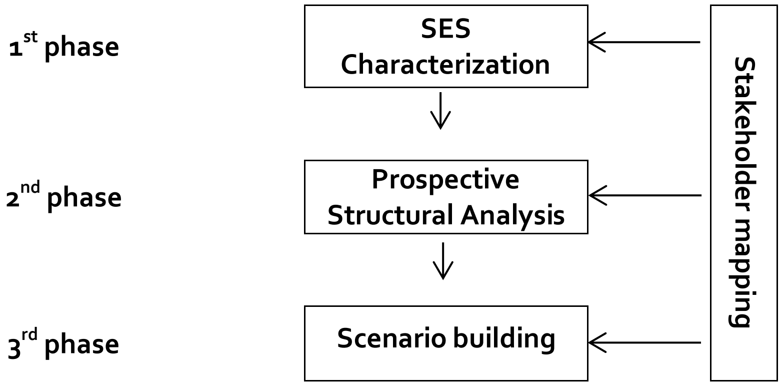
The proposed methods have been tested through application in COMET-LA's 3 CSs, during which the techniques were fine-tuned to each specific situation. For the researchers, this adaptation process has entailed an important methodological learning and interesting lessons have been extracted. In each section, the different adaptations and decisions taken in each CS are described to provide a richer understanding of how to proceed and also to facilitate the use of the adapted method to the analysis of other SESs.

A more detailed account of the processes and the obtained results can be found in the deliverables D2.2: "*Stakeholder vision on problems and drivers related to environmental challenges in Colombia case study*", D3.2 *Stakeholder vision on problems and drivers related to environmental challenges in Mexico Case Study*, and D4.2 *Stakeholder vision on problems and drivers related to environmental challenges in Argentina Case Study*, which can be downloaded on http://comet-la.eu/index.php/en/publications.html.

7.1 System and scenario horizon identification

The first step proposed by *la prospective*, identifying the problem and scenario horizon through prospective workshops, was done in the first phase of COMET-LA: *Characterization of Social-Ecological Systems* (see Figure 18 for a simplified representation of the different phases of the COMET-LA methodology). In each CS, the working teams (composed of scientists, civil society organizations and local stakeholders) worked for more than one year in doing a comprehensive characterization of the SES using the COMET-LA adaptation of the Ostrom framework for SES (Ostrom 2009). This locally-adapted framework is extensively described and can be consulted in Deliverable 1.1 *Locally-adapted tools for the Characterization of Social Ecological Systems.* The results of this SES characterization for each CS can be consulted in deliverables D2.2 *(Stakeholder vision on problems and drivers related to environmental challenges in Colombia Case Study)*, D3.2 *(Stakeholder vision on problems and drivers related to environmental challenges in Mexico Case Study)*, and D4.2 *(Stakeholder vision on problems and* *drivers related to environmental challenges in Argentina Case Study)* elaborated respectively by the Colombian, Mexican and Argentinean teams and available on the COMET-LA website[11].

Figure 18. Simplified representation of the 3 phases of the COMET-LA methodology.



Source: Own elaboration.

The Ostrom framework identifies 8 sub-systems; each described using a set of second-level variables. COMET-LA has proposed 132 third-level variables in its adapted version of the Ostrom framework that have been used for defining and characterizing the SES in each of the CSs. Thus, the SESs were analyzed and the internal and external variables were characterized in the project's Phase 1, using participatory workshops. In each CS, these SES characterizations were presented to and validated by local internal and external stakeholders during the Stakeholders Fora.

These outcomes were used as an input in phase 2 of *la prospective*. However, it is worth mentioning that in these initial workshops and fora, the prospective techniques and approaches were not presented nor used. The objective of phase 1 was to have a clear understanding of the variables characterizing each of the analyzed SES, combining the existent scientific and local knowledge. These techniques were only introduced in the phases described below.

7.2 Working with stakeholders in SESs

As mentioned, PSA is a subjective technique and its outcomes are based on the knowledge, opinions and perceptions of the participants. A good participant selection is essential to achieve useful and representative results. This should not be a one-time selection on beforehand, but some flexibility is needed to adjust the group to new needs or to the evolution of the process. The details of this process are explained in section 7.2.1.

But a good selection alone will not be the success of the workshop, the specificity of working with a diverse public, from community members over scientists to specialists from public

[11] See Deliverables on http://comet-la.eu/index.php/en/publications.html.

institutions, demands particular adaptations to the method. These have been explained in sections 7.2.2 to 7.2.6.

7.2.1 Selecting stakeholders

The first question is to decide who can be considered experts in the environmental challenges the CSs are confronted with (water and biodiversity management in Colombia, forest management in Mexico and marine and coastal management in Argentina), and consequently, invited to be part of the foresight exercise. Even if a stakeholder mapping had been performed in the previous phase of COMET-LA[12], a new one was performed, this time with a focus on who could be the stakeholders at this stage. The experience and knowledge of the previous phase were essential to develop this one.

PSA participants can be internal or external to the SES, but they need to have a deep *knowledge* of the SES and of the main problems affecting it. Also *availability* and *willingness* to participate in the process is required. Other aspects to be analyzed in the selection process are the *legitimacy* of the participants in the SES and their *capacity of influence* on SES dynamics. If they are considered as wise, ethical and reliable people, other people will more easily accept the workshop outcomes.

Internal stakeholders are usually locals directly involved in the management and/or exploitation of the natural resource; their livelihoods are linked with the natural resource. A special class of internal stakeholders was added within the framework of the project: the co-researchers. These internal stakeholders were included in the Colombian CS, and intensively collaborated during the conception, adaptation and application of the techniques[13].

In the three CSs, this group of internal stakeholders consisted of members of the community, like local authorities, representatives of relevant productive sectors (farmers, hunters, fishermen, etc.), teachers and members of the internal civil society as neighborhood societies or professional and social associations. Most of the selected stakeholders are leaders of their respective group.

External actors do not directly depend on the management/exploitation of the natural resource; they can provide broader visions, but involving them can be more complicated,

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[12] COMET-LA also did a stakeholder mapping during this first phase to guarantee that all relevant stakeholders were identified and invited to participate in the different stages of the project. See Annex II of deliverable 1.1 for the method, 2.2, 3.2 and 4.2 for the results, all downloadable on http://comet-la.eu/index.php/en/publications.html.

[13] In the case of Colombia, the research team and the community decided that an added value of COMET-LA should be to train a group of community members, including authority representatives and young people, in the techniques and tools proposed by the project. Hence, a so-called "co-researchers team", consisting of 25 men and women of both Community Councils, have been trained in relevant COMET-LA concepts (socio-ecological systems, governance, gender approaches, planning, foresight), participatory methodologies and design and implementation of surveys (for more details see Briefings: "Training Process for Co-Researchers from Community Councils of Black Communities in Alto y Medio Dagua and Bajo Calima" and "Participative Approaches to characterize socio-ecological systems and analyze governance of natural resources" on http://comet-la.eu/index.php/en/publications.html).

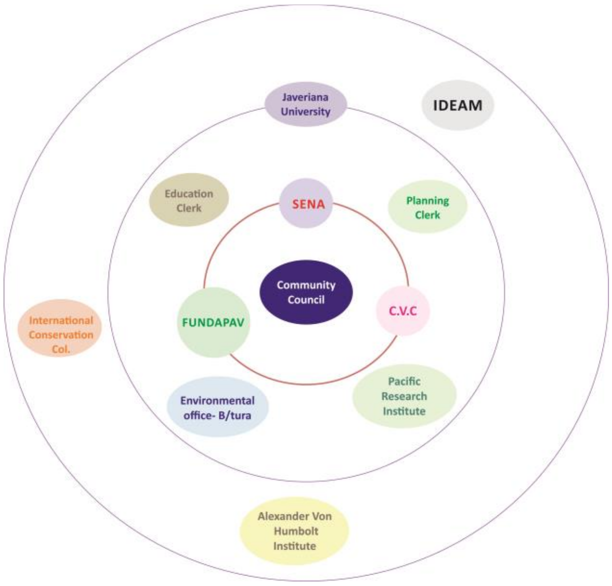
because of time constraints and because these workshops are not part of their daily work or problems. Incentives to attract them can be to present the opportunities to learn new tools that they could use in their work or to offer them the possibility of creating networks with other agents (as the international research team, in COMET-LA case). Or even to search for agents that could be doing some kind of analysis of the SES, for other reasons, and to offer them the possibility of participating in a structured analysis with innovative methodologies.

During the selection of external stakeholders, Venn diagrams and other visualization tools (see Figure 19 and Figure 20) can be used to identify the institutions, entities and organizations with influence in the territory, visualize their network of interactions and importance for the SES. When possible, introducing stakeholders with strong links to the SES (because of familiar, cultural or other reasons) but working for external institutions is highly recommended. Their capacity of influence and dissemination of results in other instances can also be factors to be considered in the selection.

Figure 19. Selection of institutional stakeholders in Colombia.

To select the external stakeholders, experts and decision makers from the public sector and civil society institutions with a role in environmental management were mainly considered, such as university lecturers, NGO managers, natural resource department or ministry delegates, and representatives from local but external municipalities with relationships and influence in the SESs.

Figure 20. The institutional stakeholder map as produced by the co-researchers.



Source: (Avendaño et al. 2013)

Once all the potential participants have been identified, a network analysis is proposed for highlighting the relationships among them. This analysis reveals two important pieces of information: which stakeholders act as strategic nodes in the network because of their dense net of relationships, but also which stakeholders could provide different views and thus, open the debate and include a wider perspective in the discussions. Both types of stakeholders should be included in the prospective exercise. The CSs concentrated on selecting institutional entities responsible for decision-making on the environmental challenges they are confronted with. The representatives of these institutions were selected as external stakeholders based upon their membership to and importance in public sector and civil society institutions with a role in the area. Depending on the particularities of each SES, representatives of organizations of indigenous people (Mexico), of Intercultural Studies Groups (Colombia) and of tourism, fisheries and industrial sectors (Argentina) were included in the list.

The number of participants in the workshops is not fixed, but the balance between open participation and workable group sizes should be searched. The important point is that relevant stakeholders representing different views and interests and having a deep knowledge of the SES are included. The lack of experience of participants in strategic prospective workshops, their time constraints and their specific training needs made it indispensable to work with small groups, not bigger than 20 participants.

In addition, the list of participants was flexible. If a new relevant stakeholder was identified, s/he was invited and added to the list. If a participant was identified as a troublemaker or s/he lost interest in participation, s/he was removed from that list. These changes in the attitude and participation of the stakeholders and their possible causes should be analyzed, as part of the learning.

7.2.2 *Organizing the workshops*

The organizational aspects of the workshops are crucial in this adaptation. Several facets need attention. The first one is how to attract the interest of the participants. Attending workshops and participating is not part of their job description, as normally is the case for strategic or corporate foresight exercises. Participants could be losing time or even money (for not going to work). So, participants need to be fully convinced of the usefulness of the outcomes they will obtain, otherwise they will lose interest. A special emphasis should be put on the benefits for the participants.

Figure 21. Images from COMET-LA PSA workshops.

Secondly, internal and external stakeholders can be split in two different groups and separate workshops hosted. Different reasons support this decision, but one very important is to guarantee free speech for all the members of the working group, for unequal power relations between internal and external stakeholders can prevent the free speech. The same arguments count for an eventual separation between internal male and female stakeholders, or separation between internal stakeholders of different zones within the SES. The list of participants and the eventual separation in different groups are decided using the results of the stakeholder analysis. The separation of external experts from the community members can encourage a more open discussion among the latter. This was considered in all 3 CSs, however, the context-specific characteristics of each one, lead to different decisions.

Thirdly, the workshops have to be very flexible and adapted to the needs of the participants, especially the community members. They have to be scheduled at the most convenient *place*, *time* and *period* for allowing optimal participation. Different challenges as the spreading of the inhabitants in different towns and villages and the lack of public and private means of transport limit the possibilities to attend the meetings. They should be hosted at the most convenient place, but when several meetings are hosted the place can be changed to distribute the costs and inconveniences of attending. The dependence of weather for livelihood and how weather conditions the participants' activities cannot be neglected when hosting this type of activities. Intensive work periods (e.g. seeding, harvesting or intensive fishing periods) should be avoided.

The schedule of the workshops can be fixed according to the availability of those identified as key stakeholders. The sessions should not be too long for avoiding fatigue, mainly when participants are not used to this type of meetings or exercises. The number of workshops per participant has to be kept at the working minimum, for guaranteeing the results, but also a good level of participation.

Fourthly, the *facilitation* has to be carefully prepared, particularly for the internal stakeholder's workshops. Most of the participants are members of the community, and know their territory and its problems, but are not the typical 'experts' expected to attend a prospective workshop. Aspects such as the used tools, the language and concepts, and the internal rules of the workshop's dynamic have to be well prepared and adapted to their visual and/or oral dynamics and computer knowledge. If the community has little experience in group dynamics, e.g. when a newly formed community lacks community structures, an extra focus should lay on imparting basic workgroup dynamics, such as respecting speaking turns, no interrupting, no expatiating, no divagating. Due to the important differences between organizing the workshops with experts and working with local stakeholders, a careful design of the course of the workshop, including questions, techniques and dynamics is necessary. A mock exercise is very advisable for calibrating and testing the facilitation techniques and adjusting them for working with community members.

Figure 22. Presentation of the PSA technique using a video projection of previous experiences (Argentina).

Before starting the workshops, participants should agree on the rules of the workshop for facilitating the discussion process. Some suggestions are:

- The diversity of opinions is fostered;
- Dissent is respected (even if decisions have to be based on consensus);
- Open communication and unrestricted freedom of expression is promoted (provided that the issue at discussion is relevant for the workshop objectives);
- No specific type of knowledge is privileged (the different perspectives – from authorities, community members, experts or scientists – are analyzed in equal conditions).

In order to ensure the fluidity of the workshop and the completeness of the gathered data, it is suggested to assign a team of 2 facilitators to this job: one concentrating on the practical facilitation, and another one penning down all the interesting information on the workshop's content and the social interaction.

Finally, a gender analysis is suggested. It can provide very interesting results comparing the similarities and differences in the visions of women and men on the analyzed issues and on the outcomes.

After the stakeholder selection, deciding where, when and how to organize the workshops and doing a test round of workshops, the invitations to attend to the workshops were sent to the stakeholders. Preferable these are to be delivered by authorities or representatives of groups of interest involved in the process, to foster the empowerment and ownership of the techniques by the community and to increase the legitimacy of the process.

7.2.3 PSA phase 1: Listing the variables

To list the variables, the workshops were structured to give answer to the following question: *which issues and matters are relevant with respect to the central environmental challenges in our SES?* This phase took place in the previously described workshops and is very important since it conditions the next phase of PSA and sets the working climate. The working method created and strengthened the relationships among the participants. It opened communication channels and gave them the opportunity to discuss about the current and potential situation of their SES, about the weaknesses and strengths, and about the external threats they can face. In short, the method opened a platform for the participants to be protagonists of the future, a platform which needed to be strengthened during the next phases of structural analysis.

At the beginning of the workshops, participants were provided with a clear understanding of the prospective tools and methods to be used and of the implications of their answers in the final outcomes. Normally, they are not familiar with these concepts, which can be very diffuse or too abstract to be understood. A clear and detailed explanation of the techniques to the participants eliminated comprehension barriers and increased transparency and ownership. It made the exercise more understandable and adapted to the participants. In the Colombian CS even a guide adapted to the oral and visual culture of the participants was elaborated. This not only helps in the development of this phase, but constitutes an important tool for the future use and mastering of the technique in future applications.

COMET-LA proposed to present all the variables in the different subsystems of the SES characterization done in the first phase for selecting those to be used in PSA. Then, the participants chose those they consider more relevant to answer the question in their CS. They were asked to select at least one variable, the most influential, from each of the 8 subsystems in the SES, for allowing the integrated analysis of such complex systems. The list focused on the variables that define system performance and those that can be used to understand and analyze the system's current and future dynamics.

The number of variables in the analysis of SESs was not fixed but the underlying idea was that it should not be too high. The original method proposed less than 80 variables, as mentioned. However, around 20 variables were considered an appropriate number to describe the main issues at stake in a SES, on condition that all of the SES's subsystems were represented. The objective was to highlight the real key variables that draw the current and future trends in the evolution of the SES.

Once a variable was selected for inclusion in the list, it had to be clearly defined and understood by all the participants. Some of the variables were very broad or abstract so the effort was focused on an accurate and transparent definition of the variables that promote a common understanding of the meaning of this variable in each specific SES.

To facilitate this task, COMET-LA proposed a template to be filled for each variable (see Figure 23). This form included a full description, the coding used to characterize the SES in the adapted Ostrom framework, but also the name that the community used for this variable.

Figure 23. Form for variable identification and description.

Form for variables identified during the PSA Workshops

Studied zone					Date			
Ostrom's framework category (check)	S	RS	GS	RU	U	I	O	ECO
Ostrom's framework subcategory								
Tags (short label)								
Complete name of the variable								
Variable description								

Instructions:

1. Ostrom's framework category (S, RS, GS, RU, U, I, O, ECO): Check the right category to which the variable belongs.
2. Ostrom's framework subcategory: Identify the subcategory to which the variable belongs (e.g.: if the variable is already classified as RU, the subcategory should be one of RU1 to RU7).
3. Tags (short label): The variable has to receive a coded name (RU1a or RU7b depending on the variable's category and subcategory). This should coincide with the "short label" in MICMAC.
4. Complete name of the variable: Corresponds with the explicative name of the variable.
5. Variable description: Corresponds with a complete description of the variable, obtained through consensus among workshop participants.

Source: Own elaboration.

In addition, each variable was identified as internal or external, depending on whether it can be influenced by the community or not. This information was then used for refining the ulterior analysis.

The facilitators imposed a strict control of the time and of the discussion topics. The participants were not used to these exercises and quite often lacked participatory arenas to discuss different issues, so they lost easily the objective of the meeting and detoured the discussions to other non-related issues.

An example of a possible outcome of this phase is given in Table 3.

Table 3. The listed PSA variables in a SES framework for Alto y Medio Dagua, Colombia.

***Social, economic and political Settings* (S)**
S2a Population; S5b Mining; S1a Tourism; S5c Road transport; S4a Public policy

Resource systems (RS)	***Governance system (GS)***
RS4a Big projects RS1 Hunting RS4b Oil pipeline	GS3a Community
Resource units (RU)	***Users (U)***
RU3 Agriculture	U9 Fishing U7a Ancestral Knowledge U7c Research U2e Higher education
Interactions (I) →	***Outcomes (O)***
I4 Aerial spraying I8 Institutionality	

Related ecosystems (ECO)
ECO1 Climate change; ECO2 Water management; ECO3a Deforestation; ECO3b Illegal crops.

Source: (Avendaño et al. 2013)

Depending on the local dynamics and the nature of the environmental challenges the studied SES faces, a single list of variables can be constructed through interaction between the internal and external stakeholders' workshops, or the different outcomes of the workshops can be analyzed separately.

7.2.4 PSA phase 2: Describing the relationships between variables

Once agreed on the comprehensive list (or lists) of variables that shape the system and its external environment, a double-entry matrix is elaborated with these variables as heading of both rows and columns.

The role of the participants now is to decide the direct influence of each row-variable on each column-variable. The software requires the use of a numeric scale from 0 to 3, and *p* for potential. However, when running the workshops at the local level, facilitators can use a qualitative scale (no-weak-moderate-strong-potential influence) or even to color the matrix cells (one color for each number in the scale) to facilitate the visual perception of the strongest and weakest influences. These qualitative values are subsequently translated to numeric values for use with the software.

In order to increase its applicability, the definition for the 'potential' *p*-value, the 5th scale value, has been reviewed and broadened: any influence that is inexistent or very weak actually, but which might be strong in the future or if something changes, is indicated with a *p* (e.g. if a road is finished, or if a law is changed, a certain influence can suddenly get stronger). This adaptation allows a broader range of potential variables to be included in the analysis, but also complicates it, so the reasoning behind each *p*-value should be described in detail for further analysis.

An extra analysis separating the internal from the external variables by the use of e.g. differently colored cards can be envisaged for investigating if a variable generates more impact on variables within or outside the reach of the community (internal or external variables), and if the system as a whole influences/depends strongly from the external variables, or not.

All relationships have to be described in detail by the facilitators for further analysis. In particular, the descriptions of the discussions on the character (positive or negative) of the influences and of the *p*-values are especially relevant for the next phase of COMET-LA, the building of scenarios.

In this step, facilitators have to put the emphasis in clearly isolate the real direct influences, (avoiding to introduce what are indirect influences through other variables), and to distinguish the direction of the influence (e.g. to recognize which of the two variables at analysis influences the other) and its character (positive or negative). The final strength of the influence has to be agreed among the participants and facilitators have to avoid that the views of any or some participants are imposed.

Attention has to be paid not only to the discussions on the strength of the relationships among variables, but also to the existence or not of relationships among variables. These debates can be very important to understand the perception of the stakeholders on their SES. They help to highlight and understand other visions, to refine ideas and to create a common view on the present and the future. In addition, as the technique do not analyze the sign of the influences, but that is central information for interpreting results, it has to be recorded by the facilitators and should be delivered to the participants together with the results of the workshop.

The workshops for this phase took half to a full day and can be directly after or separate from the PSA phase 1 workshop. To facilitate the participants' understanding in all the CSs, display tools they feel comfortable with should be used, such as panels and sheets, to fill the influence matrix (see Figure 25). Colombia and Argentina used big sheets of paper or tissue for constructing the complete matrix of direct influences in combination with smaller, colored ones for writing down the variables, as shown in Figure 24. This tool was named by the participants as *the paper computer*. In the Mexican CS, the MICMAC program was projected and the matrix directly filled by consensus.

Figure 24. The resulting matrix from the Dagua community workshop, Colombia.

Afterwards, the researchers introduce the obtained data for the Matrix of Direct Influences in MICMAC software and process it. The facility and rapidity of the software allow showing preliminary outcome of this analysis directly after the workshop, improving the ownership and understanding of the results by the participants.

Figure 25. Displays used in COMET-LA PSA workshops.

At the end of phases 1 and 2, the result matrix contains the participants' views on the system. Researchers can triangulate the results with scientific knowledge on the area, the extra data gathered by facilitators (from the discussions and social interactions), and any other available data source to test the level of subjectivity on the participants' views and to complete the knowledge about the SES. This way, the local knowledge condensed in the first result matrix is compared and completed with scientific knowledge from the researchers and universities linked with the project. Both local and scientific knowledge are considered as complementary views on the same reality.

7.2.5 PSA phase 3: Identifying the key variables

As described in chapter 5, MICMAC software offers different interpretation tools for analyzing the actual and potential: matrix of direct influences, matrix of indirect influences, rankings of variables according to influence or dependence, influence/dependence maps, influence graphs, and displacement graphs between direct and indirect influences.

These matrices and graphs have to be analyzed by researchers and workshop participants in order to detect possible errors, and eventually to validate the outcomes. The most useful PSA results for the SESs are the variable rankings, the influence/dependence maps, for both MDI and MII and the influence graphs. As previously mentioned, the MICMAC charts are not user-friendly, especially for non-expert audience, so adaptations are in order.

A first adaptation is needed in the names assigned to each of the clusters shown in the influence/dependence maps (see section 5.4.2 for the original names). These names need to be concrete and have a practical meaning for the participants. Most of the original names (in English) are too abstract and even meaningless for local stakeholders. So, understandable names in Spanish have been proposed by the researchers of the CSs. Using these new names, the system's dynamics and the role of the key variables are more easily explained to, and understood by the workshop participants.

Comparing the results of the analysis of the maps of direct and indirect influences and how the variables can change their influence/dependence rankings over time due to the indirect and potential influences, can also lead to very interesting new insights in the system's dynamics as it can uncover hidden variables or influences. The evolution of the relative position of variables shows potential future evolutions of the SES according to participant views, which opens the minds on the role that community members can play in modeling their future.

The influence graph or digraph of inter-related variables gives a better understanding on how actions in one variable can be transmitted on the system, or which variables cannot be influenced, rendering interventions on the latter useless. However, the influence graph as given by MICMAC does not give a good interpretable visualization of these networks. Other software can be used, such as VENSIM to improve the interpretability of the influence graphs, or even a more artisanal method using the drawing function of Microsoft Word. The use of complementary analysis techniques is strongly recommended, tools for which can be found in section 5.6.

This phase was mainly developed by the researchers, even if they were open to share the method with other interested stakeholders.

After the collected data in the previous phase was processed using MICMAC software, the different displays were used to understand the role played by the variables. The interpretation instruments used in all the three CSs were: (1) the influence/dependence map; and (2) the influence graph. The rankings, based upon the total direct influence of each variable, D_k, were used in the Mexican and Colombian CSs.

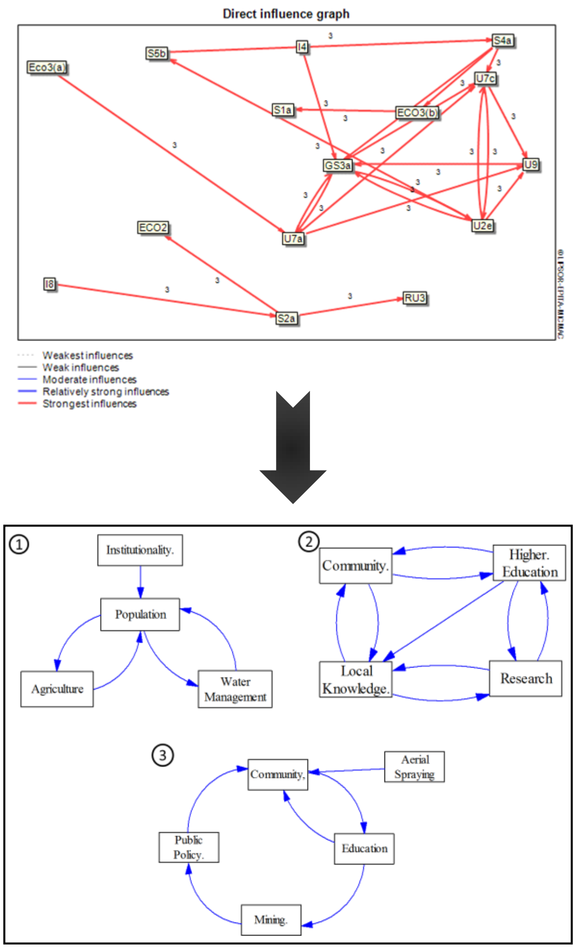
Strong attention was given in each CS to the influence/dependence map based on the MDI and MII, which were used for identifying the role of each variable in the system and the variable shifts between both maps. As the number of variables analyzed in each SES was not too high (around 20) only the rather general categories from the proposed framework as described in section 0 were used. The subtler 'environment' and 'objectives', and the distinction between regulator and secondary categories, were left out, or barely taken into account and only the more concrete, direct type of clusters were kept.

Thus, the variables were gathered in the following clusters:

- Determinant variables;
- Regulator/secondary variables;
- Key variables;
- Autonomous variables;
- Result variables.

The fuzzy chart delivered by MICMAC fostered researchers to present the results to the community members using more friendly displays. Figure 26 shows an example of this process from the CS Colombia: the MICMAC graph was transformed using VENSIM software to present the most important reinforcement cycles among variables. This was particularly useful for participants understanding how a rather small change in some variables can have a multiplied effect (negative or positive) on the system, and through the system, on itself.

Figure 26.Direct influence graph and most important reinforcement cycles, Alto y Medio Dagua, Colombia.



Source: (Avendaño et al. 2013)

7.2.6 Interpreting results

To interpret the results, two methods are used, validation workshops and triangulation of information. The validation workshops to discuss results are hosted with both internal and external stakeholders. These workshops are recommended to be open to more stakeholders than the ones in the previous phases, in order to have the opinion of a broader number of stakeholders and community members, and to see if their views fit with the ones of the workshop participants.

The final list of key variables and the results are reviewed and validated by the workshop's participants. The function played in the system by each variable according to the influence/dependence map, the ranking of variables according to their influence and dependence and the shifts in the position of the variables between de MDI and MII are examined. In all the cases, the counter-intuitive results are discussed and the different reasons that could be at its origin considered. Controversial variables and results can focus the debates and open new perspectives on what happens in the SES.

The second method is a triangulation analysis done by the researchers, checking if the views of the stakeholders are too biased and marked by too much subjectivity. In COMET-LA, the working experience in the SES and the different analysis, studies and research done since the beginning of the project have helped in doing this exercise.

7.3 Validation workshop

The different results provided by MICMAC were gathered and adapted in order to be presented to the stakeholders. The outcomes were then validated by the local, regional and national stakeholders during a validation workshop. Members of the international COMET-LA team also attended all these validation workshops.

The presentation of the results was adapted to the practical level of the local communities, explaining the used method with visual techniques or images, limiting the use of ICT to the communities with experience with computers, and translating the scientific concepts in an understandable language. A variety of interesting adaptations to the local level emerged from the project, and the most interesting are described below: translations of scientific concepts, a more adapted way to present the influence/dependence map, the cloth-o-graph, and even the so-called *spaghetti metaphor*.

The scientific concepts naming the clusters of the influence/dependence map were translated into a more understandable, practical argot. Table 4 presents the adapted names in each CS. Curiously each CS used a different Spanish name for each cluster.

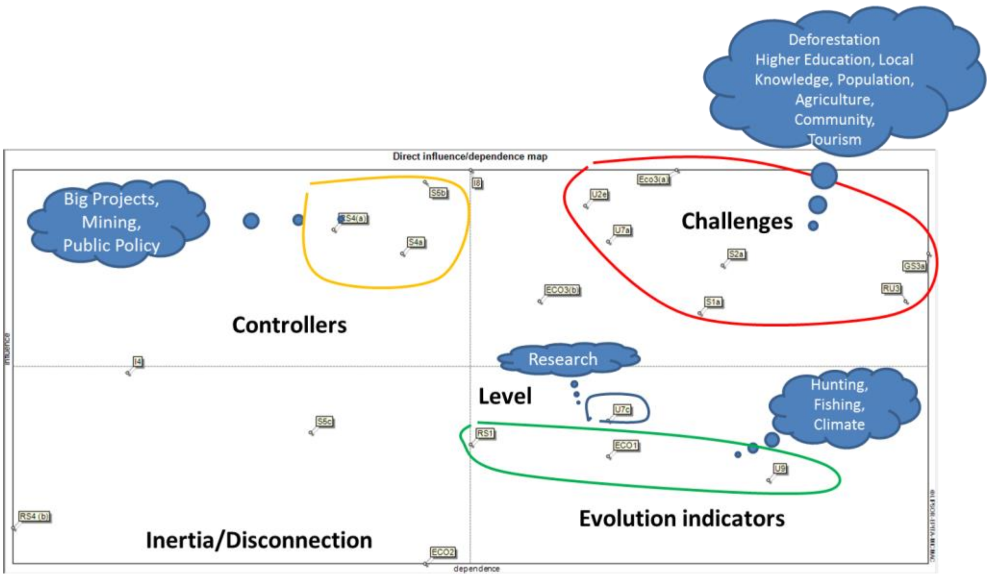
Table 4. Concept translations for the local communities (original in Spanish and translation into English).

Concept		CS Argentina	CS Colombia	CS Mexico
Determinant variables	*Sp*	*Motor o reguladoras*	*Reguladores*	*Motor*
	En	Motor or regulatory variables	Regulators	Motors
Autonomous variables	*Sp*	*Inercia o autónomas*	*Inercias/desconexiones*	*Islas*
	En	Inertia or autonomous variables	Inertias, disconnections	Islands
Regulator/secondary variables	*Sp*	*Variables palanca o control*	*Palancas*	*Soporte*
	En	Levers or control variables	Levers	Supports
Key variables	*Sp*	*Variables desafío*	*Retos*	*Puente*
	En	Challenge variables	Challenges	Bridges
Result variables	*Sp*	*Variables resultado*	*Indicadores de evolución*	*Dependientes*
	En	Evolution indicators or outcome variables	Evolution indicators	Dependents

Source: Own elaboration based on (Avendaño et al. 2013, Escalante-Semerana et al. 2013, London et al. 2013).

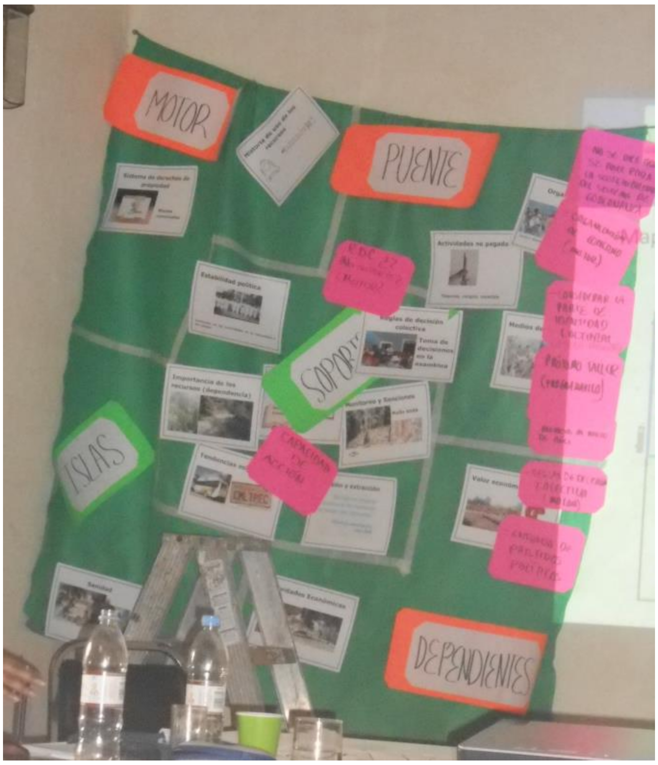
But, not only were the names adapted, also the way the influence/dependence map was presented. The Colombians and the Mexicans adapted the MICMAC influence/dependence maps including in the graph, the clusters and the names of the variables, to present them in a friendlier way (see Figure 27 and Figure 28).

Figure 27. Influence/dependence map for Alto y Medio Dagua, Colombia.



Source: (Avendaño et al. 2013).

Figure 28. The influence-dependence map on the Mexican *Franelógrafos* or cloth-o-graphs.



The Colombian facilitator used the very accurate image of spaghetti for explaining the influence graph. Indeed, when pulling on a part of the spaghetti, they come along the variables associated to. In the same light, to know the relationships of a certain variable, it can be 'pulled' from the tangle of the influence graph, and the ties that come along studied. This visualization of the method made the abstract concept of an influence graph clearer to the workshop participants.

During these presentations, the participants generally agreed upon the results and enjoyed the direct and practical results (variable classification, role identification) after a rather abstract procedure (filling a matrix with 0-1-2-3-*p*) of the previous workshops. Only some minor adaptations were demanded by the participants and consecutively integrated by the researchers. According to them, the results have allowed passing from a complex set of unstructured data to a clear and accurate picture of the dynamics in the SES.

One such interesting remark coming from the Colombian stakeholders, was that the variables located in the lower left quadrant of the influence/dependence graph should not be considered strictly as autonomous variables, and thus without influence in the system, but as variables that are hard to influence (especially by the stakeholders), but could have a strong impact if the system evolves differently than expected. This observation can be very useful for the next scenario-building phase.

8 Conclusions

The process for locally adapting prospective techniques to identify key factors in SES dynamics has given relevant conclusions on the following aspects: 1) the interest of PSA in the analysis of SES, and 2) the consequent methodological learning from its application at the local level.

8.1 On the interest of PSA for the analysis of SES

Identifying the key factors in the dynamics of SESs is essential for sustainable planning and management. Different methods have been explored but PSA was considered the most appropriate for handling the inherent SES complexity and for driving a social construction process that increases the knowledge of local communities on their SES.

Capturing and condensing the knowledge of SES users on the central environmental challenges they face without omitting its inherent complexity, is an essential step for building future scenarios and proposing adapted management actions for promoting sustainability. By using these techniques, the effect on the SES of different management actions on one or several variables can be analysed, and their impact evaluated.

PSA can analyse systems with several dozens of variables, identify those driving changes, show possible trends and evolution, identify variables that are part of separate clusters, and describe the strength of relationships, as well as potential influences. It gathers not only the direct influences among variables, but also analyses the indirect interrelationships highlighting the invisible structure of interactions among the system's elements and establishing hierarchies among them. As a result, it describes and studies in a structured manner the community's vision on the system encouraging the implication of the actors in the process.

The method encourages a local reflection process producing a picture of the participants' views which is analysed using mathematical techniques for detecting patterns and relationships in this subjective information. It transforms a complex data set to visually interpretable graphs, which are of interests for sustainable management. During the process, the community internalizes the gathered knowledge and opens their minds for new options to cope with the environmental challenges their SES faces.

The stakeholders in a SES determine strongly its actual and future state, so their vision is of utmost importance when debating its future and the necessary management actions to reach it. Therefore, participatory techniques stimulating collective reflection, like PSA, are needed. PSA enables a reflective, structured process among participants leading to the construction of the participants' vision on the SES. During this socially organized learning process, the community internalizes the gathered knowledge and opens their minds for new options to cope with the environmental challenges their SES faces.

Other advantages of using PSA to analyze SES dynamics and work at local level are: 1) it permits the systematic analysis of complex systems, including eventual subsystems and networks/loops of variables; 2) it does not require previous knowledge of the method by the participants; 3) it is easy to set up, as it requires little materials and time and uses open-access software; 4) it does not require quantitative data or data series; 5) it enhances interdisciplinary and interpersonal communication; 6) it improves local deeper understanding of the system, and 7) it permits action or policy analysis.

It is a promising tool for SES analysis for its simple but thorough methodology, and easy-to-use outcomes. Some conceptual choices made when constructing the model limit the outcomes, but are rather unavoidable, like:

- The limited typology of influences (0, 1, 2, 3 and *p*) restricts the amount of detail of the system that is used for analysis, but facilitates its analysis;
- The *p*-value is poorly defined, but this gave the opportunity to propose a well-adapted definition. In COMET-LA, *p* was used for the influences that do not exist yet, but could exist when some circumstances change;
- The calculation of the MII exaggerates the importance and influence of indirect relationships between variables, which should be stressed when interpreting the results, but this helps contrasting the MDI with the MII.

So, the outcomes of the PSA process are twofold:

- A thorough knowledge of (the stakeholders' vision on) the system, more precisely, which variables were considered as the most potent in triggering change; and
- The group effort, shared experience and ties created among the participants.

Finally, PSA has very subjective results, highly dependent on the participants. Far from being considered a limitation, this offers a stimulating potential for validating the SES's singularities. The results give information on how the stakeholders perceive the system and its evolution. This knowledge is essential for identifying the problems the people observe and for designing strategies to tackle them. Future changes depend on the local actors' perceptions and attitudes towards the system, and necessarily have to be considered in any sustainable strategy.

8.2 On the methodological learning

The COMET-LA approach of combining Prospective Structural Analysis (PSA) with the SES framework within the context of Community-based Natural Resources Management (CBNRM) constitutes a methodological innovation, as only partial references have been found in the reviewed literature on the use of prospective analysis neither in SESs nor in CBNRM.

This joint application helps to cope with the inherent uncertainty contained within the management of complex systems such as SESs. It not only helps improving the analyzing capacity of the local community for anticipating future impacts through the key variables, it also improves the joint management of the SES by both the local community and external stakeholders through the shared experience and learning arena, bringing the decision-making process closer to the local people, and helps the latter in increasing their capacity of monitoring and evaluating the actions of public policies linked with the key variables. Working together increases the options for better management decisions.

Although both the SES framework and the PSA technique are strong methods to begin with, they were mainly conceived for use by highly trained stakeholders from sectors that possess substantial means, so the adaptation of both to working on a local level was in place. Important adaptations have been done in selecting the stakeholders, translating the participatory tools, and adapting the methodology to the local level. The methodology has been adapted to the oral cultural dynamics of the local communities. Efforts have been made to increase the understandability of the scientific concepts by translating them in a lay-language and designing visual aids for explaining the techniques. The close collaboration with the community members allowed them not only to have the results of the PSA exercise, but also to understand how the technique works. Through COMET-LA, the local communities are now able to apply the cutting-edge methods of SES characterization and PSA.

The combination of an adapted version of the SES framework with locally-adjusted PSA techniques for analysing the stakeholders' vision on the central environmental challenges has led to an improved local understanding of the SES's functioning. This innovative approach of analyzing a SES by applying PSA on the SES framework has proven a strong tool for gaining a thorough understanding on (the community's views) on the SES. This process was strongly socially-organized, as the stakeholders were no mere participants in the process, but participated in adapting the very methods they were working with. During the process, the opinion of stakeholders was highly respected, even if it contradicted scientific knowledge. This mutual confidence of the participants led to high levels of participation, even where no community structures are present (Argentina CS). The mathematical basis of the PSA technique for operationalizing subjective data adds extra credibility to the process.

The PSA exercise brought together stakeholders confronted in different degrees of intensity with central environmental challenges. It allowed for new social networks to be formed and new communication platforms to be created, which COMET-LA actively fomented.

Furthermore, the results are obtained through consensus and are not the opinion of specific persons or groups. This permits more free speech, especially when dealing with variables that are not properly managed in the SESs or are sensitive to some collectives. The method establishes a firm basis for harmonizing the efforts from the different levels and encouraging their sustainability.

The working method has been firmly accepted by the communities in the 3 CSs. In Mexico the General Assembly has appointed a semi-permanent COMET-LA commission to attend these workshops in the future, which may contribute prospective insights for the Assembly to consider. In Colombia a group of 15 co-researchers has been trained as facilitators, and can now independently apply PSA whenever they need. In Argentina, this was the first experience where the internal and external stakeholders were joined for thinking about the management of their natural resources, and participation in the workshops has been enthusiastic beyond expectations.

The learning arena and communication platform thusly created are of great value for dovetailing the policies and management actions. These are important contributions of the COMET-LA project: the learning arena is encouraging the community's capacity building and it should impact in a positive way at local level in the future.

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Annex I. Foresight

Foresight can be defined as *"a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilizing joint actions"* (European Union 2013), or shorter: studying possible futures for preparing today's decisions. Its first documented practical application is situated in the 19th century in military strategy building through war games simulations, in von Clausewitz' book *"Vom Kriege"* from 1832 (von Reibnitz 1992).

Modern day foresight techniques have only emerged since the 1960 (Bradfield et al. 2005), with the emergence of three foresight schools: two in the USA and one in France:

- The intuitive logics school (USA);
- The probabilistic modified trends school (USA);
- *La prospective* (France).

The first steps in USA foresight emerged after the Second World War, when the US army had to decide which strategic direction to choose in arms development, as several new options were discovered during the war (Bradfield et al. 2005). The need to elicit and synthesize expert opinion led to the development of the Delphi technique, and the need for simulating models led to the development of scenario techniques, both developed by the RAND Corporation.

Building upon their experience within the RAND Corporation, experiments with scenarios as a planning tool where tested. Although they were first active in public policy planning, the technique was also used by the business community. The first widely documented use of scenarios in this context was the experience of the Royal Dutch Shell Company, which adopted scenario planning as a permanent strategy in 1972-73, and led to the foundation of the first USA school of foresight: **the Intuitive Logics School** (Bradfield et al. 2005).

This school views scenario planning as a framework for thinking about the future. This intuitive methodology is qualitative by nature and a rather flexible methodology, highlighting the importance of the learning process (Rialland and Wold 2009).

A second school of foresight emerged from the RAND Corporation, **the Probabilistic Modified Trends school** (Bradfield et al. 2005). This school has a quantitative approach including trend-impact analysis and cross-impact analysis. Both methods are primarily probabilistic forecasting, but are used to generate several alternative futures and can be complemented with judgments and other more qualitative assessment (Rialland and Wold 2009).

In the meantime, in Europe, the French philosopher Gaston Berger founded in the 1950s the *Centre d'Etudes Prospectives*, where he developed a scenario approach to long-term planning, a method he named prospective thinking or ***la prospective*** (Bradfield et al. 2005). It was strongly linked with public policy and planning. Based on his philosophical axiom that the future was not determined, but could be *consciously modeled to be humanly beneficial*, he developed positive images of the future for the country's politicians, so they could use them as basis for political action.

This pioneering work was continued after Berger's death in 1960 by Pierre Masse and Bertrand de Jouvenel. The seminal works shaped the prospective analysis as an alternative to the *long-range planning* techniques (Berger 1964, de Jouvenel 1972). In the 1970s, Godet and other authors gave a new impulse to the development of these techniques, which still presented a philosophical and literary shape, turning them into a research technique of the future applicable to real cases, formalized through a variety of quantitative methods which together make up a toolbox for an analytical implementation of the method (Gómez-Limón et al. 2009), but with a qualitative base since the options derived of the opinions and perceptions of the participants in the process.

After the first military experiences in the two US-based methods within the RAND Corporation, foresight was used in strategic planning and company analysis. In fact, 46% of the Fortune 1000 industrials and in excess of 75% of the Fortune 100 industrials in 1981 use it (Linneman and Klein 1983), with a similar picture in Europe around the same period (Malaska et al. 1984). The use of foresight techniques became less important in the years after, but has been rising again since 1992 (Bradfield et al. 2005). The support for these techniques coming from the European Commission through their Institute for Prospective Technological Studies (IPTS) since 1994 has also greatly contributed to fostering the availability of the foresight methods and tools to the public.

Annex II. La prospective

The 5 steps of Godet's version of la prospective are explained in the following pages. The programs mentioned in the explanation are developed by LIPSOR (Laboratory for Investigation in Prospective Strategy and Organization) and can be freely downloaded on: http://en.laprospective.fr/methods-of-prospective/downloading-the-applications.html

1. Step 1: Strategic Prospective Workshops

The first step of *la prospective* method, is organizing workshops with all the most important stakeholders. During these workshops, participants will become familiar with the tools of *la prospective* for identifying and hierarchizing the main stakes for the future.

2. Step 2: Prospective structural analysis with MICMAC and the interplay of actors with MACTOR

Prospective structural analysis (PSA) is used for evaluating the influence and dependence of each identified variable in the system. This can be done using the MICMAC[14] software, as proposed by Godet (2013), or using alternatives. The PSA part of *la prospective* method is fully explained in chapter 5.

The interplay of actors, or the balance of power between actors and their convergences and divergences in objectives, is studied by the MACTOR[15] method and software. It leads to a better understanding of relationships between actors, based upon shared objectives and/or power, and assists thusly in making decisions so that actors can implement their alliances and conflicts' policies. This method consists of 7 phases (Godet et al. 2004), and is highly participatory and mathematical in nature, as the previously described PSA.

3. Step 3: Morphological analysis with MORPHOL

During the previous steps, the system has been broken down in different components. The possible futures of each component are described in a first phase, and they form the morphological space. Within this space, all possible combinations of components' futures exist.

In a second phase, this morphological space is reduced by eliminating incompatible configurations, and thus only leaving the relevant combinations of components' futures, i.e. the possible scenarios, as a scenario in *la prospective* is nothing more than a route, a combination bringing together a configuration for each component. This method has been

[14] MICMAC is the acronym for the French *Matrice d'Impacts Croisés Multiplication Appliqués à un Classement*, or Crossed Impact Matrix Multiplication Applied to a Ranking.
[15] MACTOR is the acronym for the French *Méthode d'analyse des jeux d'acteurs*, or Analysis Method of Actor Interplay.

developed by F. Zwicky in the '40 when he was working for the U.S. army (De Jouvenel 2000, Benassouli and Monti 2005). MORPHOL software can be used for this step.

4. Step 4: Identifying the most likely scenarios with SMIC PROB-EXPERT

Using cross-impact probability methods, simple and conditional probabilities of hypotheses and/or events, as well as probabilities of combinations of events are defined, taking into account interactions between events and/or hypotheses. The software SMIC PROB-EXPERT[16] was written to support the user in these calculations.

5. Step 5: Evaluating strategic options with MULTIPOL

MULTIPOL[17], a piece of software for evaluating different strategic options, uses a simple multicriteria approach, comparing the weighted averages of the scores of the different actions.

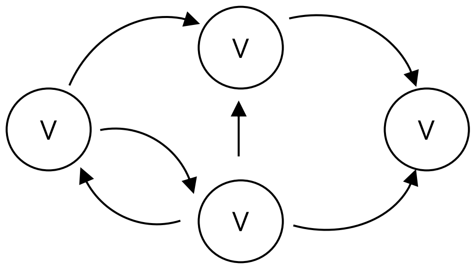
This process starts with listing of all possible actions, the analysis of the consequences, the development of criteria, the evaluation of the actions, the definition of policies and finally, the classification of the actions. Different sets of weighting values for the criteria can be defined, each set laying its accent on another policy (e.g. environment, industry, social development, etc.), which allows evaluating the robustness of the results, by comparing the weighted averages for the different formulated policies. This way, the scenario with the best weighted scores over the most important policies can be identified as the most robust option.

[16] SMIC PROB-EXPERT is the acronym for the French *Systèmes et Matrices d'Impacts Croisés Probabilistes*, or Systems and Matrices of Probabilistic Crossed Impacts.
[17] MULTIPOL is the acronym for the French *MULTIcritère et POLitique*, or Multicriteria and Politics.

Annex III. The ISM Technique

The Interpretive Structural Modelling (ISM) technique is best explained through a hypothetical example. Let us consider a system composed of 4 variables (V_1 to V_4), influencing each other through relationships (represented by arrows), for which the digraph has been constructed in Figure 29:

Figure 29. Digraph representation of the system.



The **first step** in ISM is representing the system by a binary incidence (Lin and Yeh 2013), or adjacency (Malone 1975) matrix $A = [a_{ij}]$, defined as:

$$a_{ij} = \begin{cases} 1, & if\ a\ direct\ infuence\ exists\ from\ variable\ \mathrm{i}\ to\ variable\ \mathrm{j} \\ 0, & otherwise \end{cases}$$

The system shown in Figure 29 is thusly represented by the following incidence matrix:

$$A = \begin{matrix} & V_1 & V_2 & V_3 & V_4 \\ V_1 & 0 & 1 & 1 & 0 \\ V_2 & 0 & 0 & 0 & 1 \\ V_3 & 1 & 1 & 0 & 1 \\ V_4 & 0 & 0 & 0 & 0 \end{matrix}$$

The **second step** is generating the reachability matrix R. A variable V_j is reachable from V_i when a path can be traced in the digraph from V_i to V_j. By convention, all variables can reach themselves by a path of length 0. The reachability matrix R is defined as a binary matrix where a_{ij} equals:

$$a_{ij} = \begin{cases} 1, & if\ a\ path\ can\ be\ traced\ from\ Vi\ to\ Vj \\ 0, & otherwise \end{cases}$$

This matrix can be calculated from the incidence matrix A by adding the identity matrix (all variables reach themselves) and raising the resulting matrix to successive powers until no new entries are obtained (Malone 1975). That is:

$$R = (A + I)^n \text{ with } n \text{ so that } (A + I)^{n-1} < (A + I)^n = (A + I)^{n+1}$$

The multiplications of (A+I) are Boolean (i.e. $1+1=1; 1+0=1; 1\times 1=1$; $1\times 0=0$) so all successive powering operation preserves the entries of the previous power, and matrix equality or inequality can be determined on the basis of an entry by entry comparison.

In the example given in Figure 29, stability occurs when $n=2$ and the reachability matrix is:

$$R = \begin{array}{c} \\ V_1 \\ V_2 \\ V_3 \\ V_4 \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_2 & V_3 & V_4 \end{array} \\ \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

The **third step** is cluster retrieval (Lin and Yeh 2013), grouping the variables that influence one another and form a loop. This is done by multiplying each element of the reachability matrix R by the corresponding element of the transposed matrix for R (this is called a *Hadamard* product). In the output matrix $R°R^T$ the variables Vi and Vj interact when $r_{ij}\cdot r_{ji}=1$. The clusters of variables are obtained by rearranging the matrix.

The resulting matrix is:

$$R°R^T = \begin{array}{c} \\ V_1 \\ V_2 \\ V_3 \\ V_4 \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_2 & V_3 & V_4 \end{array} \\ \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

Or rearranged (the clusters are indicated by squares):

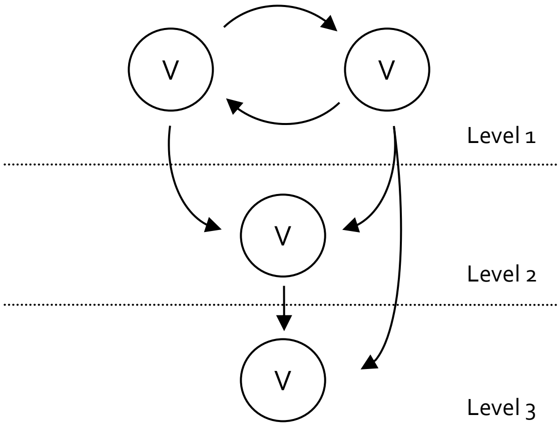
$$R°R^T = \begin{array}{c} \\ V_1 \\ V_3 \\ V_2 \\ V_4 \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_3 & V_2 & V_4 \end{array} \\ \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

In the **fourth step**, the hierarchy graph is obtained. Therefore, the reachability matrix R is rearranged according to the new order as established by the rearranged $R°R^T$ matrix.

$$R = \begin{array}{c} \\ V_1 \\ V_3 \\ V_2 \\ V_4 \end{array} \begin{array}{c} \begin{array}{cccc} V_1 & V_3 & V_2 & V_4 \end{array} \\ \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

The hierarchy graph (see Figure 30) is then obtained by identifying a cluster of variables in the rearranged matrix R that cannot reach other variables outside the cluster, and removing them from the original matrix R. This process is then repeated for the remaining matrix until a unique cluster of nodes is obtained that no other node can reach. In our example, V_4 is the dependant power, V_2 is identified second and only the cluster V_1-V_3 remains as the driving power.

Figure 30. Hierarchy graph representation of the system.



Annex IV. Calculating the matrix of indirect influences (MII) in PSA

In this annex, the method for calculating MII in PSA is explained in detail. This is done using the same hypothetical exercise with 4 variables, V_1-V_4, as in chapter 4 on page 9. The $(4 \times 3 = 12)$ questions have been answered and the MDI has been filled as shown in Figure 31.

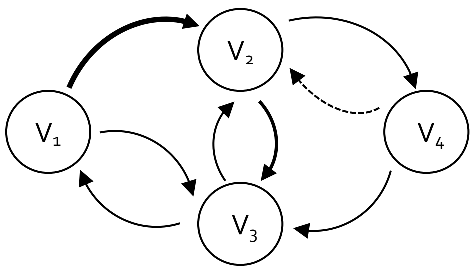
Figure 31. An example of a MDI.

$$\begin{matrix} & V_1 & V_2 & V_3 & V_4 \\ \begin{matrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} 0 & 3 & 1 & 0 \\ 0 & 0 & 2 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & p & 1 & 0 \end{bmatrix}} \end{matrix}$$

Source: Own elaboration.

The system shown in Figure 31 can be represented by a digraph for better understanding (see Figure 32). The strength of the influences are represented by the thickness of the lines, the potential influence is represented by a dotted line.

Figure 32. Digraph representation of the system described above.



Source: Own elaboration.

Now that a system has been defined, the next step is to calculate the MII. This is done by simple matrix multiplication.

Figure 33. Raising the example MDI to the second power.

$$\begin{bmatrix} 0 & 3 & 1 & 0 \\ 0 & 0 & 2 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} 0 & 3 & 1 & 0 \\ 0 & 0 & 2 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 6 & 3 \\ 2 & 2 & 1 & 0 \\ 0 & 3 & 3 & 1 \\ 1 & 1 & 0 & 0 \end{bmatrix}$$

Source: Own elaboration.

In the example given in Figure 31, the direct influence of V_1 on V_4 is zero, but becomes rather important in MDI^2. When analysing the calculations that led to the value of 3, it becomes clear why. Matrix multiplications define the value of a_{14} in MDI^2 as follows:

$$a_{14} = a_{11} \times a_{14} + a_{12} \times a_{24} + a_{13} \times a_{34} + a_{14} \times a_{44} = 0 + 3 + 0 + 0 = 3$$

Or the sum of:

- Zero multiplied by the direct influence (DI) of V_1 on V_4;
- DI of V_1 on V_2, multiplied by DI of V_2 on V_4;
- DI of V_1 on V_3, multiplied by DI of V_3 on V_4; and
- DI of V_1 on V_4, multiplied by zero.

The first and the last values of the sum are zero by definition, the other values represent each an indirect influence over one other value. When raising the MDI^2 matrix to the next power, the indirect influences over two variables will be shown in the resulting matrix.

From a given power ahead, the overall ranking of influence and dependence of a variable *k* remains constant; 7 or 8 is an usual power that guarantees ranking convergence (Godet, 1973 cited in (Collacorta et al. 2012)). This 'stable' final matrix is labeled as the Indirect Influences Matrix (MII).

In the example, stability is reached at the 5th power, as the rankings do not change at the 6th power. This MDI^5 is then called MII and is given in Figure 34.

Figure 34. The MII of the example with influence and dependence values and rankings.

$$\begin{array}{c|cccc|c} & V_1 & V_2 & V_3 & V_4 & I'_k \\ \hline V_1 & 25 & 43 & 63 & 24 & 155 \\ V_2 & 17 & 35 & 31 & 9 & 92 \\ V_3 & 12 & 33 & 42 & 16 & 103 \\ V_4 & 7 & 16 & 12 & 3 & 38 \\ \hline D'_k & 61 & 127 & 148 & 52 & \end{array}$$

Rankings

I'$_k$	**D'$_k$**
V_1	V_3
V_3	V_2
V_2	V_1
V_4	V_4

Source: Own elaboration.