Making decisions with implications networks: Methodology and examples

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Abstract. The effect of implementation of policies, programs, plans and projects on the social, economic and environmental aspects of landscapes responds to conditioning factors that give a degree of sensitivity to these landscapes. The objective of this paper is to propose a landscape analysis methodology that allows to identify guidelines and priorities for landscape management. We have called this methodology the implications networks and it is based on chains of cause-effect relationships, in which the direct, indirect and cumulative (additive or synergistic) implications of the different types of actions on landscapes are considered. This methodology has been used in Colombia to establish the socio-environmental sensitivity of landscapes to the plans for the expansion of electric transmission, nature tourism, the moving of hydrocarbons by pipelines and wagons, demonstrating their usefulness and relevance for making decisions in these sectors, as well as to analyze the incidence of land use policies in Andean landscapes. The experience gained from the implementation of the implications networks methodology allows us to conclude that this is a useful and versatile systemic analysis tool to conduct studies and establish guidelines for the integral management of territories with multiple landscape units and various socio-environmental conditions.

1. Introduction

Although authors have identified the need to consider the indirect implications of different types of implementations in the landscape [1–4], such as the development of plans, policies, programs and projects, and have even proposed methodologies to perform certain analyzes oriented in that direction, no systematic methodologies have been developed that allow a massive analysis of the different landscape units that could be defined in a physical studio space.

In this context, to achieve the goals proposed in any type of implementation on the landscape, it would be expected to have tools for decision-making that favor the recognition of indirect implications and how each of these implications could vary from one landscape to another according to the implementation, so that it was possible to establish management priorities and generic intervention guidelines to prevent, eliminate or mitigate unwanted effects.

Indirect implications are of interest because they cause effects on the social, economic and environmental landscape generating delays to obtain the goals established in the implementations, which is expressed at the time of execution, cost overruns or cumbersome socio-legal situations.

This article proposes a network-based methodology in which the direct, indirect and cumulative implications for each of the landscape units of a physical study space are identified,
to determine the incidence/sensitivity that an implementation can have on the social, economic
and environmental aspects of the landscape unit analyzed, allowing a quantification of the
relationships based on the conditions that each of the landscapes has.

2. Methodology

The implications networks is a methodology for the evaluation of the incidence or sensitivity of
a certain plan, program, project or policy in a physical study space, based on its direct, indirect
and cumulative (additive or synergistic) implications, which allows finding the socio-economic
and environmental management priorities, and define guidelines for decision making on each
priority.

In practice, the methodology has been implemented from the partition of the physical space
of study into smaller space units, which are evaluated considering the implications networks as
a general theory in these units.

The methodology comprises 7 steps: 1) definition of the object of study, 2) identification of
the landscape units of the physical space of study, 3) construction of the implications networks,
4) calculation of the incidence or sensitivity of each of the landscape units, 5) identification
of management priorities, 6) identification of management typologies and 7) definition of
management guidelines according to typologies.

Note that steps 3 to 6 are those with the highest mathematical content, however, steps 1, 2
and 7 are those that contextualize this content for the evaluation of the study object. Each of
these steps is explicitly presented below.

2.1. Definition of the study object

During the definition of the study object, 1) the identification of the type of plan, program,
project or policy to be considered is carried out, disaggregating it into activities and 2) the type
of incidence or sensitivity of the selected plan, program, project or policy to be analyzed.

2.2. Identification of the landscape units of the physical study space

In this step, which is carried out in workshops with experts or from a robust review of the
state of the art, the criteria $C_i, i = 1, \ldots , n$, for the partition of the physical study space $E$
are established, to obtain the landscape units $P$, that is, $P = E/\{C_1, \ldots , C_n\}$. These criteria must
be biological, physical and anthropic.

The information that will be used to feed the mathematical network model presented in the
next section must exist for each of the defined landscape units. Alternatively, rasterization of
the spatial databases obtained could be performed.

2.3. Building the network of implications

In this step, the construction of the network of implications is carried out, again, through
workshops with experts or from a robust review of the state of the art, and the conditions of
the network relationships are defined, which in turn determines which spatial databases will be
used for the calculation.

The networks of implications are a 3–tuple $(A, R, X)$ of socioeconomic and environmental
attributes $A$, weighted causal relationships between the attributes $R$ and spatialized
socioeconomic and environmental data $X$.

It is based on the identification of social, environmental and economic attributes that are
direct implications $A^0_i$ of each of the stages of the plan, program, project or policy, following the
attributes that are social, environmental and economic indirect implications of different orders
$A^0_j, j > 1$, until an attribute that marks the terminal implication is reached, which corresponds
to the sensitivity or incidence of the subject being studied. In this process, the multi-causalities
and multi-effects of the social, environmental and economic implications of the plan, program, project or policy being studied are made explicit.

The resulting network is a tree-like network as those typically used in Decision Theory [5], this means that it does not consider feedbacks, which makes sense because the network is the result of the analysis for a certain moment. This type of network allows the analysis of influences and dependencies, which is important in this methodology because they are the ones that lead to the establishment of socio-environmental landscape management priorities as shown below.

The relationship \( R_{jk}^{pq} : A_j^p \rightarrow A_k^q \) between attributes satisfies the following properties:

- Relationships do not switch \( R_{jk}^{pq} \neq R_{kj}^{qp} \). This property communicates two things: an implication of one attribute towards another in one direction is the same as in the other, and the calculation method rejects the feedback.

- The weights of the relationships are in the unit range \( R_{jk}^{pq} \in [0, 1] \). This property tells us that the qualification of relations will always be a value between zero and one, which in turn allows the definition of a qualitative scale. In this work the following is recommended: Null, when \( R_{jk}^{pq} = 0 \), very low, when \( R_{jk}^{pq} \in (0, 0.2] \), low, when \( R_{jk}^{pq} \in (0.2, 0.4] \), medium, when \( R_{jk}^{pq} \in (0.4, 0.6] \), high, when \( R_{jk}^{pq} \in (0.6, 0.8] \), and very high, when \( R_{jk}^{pq} \in (0.8, 1] \).

- Relationship values are established from local conditions \( x_i, i = 1, \ldots, n \), of landscape units \( R_{jk}^{pq} = f_{jk}^{pq}(x_1, \ldots, x_n) \). Conditions are specific data of each landscape that solve the question: what does the relationship depend on? and the \( f \) function sets the way in which the data \( x_1, \ldots, x_n \) condition the relationship. The networks of implications in each unit of the landscape have their own value that is determined by the data that the landscape has. Thus, each network is a general theory for the analysis that in each of the landscapes, by the values of the conditions, behaves as a special case.

On the other hand, the \( A_j^p \) attributes satisfy the following properties:

- The weight of an attribute is in the unit range and is the product of the values of the preceding relationship and attribute: \( A_k^q = A_j^p R_{jk}^{pq} \in [0, 1] \). In this property, we read that the attributes are also calculated with the weights, that such weights are between zero and one, and that they are estimated from the relationships and attributes that precede it, which allows for an integration of the results from the direct and indirect implications that precede it to the terminal implication.

- The cumulative \( R_{jk} \) relationships on a \( A_j^p \) attribute can be additive: \( A_k^q = \max \left( A_j^p R_{jk}^{pq}, A_j^q R_{jk}^{pq} \right) \in [0, 1] \) or synergistic \( A_k^q \neq \max \left( A_j^p R_{jk}^{pq}, A_j^q R_{jk}^{pq} \right) \in [0, 1] \). A cumulative relationship occurs when at least two attributes act on another. This way of articulating can make the effects of relationships add to the attribute or synergies occur. When the effects are added to the relationships it is said that there is an additive cumulative effect and its calculation is simply the superior value of the effects. But when the effects do not add up, whatever the case may be, it is said that the effect on the attribute involved is synergistic, therefore, its calculation must be established with a relationship different from that used in the additive cumulative effects.

2.4. Calculation of the incidence or sensitivity of each of the landscape units

During this step, the implications networks of each of the defined landscapes are fed with the spatial databases that were obtained to get the incidence or sensitivity of the activity on each landscape unit of the physical study space. This information obtained is presented in a geographic information system using qualitative color values.
2.5. Identification of management priorities
Considering that the incidence/sensitivity studied is obtained from a complex tree-type network of social, environmental and economic aspects, it is possible to calculate which are the set of attributes that most influence the incidence or sensitivity obtained in each landscape in relationship with the identified plan, program, project or policy and what are the attributes that most depend on the systemic web of the landscape. The first, the influencers, are called management priorities, meanwhile, the second, the dependencies, are called the expected effects. In this way, by identifying the management priorities and the expected effects, a ranking of priorities and effects of each landscape can be established.

The influences and dependencies of the attributes of the network are calculated through the PWP algorithm [6], see Equation (1), organizing from highest to lowest influences, which allows obtaining management priorities for each landscape unit:

\[ T = \frac{1}{(e-1)} \sum_{k=1}^{\infty} \frac{D^K}{k!}, \]

where \( D \) is the implications networks matrix and \( T \) is the indirect influences matrix.

2.6. Identification of management typologies
Two space units in the incidence/sensitivity map obtained can have the same qualitative qualification but not necessarily the same management priorities. The set of all space units with the same set of management priorities define a management typology.

2.7. Definition of management guidelines according to typologies
Once the management typologies have been identified, the management guidelines are defined for each of the typologies identified through workshops with experts. The guidelines address the socio-economic and environmental management of each typology in the spatial units of analysis. The way to propose the guidelines is based on the identification of strategies set that conveniently change the values of the conditions used in the relationships. Thus, the guidelines must change the weighting in the network structure.

The guidelines are expected to lead to a desired and viable socio-economic and environmental state, agreed with all parties involved that increase the chances of success of the plan, program, project or policy, inclusion, participation and benefits for the community and an action plan in the framework of established standards.

3. Results
In this section will be shown different methodology applications: the socio-environmental sensitivity of the design and preconstruction phase of transmission lines in Colombia and the potential of nature tourism in Colombia. Incidence of land-use policies on andean landscapes is commented at the end of this section because its methodological purpose is interesting although at the publication time of this paper it has not been finished calculating.

Although the transport of hydrocarbons with pipelines and carriages expansion plans also were studied with the implications networks methodology presented in this paper, these have documentary reservations and only is possible to comment on them.

3.1. Socio-environmental sensitivity of the design and preconstruction phase of transmission lines in Colombia
In spite of knowing the monetary value of the linear meter of installation of an electricity transmission line, when comparing the financial evaluation carried out before and after the
execution of this project type, it is notorious that the wide gaps obtained are related to cost overruns and delays in socio-environmental management.

In this sense, and using the methodology of implications networks, the assessment of the socio-environmental sensitivity of the different phases of these projects has been carried out establishing a map of early alerts for the management of transmission projects in Colombia, due to the overlapping of the socio-environmental sensitivity maps of each of the phases of these projects. The socio-environmental sensitivity of the design and preconstruction phase of transmission lines in Colombia is presented in the Figure 1.

Figure 1. Socio-environmental sensitivity of the design and preconstruction phase of transmission lines in Colombia.

3.2. Potential of nature tourism in Colombia
Initially, it was thought that the potential of nature tourism was given by the resources and attractions set of the country. However, the identification of resources and attractions does not account for their socio-environmental situation, which implies two things: losses in investment due to cost overruns and delays in socio-environmental management and deterioration of the socio-ecological system.

Therefore, it was proposed that the potential of nature tourism in Colombia be established with the resources and attractions set of the country and the socio-environmental sensitivity of nature tourism activities in places where resources and attractions were identified.

As a result, the tourism potential map presented in right side of the Figure 2 was obtained,
and the following management priorities [7]: 1) community feeling of exclusion and inequality, 2) local economic dependence of tourism, 3) new interactions between actors and resources, 4) impact on the tourism products implementation and 5) strengthening of skills and competencies. These results have been used to propose a set of management guidelines that are currently under evaluation.

3.3. Incidence of land-use policies on andean landscapes
Currently, the methodology is being used to calculate the incidence of land-use policies on andean landscapes. What is interesting about this implementation is that the proposed guidelines for changing the network weighting are evaluated through a mathematical model built with the methodology of systems dynamics [8, 9] with which it has been proposed to study the trend behavior of the strategies proposed in the guidelines in two ways: using bifurcation theory for the understanding of stationary behavior [10–13] and using the viability theory for the study of transient behavior [14].

4. Discussion
Although the networks presented in [1–4] are also used for the evaluation of spatial units, the methodology presented in this paper is innovative because it is capable of feeding on secondary
information, here called conditioners, which makes it possible to evaluate a large number of units of analysis in a short time from a general theory that respects the specific characteristics of each unit of them.

On the other hand, as presented in the results section, the implications networks methodology can be used to develop 1) early warning systems for a plan, program, project or policy, through the overlapping of the incidences/sensitivities of each of the implementation phases, 2) maps of potentiality, crossing the incidence/sensitivity information with that of the object to which its potential is evaluated and 3) propose strategies whose trend behavior can be evaluated with complementary tools.

Finally, and as future work, it would be interesting to evaluate the optimal routes from the socio-environmental perspective in linear projects and to study and propose a set of mechanisms for the validation of the methodology that is not only restricted to the criteria of experts as has been proposed in this document.

5. Conclusions

Through implementation is possible to conclude that the implications network must be an instrument for the systemic analysis of the current state in the strategic environmental assessments of different types of anthropic interventions and its outcomes can be used in the definition of the sustainability analysis scenarios.

It is also concluded that it is a versatile tool for the study of territory with multiple spatial units of analysis, capable of guiding the definition of comprehensive management guidelines in each of these spatial units.

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