Towards a Spatial Informatics Framework for Sustainability Analysis

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Abstract:
Sustainability has become a popular notion in current environmental policy analysis. Various definitions of this concept can be found in the literature. Analytically, the notion is relevant in the integration of socio-economic developments with environmental effects in order to obtain insight into (potential) environmental conflicts. Important in the operationalization of sustainability is the spatial as well as the temporal scale. This relates to so-called weak and strong sustainability. These interpretations determine the degrees of freedom or the trade-off possibilities for the policy maker. In environmental policy analysis - where 'what if questions are relevant - a quick and flexible exploration of these consequences is often needed. In this paper, the authors argue that Geographic Information technology particularly if embedded in a DSS environment can be a valuable instrument in sustainability analysis and in particular in exploring the consequences of several more subjective aspects of sustainability analysis: e.g., the application of various spatial levels of the sustainability constraint.

INTRODUCTION

Environmental threats and problems known at this moment are more serious than expected a number of decades ago (RIVM, 1991). On the one hand, this is a result of the increasing number of pollution sources leading to environmental effects. This is due to a general global population growth and all related activities: agriculture, traffic and transport, industry, energy supply and recreation. On the other hand, an important indicator for this seriousness of the problem is the spatial scale at which these effects occur. First, problems occurred and were recognized at local and regional scales (e.g., noise pollution, regional water pollution), but now also continental and global (climate change, depletion of ozone layer) scales are involved. Space is thus an important aspect in the assessment of impacts.

In the evaluation of impacts the broad international discussion on the term ‘sustainable development’ plays a crucial role. WCED (1987) defined the term as a ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’. From this discussion sustainability analysis emerged. Also in this phase space plays an important role as sustainability can be applied to different spatial scales which relate to
different degrees of freedom for the policy maker. In policy analysis, where ‘what if’ questions are relevant, a quick and flexible exploration of these consequences is often needed. In this paper, a spatial informatics framework will be presented to support sustainability analysis and in particular to explore the consequences of the application of various spatial levels of the sustainability constraint.

First, we will describe the various components of sustainability analysis. Second, we will discuss the spatial components of the impact assessment and third, the spatial interpretation of sustainability in the evaluation. Fourth, the various regional classifications resulting from the two earlier sections will be addressed. Fifth, a spatial informatics framework for sustainability analysis will be presented. An application from the Dutch agricultural sector - the use of pesticides - and its effects on a groundwater abstraction area for drinking water supply will serve to further demonstrate this framework. The paper will conclude with some final remarks.

SUSTAINABILITY ANALYSIS

Sustainability analysis in general requires a framework of analysis and evaluation which should be able to test actual and future states (or developments) of the economy and the ecology against a set of reference values. This requires three components in any sustainability analysis (Nijkamp, 1995):

The Identification of a Set of Sustainability Indicators

These indicators should measure all relevant dimensions of sustainable development by including environmental, social and economic characteristics. With respect to the environmental sustainability indicators, the more disaggregated the parameters the stronger the sustainability concept will be applied. More parameters can be generated by further disaggregating the natural stock and formulating non-negativity constraints for groups of environmental resources. Examples of environmental sustainability indicators are (Opschoor and Reijnders, 1991):

a. the use of renewable resources (fish, forest, groundwater) should not exceed the formation of the new stock;

b. pollution giving rise to accumulation in one or more environmental compartments or long-lasting pollution (for instance, groundwater pollution) should be such that no further accumulation of pollutants will occur;

c. the rate of extinction of species should not exceed the rate of origin.

A Structured Impact Methodology

This analysis incorporates economic as well as environmental models which generate the score for the sustainability indicators. Environmental transfer functions, for instance, describe the interaction processes between the source of pollution and receptors.
The **Identification** of a Set of Normative Reference **Values**

These values serve to evaluate impacts and identify sustainable from less sustainable situations. The identification is a normative process. Dependant on the (risk) attitude of the policy maker various values can be applied, including:

a. present levels;
b. levels at which irreversible environmental decay occurs; or
c. more specific interpretations, including critical levels, quality standards, maximum sustainable yield or carrying capacity or vulnerability.

The incorporation of spatial components in the impact assessment as well as the identification of reference values will be discussed in the next two sections.

**SPATIAL COMPONENTS OF ENVIRONMENTAL EFFECT AND IMPACT ASSESSMENT**

The spatial components of environmental effects and impacts mainly originate from (1) the spatial process and (2) the spatial characteristics of a region. The first component is related to the fact that space is a medium through which externality effects can be transferred. As a result an interdependent relationship between the scale of economic processes and environmental effects exists: local processes having their impacts on a regional or even global scale (e.g., global climate change through the emissions of CO₂) and the resulting changes in turn having an impact on local environments (climate change affecting agricultural activity). In economics these effects are also called spatial externalities. The extent to which effects transfer spatially is dependant on various factors including the economic process, the characteristics of the emission and the physical processes which happen in the various environmental compartments (air, soil and water). The second spatial component mentioned above - the spatial characteristics of a region influences these factors. The scales of externality effects of a similar activity may, for instance, be regionally diversified because of spatial variation in environmental compartments (e.g., spatial variability in the intensity of rainfall or leachability of the soil). Spatial characteristics of a region are also a relevant variable in impact analysis. Environmental effects do not uniformly impact on all regions as a result of spatial differences in the economic and environmental variables. Thus regional characteristics may determine the sensitivity to impacts. Sensitivity of an environmental system, for instance, can differ due to the presence of sensitive receptors (e.g., ecosystems) or functions (including nature and drinking water).
SPATIAL INTERPRETATION OF SUSTAINABILITY

With respect to the spatial interpretation of reference values the following key question is relevant: should it be our aim to achieve sustainability at all spatial levels separately, or would it be more tolerable to achieve sustainability at level A, while non-sustainability occurs at a lower level B? (Van Pelt, 1993). This brings us to the discussion of substitution. First, we will address substitution between natural and man-made capital stock. What level 1 of natural capital stock is acceptable and what changes in this stock are acceptable? Different points of view in this discussion are related to the fundamental distinction between weak and strong sustainability (Foy and Daly, 1989). Weak sustainability requires that the total capital stock (man-made capital stock and natural capital stock) does not decline. No limits are however, imposed on the possibility to substitute man-made capital for natural capital (see Figure 1). Strong sustainability on the other hand reflects the idea that neither man-made capital nor natural capital should decline, implying that natural resources put a constraint on activities.

Substitution becomes even more complex if we incorporate time and space. The time dimension is an important thought underpinning the WCED definition of sustainability. Strong sustainability regarded in a time context refers to non-decreasing patterns of environmental and resource stocks at any point in time. Strong sustainability in a spatial context demands that these patterns do not decrease for single spatial units (see also Van Pelt, 1993). Taking the two interpretations together the most rigid interpretation states that each type of stock is maintained at each point in time and space (see Figure 1).

<table>
<thead>
<tr>
<th>Sustainability level</th>
<th>Level of capital aggregation</th>
<th>Level of temporal and spatial aggregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>super weak</td>
<td>aggregated (natural and man-made &gt; 0)</td>
<td>aggregated</td>
</tr>
<tr>
<td>weak</td>
<td>disaggregated (natural as well as man-made &gt; 0)</td>
<td>disaggregated (natural as well as man-made &gt; 0 at any point in time or space)</td>
</tr>
<tr>
<td>strong</td>
<td></td>
<td></td>
</tr>
<tr>
<td>super strong</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Various ways of interpreting sustainability

A global sustainability (the world uses less resources than the threshold) would allow a considerable scope for trade-offs at lower levels. A much more strict interpretation of the sustainability concept would be achieved with local sustainability. In that case there would be no scope for substitution. Van Pelt (1993) lists several proposals with respect to the spatial level of the sustainable constraint; e.g., the project level, the programme level (i.e. across a set of projects), the level of ecosystems or sectors (for instance, the agricultural sector), the regional level and the national or global levels. The spatial levels listed indicate an increasing weakness in the interpretation of sustainability.
THE IDENTIFICATION AND INTEGRATION OF REGIONS

From the impact assessment as well as the evaluation of impacts various regional classifications result: economic regions, effect regions, impact regions, environmental region, political regions and regions where the sustainability constraint will be applied. The economic, environmental and political regions are determined by the respective systems. The effect and impact regions are as we saw before a result of the combined economic and environmental processes. An economic system can be based on socio-historical or cultural criteria; and an environmental system on environmental characteristics (groundwater system, river system) or on pollution information. Planning systems offer the basis for certain development programmes, i.e., they allow for certain planning objectives to be attained in the most efficient way. All can show a hierarchical structure with respect to the spatial dimension; for instance, environmental systems range from micro-level systems (e.g., ditches or ponds) to global systems (e.g., the ozone layer). Different dimensions and characteristics of the economic, environmental and planning systems can thus lead to different spatial dimensions. An effect region, for instance, does not necessarily have to match with the region of an environmental system. It can affect part of the system or more than one system. In the identification of the regions mentioned objective as well as subjective elements play a role. Above some examples of more objective classifications have been mentioned. The identification of the spatial scale of the sustainability constraint is the most subjective, something which is also inherent in the notion of sustainability.

The integration of the various regions would offer better spatial insight into potential environmental problems (location of sources, the extent of spatial externalities and resulting effect areas) and environmental conflicts (the impact of effect areas).

A SPATIAL INFORMATICS FRAMEWORK FOR SUSTAINABILITY ANALYSIS

In sustainability analysis an environmental policy maker is supposed:

a. to need information on sustainability indicators; and

b. to confront these indicators with reference values.

As discussed in the previous sections a spatial insight is relevant due to the characteristics of environmental problems, the spatial conflicts and the spatial trade-off possibilities for policy makers.

To obtain information on sustainability indicators integration is required; integration of data and impact models to compute environmental impacts and integration of regions (economic, effect/impact and environmental regions). This phase can be defined as more or less objective. Scientific requirements for spatial resolution (including regional classifications) and other characteristics of models and data should define the outcome more than political.
At this stage the policy maker should however be able to interact by means of the selection of sustainability indicators as well as the level of resolution of presentation. Figure 2 depicts the potential conflict of resolution requirements where the level of spatial resolution required by the policy maker (right-hand side of scheme) differs from the more detailed resolution needed to represent the real-world in a correct scientific manner (see also Van Beurden & Padding 1994). Through aggregation procedures model results can be aggregated to the selected presentation resolution.

In order to get insight in the sustainability of the development under study reference values are required. These are entirely set by the policy maker. He should be able to select them together with the level (e.g., the spatial level) at which they will be applied. This level of aggregation then determines the interpretation of sustainability. It should be noted that already in the selection of the spatial resolution of indicators (for presentation purposes) some aggregation can take place and thus allowance for substitution.

The spatial informatics framework depicted in Figure 3 comprises the functionality described above. Geographic Information technology in combination with the modelbase assesses effects and impacts and thus the score on indicators at a scientifically correct resolution level. The evaluation module confronts indicators with reference values. Combined with Geographic Information it supports the analysis and evaluation of spatial impacts. Geographic Information technology also offers the functionality to aggregate and visualize results. The selection of the spatial resolution of presentation by the policy maker is treated as an ‘aggregate view’. Such a view is created by applying aggregating techniques on the indicators in the spatial database. Geographic Information technology and evaluation technology are integrated within an user-interface. It enables the user of the system to analyze the problem context in a more open and flexible manner. Interactive elements integrated in the user-interface to select indicators, select the spatial resolution of presentation, select reference values, select the spatial scale of the sustainability constraint and to identify scenario’s support this concept. In this way subjective elements can be entered and thus the spatial trading-off context of the problem and the
consequences of what-if questions in this area explored.

APPLICATION: THE SUSTAINABLE USE OF GROUNDWATER

In the last part of this paper we will focus on an empirical application in the area of groundwater management.

Introduction

Groundwater resources are of great importance for a number of vital functions such as public, industrial and agricultural water supply. The public water use in the Netherlands has been increased in the past 20 years with 50% while population grew with 12%. The average public water use in 1991 was 125 litre a day. Without additional policy measures it is expected to become 135 litres in 2010. The source of drinking water in the Netherlands is groundwater (70%) and surface water (30%). Due to the increasing demand for drinking water more groundwater will be needed (RIVM, 1991). Agricultural activity causes among others a threat to the quality of the groundwater (the use of nitrogen, use of pesticides). In order to secure drinking water quality in the future groundwater management is required. In this light an analysis of a groundwater abstraction area for drinking water supply in the East of the Netherlands will serve to demonstrate the informatics framework presented above.
Sustainability Analysis: Indicators and Impact Assessment

Sustainable use of groundwater basically requires two conditions:

a. no loss of the groundwater’s potential functions;
b. preservation of the diversity of the ecosystem and maintenance of the richness of species.

In this study we will focus on the first condition and more specifically the drinking water function. The indicator selected to test this condition is the concentration of a pesticide in the groundwater (the predicted environmental concentration in micrograms/litre).

For the assessment of the indicator a process model is used that simulates fate and transport of the pesticide Atrazine (a herbicide used in fodder maize) to the upper groundwater layer. Douven, van Veldhuizen en Scholten (1993) describe the way the model is linked to a spatial database resulting in regionalized effect maps. Besides the data needed by the model, the spatial database also contains information about landuse (in combination with pesticide application rates) to indicate where the potential sources are located as well as the location of the groundwater abstraction area. The level of spatial resolution of the indicators is determined by the data resolution of the spatial database and the models. Scientific requirements set the resolution level on gridcells of 1 by 1 kilometre.

Geographic Information technology in the spatial information framework takes care for the integration of data and models, the integration of regions, the aggregation of results as well as the presentation of the information.

Sustainability Analysis: Reference Values

With respect to a sustainable use groundwater intended for drinking water should be potable without additional purification. The reference value set by the EU is 0.1 microgram/litre. Table 1 lists the results of the confrontation between indicators and reference values based on several options for the spatial constraint of sustainability.

<table>
<thead>
<tr>
<th>application area</th>
<th>region</th>
<th>below/ above reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>local:</td>
<td>grid 25 x 25</td>
<td>&lt; 75% below, 75% above</td>
</tr>
<tr>
<td>programme:</td>
<td>fodder maize</td>
<td>below</td>
</tr>
<tr>
<td>ecosystem:</td>
<td>abstraction area</td>
<td>below</td>
</tr>
</tbody>
</table>

Table 1: Application of various spatial levels of sustainability constraint.

The table above shows that through the application of various spatial levels of the sustainability constraint different evaluation results are obtained. This gives insight in the consequences of various normative judgements on the desirability of spatial trading-off on the sustainable use of groundwater use. These various judgements will be identified by the policy maker based on e.g., variability of effects and impacts, the seriousness of the impact, normative judgements. An analysis of local regions is of course much more detailed than the application of the abstraction area as a whole. A decision based on the latter approach implies
a more weak spatial interpretation of the sustainability notion. Such an approach can however be advocated as all groundwater in the abstraction area will be pumped up at one location.

**Sustainability Analysis: Scenario Analysis**

Scenario analysis enables the policy maker to scan possible futures states of the agricultural system. Such scenarios may originate from different assumptions on future pathways, e.g.:

a. behavioural change (e.g., lower Atrazine use, transition to other less harming alternatives, transition to other types of landuse than fodder maize);

b. policy response (e.g., a ban or levy on Atrazine).

**CONCLUSION**

The spatial information framework presented in this paper offers policy makers integrated Geographic Information technology and evaluation functionality to analyze environmental problems. It is a valuable instrument in sustainability analysis and in particular in exploring the consequences of several more subjective aspects of sustainability analysis: e.g., the application of various spatial levels of the sustainability constraint. Through a quick and flexible exploration of ‘what if questions trade-offs between environmental attributes and spatial levels are made more transparent, ‘what-if questions in particular relate to the selection of sustainability indicators, the spatial constraint of sustainability and the generation of scenarios.

It should be noted that the spatial data requirements are large. This is of course dependant on the indicators selected. The gathering and computation of correct environmental and economic information on a scientific reliable resolution level is a time-consuming activity. The spatial dimension makes this process even more complex.

**REFERENCE**


Foy, G. and H. Daly, 1989, *Allocation, distribution and scale as determinants of environmental degradation: case studies of Haiti, El Salvador and Costa Rica,* Environment working paper no 19, Environment Department, World bank,
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