# 5. Scaling issues in Integrated Assessment: Theoretical issues and practical implementations in land use analysis

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## Introduction

This paper aims at providing an overview of the theory and practice of scaling issues in Integrated Assessment studies. First, theoretical problems associated with the notion of 'scale' are explained and the consequences especially within Integrated Assessment studies are elaborated upon. Second, two practical applications of multi-scale studies are given, both of which mainly deal with land use changes. The focus is on spatial resolution in land use modelling (CLUE) and spatial extent in scenario development (MedAction project). The paper finishes with indicating promising future developments.

The theoretical considerations are largely based on Kok (2001). Information on the CLUE modelling framework is extracted from Kok and Veldkamp (2001) and Kok et al. (2001). The results of scenario development in MedAction will also be published by Kok et al. (2006a (in press)), Kok et al. (2006b (in press), and Patel et al. (forthcoming).

## Theoretical considerations

The land use system is highly complex (Hart, 1985; Fresco and Kroonenberg, 1992; Skole *et al.*, 1994). Through a web of bottom-up and top-down feedback mechanisms, relationships between land use and their driving forces can disappear, can be strengthened, or can become non-linear. The notion of complexity has consequences for the way the system should be described (Kolasa, 1989; Pickett *et al*., 1989). In recent years, awareness is growing within the community of land use/cover change (LUCC) researchers (Turner *et al*, 1995; Nunes and Augé, 1999), that a correct interpretation of observed processes is only possible when acknowledging the complexity of the land use system. The land use change community lags behind in the recognition of the need for research that deals specifically with complex systems. Much of the theoretical issues in land use modelling draw from theories that were developed in ecology. Despite existing differences, complex system theories as developed for the ecosystem might apply to the land use system (see Loucks, 1977; Conway, 1987, Fresco, 1995). Ecologists have particularly stressed two aspects of a complex system (Allen and Starr, 1982; Kolasa and Pickett, 1992; Jørgensen, 1994): functional complexity and structural complexity. The system is functionally complex in the sense that it is influenced by a great number of different factors, from a great variety of disciplines. Structural complexity relates to the fact that the observed patterns and processes differ with the scale of observation. In the following, both structural and functional complexity is addressed.

### *Structural complexity*

The key concept of structural complexity is the existence of hierarchically nested levels within the system. Allen and Starr (1982) first conceptualised the Hierarchy Theory for ecology, which was later elaborated by O'Neill (O'Neill et al., 1986; O'Neill, 1988). To avoid confusion, it is essential to differentiate between *scale* and *level,* following O'Neill and King (1998) in landscape ecologists' most recent plea for recognition of scale dependency (Peterson and Parker, 1998). *Level* is defined as *level of organisation* and *scale* as *level of observation*. Whether the existence of organisational levels emerges from the analysis depends on the adopted scales, which are mostly selected arbitrarily. For some disciplines, level and scale coincide. Particularly in the social sciences (economy, sociology, politics), levels are often defined by those who determine the scale. Provinces and planning regions are examples of units at which planning measurements are implemented (level) as well as data collection takes place (scale). While the levels of organisation within land use systems are still poorly understood, data collection takes place at scales that are sometimes defined by other disciplines or techniques.

Again in agreement with ecologists the two main axes of scale are defined as: Both the limit of resolution where a phenomenon is discernible and the extent over which the phenomena is characterised in *space* and *time*. Numerous diagrams have been published that depict position of a number of hierarchically nested levels in space and time. Recently, there has been a lively debate on whether there is a third axis that is needed to define scale in human-influenced sciences (see (Agawar et al., 2002; Rotmans and Rothman, 2003)). Proposals include terms like ‘functional scale’ (Rotmans, 2003) or human decision making (Agawar et al., 2002).

A different issue, which is related to the level of observation is the so-called ‘aggregation error’. This systematic ‘error’ always occurs when non-linear relationships are translated to more aggregated scales and can be explained with simple mathematics (see (Rastetter et al., 1992; Easterling, 1997). Rastetter and his co-workers have mathematically shown how non-linear relationships will always become more linear when data are aggregated. An example that is known to occur is the non-linear relation between yield and fertiliser input at the field scale, which tends to become linear at coarser scales. In literature, this property is often referred to as aggregation error (e.g. (Bartel et al., 1988; Turner and O’Neill, 1994; Jansen and Stoorvogel, 1998)).

*Functional complexity (integrated approach)*
Functional complexity indicates that a complete analysis of any complex system needs to be multidisciplinary (Loucks, 1977; Clayton and Radcliffe, 1995). An integrated approach is then indispensable when the system’s behaviour is to be fully understood. Until now, (spatially explicit) land use studies have focussed primarily on biophysical land use drivers enthused by data availability in various earth sciences. Recently, incorporation of data from other disciplines has been promoted (Turner et al., 1995; Musters et al., 1998; Wilbanks and Kates, 1999), but unfortunately, the statement that there is a “theoretical and methodological failure to combine social and natural science…” (Blaikie and Brookfield, 1987) still appears to be valid.

**Practical examples**
The two examples serve the purpose to illustrate the problems that are encountered when “translating“ the theory of scale to the practicalities of data limitations, uncertainties, and imperfect knowledge of the system’s properties. Information is largely similar to the articles mentioned in the introduction, but the two – partly complementary – examples have not been published together.

*The CLUE modelling framework*
A model can serve as a good tool to mimic part of the complexity of the land use system. It offers the possibility to test the sensitivity of land use (patterns) to changes in selected variables and the stability of the entire system by executing a range of scenarios. While a model will always fall short in incorporating all aspects of the ‘real world’, it provides valuable information on the system’s behaviour under a range of different future pathways of land use change.

The model CLUE (Conversion of Land Use and its Effects) (Veldkamp and Fresco, 1996; Verburg et al., 1999) is a projective model that was designed to deal with the issues mentioned above, and can be described as a spatially explicit, multi-scale land-use change model. Within the framework, an attempt is made to describe land use patterns at different spatial scales with a set of potential land-use change drivers. Using this description, the dynamics of the system are examined by analysing the spatial effects of different possible future pathways of land use change. In order to quantify scale dependencies, the statistical description of land use patterns by a set of drivers is determined at a basic grid and at a series of coarser resolutions. At national level, scenarios are developed to explore plausible future land-use changes, mostly based on macro-economic and demographic developments. Those yearly changes are subsequently allocated in a spatially explicit manner in the grid-based allocation module (Verburg et al., 1999), that consists of a two-step top-down iteration procedure with bottom-up feedbacks. The allocation module uses the statistical descriptions of two spatial resolutions, the basic grid and a higher resolution that is considered optimal in terms of statistical properties. The general structure of CLUE is given in Figure 1.

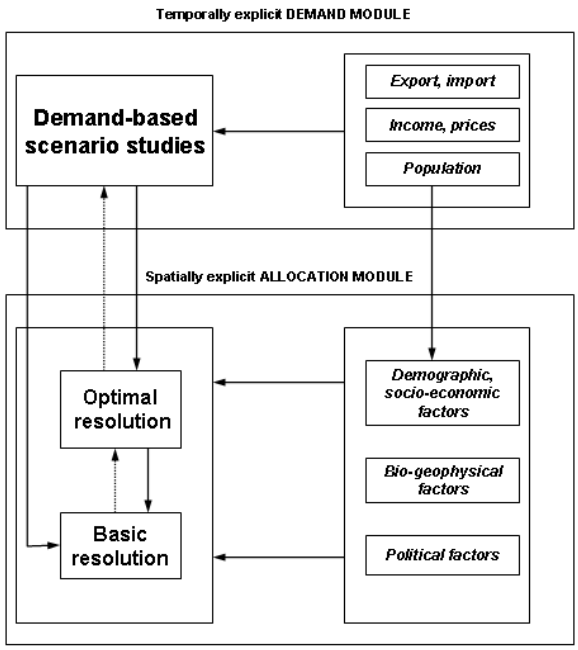


**Figure 1: General structure of CLUE.**

The model was initially developed (Veldkamp and Fresco, 1996) and tested (Veldkamp and Fresco, 1997) for the country of Costa Rica. Since then, the model has been applied to a range of countries and regions. In Central America, applications of the CLUE methodology include: The Atlantic zone of Costa Rica (Kok and Veldkamp, 2000), Costa Rica (Veldkamp and Fresco, 1996; Kok, unpublished results), Honduras (Kok, unpublished results; Kok and Bouma, in press), and Central America (Kok et al., 2001).

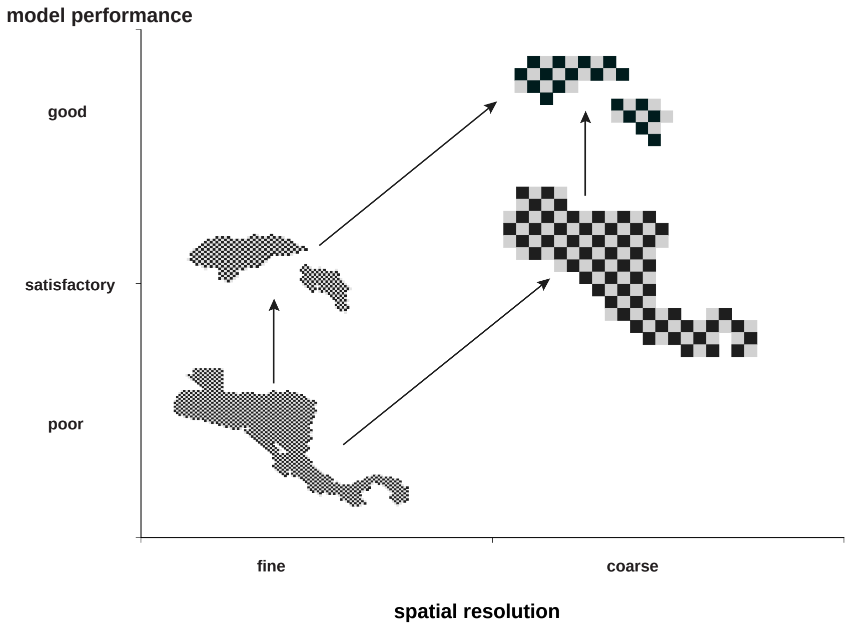


**Figure 2. Schematic representation of model performance as a function of spatial extent and spatial resolution. Redrawn from Figure 5 in Kok and Veldkamp (2001).**

Figure 2 summarises the results of the statistical model performance (in terms of $R^2$) over a range of spatial extents and resolutions. What is depicted here is *not* the explanatory power of the results of the CLUE model, but of one of the key inputs of the model. It is assumed that the explanatory power of this input has similar effects on the model outputs.

In general it can be stated that when increasing the spatial resolution, the explanatory value of the multiple regression equations increases, while there is a decrease of explanatory power when increasing the spatial extent. There is an apparent paradox, which when observed more closely, nicely illustrates the difference between changing the spatial resolution and the spatial extent. By enlarging the extent from country to region in Central America, a border of a level of organisation is crossed. In the regional analysis, six differently organised units are combined in one analysis, which explains the lower model fits. By increasing the spatial resolution, borders between levels of spatial organisation might also have been crossed, but those sub-national levels apparently do not have a significant effect in Central America. Aggregation effects (see (Rastetter et al., 1992)) and changes in variance within one level of organisation become major differentiators, which results in an increase of model performance.

*The Med Action project: Multi-scale scenario development*

As in most other semi-arid regions, desertification in the Northern Mediterranean region is largely a society-driven problem, which can be effectively managed only through a thorough understanding of the principal ecological, socio-cultural, and economic driving forces associated with land use and climate change, and their impacts. A web of global (globalisation), regional (EU policies; EU enlargement), and local (water distribution) forces with a multitude of feedbacks and interactions influence local stakeholders. Integrated scenarios can play an important role in understanding this complexity and possible future changes.

A good example of such integrated scenario analysis is given by the MedAction project. MedAction is a multi-disciplinary research project funded by the EC aiming to assess the main issues underlying the causes and effects of land degradation and develop integrated policy options and mitigation strategies to combat desertification in the Northern Mediterranean region. The specific problems are addressed at the European, Mediterranean and local scales. Four target areas are investigated in greater detail: Alentejo (Portugal), Guadalentín (Spain), Val d'Agri (Italy) and Lesbos (Greece). As part of MedAction, scenarios were developed at all three spatial scales. The basic methodology is illustrated in Figure 3. European scenarios were based on three existing scenarios as developed in another European project called VISIONS (Rotmans et al., 2001). These translate directly into three Mediterranean scenarios (Kok and Rothman, 2003). Target Area scenarios were based on the main driving forces as present in the Mediterranean scenarios, but results can differ substantially, depending on the particularities of the local circumstances. Main conclusions of the local scenarios were scaled-up and incorporated in the Mediterranean scenarios. Specifics of the scenarios that were used and generated can be found in Kok et al. (2006a), Kok et al. (2006b), Patel et al. (forthcoming) and on the MedAction homepage (www.icis.unimaas.nl/medaction/).

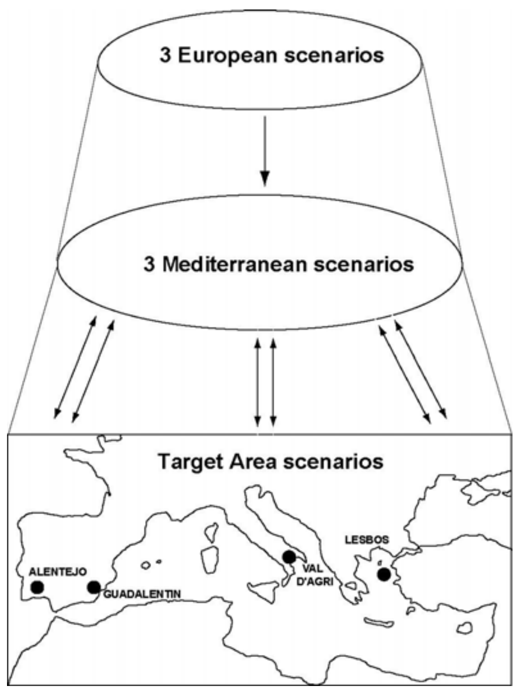


**Figure 3: European, Mediterranean, and Target Area scenarios.**

During the entire process, the focus was on the different key processes and thus key decision makers that are important at the different spatial levels. As desertification is largely human-driven, one could argue that the multi-scale aspect of MedAction is closely related to the third axis of scale, that of human decision-making or functional scale.

**The way ahead**

The two examples above focus on spatial and functional scale. Therefore, recommendations below apply most to studies, where spatial scale is explicitly incorporated. Besides, both examples deal with land use related subjects and recommendations are therefore focused on this field. Nevertheless, most will also apply to Integrated Assessment studies with another focus.

There are three basic manners in which practical applications of multi-scale methods can and should be improved. Existing techniques as explained about should be improved; existing techniques should be combined in one toolbox; new techniques need to be developed.

*Improve existing techniques*
As should be clear from the two examples, the current state of multi-scale methods are far from capturing all important aspects of scale. Direct improvement could include linking global and sub global scenarios as is advocated by the Millennium Ecosystem Assessment initiative. In the modelling community, improvements focus on increasing the range of spatial resolutions and extents that can be handled by one multi-scale modelling framework.

*Develop new techniques*
Obviously, emphasis should also be on the development of new techniques. Promising advances are being made in Agent Based Modelling, where behaviour of individual actors can be modelled.

*Combine existing techniques*
An important and relatively straightforward improvement to the current state of multi-scale techniques lies in the combination of various existing techniques. In my view, a large step forward could be made by combining (see Figure 4):

- Local-scale process-based models. Focus on structural (human decision-making scale) and functional (multidisciplinarity) complexity at local scale providing quantitative data.
- Multi-scale explorative models (cf. CLUE). Focus on structural (spatial) complexity at multiple scales providing quantitative data.
- Multi-scale narrative scenarios (cf. MedAction). Focus on structural (human decision-making) and functional complexity at multiple scales providing qualitative stories.

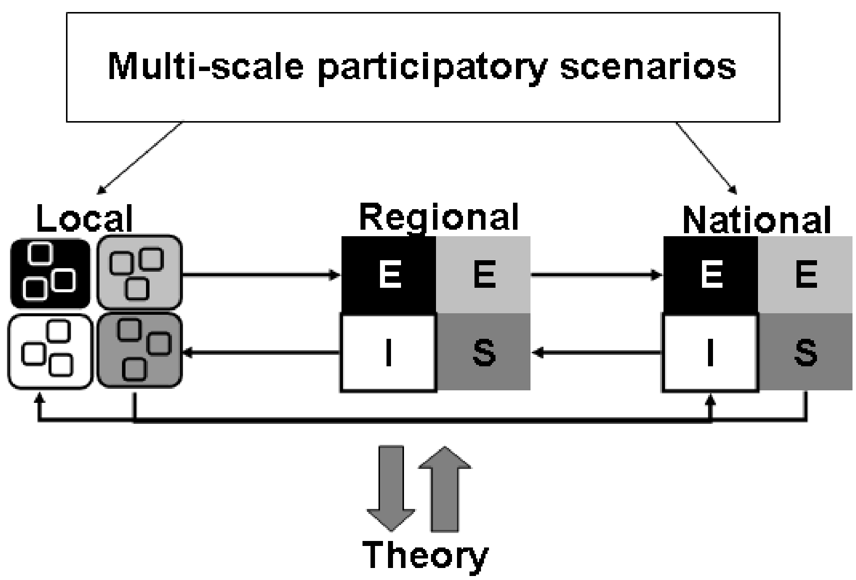


**Figure 4: Combining multi-scale scenarios, multi-scale models and local-scale process-based models to improve our understanding of the effect of scale.**

In order to link these approaches, research focus will have to be on:

1. Linking qualitative and quantitative scenarios.
2. Linking local scale process-based and multi-scale explorative models.

In both directions various initiatives exist.

It can be concluded that our knowledge on how various aspects of scale can be conceptually be described outpaces our knowledge on the practical implications. Focus should therefore be on the development of practical applications, from which additions to the theory might follow.

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