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REVIEW

Evolution of land use-change modeling: routes of different schools of knowledge

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Abstract Although much has been published on land use-change models (LUCMs), no study has comprehensively dealt with the evolution of land use models based on schools of knowledge. The primary objective of this paper is an explanation of the progress and growth of LUCMs concerning their main ontological, epistemological, and methodological origins. Five main paradigms, i.e., positivism, post-positivism, constructivism, participatory, and pragmatism approaches, are discussed in order to assess the current orientations of LUCMs. Given the complexities of LUCM components, the study concludes that one paradigm cannot adequately address all methodological aspects. Accordingly, it is necessary to combine quantitative and qualitative paradigms to create mixed-method approaches within a systemic framework. Such systemic approaches could shape the most probable future generations of LUCMs, which would be able to cope with the complexity of various subsystems, including biophysical and socioeconomic ones.

Keywords Environmental planning · Land management · Land use · Modeling · Knowledge school · Sustainable land use

Introduction

Land use-change models (LUCMs) can be developed with different goals in mind and ina variety of forms through the combination of models which caninterpret and project land use-change systems, represent human decision-making, createlinks between human and environmental systems, and deal with questions about thechallenges of environmental sustainability (Brown et al. 2013). When reviewing LUCMs, there are many criteria that can be identified and used to classify different models (Overmars et al. 2007). According to Verburg et al. (2004), there are a significant number of models that outline land use within the context of different subject areas that have been developed by researchers from a variety of disciplines. They emphasize that the most important tasks for future research is to combine the strengths of all existing ideas, methods and tactics rather than expounding upon the method that belongs to the modeler's own field of study. Moreover, for modelers to further the traditions of their respective fields and build models that truly span different fields of study they need to increasingly integrate tactics and approaches that have been developed in various areas of expertise (Koomen et al. 2008; Witlox 2005).

Our literature review reveals that there has been great advancement in the development of models that outline land use change. Nevertheless, new forms of land use

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modeling need to be devised in order to examine more dimensions of land use systems; such models are more likely to be successful when dealing with the multi-dimensional components of land use systems. They can better incorporate new approaches for the measurement of neighborhood impacts, determination of accurate responses to temporal changes, and can more fully integrate various disciplinary methodologies, as well as create more combinations of LUCMs for rural and urban areas. Through such advances in the development of LUCMs, researchers are better able to evaluate land use changes and develop effective land use policies (Verburg et al. 2004).

There are many examples that demonstrate the importance of understanding philosophy, especially when developing a proper LUCM. An appreciation of philosophy gives the land use modeler the opportunity to clarify and identify the methods used within the model (Easterby-Smith et al. 1997). This includes different methods of collecting data and their sources, the explication of the data, and the way the data respond to research inquiries. Moreover, with a better understanding of philosophy, the land use modeler can become more inventive and imaginative when choosing or refining methods that s/he has never utilized before. The philosophical orientation of the land use modeler also has implications for the creation and application of preferred LUCMs, including the choice of the applied method. Working without being aware of the philosophy that underlies the method does not necessarily signify that the modeler does not also hold such assumptions, rather that the process of developing a model has resulted from assumptions that have not yet been examined or recognized. Therefore, it is crucial that the prevailing paradigms and the basic philosophical assumptions are understood when creating and conducting LUCMs and when contributing to the theoretical and methodological discussions regarding a model. During the last few decades, numerous LUCMs have been conducted to fulfill land management requirements, to improve the evaluation process, and to plan the future role of land use and cover changes (LUCCs) in natural system functioning (Veldkamp and Lambin 2001). Numerous literature reviews (Agarwal et al. 2002; Heistermann et al. 2006; Wainger et al. 2007; Mitsuda and Ito 2011; Wicke et al. 2012; Terry et al. 2013; Lee et al. 2015) regarding the approaches in land use modeling have been conducted over the last few years due to different viewpoints and the development of various typologies. According to Briassoulis (2000), both the epistemological basis and the contributing disciplinary characteristics critically influence an appreciation of land and land use which, in turn, affects the methods of theorizing and modeling land use change. As a result, the role of schools of knowledge claim in terms of land use change needs to be stressed.

One of the compelling reasons for a need for research on the philosophical routes to LUCMs is that changes to land use occur through the effects of many macro- and micro-factors, functioning within differing time frames and geographical space. Models are used to estimate and do not give precise predictions. Thus, the results that they produce should be considered with regard to the model's qualification, assumptions, and limitations. Models depend on mathematical equations and data in order to simulate the "real world." Their reliability is mostly due to the quality of the data used, the principles that govern decision-making, and on the assumptions applied. Therefore, understanding the philosophical routes which lead to a model will help us recognize the ontological, epistemological, and methodological nature of LUCMs. Such an understanding directs thoughts concerning land use change, illustrates conceptual and operational expressions of change, their determinants and their relationships, and suggests explanatory approaches for making sense of available empirical evidence, i.e., to support model building. Accordingly, an understanding of the philosophical routes leading to a specific model could be an effective guide when predicting the future orientations/generations of a LUCM (determining which elements should be included or excluded in the next LUCM). This should help us obtain a better understanding of complex land use systems and allow us to more efficiently interact with those that determine land use change (Verburg et al. 2004). Otherwise, according to Briassoulis (2000), inappropriate and inadequate awareness of the influence of schools of knowledge claims regarding land use change may mislead policy creation and create more challenges which will need to be dealt with. This review aims to outline the evolution of LUCMs based on different worldviews (positivism, post-positivism, constructivism, participatory, and pragmatism). To meet this objective, we will first explain the different philosophical aspects (including ontology, epistemology and methodology) of each worldview and then try to compare the better known LUCMs. Then, we will try to predict the most probable future of LUCMs.

Schools of knowledge claim

The definition of a worldview is "a basic set of beliefs that guide action" (Guba 1990, p 17) or a common orientation of a researcher with regard to the universe as well as the contents of a given study (Creswell 2009, p 5). Ontological, epistemological, and methodological assumptions may belong to different worldviews. Setting a knowledge claim means that researchers launch a project with concrete assumptions about the subject under study, as well as the way of learning (Creswell 2003). From the philosophical

Table 1 A descriptive overview of philosophical aspects of the five research paradigms

Paradigms	Philosophical aspects		
	Ontology	Epistemology	Methodology
Positivism	External single (objective) reality, Aristotelian logic, realism, Boolean algebra	Research on people, focus on the actor, starting with a falsifiable value-free theory, variable-based knowledge, deductive reasoning, empirically justifiable hypotheses understating, non-action-oriented knowledge	Multi-disciplinary, explanatory goal-oriented, pro-artificial instrument oriented, structured analysis of variables regardless of interviewees' environment, correlational/causal analyses, numerical hard stiff data, avoiding bias
Post-positivism	External single reality, internal multiple (subjective) realities	Logical positivism, critical realism, challengeable human knowledge	Focus on the act and the actor, variable/case-based knowledge, de/inductive reasoning
Constructivism	Internal multiple (subjective) realities, Platonian logic, idealism, non-algebra	Research with people, focus on the act, starting with non-theoretical process, case-based knowledge, inductive reasoning, interpretative understating, action-oriented knowledge	Inter-disciplinary, exploratory process-oriented, pro-human instrument oriented, unstructured analysis of participants in their environment, hermeneutics dialectical analyses, verbal soft flexible data, embracing bias
Participatory	'Both-and'; 'positive-sum' thinking, fuzzy algebra	Focus on the act and the actor, variable/case-based knowledge, de/inductive reasoning	Trans-disciplinary, triangulation, cross-checking
Pragmatism	Experienceable reality, reality for use	Function of knowledge, practical reasoning, predictable knowledge, validity tested idea	Instrumentalism, learning by doing, empirical models

point of view, researchers mainly make claims about the definition of knowledge (ontology), the way we recognize it (epistemology), as well as the procedures of investigating that knowledge (methodology) (Creswell 1994). Tables 1 and 2, respectively show a descriptive overview and a summary of the three main philosophical aspects and empirical dimensions of the five schools of thought about knowledge claims.

Further clarifications of Tables 1 and 2 are devoted to a brief discussion of the relationship between each of the five research paradigms and the main LUCMs. However, prior to this, it is necessary to discuss the need for and the uses of models within the context of an analysis of changes to land use. LUCMs may have an effective role in evaluating different effects caused by previous human activities or those that will occur in the future within natural and/or socioeconomic contexts, both of which could provide useful information on possible future land use configurations (Koomen et al. 2008). Lambin et al. (2000) recognized a number of categories of LUCMs, such as empirical-statistical, stochastic, optimization, dynamic (process-based) and integrated. Briassoulis (2000) distinguished statistical and econometric, spatial interaction, optimization, and integrated models, including a category of model types that incorporate but do not fall into any of these categories. Yet Heistermann et al. (2006) classify LUCC into geographically based (empirical-statistical or rule-based/process-based), economic, and integrated models. All inventories demonstrate groups of heterogeneous model approaches that have noticeable differences regards their theoretical backgrounds, their starting points, their range of application and so on (Koomen et al. 2008). In this study, five categories of LUCMs have been considered in regard to the main research paradigms. Table 3 summarizes the most important features of each philosophical viewpoint of the LUCMs.

As shown in Table 3, there are often some common methodological, epistemological or ontological aspects of each model that may be attributed to one or more groups. Importantly, Fig. 1 illustrates how an understanding of land use change has shifted from a simplistic (positivism) to a more realistic and complex (pragmatism) paradigm over time. Such new models have tried to better address land use systems and their multi-scale characteristics, and to integrate disciplinary approaches at a higher level (Verburg et al. 2004; Courtney et al. 2015). The evolution of research questions, methods, and the scientific paradigm is reflected in this change (Lambin et al. 2003).

Main land use-change modeling

Linear models: pro-positivism?

In linear programming (LP), all mathematical expressions for objective functions and constraints are quantitative and linear. The inescapable underlying assumption that is made by modeling the real world via LP is that a linear model is suitable. Yet models constructed solely from linear relationships have certain limitations. The most obvious is that

Table 2 The main features of each worldviews of three main philosophical aspects

Paradigms	Methodology					Epistemology		Ontology	
	Reasoning	Language	Data	Theory	Goal (strives for)	The role of researcher values	The situation of researcher	The nature of reality	The rate of knowing reality
Positivism	Extreme deductive	Formal	Numeric	Testing	Generalization	Completely unbiased	Separate from society	Singular (naive objective)	Perfect
Post-positivism	Semi-deductive	Formal	Numeric	Testing	Generalization	Mainly unbiased	Separate from society	Singular (mainly objective)	Imperfect
Constructivism	Extreme inductive	Informal	Non-numeric	Developing	Uniqueness	Biased	Part of society	Multiple (mainly subjective)	(Im)perfect (depending on context)
Participatory	Semi-inductive	Advocacy and change	Non-numeric	Developing	Uniqueness	Biased and negotiated	Separate from or part of society	Multiple (critical subjective)	(Im)perfect (depending on context)
Pragmatism	Deductive-inductive	Formal or informal	Numeric or not	Developing or testing	Generalization or uniqueness	Multiple stances	Separate from or part of society	Singular-multiple (objective-subjective)	(Im)perfect (depending on context)

lines poorly model some real world phenomena. A weakness common to all mathematical programming models is the assumption that input data are considered to be absolutely accurate (Chinneck 2001). Nevertheless, the main advantage of LP techniques is their capability to be managed, understood and computed.

Single and multi-objective models are two major types of LP models. The first one is conducted in studies that only consider one goal when solving problems, and the second one deals with more pragmatic problems for which several objectives need to be optimized. In both situations, there are one or more objective functions as well as a range of limitations within the procedure used to solve the problem. The objective function(s) of the problem(s) of land use is(are) displayed within a mathematical format, bringing about the question: how much land should be allocated to each of a number of land use types in order to optimize objective A (or, B, C, D)? The objective may be, for instance, to reduce the environmental effects and the development cost of land conversion to a minimum, or to increase the advantages of such development to an optimum level, etc. (Briassoulis 2000). Two more important types of model in this group are the linear regression model (LRM) (Chapin 1965) and canonical correlation analysis model (CCAM) (Briassoulis 2000). There are two groups of linear models, economic and mathematical, that apply statistical techniques in order to derive a mathematical relationship between the dependent and sets of independent (or predictor) variables. The study area is often split into several zones according to the selected density and the data gathered. They are usually cross-sectional, fixed models functioning according to annual data collection (Briassoulis 2000). In this type of situation, it is necessary to have rich datasets and elaborate statistical models (Agarwal et al. 2002). Economic models are produced through general or partial equilibrium sets of macro-economic equations that do not consider land as spatially explicit; rather, land is usually represented as a factor of production (Alcamo et al. 2006). The main goal in econometric modeling is to estimate the changes in some determinants of land use (such as population density, retail and housing demand, employment, rates of salary, rents, earnings) and then utilize land use/activity factors and coefficients whose estimations are expressed in the form of land use type demands. The EMPIRIC model is one of the well-known econometric models (Hill 1965; Pack 1978) which represents a prototype model built in the 1960s and was used as a rather simple vehicle to model metropolitan structure (Briassoulis 2000). Other examples include the GTAP and the NEMESIS models. GTAP is an example of a general equilibrium model that deals with land use change and represents the entire economy and the primary interactions between economic sectors of one or multiple regions

Table 3 Evolution of land use-change models according to different knowledge claims

Paradigm	Assumptions	Reasoning	Methodology	Measurement	Model direction	Focused on	Resolution	Main attributes	Target group	Scale	Applied techniques	Model type (closer to the worldview)
Positivism	Simplified models, landscape homogeneity, disciplinary study	Extreme deductive	Quantitative	Economic criteria	Top down	Land cover	Low	Land based, goal oriented	Flora	Local	Logistic regression	Linear
Post-positivism	Landscape heterogeneity, multidisciplinary	Semi-deductive (unstructured)	Quantitative	Economic criteria	Top down	Land cover	Low-medium	Land based, goal oriented	Flora	Local	Mathematics	Spatial
Constructivism	Landscape heterogeneity	Extremely inductive	Qualitative	Socioeconomic criteria	Bottom up	Land management	Low	Agent based, process oriented	Human	Local	Action in context	Dynamic
Participatory	Complex models	Semi-inductive (theory based)	Qualitative	Socioeconomic criteria	Bottom up	Land management	Low-medium	Multi-agent based, process oriented	Human, flora	Local	Participatory action research	Hybrid
Pragmatism	Landscape heterogeneity, complex models, trans-disciplinary study	Deductive-inductive	Mixed method	Biophysical and socioeconomic criteria	Top down, bottom up	Land use system	Low, medium, high	Land based and multi-agent based, process oriented as a goal	Human, flora, fauna	Local, regional, national, global	Simulation, scenario writing	Integrative

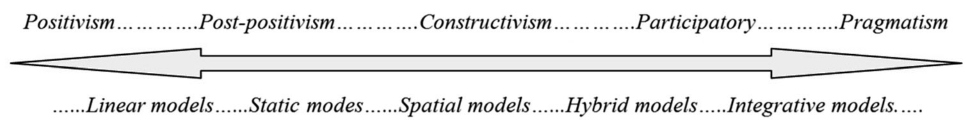

Fig. 1 Classification of the land use-change models based on different schools of knowledge

(Center for BioEnergy Sustainability 2009). These models can be used to define the global demand for various kinds of land use (Mudgal, et al. 2008), e.g., the natural environment land use program (NELUP) (O'Callaghan 1995) and MetroSim [US Environmental Protection Agency (USEPA) 2000].

While LP is a very effective method that is capable of solving problems that have very high dimensions (in terms of the number of variables, relations, and constraints), it also has the intrinsic drawback that all of the relations, constraints and objectives need to be formulated linearly. It is also necessary for the variables to be continuous (quantitative). This linear quality is not often applied within land use planning due to the qualitative characteristic of the relations as well as the discrete characteristic of (a number of) the variables that have to be optimized (Loonen et al. 2007). Accordingly, land use linear modelers believe that they are able to control their biases and the environment sufficiently enough in order to identify a true objective which is able to, in turn, become generalized into universal laws or principles (Coyle and Williams 2000; Greenfield et al. 2007). In order to test a specific part of a general theory, or principle, to determine a conclusion, they use deductive reasoning. As positivists, land use linear programmers usually put forth a hypothesis or prediction about a set of variables from a particular theory and then attempt to test and verify the relationships between these variables. Consequently, since land use linear modelers believe that such tests have a firm methodology and trust that reality can completely be formulated, the biases of the researcher have no place in the model and they believe that the future can be fully predicted.

As a result, from the philosophical point of view and according to Table 3, linear models are oriented in a positivism worldview, but from an ontological aspect, they are more in line with post-positivism. Similar to positivism in which the researcher's job is mainly to discover reality using quantitative and experimental methods that may not involve a researcher's personal biases which influence the outcomes, the modelers also use such methods, mostly regression analysis, to describe the constant relationships between variables. In both positivism and LP approaches, the modeler and participants are supposed to be independent and should not influence each other (Lincoln and Guba 2000). However, similar to the post-positivists, LP modelers concur that they are able to discover the actuality of the situation within a certain realm of probability while only inhibited by the researcher's human limitations. Therefore, in LP models, the modeler may not be able to prove a theory, and primarily, may be able to make an even stronger case by discounting alternative explanations; a method that is in line with post-positivist principles.

Static models: pro-post-positivism?

The static models (stationary, steady state or cross-sectional models) describe the state of the system as an equilibrium resulting from a long period of constant inputs. The static models do not simulate the transient behavior of the system for the time interval that it is unstable, but these models give a description of the stable equilibrium of a system, which may be reached after a very long time span. These models describe the structure of a system of distributed parameters as a set of qualitative physical fields, and consist of a distribution model for each individual field and an intersection model for each pair of fields that are to be combined in a composite field (Lundell 1996). One of the well-known static models is the multi-agent system model of changes in land use/cover [multi-agent simulation (MAS)/LUCC] that can overcome certain important limitations of existing techniques. MAS/LUCC models are particularly well suited to representing complex spatial interactions within heterogeneous conditions and when making models of decentralized, autonomous decision-making (Parker et al. 2003).

Static models of land use are a function of certain fixed (unchanging) driving factors. These kinds of models are often strongly based in a statistical regression analysis that demonstrates past and present spatial developments. Static models can be used in order to test our knowledge of the driving factors of land use changes, though this kind of model does not take into account temporal feedback and path dependencies (Verburg et al. 2006b). Non-temporal static models, naturally, are not based in time, but rather, on the key ecological landscape attributes such as the land's patch size and its connectivity. These models may be built within a variety of scenarios, ranging from static land use to from management decisions through the use of appropriate ecological indicators. The model of the ecological impact of land use change is, essentially, a simple model that does not reference time.

Although these models predict the following phenomena of causal relationships, just as post-positivism does, they are not stable in all situations (unlike linear models and positivism); rather, they are constructed by those that are engaged in the study. These researchers are of the opinion that reality has a multiple (rather than singular) nature, is subjective, that individuals mentally construct it, that our understanding of reality can be different depending on the context, and that reality cannot be fully understood otherwise. Although a great amount of effort and time is given to static models, the ability to generalize the results brings them into question due to the studies' focus on situational and conditional contexts. Thus, just like in post-positivism, the conclusions are all the more conditional and temporary (Tekin and Kotaman 2013). One of the strengths associated with static models is that, like post-positivism (Ponterotto 2005), researchers recognize that not all knowledge is gained from one single method. Instead, the modeler aims to implement several measurements in the investigation process and rejects the notion that they are able to capture objective reality seamlessly. Indeed, idealism is disproved and critical realism and multiplism are accepted, which prove that the model can usually be considered from different dimensions. In-depth information from a variety of sources allows the complex web of interactions among variables to be understood, providing a greater chance for improvement (Lor 2011). Static models as well as a post-positivist paradigm tend to be used like quantitative methods to collect data and analyze them; however, the increasing use of qualitative techniques is also recognized (Mertens 2005). The researcher interacts with the subject under consideration and the results in the static models are the consequences of this interplay that focuses on the concept and comprehension of the stance being researched. Consequently, in order to demonstrate valid research, a degree of proof that corresponds with the study's results is necessary (Hope and Waterman 2003).

Dynamic models: pro-constructivism?

Transient or dynamic models describe the reaction within a system to dynamic inputs. They describe the transient state of a system, even if it is not in an equilibrium state. Rather, they describe the behavior of a system during the time span needed to reach equilibrium. This approach is usually taken when a time-varying input requires a response from the system. Time is one of the important variables in model algorithms, and the results can be interpreted as the state of the system at a certain point of time. Dynamic models describe the behavior of a distributed parameter system in terms of processes acting on fields, the qualitative functional relationships between the parameters and the changes to the static model (Lundell 1996). Each of these works in junction with intermediate time steps that could possibly become the starting point calculations of the following situation. Dynamic modeling, therefore, takes into account possible progress (throughout the time of the simulation) and tries to provide a richer model of behavior and the chance to more thoroughly mimic real life spatial developments (Koomen and Stillwell 2007).

Some examples of these LUCMs are the general ecosystem model (GEM), the Patuxent landscape model (PLM), the forest and agriculture sector optimization model (FASOM) (Agarwal et al. 2002), conversion of land use and its effects (CLUE-s) (Verburg et al. 2006a) and cellular automata (CA) (Voigt and Troy 2008). Dynamic models specifically concentrate on the dynamics of land use systems that involve time as it is depicted by the competition between land uses, the path dependence in system evolution due to irreversible past changes, and trajectories of land use change that are fixed. Another category of LUCMs is dynamic models that apply optimization methods that are presented by dynamic programming models, which have been useful in dealing with constraints related to land use analysis (Briassoulis 2000). Modelers of dynamic land use models conduct a mathematical form of programming that is usually beneficial in finding a suite of interconnected solutions. This technique provides the dynamic land use programmers with a systemic procedure that determines the composite decisions that maximize the general efficiency of policies. Azadi et al. (2009a) and Azadi et al. (2007) used such approaches in their study of sustainable rangeland management. In contrast to Land use linear programming (LULP), dynamic land use programmers do not apply a standard mathematical formulation of programming to a problem. Instead, a tailored approach is developed to deal with a problem, and specific equations devised by programmers need to be modified in order to adjust models to different conditions (Briassoulis 2000; Hillier and Lieberman 1980).

Unlike constructivism, by using dynamic models as statics, the reality of the situation is external and is considered to come from outside of the researchers' minds and the researchers are unable to import their bias into the models. However, in constructivism, and in contrast to the development of static models, the modeler's background and experience are important when it comes to understanding the reality of the topic; such understanding not only differs according to place, but also according to time. It means that reality is not one singular facet, but multiple and socially constructed within these models; how reality is perceived may change through or at any point during the process of study (Mertens 1998). In other words, studies where the modelers follow the constructivist view, in which those conducting the research interact with the participants of the study in order to get information and knowledge, are dependent on the context and the time of the study (Coll and Chapman 2000; Cousins 2002). In these models, as with constructivism, inputs and independent variables are not fixed; they can be diverse and flexible in scale and type. The dynamic modelers as well as constructivist researchers are mainly in favor of methods that collect qualitative data and analyze them or a combination of the two methods, both qualitative and quantitative (Mackenzie and Knipe 2006). For instance, Houet and Hubert-Moy (2006) utilized a time series of aerial photographs and satellite imagery comprising different spatiotemporal scales in order to identify landscape characteristics as well as spatial features and the temporal changes of land use/cover from 1950 to 2003. Furthermore, in the constructivism approach, quantitative data can be used in a manner that supports or elaborates upon qualitative data and efficiently enhances the description. Houet and Hubert-Moy (2006) also determined both biophysical and socioeconomic drivers of existing dynamics by collaborating with members and organizations that were interested in sharing information and materials, and were also interested in conducting developed methods and tools as well as model outcomes. All of these input data were confirmed, examined, and evaluated in terms of applying spatial statistical methods in order to measure spatial associations. Furthermore, the modeling processes of cellular automaton are used to provide a spatially explicit model according to the simulations of future trends of LUCC. As a result, in these models, the outcome of the inquiry is constructed through the joint effort of the researcher and respondents during the modeling process.

Dynamic models are clearly different from statistical models due to the way a phenomenon is represented and built with parts of a system that we can confirm occur in reality and describes input–output relationships. They do not depend on historical or cross-sectional data in order to reveal those relationships. The advantage this provides also permits dynamic models to be utilized in further applications apart from empirical models (Agarwal et al. 2002). As shown in Table 3, according to methodological and epistemological aspects, these models can belong to post-positivism and pragmatism worldviews, both of which depend on the values of the researchers so that the research cannot be independent from them. These models rely on how reality is socially constructed in ways that a study can only be carried out through interactions between the investigator and the respondents (Lincoln and Guba 2000). Since, from an ontological point of view, dynamic models are related to constructivism and post-positivism worldviews, the aim of the modeler is to comprehend the multiple social constructs regarding meaning and knowledge and that objective reality can be known.

Hybrid models: pro-participatory?

The participatory approach is a group of procedures that experts and stakeholders use to cooperate in order to produce different scenarios (Alcamo et al. 2006). Often, the hybrid approach is used as a means to overcome the limits of the previous approaches and to take advantage of their strengths (Rindfuss et al. 2004) by trying to include the strengths of each representation (Bonan et al. 2004). The result is a hybrid model, i.e., a mixture of other models (Wien et al. 2010).

Hybrid models of LUCC begin with an estimator model, but continue with simulation patterns. The patterns utilize the estimation model's parameters in order to predict the spatial drivers of LUCC that can possibly occur within various scenarios imposed exogenously (Irwin and Geoghegan 2001). Some examples of hybrid models are: land use scanner (LUS) (Hilferink and Rietveld 1999), spatially explicit landscape event simulator (SELES) (Haase et al. 2007), ProLand and UPAL (Sheridan et al. 2007), the simulated land use-dependent on edge-effect externalities (SLUDGE) (Verburg et al. 2006b), Dyna-CLUE (Verburg et al. 2008), and monitoring land use changes (MOLAND) (Engelen et al. 2007). Hybrid models try to combine some of these techniques, every one of which is a moderately discrete approach. A relevant example is the estuarine LUCC transition model which consists of an explicit, cellular model connected to a system dynamics model. Other similar combinations of these models include DELTA, which integrates sub-models that pertain to human colonization and ecological interactions in order to estimate the amount of deforestation that occurs in various immigration and land management scenarios. Further examples that utilize different statistical techniques in combination with cellular and system models consist of larger-scale models, such as GEOMOD2 (Hall et al. 1995) and the CLUE family (Veldkamp and Fresco 1996b). The latter is a cross-disciplinary approach, integrating both socioeconomic and biophysical aspects that can be described as an integrated, spatially explicit, multi-scale, dynamic, and economy-environment-society-land use model (Briassoulis 2000). Gibon et al. (2010) noted that the socio-ecological processes in the modeling need to be taken into account and that the scenarios need to be elaborated using a hybrid or integrated and participatory approach for the investigation of alternative futures in land change (Houet et al. 2010).

During the process of participatory research, participants actively create, modify, and test the different forms of knowledge in an iterative research process, validating the outcomes of the research (Hosseininia et al. 2013; Breu and Peppard 2001). Similarly, in hybrid models, modelers try to develop a combined method from two separate models in order to offer a useful method that optimizes the performance models that track land use change. Such a combination can be found in the study of Soares-Filho et al. (2013), who developed a hybrid analytical heuristic method for calibrating LUCMs. They constructed and applied a tool using a genetic algorithm to produce optimal deforestation probability maps that are generated using the weights of evidence method in 12 different case study sites in the Amazon in Brazil. The results showed that by modeling deforestation after the genetic algorithm tool was coupled with the weights of evidence method one was able to surmount problems of fitting and improve the validation of the fitness scores at a computational cost that was acceptable. There is also an established body of research that uses the participatory approach in developing LUCMs through the involvement of stakeholders in developing hybrids models. One good example of this is the participatory model of land use change that is agent based, which is only one of a sequence of tools utilized in assessing integrated environmental situations (Hisschemoller et al. 2001). Varieties of participatory agent-based modeling are participant observation and "companion modeling" (Barreteau et al. 2003), which consists of members of the study population becoming actively involved in model design and its validation (e.g., Bharwani et al. 2005). For example, D'Aquino et al. (2003) applied the method of companion modeling to management issues of land use in Senegal. Ramanath and Gilbert (2004) reviewed different general methods to participatory agent-based modeling.

Perhaps linear, static and dynamic models cannot be attributed or related to a particular worldview, but according to some features, it can be claimed that the principles of these models are closer to a participatory worldview than any other. Those features are as follows:

– Using a combination of (usually two) methods.
– Believing that the complexity of the process is comparable to reality.
– The need for people with diverse expertise to participate in the process of designing a model.
– The methodological imperative that requires the researcher to engage in research with people rather than in doing research on people.
– Avoiding purely top-down methods in model design.
– Attention to non-biophysical variables in addition to the biophysical in a model.

Accordingly, this group of modelers mainly has post-positivism, participatory and pragmatism worldviews regarding the methodological and epistemological aspects of models, while from an ontological view, they mostly take constructivism, participatory and pragmatism worldviews. Similar to that seen in pragmatism approaches, hybrid modelers emphasize the creation of knowledge using trajectories aimed at types of "joint actions" or "projects" that different people or groups are able to accomplish while working together (Morgan 2007). However, like constructivism, reality is socially constructed in hybrid models, and how reality is perceived may change through and during the study's process as some of the perceptions may conflict. Above all, hybrid modelers use a combination of approaches available to an understanding of the problem. In these models, the effectiveness of the approach becomes the criterion that is used to judge the worth of research, instead of the findings corresponding to a "true" aspect of reality.

Integrative models: pro-pragmatism?

Integrated models generally arose in the 1960s in a "quantitative revolution" in regional, urban, and geographic assessments. Integrated models, also called "comprehensive" or "general models," are increasingly based on integrating different elements of modeling techniques. Indeed, the most effective elements are put together in order to answer the specific questions in ways that are the most appropriate. Accordingly, in the pragmatic tradition, when we first face a problem, our first task is to understand our problem by describing its elements and identifying their relationships. Integrated models consider various environmental, social, economic, as well as institutional aspects of an issue (Rotmans and van Asselt 2001). Increasingly, these models are called "integrated models." Even though in numerous cases, due to the fact that the level that they are integrated on is sometimes low, they are more fittingly described as hybrid models (Lambin et al. 2000). Numerous integrated models have been built since the mid-1960s. They are spatial models, meaning that they focus on the interplay between a range of dimensions within a spatial structure, but do not comprise a spatially explicit reference (for instance, energy-economic, demographic-economic, environmental-economic, and so on). Some examples of these models are integrated planning and decision-making systems (IPDMSs), MEPLAN, tranus integrated land use and transport planning system (TRANUS) (USEPA 2000), CLUE-CR (Veldkamp and Fresco 1996a), PLM (Voinov et al. 1999), UrbanSim (Waddell 2002), dynamic settlement simulation model (DSSM) (Piyathamrongchai and Batty 2007), land use modeling system (LUMOS) (Beurden et al. 2007) and MAS models (Loibl et al. 2007). Given the fact that values, aesthetics, politics, and social and normative preferences are an integral part of pragmatic research as well as how it is interpreted and utilized, it is noticeable that integrative models are in line with this integral principle of pragmatism.

One of the general features of integrated models is their large scale, besides their integration characteristic discussed above. Considering the objective of the model, the concept of integration differs and is represented in the integrated system (Briassoulis 2000). The complex nature of the causes, processes, and impacts of land change has impeded the development of an integrated theory regarding land use change (Lambin and Geist 2006). Integrative models have been suggested as key methods to improve how complex systems are managed and to provide information that is objective on the options decision makers have regarding policy (van Ittersum and Brouwer 2010).

Therefore, the goal of these modelers, like pragmatists, is to search for useful points and ways of connecting that also combine different techniques from different disciplines or models in order to improve their knowledge and practical understanding of reality. Both groups also believe that how we combine different methods depends on their political, economic and social aspects, all of which can be interpreted in many different ways depending on time and place. Similar to pragmatists who clarify a hypothesis by identifying its practical consequences when applying integrated models, it is not necessary to combine all components of two or more models either. Additionally, depending on the situation, certain techniques can be chosen. The scientific method in integration models is similar to pragmatism, in which an experimental methodology is conducted, and the application of the pragmatist maxim reveals how hypotheses can be subject to experimental tests. As seen with pragmatism, someone who is knowledgeable of integrative models is an agent who obtains empirical support for his/her beliefs by making experimental interventions in his/her surroundings and by learning from the experiences that his/her actions elicit. Recently, many national and international programs have re-enforced the need to produce models that involve different processes, that ultimately aim to develop integrated models that are able to simulate the processes and consequences that are important for certain landscapes or societies (Janetos 2004). These models mainly represent a pragmatic worldview of all the three ontological, epistemological, and methodological aspects. Although, the former may have some elements of the participatory paradigm.

Discussion and conclusions

As discussed in this paper, establishing multi-scale methodologies as a basis for enhancing and conducting evaluations, on both a small and large scale, is a critical challenge that has not yet been addressed. Such a development could provide the opportunity to identify various influential drivers at different levels. As such, out of all of them, the main obstacle is obtaining data of specific regional economies and policies. Information is relevant on regional or local levels to establish how land claims are allocated between different sectors (Azadi et al. 2011). Most modeling frameworks and tools utilize a top-down

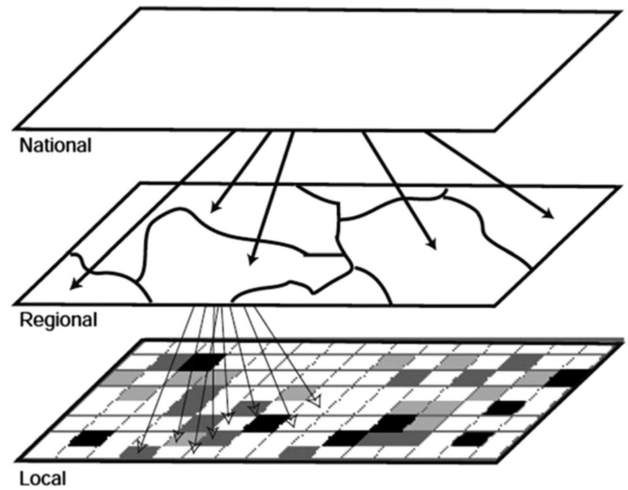

Fig. 2 Top-down allocation procedure (adapted from Verburg et al. 2004)

method, which takes into account different national scales and two different spatially explicit scales (Fig. 2). Consequently, driving social forces like quality of life, official and unofficial social regulations, and the priorities and customs of local people are usually not appropriately indicated in the majority of modeling methods (Mudgal et al. 2008). However, such drivers can have substantial effects on changes in land use, especially at regional and local levels. In this regard, Azadi et al. (2009b), Ho and Azadi (2010) also emphasize that, unlike environmental factors, socioeconomic drivers, for example, are not usually used to assess the severity of degradation. Also, they argue that if socioeconomic factors were taken into consideration, the evaluation of degradation trends would relate more fully to real life.

Therefore, land use modelers will not only need to take into consideration the relative importance of various drivers of land use change (Agarwal et al. 2002), but will also need to integrate various drivers to make important improvements to land use models in the future. Issues like the integration of socioeconomic and biophysical drivers, improving agent-based decision-making models, enhancing the ability to model land use decisions in terms of lag time and their thresholds, and using mixed methods in multi-source integration of data (e.g., remote sensing using a census and data from household surveys) gain additional importance in this context. As a result, assessing different LUCMs based on different schools of knowledge claim in this study showed that modelers have moved towards more qualitative approaches. Denzin (2001) also states that "the days of naive realism and naive positivism are over," and adds that "the criteria for evaluating research are now relative." Qualitative researchers are primarily concerned with the process, rather than outcomes or products. Yet, there is no escaping the reality in qualitative research that the researcher is a tool that screens data through his/her own respective paradigms. Those that conduct research cannot be objective and their research and intuition will be laden with values. It is significant that research design and the researcher are separated in terms of their paradigmatic, ontological, epistemological, and methodological aspects.

Therefore, evaluating different LUCMs according to their philosophical routes demonstrates that, due to the complex nature of the LUCMs, there is no single paradigm that could satisfactorily deal with all of the required methodological aspects. As a result, it is necessary to combine quantitative with qualitative paradigms to create mixed-method approaches within a systemic framework. The blending of both paradigms can provide land use-change modelers with the ability to cope with the limitation of the existing methodology of LUCMs, thus allowing for the collection of multiple sets of data using different research methods, epistemology, and methods in a manner that results in a mixture or combination that has complementary strengths and does not have any overlapping weaknesses (Johnson and Turner 2003). These models ought to rely on scales that are global, regional and local, and on digital databases, not only on land cover classes, but also on methods of land management (like fertilization, irrigation, etc.) that allow for increased participatory, open geographic information systems and data sharing. Furthermore, researchers of change in land use will need to diversify their portfolios of analytic methods further, not only with multiple regressions, but with narrative, system and agent-based approaches, and network analysis, etc., as well. (Lambin et al. 2006). On the other hand, when LUCMs do not take the presence of nonlinearities and spatial and temporal lags into account, which exist in environmental systems, their ability to elucidate the mutual complexities between human and environmental systems may be significantly reduced.

All this reveals that there is a crucial necessity to produce a systemic framework for collaboration and the development of models (Agarwal et al. 2002) that can cope with the complexities and interactions of various subsystems (biophysical as well as socioeconomic). Systemic models are more complex than other types and difficulty lies in deciding how to incorporate such complexities. Nevertheless, once a systemic model is constructed, if–then scenarios can be more readily formulated in comparison to other modeling approaches that are not oriented systemically. Particularly, a systemic approach is able to examine the feedback that exists within socio-ecological systems. In this regard, many studies (Houet et al. 2010; Gaucherel et al. 2010; Valbuena et al. 2010; Sohl et al. 2010; Verburg et al. 2010; Courtney et al. 2015) emphasize the need to combine modeling approaches and techniques in order to further reduce the uncertainties of future landscapes. In order to monitor, model, and assess the interactions among and in humans/nature, temporal dimensions of landscapes have to be considered as significant as their spatial dimensions. Communally combining modeling approaches and techniques opens up new avenues of research in the science of LUCMs. The systemic perspective represents the dynamics of the links between the economy and environment that operate from regional to global scales (Azadi and Filson 2009). It concerns issues such as technological innovations, changes in policy and institutions, environmental conservation, ownership of collective land resources, physical geography, dynamics of rural–urban areas, and macroeconomic transformations (Briassoulis 2000). Hence, it appears more sensible to use a systemic approach rather than to rely on a single theoretical schema, which will inevitably miss some dimensions of the case under study or will be too complex to be easily understood and useful. Nonetheless, to achieve this systemic model successfully, it is necessary to critically examine which paradigm is suitable for which study scale. To do so, research paradigms help modelers conduct studies in more effective ways. According to Johnson and Christensen (2010), research paradigms are perspectives that are based on a set of shared assumptions, values, concepts, and practices, which would indeed be helpful in developing a systemic approach when analyzing LUCMs. Most researchers agree that it is very important to begin the research process by identifying the researcher's own worldview (Creswell 2007) and the research paradigms that consist of different approaches and research philosophies. The combination of all this helps researchers come to an understanding and develop a knowledge base of the topic being studied, which, in our case, is developing a systemic approach within LUCMs. In the research paradigms, there are different factors that affect a researcher's ability to effectively take a certain approach, like time constraints, budget constraints, etc. By using a suitable research paradigm and philosophies, researchers help exclude these factors from their studies. Moreover, the specialist needs more useful data to reinforce the utilization of LUCMs, the integration of models that work at various levels, and the coupling of models that address both positive and normative dimensions of land use and cover patterns, as well as their dynamics (Brown et al. 2013). In this regard, when a modeler understands the philosophy of a study, he is able to conceive the constraints of special methodologies. Which in turn will help him to assess the various approaches and techniques and will prevent him from making burdensome mistakes when selecting suitable methods or wasting his time performing non-essential tasks (Easterby-Smith et al. 1997). If a researcher, for instance, can evaluate the difference between a model constructed according to a positivist paradigm and a model that is based on a post-positivist worldview, the suitability to the model requirements will be noticeable and selecting the most suitable approach can then simply be specified. This was confirmed by Brown et al. (2013), who emphasized that it is essential to select an appropriate modeling approach for the scientific or decision-making goals under consideration. This paper also describes the major paradigms so that new modelers can justify selecting and combining different paradigms that best fit their proposed systemic approach in LUCC studies. Since research is described as a systemic process (Wiersma and Jurs 2004), it would seem reasonable to make the future trend of LUCMs as systemic as possible. This study clearly shows that the function of paradigms is more important than selecting an approach, yet does not effectively address developing LUCMs within a systemic framework.

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