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1	Evolution of land use change modeling: routes to different knowledge
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19 Evolution of land use change modeling: routes to different knowledge schools

20 Abstract

Although much has been published on land use change modeling (LUCM), no study has 21 comprehensively dealt with the evolution of land use models based on knowledge 22 schools. The primary objective of this paper is an explanation of the progress and growth 23 of LUCMs considering their main ontological, epistemological, and methodological 24 origins. Five main paradigms; i.e. positivism, post-positivism, constructivism, 25 participatory, and pragmatism approaches are discussed in order to assess the current 26 orientations of LUCMs. Given the complexities of the LUCMs components, the study 27 concludes that one paradigm cannot adequately address all methodological aspects. 28 Accordingly, it is necessary to combine quantitative and qualitative paradigms to create 29 30 mixed method approaches within a systemic framework. Such systemic approaches could shape the most probable future generations of the LUCM, which would be able to cope 31 32 with the complexity of various subsystems, including biophysical and socioeconomic. Keywords: environmental planning; land use; land management; modeling; knowledge 33

34 school; sustainable land use.

35 **1. Introduction**

Land use change models (LUCMs) can be developed with different goals in mind and in 36 a variety of forms through the combination of models and due to their ability to 37 understand and project land use change systems, represent human decision making, create 38 links between human and environmental systems, and deal with questions about the 39 challenges of environmental sustainability (Brown et al. 2013). When reviewing LUCMs, 40 there are many criteria that can be found and used to classify the different models 41 42 (Overmars et al. 2007). Based on Verburg et al. (2004), there are a significant number of models that outline land use from different backgrounds that have been developed by 43 those that have researched and studied a variety of disciplines. They emphasize that the 44 most important tasks for future research is to combine the strengths of all existing ideas, 45 46 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 47 48 respective fields and build models that truly span different fields of study, it is necessary to increasingly integrate tactics and approaches that have been developed in various areas 49 50 (Kooman et al. 2008; Witlox 2005).

The literature review revealed that there has been great advancement in developing 51 models that outline land use change. Nevertheless, the new forms of land use modeling 52 need to be made in order to create more dimensions of land use systems; such models are 53 54 more likely to be successful when dealing with the multi-dimensional components of land 55 use systems. They can better utilize new approaches when it comes to measuring neighborhood impacts, determining accurate responses to temporal changes and can more 56 fully integrate various disciplinary methodologies as well as create more combinations of 57 LUCMs for rural and urban areas. By gaining such advancements in the development of 58 LUCM, researchers are able to evaluate land use changes and to better develop effective 59 land use policies (Verburg et al. 2004). 60

There are many reasons that demonstrate the importance of understanding philosophy, especially when it comes to developing a proper LUCM. Philosophy gives the land use modeler the opportunity to clarify and identify the methods conducted within the model (Easterby-Smith et al. 1997). This would include the assorted collected data and its source, the explication of the data, and the way it responds to research inquiries.

Moreover, with a better understanding of philosophy, the land use modeler can become 66 more inventive and imaginative when choosing or refining methods that s/he has never 67 utilized before. The philosophical orientation of the land use modeler also has 68 implications for the creation and application of preferred LUCMs, including the choice of 69 the applied method. Working without being aware of the philosophical that underlie the 70 situation does not necessarily signify that the modeler does not also hold such 71 72 assumptions, rather, they in the process of developing a study that has resulted from 73 assumptions that have not yet been examined or recognized. Therefore, it is crucial that the prevailing paradigms and that the basic philosophical assumptions are understood 74 when creating and conducting LUCM and when contributing to the theoretical and 75 methodological discussions in the model. During the last few decades, numerous LUCMs 76 77 have been conducted to fulfill land management requirements, to improve the evaluation process, and to plan the future role of LUCCs in the natural system function (Veldkamp 78 79 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 and Sohl 80 81 2013; Lee et al. 2015) regarding the approaches of land use modeling have been conducted over the last few years due to different views and the development of various 82 typologies. According to Briassoulis (2000), both the epistemological basis and the 83 contributing disciplinary characteristics critically influence the view of land and land use 84 which, in turn, affect the methods of theorizing and modeling land use change. As a 85 86 result, the role of knowledge claim schools in terms of land use change needs to be stressed. 87

One of the compelling reasons why there is a need for research on the 88 philosophical routes of LUCMs is because the changes to land use occurs through the 89 90 effect of many macro and micro factors, functioning within differing time frames and geographical space. Models are used to estimate and do not predict things precisely. 91 Thus, the results that they produce should be considered with regard to the model's 92 qualifications, assumptions, and limitations. Models depend on mathematical equations 93 and data in order to simulate the "real world". Their reliability is mostly due to the quality 94 of the data used and the principles that govern decision making and on the assumptions 95 applied. Therefore, understanding the philosophical routes will help us recognize the 96

ontological, epistemological, and methodological nature of LUCMs. Such an 97 understanding directs thoughts concerning land use change, illustrates conceptual and 98 operational expressions of change, its determinants and their relationships, and suggests 99 explanatory plans for making sense of available empirical evidence; i.e. to support model 100 building. Accordingly, understanding the philosophical routes could be an effective guide 101 when predicting the future orientations/generations of LUCMs (determining which 102 103 elements should be included or excluded in the next LUCMs). This would help us obtain 104 a better understanding of the complex land use systems and to allow us to more efficiently interact with those that determine land use change (Verburg et al. 2004). 105 Otherwise, according to Briassoulis (2000), inappropriate and inadequate awareness of 106 the influence of the knowledge claim schools regarding land use change may mislead 107 108 policy creation and create more challenges to deal with. This review paper aims to outline the evolution of LUCMs based on different worldviews (positivism, post-positivism, 109 110 constructivism, participatory, and pragmatism). To meet the objective, we will first explain the different philosophical aspects (including ontology, epistemology and 111 112 methodology) of each worldview and then try to compare the most known LUCMs against each aspect. Then, we will try to predict the most probable future of LUCM. 113

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115 2. Knowledge claim schools

116 The definition of a worldview is "a basic set of beliefs that guide action" (Guba 117 1990, p. 17) or a common orientation of a researcher with regard to the universe as well as the content of a given study (Creswell 2009, p. 5). Ontological, epistemological, and 118 methodological assumptions may belong to different worldviews. Setting a knowledge 119 claim means that researchers launch a project with concrete assumptions about the 120 121 subject under study as well as the way of learning (Creswell 2003). From the philosophical point of view, researchers mainly make claims about the definition of 122 knowledge (ontology), the way we recognize it (epistemology), as well as the procedures 123 of investigating that knowledge (methodology) (Creswell 1994). Table 1 and 2 124 respectively show a descriptive overview and a summary of the three main philosophical 125 aspects and empirical dimensions of the five schools of thought about knowledge claims. 126

127

[insert Table 1]

[insert Table 2

Further clarifications of Table 1 and 2 are devoted to a brief discussion of the 130 relationship between each of the five research paradigms and the main land use change 131 models. However, prior to this presentation, it is necessary to discuss the need for and the 132 uses of models within the context of a analysis of the changes to land use . LUCMs may 133 have an effective role in evaluating different effects caused by previous human activities 134 135 or those that would occur in the future within the nature and/or the socioeconomic contexts. All of which could provide useful information on possible future land-use 136 configurations (Koomen et al. 2008). Lambin et al. (2000) recognized a number of 137 categories of land-use change models, such as the empirical-statistical, the stochastic, the 138 139 optimization, the dynamic (process-based) and the integrated models. Briassoulis (2000) distinguished the differences of statistical and econometric, spatial interaction, 140 141 optimization, and integrated models, including a category of model types that incorporate and do not fall into any of these categories. Yet Heistermann et al. (2006) classify LUCC 142 143 into geographically based (empirical-statistical or rule-based/process-based), economic, and integrated models. All inventories demonstrate that a group of heterogeneous model 144 approaches that have noticeable differences within their theoretical backgrounds, the 145 points where they start, their range of application and so on (Koomen et al. 2008). In this 146 147 study, five categories of LUCMs have been considered in regard to the main research 148 paradigms. Table 3 summarizes the most important features of each philosophical view of the LUCMs. 149

[Insert Table 3]

150 151

As shown in the table, there are often some common methodological, epistemological or ontological aspects for each model that may be attributed to one or more groups. Importantly, Fig. 1 illustrates how land-use change is understood 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).
[insert Fig. 1]

161

162 **3. Main land use change modeling**

163 *3.1. Linear models: pro-positivism?*

In linear programming (LP), all mathematical expressions for objective functions 164 165 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 166 167 constructed solely from linear relationships have certain limitations. The most obvious is that lines poorly model some real-world phenomena. A weakness common to all 168 169 mathematical programming models is the assumption that input data are considered to be absolutely accurate (Chinneck 2001). Nevertheless, the main advantage of LP techniques 170 171 is their capability to be managed, understood and computed.

The single and the multi-objective models are two major types of LP models. The 172 173 first one is conducted in studies that only consider one goal when solving problems and the second one copes with more pragmatic conditions that deal with problems in which 174 175 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 to solve the 176 177 problem. The objective function(s) of the problems of land use is displayed within a 178 mathematical format, bringing about the question: "how much land to allocate to each of a number of land use types in order to optimize objective A (or, B, C, D)?" The objective 179 is, for instance, to reduce the environmental effects and the development cost of land 180 conversion to a minimum or to increase the advantages of such development to an 181 182 optimum level, and the like (Briassoulis 2000). Two more important models in this group are the LRM (Linear Regression Models) (Chapin 1965) and CCAM (Canonical 183 Correlation Analysis Model) (Briassoulis 2000). There are two groups of linear models, 184 economic and mathematical, that apply statistical techniques in order to derive a 185 mathematical relationship between the dependent and sets of independent (or predictor) 186 variables. The study area is often split into several zones according to the selected density 187 and the data gathered. They are usually cross-sectional, fixed models functioning 188

according to the yearly-based data collection (Briassoulis 2000). In this type of situation, 189 it is necessary to have rich datasets and elaborated statistical models (Agarwal et al. 190 2002). Economic models are produced through general or partial equilibrium sets of 191 macro-economic equations that do not consider land as spatially explicit, rather, it is 192 usually represented as a factor of production (Alcamo et al. 2006). The main goal in 193 econometric modeling is to estimate the changes in some determinants of land use (such 194 195 as: population density, retail and housing demand, employment, rates of salary, rents, 196 earnings) and then through utilizing land use/activity factors and coefficients whose estimations are expressed in the form of land use type demands. The EMPIRIC model is 197 198 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 199 200 metropolitan structure (Briassoulis 2000). Other examples include the GTAP and the 201 NEMESIS models. GTAP as an example of a general equilibrium model that deals with 202 land-use change and represents the entire economy and the primary interactions between economic sectors of one or multiple regions (CBES 2009). These models are able to be 203 used in order to define the global demand for various kinds of land-use (Mudgal, et al. 204 2008), NELUP (Natural Environment Land Use Program) (O'Callaghan 1995) and 205 METROSIM (U.S. E.P.A. 2000). 206

207 While LP is a very effective method that is capable of taking care of problems that have very high dimensions (in terms of the number of variables, relations, and 208 constraints). It also has the intrinsic drawback that all of the relations, constraints and 209 210 objectives need to be formulated linearly. It is also necessary for the variables to be 211 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 212 213 (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 214 environment sufficiently enough in order to identify a true objective which is able to, in 215 turn, to become generalized into universal laws or principles (Coyle and Williams 2000; 216 Greenfield et al. 2007). In order to test a specific part of a general theory, or principle, in 217 218 order 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 219

from a particular theory and then attempt to test and verify the relationship between these variables. Consequently, since land use linear modelers believe that such tests have a crisp 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 225 models are oriented in a positivism worldview, but from the ontological aspect, they are 226 227 more in line with post-positivism. Similar to positivism in which the researcher's job is mainly to discover the reality using quantitative and experimental methods that may not 228 229 involve researcher's personal biases to influence the outcomes, the modelers also use such methods, mostly regression analysis, to describe the constant relationships between 230 231 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 232 233 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, only inhibited 234 235 by the researcher's human limitations. Therefore, in LP models, the modeler may not be able to prove a theory, and primarily, they are able to make an even stronger case by 236 237 getting rid of alternative explanations; a method that is in line with post-positivist principles. 238

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240 *3.2. Static models: pro-post positivism?*

The static models (stationary, steady state or cross-sectional models) describe the 241 state of the system as an equilibrium resulting from a long period of constant inputs. The 242 static models do not simulate the transient behavior of the system for the time of interval 243 244 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 span of time. These models describe the 245 structure of a system of distributed parameters as a set of qualitative physical fields. It 246 consists of a distribution model for each individual field and an intersection model for 247 each pair of fields that are to be combined in a composite field (Lundell 1996). One of 248 the well-known static models is the multi-agent system model of changes in land-249 use/cover (MAS/LUCC) that can overcome certain important limitations of the existing 250

techniques. MAS/LUCC models are particularly well-suited when representing complex
spatial interactions within heterogeneous conditions and when making models of
decentralized, autonomous decision making (Parkera et al. 2003).

Static models of land use are a function certain of fixed (unchanging) driving 254 factors. These kinds of models are often strongly based in a statistical regression analysis 255 that demonstrates past and present spatial developments. Static models are able to be used 256 257 in order to test our knowledge of the driving factors regarding land-use changes, though 258 this kind of model does not take into account temporal feedback and path dependencies (Verburg et al. 2006). Non-temporal static models, naturally, are not based in time, but 259 260 rather, on the key ecological landscape attributes that are by the land's patch size and its connectivity. These models may be built within a variety of scenarios, ranging from static 261 262 land use or from management decisions through the use of appropriate ecological indicators. The ecological impact of land use change is, essentially, a simple model that 263 264 does not reference time.

Although these models predict the following phenomena of causal relationships, 265 266 just as post-positivism, the fact is, they are not stable in all situations (unlike linear models and positivism); rather, it is constructed by those that are engaged in the study. 267 268 They are of the opinion that the reality has a multiple (rather than singular) nature, is subjective, and that individuals mentally construct it, that our understanding of reality can 269 270 be different depending on the context, and that reality cannot be fully understood 271 otherwise. Although a great amount of effort and time is given to static models, the ability to generalize the results brings them in to question due to the studies focus on 272 situational and conditional contexts; thus, just like post-positivism, making the 273 274 conclusions all the more conditional and temporary (Tekin and Kotaman 2013). One of 275 the strengths associated with static models is that, like post-positivism (Ponterotto 2005), 276 these models recognize that not all knowledge is gained from one single method. Instead, the modeler aims to implement several measurements in the investigation process and 277 rejects the notion that they are able to capture objective reality seamlessly. Indeed, 278 idealism is disproved and critical realism and multiplism are accepted, which prove that 279 the model can usually be considered from different dimensions. In-depth information 280 from a variety of sources allow the complex web of interactions among variables to be 281

understood, providing a greater chance to improve (Lor 2011). Static models as well as a 282 post-positivist paradigm leans towards the predominant use of quantitative methods in 283 order to collect data and analyze it, however, the increasing use of qualitative techniques 284 is also recognized (Mertens 2005). The researcher interacts with the subject under 285 consideration and the results in the static models are the consequences of this interplay 286 that focuses on the concept and comprehension of the stance being researched. 287 Consequently, in order to demonstrate valid research, a degree of proof that corresponds 288 289 with the study's results, is necessary(Hope and Waterman 2003).

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3.3. Dynamic models: pro-constructivism?

Transient or dynamic models describe the reaction within the system to dynamic 292 293 inputs. They describe the transient state of the system, even if it is not in a state of 294 equilibrium. But rather, they describe the behavior of the system during the time span 295 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 296 297 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 298 299 of processes acting on fields, the qualitative functional relationships between the 300 parameters and the changes to the static model (Lundell 1996). Each of these works in 301 junction with intermediate time-steps that could possibly become the starting-point 302 calculations of the following situation. The case of dynamic modeling, therefore takes into account possible progress (throughout the time of the simulation) and tries to provide 303 a richer model of behavior and the chance to more thoroughly mimic the real-life spatial 304 developments (Koomen and Stillwell 2007). 305

Some of these models in LUCM consist of the General Ecosystem Model (GEM), the Patuxent Landscape Model (PLM), the Forest and Agriculture Sector Optimization Model (FASOM) (Agarwal et al. 2002), CLUE-s (Conversion of Land Use and Its Effects) (Verburg et al. 2006) 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 includes dynamic models that apply 313 optimization methods that are presented by dynamic programming models which have 314 been useful in dealing with constraints related to the land use analysis (Briassoulis 2000). 315 Modelers of dynamic land use models conduct a mathematical form of programming that 316 is usually beneficial in finding a suite of interconnected solutions. This technique 317 provides the dynamic land use programmers with a systemic procedure that determines 318 319 the composite decisions that maximizes the general efficiency of policies. Azadi et al. 320 (2009a) and Azadi et al. (2007) used such approaches in their study of sustainable rangeland management. In contrast to LULPs, dynamic land use programmers do not use 321 322 a standard mathematical formulation of programming on the problem. Instead, a tailored approach is developed to deal with the problem, and specific equations conducted by 323 324 programmers need to be modified in order to adjust to different conditions (Briassoulis 2000; Hillier and Lieberman 1980). 325

326 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 327 328 the researchers are unable to import their bias into the models. But like constructivism and unlike the static models, the modeler's background and experience have an important 329 330 role when it comes to understanding the reality of the topic; such reality is not only different in different places, but also in different times. It means that the reality is not one 331 332 singular facet, but multiple and socially constructed within these models and that how 333 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 334 view, in which those conducting the research interact with the participants of the study in 335 order to get information and knowledge, are dependent on the context and the time of the 336 337 study (Coll and Chapman 2000; Cousins 2002). In these models, like constructivism, inputs and independent variables are not fixed; they can be diverse and flexible in scale 338 and type. The dynamic modelers as well as constructivist researchers are mainly in favor 339 of methods that collect qualitative data and analyze them or a combination of the two 340 methods, qualitative and quantitative (Mackenzie and Knipe 2006). For instance, Houet 341 and Hubert-Moy (2006) utilized a time-series of aerial photographs and satellite imagery 342 comprised of different spatio-temporal scales in order to identify landscape 343

344 characteristics as well as the spatial features and the temporal changes of land-use/ -cover from 1950 to 2003. Furthermore, in the constructivism approach, quantitative data is able 345 to be utilized in a manner that backs or elaborates upon qualitative data and efficiently 346 enhances the description. Houet and Hubert-Moy (2006) also determined both 347 biophysical and socio-economic drivers of existing dynamics by collaborating with 348 members and organizations that are interested in sharing information and materials and 349 were interested in conducting developed methods and tools as well as model outcomes. 350 351 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 352 353 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 354 355 outcome of the inquiry is constructed through the joint effort of the researcher and 356 respondents during the modeling process.

357 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 358 359 reality and describes input-output relationships. They do not depend on historical or cross-sectional data in order to reveal those relationships. Though, the advantage this 360 361 provides also permits dynamic models to be utilized in further applications apart from empirical models (Agarwal et al. 2002). As shown in Table 3, from the methodological 362 363 and epistemological aspects, these models can belong to post-positivism and pragmatism 364 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 365 constructed in ways that the study can only be carried out through the interactions 366 between the investigator and the respondents (Lincoln and Guba 2000). Since from an 367 368 ontological point of view, dynamic models are related to constructivism and postpositivism worldviews, the aim of the modeler's is to comprehend the multiple social 369 constructs regarding meaning and knowledge and that objective reality can be known. 370

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372 *3.4. 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 boundaries of the previous
approaches and to take advantage of their strengths (Rindfuss et al. 2004), trying to
include the strengths of each representation (Bonan et al. 2004). The result is a hybrid
model that usually is a mixture of other models (Wien et al. 2010).

Hybrid models of LUCC begin with an estimator model, but continue with 379 simulation patterns. The patterns utilize the estimation model's parameters in order to 380 predict the spatial drivers of LUCC that can possibly occur within various scenarios 381 382 imposed exogenously (Irwin and Geoghegan 2001). Some examples of hybrid models are: LUS (Land Use Scanner) (Hilferink and Rietveld 1999), SELES (Spatially Explicit 383 Landscape Event Simulator) (Haase et al. 2007), ProLand and UPAL (Sheridan et al. 384 2007), the Simulated Land Use Dependent on Edge-Effect Externalities (SLUDGE) 385 386 (Verburg, et al. 2006), Dyna-CLUE (Verburg et al. 2008), and MOLAND (Monitoring Land Use Changes) (Engelen et al. 2007). Hybrid models try to combine some of these 387 388 techniques together, every one of which is a moderately discrete approach in and of itself. A relevant example is the estuarine LUCC transition modeling which consists of an 389 390 explicit, cellular model connected to a system dynamics model. Other similar combinations of these models include DELTA, which integrates sub-models that pertain 391 392 to human colonization and ecological interactions in order to estimate the amount of 393 deforestation that occurs in various immigration and land management scenarios. Further 394 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 395 the CLUE family (Veldkamp and Fresco 1996b). The latter is a cross-disciplinary 396 approach, integrating both socio-economic and biophysical aspects that can be described 397 as an integrated, spatially explicit, multi-scale, dynamic, and economy-environment-398 399 society-land use model (Briassoulis 2000). Gibon et al. (2010) noted that it is necessary 400 that the socio-ecological processes in the modeling are taken into account and to elaborate the scenarios with a hybrid or integrated and participatory approach that regards 401 402 the investigation of alternative futures inland 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 406 order to offer a useful method that optimizes the performance models that track land-use 407 change. Such a combination can be found in the study of Soares-Filho et al. (2013), who 408 developed a hybrid analytical-heuristic method for calibrating land-use change models. 409 They constructed and applied a tool using a Genetic Algorithm in order to produce 410 optimal deforestation probability maps of that are generated using the Weights of 411 412 Evidence method in 12 different case-study sites in the Amazon in Brazil. The results 413 showed that by modeling deforestation after the Genetic Algorithm tool was coupled with the Weights of Evidence method, was able to surmount fitting and improved the 414 415 validation of the fitness scores at a computational cost that was acceptable. There also is an already established body of research that uses the participatory approach in developing 416 417 LUCMs through the involvement of stakeholders in developing hybrids models. One good example of that is the participatory model of land use change that is agent-based, 418 419 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 420 421 are participant observation and 'companion modeling' (Barreteau et al. 2003), which consists of members of the study population that become actively involved in model 422 423 design and its validation (e.g. Bharwani et al. 2005). For example, D'Aquino et al. (2003) applied the method of companion modeling regarding management issues of land use in 424 425 Senegal. Ramanath and Gilbert (2004) reviewed different general methods to 426 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:

431 - 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 ofdesigning a model,

The methodological imperative that requires the researcher to engage in research
with people rather than in doing research on people,

- 437
- Avoiding purely top-down methods in model design, and
- Attention to non-biophysical variables in addition to the biophysical in a model.
- 439

Accordingly, this group mainly has post-positivism, participatory and pragmatism 440 worldviews regarding the methodological and epistemological aspects of models, while 441 from an ontological view, they mostly take constructivism, participatory and pragmatism 442 443 worldviews. Similar to pragmatism, hybrid modelers emphasize the creation of knowledge from lines of points of action directed toward the types of "joint actions" or 444 "projects" that different people or groups are able to accomplish while working together 445 (Morgan 2007). However, like constructivism, reality is socially constructed in hybrid 446 models and how reality is perceived may change through and during the study's process 447 as some of the perceptions may be in conflict with each other. Above all, hybrid modelers 448 use a combination of approaches available to understand the problem. In these models, 449 the effectiveness of the approach is becomes the criteria that is used to judge the worth of 450 research, instead of the findings corresponding to a "true" aspect of reality. 451

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3 3.5. Integrative models: pro-pragmatism?

454 Integrated models generally arose in the 1960s in a "quantitative revolution" in 455 regional, urban, and geographic assessments. Integrated models, also called comprehensive or general models, are based on integrating different elements of 456 modeling techniques more and more. Indeed, the most effective elements are put together 457 458 in order to answer the specific questions in ways that are the most appropriate. 459 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 relationship. 460 461 Integrated models consider various environmental, social, economic, as well as 462 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 463 level that they are integrated is sometimes low, they are more fittingly described as 464 hybrid models (Lambin et al. 2000). Numerous integrated models have been built since 465 the mid-1960s. They are spatial models, meaning that they focus on the interplays 466 between a range of dimensions within a spatial structure, but are not comprise of a 467

spatially explicit reference (for instance, energy-economic, demographic-economic, 468 environmental-economic, and so on). Some examples of these models are: IPDMSs 469 (Integrated planning and decision-making systems), MEPLAN, TRANUS (Tranus 470 Integrated Land Use and Transport Planning System) (U.S. E.P.A. 2000), CLUE-CR 471 (Veldkamp and Fresco 1996a), PLM (Patuxent Landscape Model) (Voinov et al. 1999), 472 UrbanSim (Waddell 2002), DSSM (Dynamic Settlement Simulation Model) 473 (Piyathamrongchai and Batty 2007), LUMOS (Land Use Modelling System) (Beurden et 474 475 al. 2007) and MAS (Multi-Agent Simulation) models (Loibl et al. 2007). Given the fact that values, aesthetics, politics, and social and normative preferences are an integral part 476 477 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. 478

479 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 480 481 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 482 483 impeded the development of an integrated theory regarding land-use change (Lambin and Geist 2006). Integrative models have been suggested as a key method in order to improve 484 485 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). 486

487 Therefore, the goal of these modelers, like pragmatists, is to search for useful 488 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 489 reality. Both also believe that how we combine the different methods depends on the 490 time, place and circumstances of their political, economic and social aspects, all of which 491 492 can be mean different things from one another depending on time and place. Similar to 493 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 494 models either. Additionally, depending on the situation, certain techniques can be chosen. 495 The scientific method in integration models is similar to pragmatism, in which an 496 experimental methodology is conducted, and the application of the pragmatist maxim 497 reveals how hypotheses can be subject to experimental tests. Like pragmatism, someone 498

who is knowledgeable of integrative models is an agent who obtains empirical support for 499 his/her beliefs by making experimental interventions in her surroundings and by learning 500 from the experiences that his/her actions elicit. Recently, many national and international 501 502 programs have enforced the necessity to produce models that involve different processes, that ultimately aim to develop integrated models that are able to simulate the processes 503 and consequences that are important for certain landscapes or societies (Janetos 2004). 504 These models mainly have a pragmatism worldview of all the three ontological, 505 506 epistemological, and methodological aspects. Although, the former may have some elements of the participatory paradigm. 507

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509 4. Discussion and conclusions

510 As discussed in this paper, establishing multi-scale methodologies that lead to enhancing and conducting evaluations, on both a small and large scale, is a critical 511 challenge that has not yet been addressed. Such development can provide the opportunity 512 to identify various influential drivers at different levels. As such, out of all of them, the 513 main obstacles is obtaining data of specific regional economies and policies. Information 514 that would be relevant on regional or local levels in order to establish how land claims are 515 allocated between different sectors (Azadi et al. 2011). Most modeling frameworks and 516 517 tools utilize a top-down method, which takes different the national scale and two different spatially explicit scales, into account (Fig. 2). Consequently, driving social forces like 518 quality of living, official and unofficial social regulations, and the priorities and manners 519 of local people are usually not appropriately indicated in the majority of modeling 520 methods (Mudgal et al. 2008). However, such drivers can pose substantial effects on the 521 changes of land-use, especially at regional and local levels. In this regard, Azadi et al. 522 (2009b), Ho and Azadi (2010) also emphasize that, unlike environmental factors, for 523 example, socio-economic drivers are not usually used to assess the severity of 524 525 degradation. Also, they argue that if socioeconomic factors were taken into consideration, 526 the evaluation of degradation trends would relate more fully to real life.

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[insert Fig. 2]

Therefore, land-use modelers will not only need to take into consideration of the 530 relative importance of various drivers regarding land-use change (Agarwal et al. 2002), 531 but also will need to integrate various drivers to be able to provide important 532 improvements in land use models in the future. Issues like the integration of 533 socioeconomic and biophysical drivers, improving agent-based decision-making models, 534 enhancing the ability of modeling land-use decisions in terms of lag time and their 535 thresholds, and using mixed methods in multi-source integration of data (e.g., the remote 536 537 sensing using a census and data from household surveys) gain additional importance in this context. As a result, assessing different LUCMs based on different knowledge claim 538 539 schools in this study showed that modelers have moved towards more qualitative approaches. Denzin (2001) also says that "the days of naive realism and naive positivism 540 541 are over" and adds that "the criteria for evaluating research are now relative". Qualitative 542 researchers are primarily concerned with the process, rather than outcomes or products. 543 Yet, there is no escaping the reality in qualitative research that the researcher is an tool 544 that screens data through their own respective paradigms. Those that conduct research 545 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 546 547 paradigmatic, ontological, epistemological, and methodological aspects.

Therefore, evaluating different LUCMs according to their philosophical routes 548 549 demonstrates that due to the complex nature of the LUCMs, there is no single paradigm 550 that could satisfactorily deal with all of the required methodological aspects. As a result, it is necessary to combine the quantitative with qualitative paradigms in order to create 551 mixed method approaches within a systemic framework. The blending of both paradigms 552 can provide land use change modelers with the ability to cope with the limitation of the 553 554 existing methodology of LUCMs. Thus allowing for the collection multiple sets of data that use different research methods, epistemologies, and methods in a manner that results 555 in a mixture or combination that consists of complementary strengths and does not have 556 any overlapping weaknesses (Johnson and Turner 2003). These models ought to rely on 557 scales that are global, regional and local, and on digital databases. Not only on land-cover 558 classes, but also on methods of land management (like fertilization, irrigation, etc.) that 559 allow for increased participatory, open GIS and data sharing. Furthermore, researchers of 560

change in land-use will need to diversify their portfolios of analytic methods further: not only with multiple regressions, but with narratives, system and agent-based approaches, 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 understand the mutual complexities between human and environmental systems may be significantly reduced.

All these reveal that there is a crucial necessity to produce a systemic framework 567 568 in order to collaborate and develop models (Agarwal et al. 2002) that can cope with the complexities and interactions of various subsystems (biophysical as well as socio-569 570 economic). Systemic models are more complex than others and the difficulty lies in deciding how to incorporate such complexities. Nevertheless, once a systemic model is 571 572 constructed, if-then scenarios are able to be more readily formulated in comparison to 573 other modeling approaches that are not oriented systemically. Particularly, a systemic 574 approach is able to examine the feedback that exists within socio-ecological systems. In 575 this regard, many studies (Houet et al. 2010; Gaucherel et al. 2010; Valbuena et al. 2010; 576 Sohl et al. 2010 and Verburg et al. 2010; Courtney et al. 2015) emphasize the need to combine modeling approaches and techniques in order to further reduce the uncertainties 577 578 of the future landscape. In order to monitor, model, and assess the interactions among and in humans/nature, landscapes' temporal dimensions have to be considered as significant 579 580 as its spatial dimensions. Communally, combining modelling approaches and techniques 581 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 582 from regional to global scales (Azadi and Filson 2009). It concerns issues such as 583 technological innovations, changes in policy and the institution, environmental 584 585 conservation, ownership of collective land resources, physical geography, dynamics of rural-urban areas, and macroeconomic transformations (Briassoulis 2000). Hence, it 586 appears more sensible to use a systemic approach, rather than to rely on a single 587 theoretical schema, which will inevitably miss some dimensions of the case under study 588 or will be too complex to be easily understood and useful. Nonetheless, to achieve this 589 systemic model successfully, it is necessary to critically examine which paradigm is 590 suitable for which study scale. To do so, research paradigms help modelers conduct the 591

study in a more effective method. According to Johnson and Christensen (2005), research 592 paradigms are perspectives that are based on a set of shared assumptions, values, 593 concepts, and practices, which would indeed be helpful in developing a systemic 594 approach when analyzing LUCMs. Most researchers agree that it is very important to 595 begin the research process by identifying the researcher's own worldview (Creswell 596 2007) and the research paradigms that consist of different approaches and research 597 philosophies. The combination of all this helps researchers come to an understanding and 598 599 develop knowledge base regarding the topic being studied, which, in our case, is developing a systemic approach within LUCMs. In the research paradigms, there are 600 601 different factors that affect the study's ability to effectively apply a certain approach, like time constraints, budget constraints, etc. By using the suitable research paradigm and 602 603 philosophies, researchers help exclude these factors from the study. Moreover, the specialist needs more useful data in order to reinforce the utilization of LUCMs, the 604 605 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 its 606 607 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 608 609 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 610 611 performing non-essential tasks (Easterby-Smith et al. 1997). If a researcher, for instance, 612 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 613 model requirements will be noticable and selecting the most suitable approach can then 614 simply be specified. This was confirmed by Brown et al. (2013), who emphasized that it 615 616 is essential to select an appropriate modeling approach for scientific or decision-making goals under consideration. This paper also described the major paradigms so that new 617 modelers can justify selecting and combining different paradigms that best fit their 618 proposed systemic approach in LUCC studies. Since research is described as a systemic 619 process (Wiersma and Jurs 2004), it would seem reasonable to make the future trend of 620 LUCMs as systemic as possible. This study clearly discussed that the function of 621

- 622 paradigms is more important than selecting an approach, yet does not effectively address
- 623 developing LUCMs within a systemic framework.

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- **Fig. 1.** Classification of the LUCMs based on different knowledge schools.
- **Fig. 2.** Top-down allocation procedure (Adapted from Verburg et al. 2004).