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Combining narratives and modelling approaches to simulate fine scale and long-term urban growth scenarios for climate adaptation

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ABSTRACT

Although climate scientists explore the effects of climate change for 2100, it is a challenging time frame for urban modellers to foresee the future of cities. The question addressed in this paper is how to improve the existing methodologies in order to build scenarios to explore urban climate impacts in the long term and at a fine scale. This study provides a structural framework in six steps that combines narratives and model-based approaches. The results present seven scenarios of urban growth based on land use strategies and technological and socio-economic trends. These contrasted scenarios span the largest possible world of futures for the city under study. Urban maps for 2010, 2040 and 2100 were used to assess the impacts on the Urban Heat Island. The comparison of these scenarios and related outputs allowed some levers to be evaluated for their capacity to limit the increase of air temperature.

1. Introduction

Exploring the future is essential if efficient land management policies are to be defined with mid-to long-term perspectives (Godet, 1986; Godet and Roubelat, 1996; Peterson et al., 2003; Amer et al., 2013). The use of qualitative scenarios and quantitative models is therefore becoming a common approach (Veldkamp and Lambin, 2001; Verburg et al., 2004; Kok et al., 2004; Lambin and Geist, 2006). The coupling of scenarios and models is still uneasy and remains a great challenge due to the different philosophies and assumptions underlying them (van Vliet et al., 2010). The term 'scenario' is widely use in various disciplines and may have several meanings such as model outputs, narratives or simulations. In this study, scenario is defined as a narrative, i.e. an imaginative and qualitative description of the future. When focusing on linking scenarios with Land Use and Cover Change (LUCC) models, three types of approaches can be distinguished, each with its own advantages and drawbacks.

The first one, called hereafter 'model-based approach' consists of scenarios based on a quantitative approach and assimilated to model outputs. In this case, scenarios are defined by a set of input parameters, which are varied to provide contrasts among them (Paegelow et al., 2014). The simulated outputs, relying on an exploratory inference, are quantitative (e.g. economic indices, 2D or 3D maps) and are often used as input to feed environmental models (Alcamo, 2008). However, by definition, they depend on the model theory and architecture, which limits the range of possible futures that can be explored (Mas et al., 2014).

The second approach, called 'narrative-based', favours the production of highly imaginative scenarios that are not limited by the issue of which models may eventually be used afterwards. Scenarios are first co-constructed with interested parties or by experts

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in a participatory mode (Strengers et al., 2004; Alcamo, 2008; Kok and van Delden, 2013; Kok et al., 2014). These scenarios are assimilated to qualitative narratives that include a wide diversity of futures, highlighting various land use strategies and interactions. They use exploratory or anticipatory assumptions, with potentially strong breaks with past trends. Spatially explicit models, when they are used, provide virtual views of the future landscape by allocating future LUCC to illustrate the narratives. This approach requires the development of specific models or the coupling of models according to the selected assumptions and the processes that may occur in the defined scenarios. Such an approach assumes that models may not be path-dependent (Brown et al., 2005) and challenges their calibration (Kok, 2009), validation and architecture (Houet et al., 2015). This corresponds to the Storyline And Simulation (SAS) approach defined by Alcamo (2008) which:

- first, defines the narratives;
- second, uses an appropriate model to allocate future LUCC;
- is dedicated to an integrated assessment of environmental impacts.

The third approach, called 'intimately coupled narratives & models', consists of possible combinations of the first two in developing a scenario. Models can be used in a participative way in order to co-construct the narratives with local participants and stakeholders (Rouan et al., 2010; Gourmelon et al., 2008). The same (or other) model(s) can then be used to assess management strategies on future LUCC as suggested by the companion modelling framework (Etienne, 2011). This approach and the model(s) that may be developed, depend strongly on the site specificities and the involvement of the various players. The scenarios provided will be more adapted to, and probably more effective for, involved stakeholders. This 'intimately coupled narratives & models'approach integrates the other two as it combines both qualitative/quantitative approaches and inductive/deductive inferences. It can belong to the SAS approach as models are used to help defining players' strategies and environmental stakes, as a first step towards building the narratives.

The chosen approach in the present study belongs to the SAS approach to build quantitative contrasted scenarios of city evolution. It constitutes a concrete application of the theoretical scheme of the Land System theory described by Kok et al. (2004) where participation and models are tightly linked to explore the future. These authors pointed out that most of the applications (before 2004) relied greatly on the 'model-based' approach. In this study, the focus is on the methodology, which provides a structural framework for benefiting from the respective advantages of the participatory and the modelling approaches.

The research reported in this paper aims to propose a framework for building quantitative and highly imaginative scenarios. It is applied to urban growth and impact studies and must fulfil the following objectives:

- cover a period of time up to one century. A perspective over half a century at least, if not a century, is required to account for and anticipate the contrasting effects on climate change of greenhouse gas emission scenarios, which are expected to differ markedly after 2050. Such a long-term approach is quite challenging considering the traditional urban planning exercises that commonly look only 20–30 years ahead, and it can only be applied through innovative prospective reflection.
- be able to integrate discontinuities (crises), into impact research. Even if high or low trend assumptions of future changes are considered as a reference baseline, exploring contrasted futures can be more fruitful to help decision makers to anticipate (un) expected events (Godet and Roubelat, 1996, 2000).
- provide quantitative scenarios applicable to a town as a whole, at the resolution of the urban block which is the relevant scale for urban planners to adapt and intervene on climate and energy consumption issues In France, for instance, public policies in this sense were set up in the period from 2000 to 2010 (see, for example, the French National Adaptation Plan[1]) for the next 20 years approximately. Worldwide, town authorities are confronted today with the need to define long-term territorial development strategies to limit the impacts of combined urban growth and climate change.

This paper presents the overall methodology used to build qualitative scenarios of land use change drivers, defined through a participatory framework, and coupled with multiple models allowing quantitative assessment of their impact on the urban climate and energy consumption. Section 2 details the innovative methodology based on six steps. It pays particular attention to the description of the variables identified in the participatory scenario building process and their links with the economic, geographic and architectural models then used to simulate the urban growth. Section 3 presents the 'quantified narrative' scenarios that we produced, which show a great diversity of possible futures. While examples concerning the city of Toulouse, France, studied in our ACCLIMAT project (Masson et al., 2014) will be presented, this original study is intended to contribute to any further methodological meta-study on this issue, and is applicable to any city and for other impacts. In section 4, the method is discussed with respect to the SAS approach and Fuzzy Set theory. Its interest also lies in the scenarios generated, providing key insights to help decision-makers in the definition of strategies for adapting to climate change at the city scale.

2. Combining narratives and models

The methodology developed to combine narrative and model-based approaches can be divided into six steps (Fig. 1):

1. Identify the main variables of sectors whose evolution will be studied, and their possible contrasting assumptions;
2. Combine assumptions into consistent sectorial scenarios (worldwide trends, local trends, land use planning strategies, technology trends);
3. Combine sectorial scenarios into integrated systemic scenarios;
4. Link scenario-driving variables to models input data;
5. Build quantitative projections for each type of input data;
6. Enrich the narrative with the quantitative data

Narratives were based on a participatory approach or the use of external prospective studies and projections. Participatory workshops were dedicated to the identification and combination of the variables needed for the scenario building process that were consistent with the scope of the study. Based on the pre-defined sectorial and systemic scenarios and the identification of suitable and useful models, variables defined as inputs to models were distinguished from those helpful to an understanding of the context and circumstances of the narratives. Finally, the simulated outputs were used to illustrate and quantify some of the context variables of the narratives.

The main novelty of our work lies in a step-by-step combination

[1] http://www.developpement-durable.gouv.fr/The-national-climate-change.html.