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Downscaling long term socio-economic scenarios at city scale: A case study on Paris☆

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ABSTRACT

The NEDUM-2D model is used to downscale four global socio-economic scenarios at city scale and simulate the evolution of the Paris urban area between 1900 and 2100. It is based on a dynamic extension of the classical urban economic theory, to explain the spatial distribution of land and real estate values, dwelling surfaces, population density and building heights and density. A validation over the 1900–2010 period shows that the model reproduces available data and captures the main determinants of city shape evolution. From four global scenarios and additional local inputs, 32 local scenarios are created and analyzed.

Main drivers of urban sprawl and climate and flood vulnerability appear to be local demographic growth and local policies; global factors, such as energy and transport prices, even including possible peak-oil and carbon taxes, have only a limited influence on them. Conversely, transport-related greenhouse gas emissions are mainly driven by global factors, namely vehicle efficiency changes, not by land use. As a consequence, very strict urban policies – including reconstruction – would become necessary to control emissions from urban transportation if technologies reveal unable to do so. These scenarios are a useful input for the design and assessment of mitigation and adaptation policies at local scale.

1. Introduction

Climate change adds new and unprecedented challenges to urban planning. Urban transport, land-use, and housing policies are indeed increasingly recognized as major tools for climate change mitigation (e.g., [1–3]). At the same time, due to their high concentration in population and economic activity, cities are particularly vulnerable to climate change impacts, and their vulnerability is greatly determined by city structure. Urban adaptation policies will thus need to be developed [4–6].

Downscaling long term global socio-economic scenarios at city scale is useful at the urban area level, to help local decision makers develop these local adaptation and mitigation policies. Indeed, using urban planning as a tool for mitigation and adaptation is made extremely difficult by the high inertia of city built structure [7,8]. Anticipated action is required if one wants cities to be adapted to the climate of the end of the century and to contribute less to global CO_2 emissions. But the impacts of policies depend on several external factors: demographic, socio-economic, cultural, political and technological changes will play a major role. For instance, the success of strategies aiming at reducing transport energy consumption is dependent on future transport prices. Prospective studies that explore various possible evolutions of these variables are thus required to design the best policies.

This exercise is also useful on a global scale, as scenarios on the evolution of urban forms would also be relevant for the building of long-term narratives of future greenhouse gas

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emissions [9–12], and future climate change vulnerability [13,14].

A growing body of literature is now trying to establish such long term scenarios (often until 2100) at city scale and related to global environmental change for climate change impacts or mitigation analysis [15,9,16–19]. Such long-term scenarios related to global environmental change are different from traditional city scenarios designed to support urban planning, which generally consider time horizons of 30 years or less and are not connected to global scenarios, in which global environmental change can be represented (cf. for instance [20,21], or studies listed in [22]).

In our study, the NEDUM-2D model[1] is used to simulate the evolution of the Paris urban area between 1900 and 2100. It uses a dynamic extension of the classical urban economic theory to explain the spatial distribution of land and real estate values, dwelling surfaces, population density and building heights and density. A validation over the 1900–2010 period shows that the model reproduces fairly faithfully the available data and captures the main determinants of city shape evolution, suggesting that this tool can be used to inform policy decisions. Our approach is, a priori, applicable to most urban areas where data is available.

In Section 2, we briefly present our model and its equations. Section 3 presents the results of the model calibration and its validation over past evolution of the Paris urban area. Section 4 describes the hypotheses that have been used in our scenarios. Section 5 investigates the results of our simulations, and draw general conclusions regarding climate change mitigation and adaptation. Finally, Section 6 concludes.

2. Modelling urban growth

Although models are highly simplified descriptions of reality, they are useful to create prospective scenarios. By enabling decision makers and stakeholders to understand the main mechanisms and interactions between variables, they can create a basis for policy discussion. It should be highlighted that prospective scenarios do not “predict” the future. They are possible and coherent scenarios, which represent conceivable futures in the spirit of the SRES scenarios [23,24]. Prospective scenarios can fuel the debates about Paris' future and inform policy-making, but they have no predictive value.

Several methods can be used to create scenarios for urban development and extensive reviews of land-use change models exist (for examples, see [22,25]). One first set of methods extrapolates past tendencies: it studies the past evolution of the city to anticipate its future. Models can rely on statistical regressions (see for instance [26]), Markov chains or cellular automata (see for instance [9]). A second set of methods proposes to model main evolution drivers, especially land-use transport interaction (see [27], for a review). The main disadvantage of this method is that many phenomena are neglected: the outcome is only an approximation of reality. The main advantage is that the simulations are easily understandable, as is the influence of each parameter, and that these models are based on mechanisms that are supposed to remain valid in the future, while past-trend extrapolation is always questionable.

This analysis is based on such a model of city evolution. To produce scenarios going until the end of the century, it uses only general and fundamental economic principles, which are likely to remain constant over the long term.

The model we use here, NEDUM-2D, is able to capture the dynamics of urban systems, and the importance of inertia. It is based on a model developed in Gusdorf and Hallegatte [7,28], Gusdorf et al. [8], Viguié and Hallegatte [29,30], and Viguié [31]. It is a dynamic model which relies on the classical urban economics framework, an economic modeling approach developed since the end of the 1960s [32–34] which explains the spatial distribution – across the city – of the costs of land and of real estate, housing surface, population density and building heights and density.

As explained in Gusdorf et al. [8], urban economics has been mostly used to explore the characteristics of long run equilibriums. However, the existence of urban stationary equilibriums is questionable: when population, transport prices, or income vary, housing infrastructure cannot adapt rapidly to changing conditions and is always out of equilibrium. Our model takes explicitly into account this dynamics and describes cities as non-equilibrium systems.

A complete description of the model, with the full set of equations, is available in Appendix A. It is based on three main mechanisms.

First, we suppose that households choose their accommodation location and size by making a trade-off between the time and money they spend in transport (i.e. to commute to their jobs) and the real estate price level (or, equivalently, between the proximity to the city center and the housing surface they can afford).

Second, real estate developers choose to build more or less housing (i.e. larger or smaller building) at a specific location, depending on the local level of real estate prices. When these prices are low, developers tend to build low density buildings, and when these prices are high, they tend to build high density buildings.

Third, we suppose that various city characteristics do not evolve and adjust at the same speed. For instance, rents can evolve very quickly, whereas buildings change with a much longer timescale. Building depreciation is also very low, leading to path dependency and lock-ins in city evolution.

Using these mechanisms, it is possible to determine the structure of the city from information on population size, households' income, transport network location, building construction costs and developers' behavior parameters.

Let us present briefly two classical results of urban economics which are of relevance for our analysis.[2] These results are still valid in our modeling. The first is that variation of real estate prices across the urban area is uniquely determined by transport generalized prices. An increase in transport price (or a decrease in transport speed) results in a steeper decrease in real estate prices with distance from the center. Developers react to this change, and population density tends to increase, or decrease, where real estate prices respectively increase or decrease. Conversely, a decrease of

[1] Source code available upon request.

[2] For a detailed analysis of urban economic framework see Fujita [35].

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