Numerical Tools for Low-Carbon Urban Development Studies

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In recent years the topic of urban sustainability and its relation with the climate change has increasingly attracted the attention of researchers from different fields. In scientific literature we find two main research lines. On one hand, a large amount of effort has been devoted to quantitative estimates the urban metabolism components, that are the relevant energy and matter fluxes between city landscapes and the atmosphere. In particular, several advanced models, operating at different spatial and temporal scales, have been developed and used for this purpose.

On the other hand, it has been recognized the need to develop suitable tools and quantitative indicators in order to effectively support urban planning and management with the goal of achieving a more sustainable metabolism in future cities. In fact, it is well known that many urban landscape features can significantly influence both energy and material flows.

For example, sprawled, low-density cities usually have higher per capita energy consumption for transportation than compact cities (e.g. different rates of motor vehicle use) and, ultimately, different scenarios of carbon emissions. In addition, other anthropogenic sources, such as those related to heating and hence to the characteristics of the buildings, play an important role in the urban metabolic balance. Also, different extension and position of urban green areas can influence the balance of carbon and heat fluxes. Further urban characteristics which might also impact its metabolism are the age of the city, its overall infrastructure and its degree of industrial development. Besides factors strictly related to the urban fabric and to anthropic activities, climate also has an impact on the urban metabolism. For example, a city with continental climate usually consumes more energy for winter heating and summer cooling than a city with a more temperate climate. Also, regardless of their natural or anthropogenic origin, the involved fluxes of matter and energy interact in a complex, nonlinear way with the local weather conditions.

Another aspect, which should be taken into account to support a urban planning and management oriented to achieve sustainable metabolism, is related to the nature of the complexity that characterizes urban systems. In fact, urban planners intervene in a spatial system inhabited by *free* human agents in which the detailed location of activities is controlled by spatial interaction between them (usually competing heterogeneous agents) and between different (attractive and repulsive) land uses and functions. As a result, given a temporal horizon, decisions about a planning alternative (e.g. to allocate a specific area to one or more land uses, to build specific infrastructures or to make available public services) usually do not lead to easily predictable configurations of the urban land uses (intended as a map of the allocation of the relevant urban activities/functions).

Given the above considerations, the development of an integrated modeling system able to link urban planning decisions to the indicators of sustainable urban metabolism estimates , is a nontrivial task necessarily involving an interdisciplinary modelling effort.

A contribution in such direction is provided by the development of a software framework for estimating carbon exchanges alternative scenarios of urban development. The modelling system is based on four main components: (i) a Cellular Automata model for the simulation of the urban land-use dynamics; (ii) a transportation model, able to estimate the variation of the transportation network load and (iii) a SVAT (Soil-Vegetation-Atmosphere Transfer) model which was tightly coupled with the (iv) mesoscale weather model WRF for the estimation of the relevant urban metabolism components at regional scale.

SVAT (Soil-Vegetation-Atmosphere Transfer) models are used to accurately describe how soil, vegetation, and water surfaces exchange energy (heat), moisture, and trace gases with the atmosphere. Traditionally, such models have been embedded into meteorological simulations because they provide essential information on the heat and moisture input to the atmosphere from the Earth's surface (e.g., soil, vegetation, water bodies) and on how the surface extracts momentum and kinetic energy from the atmosphere. SVAT models are used for producing and updating surface-air forcing boundary conditions needed by atmospheric circulation models such as WRF. In addition, biophysicists and ecologists use SVAT models to determine how plants and plant communities respond to environmental conditions. In the context of climate change, simulating future climate and land use scenarios using SVAT models that incorporate CO_2 exchange processes can play an important role in helping policy makers design the most efficient climate protection strategies.

The SVAT model adopted in the present study is the Advanced Canopy- Atmosphere-Soil Algorithm (ACASA), a multilayer model which was originally developed by the University of California Davis (UCD) to simulate the exchange of heat, water vapour and CO_2 within and above a canopy. ACASA has been widely applied as a stand-alone (in-situ) model over natural and agricultural ecosystems and the model ability to adequately reproduce turbulent fluxes in different environmental conditions has been evaluated as obtaining reliable flux simulations. To properly work in urban environments, the model was recently modified to account for the anthropogenic contribution to heat exchange and carbon production.

The software framework is organized in a manner that the land-use dynamics simulation module takes as main input the current map of land uses, the street network, the constraints related to the zoning regulation, the suitabilities of the cells to support the modelled land uses and the hypothesis on the future land-use trends. The latter may come from a demographic study and/or from assumption on the development of specific economic sectors. The results produced by the land-use dynamics module consist of a map of future land uses, which represent a spatial distribution of the aggregate land-use demand consistent with the main rules governing the functioning of an urban system. Such future land use map, together with the street network including the current traffic data, are used by the transportation module for estimating future traffic data coherent with the assumed land uses trends. As the final step of the modelling workflow, the future scenario of land use and traffic data, together with other relevant input data, are used by the coupled model WRF-ACASA for estimating future maps of CO_2 fluxes in the urban area under consideration.

An in-progress application of this system to the city of Florence is presented here.