A spatially-resolved material flow model

of the Lisbon metropolitan area

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Keywords: material flow analysis, metropolitan area, spatial disaggregation, online mapping

Introduction

Urban systems are the locus of consumption and engines of economic growth in a globalized world. Major cities offer then the most striking examples of the environmental and energy problems that accompany intense urbanization: as cities grow the flow of energy and materials increase and pose serious problems to global sustainability.

It is therefore critical to understand the interactions between the socio-economic urban development and environmental pressures, and to develop models that may explain these interactions. Early efforts led to conceptual models of cities as urban ecosystems [1,2,3,4,5]. Ecologists have described the city as a heterotrophic ecosystem highly dependent on large inputs of energy and materials and a vast capacity to absorb emissions and waste [1,3]. Wolman was the first to apply an urban metabolism approach to quantify the flows of energy and materials into and out of a hypothetical American city with a population of one million [6]. Systems ecologists provided formal equations to describe the energy balance and the cycling of materials [2,7]. Although these efforts have never been translated into operational simulation models, they have laid out the basis for urban-ecological research. A critical challenge in this context is how to balance service levels, asset management (at times with a growing maintenance backlog), and resource efficiency with respect to materials, energy and cost.

In this paper the outline of a spatially resolved model of urban systems is described. The proposed model aims to characterize the link between the metabolism of an urban system, the socio-economic dynamics at the neighborhood level and the infrastructural network for Energy, Water and Waste, as represented in Figure 1. This model represents a spatially explicit, regional and integrated model, which characterizes the socio-economic dimension of urban metabolism. The model combines land use information with household and business distributions using GIS tools. These tools open the possibility of integrating spatial heterogeneity of urban land uses together with different layers of information (on population density, household characteristics, purchase levels, energy or water consumption or residues generation) and cross correlate them to identify their drivers and pressures. The output of the model will thus reveal potentials to develop policies to promote sustainability or to develop new business models capable of combining economic development with better environmental performance in a holistic perspective and in a cost effective way.

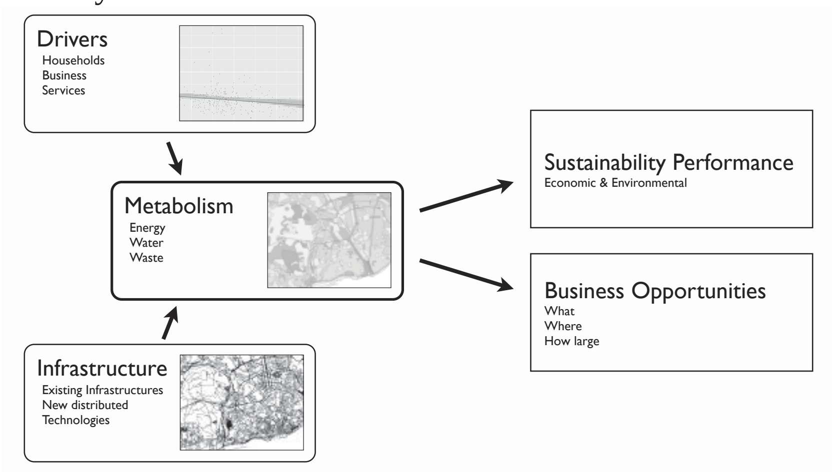

Figure 1: Conceptual diagram of the proposed spatially resolved material flow model.

Methods and data

The method involves quantifying material and energy flows at a neighborhood level and describing the relevant infrastructure (namely electricity, water and waste networks) that supports those flows. By comparing the age and quality of the existing infrastructure with the consumption figures, areas can be identified where improving the infrastructure or reduce the pressures are most urgent. The following subsections describe the proceedings of the proposed method in detail.

Quantification of urban material and energy consumption

The urban material flows in the Lisbon metropolitan area (LMA) have been calculated in the aim of the ResiSt project (PTDC/SEN-ENR/103044/2008). This measurement allowed obtaining data about material consumption at the neighborhood scale. In the aim of the model, these flows will be quantified separately for the residential sector and the businesses and services sector. In both cases detailed statistical data about the distribution of the sectors in the study area are collected. The spatial resolution of the data is given on the Freguesia level, which is the smallest political unit in the Portuguese political system with an average population of about 12000 people. For the residential sector the information is collected from the 2001 Portuguese Census that has a high spatial resolution and socioeconomic disaggregation. The distribution of businesses and services in the study area is obtained from the Strategy and Planning Office, Gabinete de Estratégia e Planeamento (GEP), of the Portuguese Ministry of Labour, Ministério do Trabalho e da Solidaridade Social, which produces a yearly database on all the existing businesses in Portugal.

The described characterization will be coupled with information about residential consumption. For the households, the latest Portuguese consumer expenditure survey (Inquérito às Despesas das Famílias, IDEF 2005-2006) will be used to determine the drivers of residential material consumption in the Lisbon Metropolitan Area. Information about the households in the survey includes the expenditure on 200 different products and service categories as well as the presence of 30 different appliances in each household.

From previous studies the type of dwelling and the number of people per household have been identified as important socioeconomic drivers of consumption [8,9,10]. Using the Ordinary Least Squares (OLS) regression method econometric models that allow testing the significance of socioeconomic factors and dwelling characteristics in explaining product consumption will be developed and used to locally predict consumption.

To describe the material consumption from businesses and services, the Structural business statistics (Inquérito Annual às Empresas, IAE) will be used. In this database the statistics can be broken down to a vey detailed sectoral level (several hundred economic activities). The description of the businesses structure and activity, as well as productivity factors and competitiveness allows establishing econometric models to test the significance of the businesses activity and production factors in explaining material and energy consumption.

In both cases the expenditure of households and the activity level of businesses will be converted into material and energy consumption using a product composition database *ProdChar* also developed as part of the ResiSt project.

Describing urban services supply and conversion technologies

This part of the analysis entails analyzing the type and age distribution of existing supply infrastructures, including the typical quantity and quality performance of each Type/Age-cohort, and their relevance with respect to flows of high policy-importance, resource efficiency, cost efficiency and environmental impact. Type-Age-Matrices provide a quantitative in-depth basis for technology characterization of existing infrastructure assets for urban energy, urban water and urban solid waste systems [11]. Sources of data to build Type-Age-Matrices include municipalities, the main players of the market operating in the Lisbon Metropolitan Area (e.g. EPAL, EDP, GALP, REN) and civil engineering research entities (e.g. Civil Engineering Laboratory – LNEC, Civil Engineering department at IST).

Links between these critical support systems and critical flows affecting political performance targets of resource efficiency (e.g. National Action Plan for Energy Efficiency; Covenant of Mayors), cost efficiency and environmental impact will be assessed.

Matching the supply technologies with the estimated consumption

Once the demand side and the supply side are quantified and spatially referenced, the two aspects can be compared. By comparing the capacity and state of the infrastructure with the estimated load on the systems, zones of the study area can be identified where the load is close to the capacity limit. This allows suggesting possible focus areas for future in-depth analysis of the infrastructure systems. Furthermore it helps identifying possibilities synchronizing maintenance efforts for different infrastructure systems.

Conclusions

The proposed model provides a holistic analysis and performance evaluation, from a citywide engineering systems perspective, across the traditionally segregated analyses of different urban departments and utility companies. Possible synergies in the improvement of the infrastructure systems will be established and areas that have the most need for action, and therefore to be the target of policy measures, can be specified. Through this analysis planning efforts can be coordinated to be more efficiently, particularly to support urban strategies to accommodate the main objectives expressed in political initiatives.

Acknowledgments

This research is funded through Fundação para a Ciência e Tecnologia under the MIT-Portugal Program.

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