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Identifying key technology and policy strategies for sustainable cities: A case study of London

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ABSTRACT

Assuming communities in a city may formally express their aspirations for the future sustainability of their city, which technological innovations for changing the city's infrastructure and metabolism might they introduce today, as a first step towards realizing their distant aspirations? What is more, recognizing the diversity of aspirations that may never be reconciled into a consensus, might some innovations and policy interventions be nevertheless more privileged than others, in being non-foreclosing? How might we discover this? These questions are addressed through a computational case study of London. The city's metabolism is modeled as the set of interacting, cross-sectoral (water, food, energy, waste) flows of carbon (C), nitrogen (N), phosphorus (P), water, and energy. Given various degrees of target improvements in an accompanying set of metabolic performance metrics, and given four candidate technological innovations in the water sector, an inverse (or "backcasting") analysis is implemented in order to identify the key technological, policy, social, and climate-related features determining whether the community's aspirations — through the surrogates of the metabolic performance metrics — are attainable (or not), under substantial uncertainty. From this, the paper proceeds to examine which businesses are currently marketing some of the so-identified key technological innovations. It closes with a brief review of the related status of the economic justifications and social changes that may either promote or stifle the opportunities for London to move towards a higher niveau of sustainability.

1. Introduction

Increases in resource consumption in recent decades have been driven mainly by population growth and improvements in the economic status of many countries. According to the World Bank, global GDP growth has been around 3–4% annually since 1965. Latterly, it has been propelled mostly by developing countries, notably East Asia and Pacific countries. The annual growth for developing countries was estimated to be 7.1% for 2013, while for OECD countries it was estimated at 1.2% (World Bank, 2016a). The fact that 60% of the global GDP is generated in only 600 urban centers illustrates the economic power of cities (Dobbs et al., 2011). As with these GDP increases, urbanization is experiencing a faster rate of growth in developing countries and is projected to be 1.6% annually between 2025 and 2050. This will be reflected in a two-fold urban population increase in these countries, from 2.5 billion in 2010 to over 5 billion in 2050. However, in high-income countries urban population will remain relatively unchanged,

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increasing at just 0.17% annually, from a little over 1 billion in 2015 to over 1.1 billion in 2050 (WHO, 2014; World Bank, 2016b). These urbanization growth-rates are seemingly mild in percentage terms, but they reflect an exponential growth pattern that puts pressure on the availability of resources and increases pollution. Managing such pressures effectively requires a profound change in how cities operate and, while cities do indeed set targets to reduce such pressures, the systematic means to assess the attainability of these targets are currently lacking.

Rapid urban population growth, the complexity of cities, the relative "inertia" of the built environment, and the large investment costs sunk into urban infrastructure, together represent a great challenge in managing transitions towards more sustainable and resilient cities (Beck and Villarroel Walker, 2013; Dixon et al., 2014). Scenario-based assessment is a well-known modelling approach for addressing questions about how to plan and prepare cities for the future and identify long-term consequences of strategic decision making. This approach has been in practice since it was first used for military planning in the 1960 s (Chermack, 2011), but it has expanded since then to business, policy, and environmental analyses. Scenario assessment is found in exploring the human and natural influences on climate change (Iyer et al., 2013; Moss et al., 2010), energy (SHELL, 2013; Wilkinson and Kupers, 2013), in waste management (Williams et al., 2010) and in water resources management (UNESCO, 2014). Life Cycle Assessment (Heidrich and Tiwary, 2013; ISO, 2006) and Material Flow Analysis (Brunner and Rechberger, 2003; Kennedy et al., 2011) are examples of quantitative and standardized operational methods for scenario assessment in the area of environmental sustainability. We, however, will adopt a different approach in this paper.

Understanding the synergies (and antagonisms) among the various economic sectors that service the city — its access to water, energy, and food; the nexus, that is — is becoming increasingly important (Beck and Villarroel Walker, 2013; Villarroel Walker and Beck, 2012). Dealing with such intricate complexity sheds light on how scenario analysis, though sophisticated, can be limited by both the expertise of the practitioner and how alternatives are defined (Mietzner and Reger, 2005). Scenario analysis can be useful for forecasting and backcasting applications, but it does rely on the simplification of the problem and the definition of a small number of pathways towards the future (Holroyd et al., 2007; Swart et al., 2004). For this reason, scenario analysis might not necessarily account for some of the key sensitivities of the system, upon which change towards less urban sustainability, for instance, might crucially turn (Beck, 2002; Nawaz Sharif and Nazrul Islam, 1982). To succeed in this it is hard to escape the need for a computational model, and generally a more complex (as opposed to simple) model. Accordingly an approach that can help to overcome the limitations of scenario assessment is the Regionalized Sensitivity Analysis (RSA) procedure (Osidele and Beck, 2003). It explores the complex logic embedded in the assessment model and identifies which features thereof are key for achieving a certain output target. In this way, the assessment is not limited to the changes introduced a priori by the practitioner; moreover, RSA may reveal potential technological and policy interventions that would otherwise be difficult to find.

The present paper describes and applies a quantitative approach to the analysis of urban metabolism (Barles, 2009; Beck et al., 2013; Brunner, 2007; Kennedy et al., 2011; Wolman, 1965) for the Greater London area. For this it uses the Multi-sectoral Systems Analysis (MSA) framework (Villarroel Walker et al., 2014). MSA is coupled with the Regionalised Sensitivity Analysis (RSA) to investigate and reveal the technological innovations and features of an urban system that have significant potential influence in achieving sustainability targets. This analysis can be referred to as a target-oriented analysis. In our present study for London, the focus is on targets associated with energy production, water use, and nutrient recovery. For the purposes of this work, *features* are defined as those elements of the urban system that define its characteristics and behavior, such as population growth, consumption patterns, diet, efficiencies of technological processes, climate conditions, and the infrastructure in place.

The objectives of the paper can be expressed as follows:

a. Based on a set of sustainability metrics, determine whether future targets for these metrics are attainable and how this attainability changes as these targets are made more stringent.
b. Identify which features of the system enable or disable the attainability of future targets of direct carbon emissions, energy and water use, and resource recovery from the water sector.
c. Establish which of these key features are associated with which aspects of the city's current metabolism, and conversely determine which are dependent on innovation, or technologies yet to be invented or brought to the market place, along with equally innovative policies that would need to depart from current conventions.
d. Illustrate with examples which businesses or organizations have programs or technologies that are already influencing the so-identified key features.

The paper starts by describing the methodological framework, which builds upon the Multi-sectoral Systems Analysis (MSA), but crucially extends this by incorporating the Regionalized Sensitivity Analysis (RSA) procedure. This is followed by defining a set of metabolic performance metrics, with a focus on circular metabolism; these metrics are in turn used to formulate targets (in terms of energy production, nutrient recovery, and water use). The MSA/RSA framework is then employed for identifying those features of Greater London (referred to as London for the purpose of this paper) that are key for reaching the prescribed targets. The results obtained are then used to illustrate how these key features are related to facets not only of technology, but also policy and human behavior.