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Eco-cities: An integrated system dynamics framework and a concise research taxonomy

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ABSTRACT

Urbanism is an emerging phenomenon and international predictions demonstrate that more than half of the increasing world population will live in cities by 2050. Interdisciplinary studies try to develop smart and eco-friendly solutions in order to enhance urban living. This paper validates that the eco-city urban modeling emerges radically and concerns an ideal paradigm for sustainable urban development. After comparing alternative methods for eco-city modeling, this paper attempts to assess the sustainability of the eco-city with the system dynamics (SD) simulation-based technique. A holistic SD methodological framework is proposed, as a means to assist decision-makers, local governments and managers designing and adopting effective policies for monitoring and assessing the sustainable performance of eco-cities. This framework is formed and tested with two case studies respectively and useful findings about the efficiency of the eco-city modeling are generated.

1. Introduction

Today, more than 3.5 billion people live in urban areas, while the projections of the United Nations reveal that by 2050 more than half of the urban population will live in cities (United Nations, 2012). This urbanization trend results to intensive energy and natural resource demands in modern cities (Agudelo-Vera, Mels, Keesman, & Rijnaarts, 2011). However, cities are considered the centers of innovation and can advance clean energy systems, sustainable transportation, waste management and spatial development strategies to reduce greenhouse gases (Khare, Beckman, & Crouse, 2011). In this context, scientific urban design and management are necessary to promote urban sustainable development in order to secure the appropriate agglomeration conditions for well-being (Cao & Li, 2011; Chen, Acey, & Lara, 2015; Gaitani et al., 2014; Ruza, Kim, Leung, Kam, & Ng, 2015) and mitigate the ecological (global) footprint of cities (Monstadt, 2009; UN-HABITAT, 2008).

On this ground, the development of green, ecological cities has been introduced as a means to support sustainable urban development within a social, economic, environmental and demographic context. The ecological city or eco-city concept was introduced by Urban Ecology, a nonprofit organization that was founded in 1975 by the philosopher Richard Register (Roseland, 1997). He was the first to coin the term "eco-city", a city that ensures the well-being of its citizens via a holistic urban planning and management approach with the aim of eliminating waste and emissions.

Nevertheless, an eco-city is a synthesis of different complex subsystems that need to be adjusted and coordinated in order to deliver the desired outcomes. As such, many researchers study only "myopically" the eco-city system, while research problems arise due to the lack of analytical tools that can capture the complex and dynamic nexus of the involved urban ecological factors and systems, and assess their development both in terms of environmental impact and business growth. Furthermore, literature lacks in robust analytical tools that can perform monitoring, benchmarking and assessment of the impact of corresponding planning policies (Lizarralde, Chmutina, Bosher, & Dainty, 2015; Murakami et al., 2011; Price et al., 2013; Zhou & Williams, 2013).

This paper addresses the complex structure of the eco-city in an attempt to answer the following research questions (RQs):

(a) RQ1: how can an eco-city be modeled in order to support decision makers in appropriate planning and future predictions?
(b) RQ2: what is the structure of an eco-city with the application of system dynamics (SD) modeling technique?
(c) RQ3: how effective is eco-city modeling with SD techniques?

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All the above research questions are critical to be answered, since the eco-city appears to be adopted as the ideal urbanism approach across the globe (Anthopoulos & Fitsilis, 2013) without the suitability of this approach for effective urban sustainability been validated yet. More specifically, the answer to RQ1 will compare alternative eco-city modeling tools and justify the applicability of SD as the most appropriate eco-city simulation tool. The answer to RQ2 will demonstrate the complex eco-city system with the use of SD with data from a real case study. Finally, in an attempt to answer RQ3 the SD model – defined with the answer to RQ2 – is tested with simulations and data from a second prestigious eco-city case study and returns important findings regarding both the applicability of the proposed SD model and the effectiveness of eco-city paradigm for urban development.

This paper follows a multi-method approach to answer all these questions. More specifically, literature findings are utilized to answer RQ1. Both literature findings and the case study of Hsinchu Science Park in Taiwan are utilized for answering RQ2. Finally, simulation scenarios with data from a second case study from Tianjin Eco-City in China, return useful findings, which give answer to RQ3 and generate future research potentials.

The remainder of this paper is structured as follows: Section 2 performs a literature review on eco-cities and the corresponding modeling tools. The objective of Section 2 is two-fold: (i) to capture the critical factors and subsystems that have been identified as vital to an eco-city structure in order to consider them in the proposed modeling framework, and (ii) to document the actual added-value of this work compared to the existing modeling approaches that have been developed thus far in previous studies. Then, Section 3 composes a conceptual SD modeling framework, which is considered to be effective to analyze the complex eco-city system. The application of the proposed framework is tested with simulation scenarios and data from a prestigious eco-city case study, and interesting insights are provided. Finally, Section 5 discusses findings and highlights future research potentials.

2. Eco-cities: literature review and critical taxonomy

2.1. Background

Regarding the ecological cities, the existing literature is rather limited and mainly refers to real case studies of: (i) reforming attempts of existing urban settings toward the eco-city conceptual paradigm, and (ii) new construction projects for establishing eco-cities, mainly in China where the urbanization and environmental problems are more prominent. To this end, the Chinese government launched a demonstration program of 5 low-carbon pilot provinces and 8 pilot cities in 2010, in its attempt to promote low-carbon urban development (Khanna, Fridley, & Hon, 2014).

Eco-cities, a step before the utopia of a "gaia-level city", are considered the epitome of an environmental sustainable city (Ecocity Builders, 2011). The first recorded publication that created a momentum regarding the issue of eco-cities is the "Eco-city Berkeley" (Register, 1987). In the aforementioned publication, the author discusses innovative solutions to ecologically improve the city of Berkeley in California. Recently, according to a survey conducted by Joss, Tomozeiu, and Cowley (2011), the number of eco-cities globally is reported to be 174 while the corresponding amount in 2009 was only 79. Recently, only in South Korea alone (Yigitcanlar & Lee, 2014), 64 corresponding eco-city projects were under development across the country in 2013. South Korea has capitalized eco-city and developed an ideal prototype in New Songdo, Seoul, which is expected to position the country possibly at the forefront of new eco-city development, potentially producing a model for export (Shwayri, 2013).

The funding schemes to support eco-city initiatives have gained great interest and this is further implied by the capital focus on a plethora of related constructions projects. Remarkably, the World Bank, motivated by the challenges confronted by modern cities, launched the "World Bank Urban and Local Government Strategy" (The World Bank, 2000). The respective published strategic roadmap clearly states the four main axes of the Bank's urban support scheme to achieve greater impact, which are namely: (i) Formulating national urban strategies, (ii) Supporting city development strategies, (iii) Scaling up services for the poor, including upgrading low-income urban neighborhoods, and (iv) Expanding assistance for capacity building. Indicatively, the World Bank supports the Sino-Singapore Tianjin Eco-City and published an extensive technical report regarding the key issues and the related challenges that may arise during the development of an eco-city (The World Bank, 2009). Following, the above strategy declaration, the World Bank realized the economic implications of ecological cities and launched the "Eco^2 Cities" initiative. In the respective report the Bank claims the significance and practicability of the application of both qualitative and quantitative indicators in eco-cities with regard to the assessment of the value creation and the derived financial benefits (The World Bank, 2010). The Bank also offers a framework that can be tailored to the specific case of each city as to secure environmental and economic sustainability.

Except for the publications supported by international organizations, there has been a great academic interest on the issue of ecological cities. Specifically, Li, Zhang, and Li (2011) leverage a plethora of indicators to evaluate the construction progress of Chinese cities toward the eco-city paradigm and provide evidence that Central and Eastern Chinese cities are more advanced than those located at the Western side of the country. Furthermore, Wu, Jiang, and Yang (2012), motivated by the prevailing concern over the rapid urbanization in China and the increased interest over eco-city projects, recommend the incorporation of carbon footprint into the least-cost planning of eco-city schemes. Through the analysis of the Tianjin eco-city and the Ningbo-Cixi Wetland Center cases, the authors conclude that carbon costs should be taken in account when financially evaluating alternative ecological interventions within an eco-city project. Their main aim is to assist decision-makers in achieving optimal outcomes with refer to financial, social and environmental dimensions throughout the lifespan of an eco-city project.

2.2. Critical planning components

Designing, constructing, and managing urban settings involves a complex and integrated decision-making process. This is even more accentuated when urban planning deals, for example, with flagship eco-city projects that have to balance social, environmental and economic ramifications (Caprotti, 2014; Thornbush, Golubchikov, & Bouzarovski, 2013). In general, eco-city design and planning should tackle critical planning constituents related to specific components, such as sustainable urban growth dynamics in terms of population and economic growth accompanied by the appropriate life-style and education development efforts; urban transportation; greenhouse gas (GHG) emissions and solid waste management; and energy consumption, in terms of efficiency and clean energy provision against local demands (Khanna et al., 2014), as seen in Fig. 1. In the following sub-sections, we discuss each one of the components involved along with the related research works.

2.2.1. Sustainable urban growth dynamics

The issue of urban sustainability and growth has attracted the intense academic interest by researchers over that last two decades (Fung & Kennedy, 2005; Gülen & Berköz, 1996; Ho, Wang, & Lu, 2002; Lehmann, 2011; Nijkamp & Perrels, 1994; van Bueren & ten

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