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Using Material and Energy Flow Analysis to Estimate Future Energy Demand at the City Level

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Abstract

Cities undergoing rapid growth encounter tremendous challenges, not only in terms of providing services to meet demand, but also in ensuring that development occurs in a sustainable way. This research evaluates the potential contribution of the material and energy flow analysis framework to predicting future energy flows and corresponding CO2 emissions in Riyadh, Saudi Arabia. The research presents a generic material and energy flow analysis model and applies it to the housing stock in Riyadh to estimate future energy demand and to assess associated effects. As the country starts to adopt sustainability measures and plan its transition from a fossil fuel-based energy system towards a renewable-based energy system, an understanding of future energy flows will allow early recognition of potential environmental impacts and provide information to enable accurate predictions of future demand for resources.

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Keywords: Material and energy flow analysis; Sustainability; Urban development; Resource cosmuption; Developing countries

1. Introduction

In 2014, 54% of the global population resided in urban areas; this percentage is expected to reach 66% by 2050 [1]. Not only do cities have a higher population than in the past, but the typical resident in modern cities is also likely to consume more resources compared to the average out-of-city person [2]. Managing urban growth is a key challenge of the 21st century [3]. Rapid urban growth is usually associated with tremendous challenges, such as

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increases in materials and energy flows that enter and exit urban systems [2]. This places considerable pressure on urban societies to adopt sustainability as the main mechanism for development.

Riyadh, in Saudi Arabia, is one of the world's fastest growing cities. The population of Riyadh has grown from almost one million in 1980 to nearly six million today and is expected to reach 8.2 million by 2029 [4]. Between 2004 and 2010, the population of Riyadh grew at an annual rate of 4%. The increase in population is still the most noticeable feature of Riyadh and has led to growth in other sectors; in 2015 the overall population of Riyadh reached 6,152,180 [4]. In addition, Riyadh's population growth is characterized by qualitative improvements in its residents' standard of living [4]. According to the Arriyadh Development Authority, Riyadh needs 510,000 housing units built before 2030 [5]. This growth is inextricably linked to the consumption of materials, energy, and water resources. There is, therefore, a need for a framework that provides information on future resource demand, because this type of information is valuable for the evaluation of future development.

This study applies a general dynamic material flow analysis to evaluate the long-term development of Riyadh's housing stock. This approach estimates the future energy demands and corresponding greenhouse gas (GHG) emissions. The advantage of applying this method is the ability of quantifying the flows and in-use stocks for each year under study. The analysis evaluates the dynamics of floor area of Riyadh's housing stock and corresponding energy demand. When analysing the built environment, a dynamic MFA approach should be used due to the long service life of built structures and their significant role in mobilizing flows such as materials, energy, emissions and wastes [7].

2. Literature review

The MFA comprises a systematic accounting of the flows and stocks of materials within a defined system. When implementing a dynamic MFA model, the system variables are functions of time [8]. A historical and future analysis of the system can be performed, the dynamic behaviour of which can be explained [9]. Dynamic MFA is a useful tool when analysing long-term changes in the system [10]. In the literature, assessment of building stock has been approached by using a dynamic MFA to analyse floor area and corresponding construction materials. Müller [11] has applied a dynamic MFA to Dutch dwelling stock to study the long-term changes of material flow cycles for the period 1900–2100. In his study, the author relates the material stock in use and flows to consumption of building services in order to satisfy the demands of the population and its lifestyle, which are the driving forces. Population lifestyle is further explained by introducing two parameters; average size (area) of a dwelling and persons per dwelling. To estimate the stock demand or stock in use, these parameters can be expressed as a function of time [11].

Several other studies on building stock modelling have followed the same approach proposed by Müller [11]. Bergsdal et al. [8] applied this method when studying the dynamics of floor area and material use in Norwegian residential stock. The same method was also applied in a study by Sartori et al. [12] to model the construction, renovation and demolition activities for Norwegian residential stock. In another study, Brattebø et al. [7] applied this approach when studying the material and energy metabolism of built environment stocks. This method was also applied in a developing country, China, with the aim of investigating the relation between the urbanization progress and resulting material flows [13]. In another study, Hu et al. [14] have applied a dynamic MFA to study the urban housing system in Beijing with the focus on understanding the mechanism of future construction and demolition waste generation.

In conclusion, these studies shed light on the importance of using dynamic stock modelling to understand development patterns of urban systems from a long-term perspective. When sustainability is sought to guide urban development, the long-term aspect is essential. Dynamic material flow analysis provides a framework for analysing the development of building stock that is missing in static analysis [15]. However, this type of analysis requires a