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Incorporating built environment factors into climate change mitigation strategies for Seoul, South Korea: A sustainable urban systems framework

J.H. Jo [a], J.S. Golden [b,*], S.W. Shin [c]

[a] School of Sustainability, Arizona State University, Tempe, AZ, USA
[b] School of Sustainability and National Center of Excellence on SMART Innovations for Urban Climate & Energy, Arizona State University, P.O. Box 5402, Tempe, AZ 85287-5402, USA
[c] Sustainable Building Research Center, Hanyang University, South Korea

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A B S T R A C T

Major cities have a significant impact on global and regional climate change due to their intensive material and energy use accompanied by population growth and the physical expansion of the metro region. This study presents the Sustainable Urban Systems Framework for assessing the causes and effects of climate change involved with the built environment at different scales with a case study of Seoul, South Korea. The Seoul metro region is the sixth most densely populated area in the world, and the region's rapid population growth has resulted in dramatic increases in both energy consumption and land-use and land-cover (LULC) changes. South Korea is now the ninth largest Carbon Dioxide (CO_2) emitter in the world and the third largest in Asia. Our results indicate that the system inputs and impacts of the proposed framework (urban population, LULC change, greenhouse-gas (GHG) emissions, and energy consumption) are closely related to the system pressures of energy security and GHG-reduction requirements. To meet the goal for the next phase of the Kyoto Protocol, Seoul must cut down its annual CO_2 emissions by 3.4 million metric tons. The city's current intervention strategies will result in a reduction of only 2.1 million metric tons a year, a deficit of 1.3 million metric tons. Our preliminary results indicate that the Seoul government can strengthen its CO_2 reduction strategy by incorporating built environment factors from the Sustainable Urban Systems Framework. By adopting energy-efficient-building standards, CO_2 emissions can be reduced by up to 1.34 million metric tons per year, suggesting a promising approach to lowering the city's energy use and GHG emissions.

Introduction

For the first time in history, more than half of the planet's population lives in cities. Urban areas gain an estimated 67 million people annually and approximately 5 billion people will live in urban areas by 2030 (UN, 2002). This rapid population growth, in conjunction with intensive energy consumption, will inevitably have an adverse effect on climate change due to anthropogenic greenhouse-gas (GHG) emissions (IPCC, 2007). Elevated levels of GHG emissions have led to a 0.6 °C increase in the global average surface temperature since 1900. This is expected to increase an additional 1.8–4.0 °C by 2100 if current emissions trends are not altered (IPCC, 2007). Carbon Dioxide (CO_2) is the most important heat-trapping GHG, and CO_2 comprises more than 85% of total GHG emissions (IPCC, 2007). Addressing climate change is one of the current generation's most urgent challenges because of its adverse effect on the planet.

Urban areas are also subject to *regional* climate change. The urban-heat-island (UHI) effect, the temperature difference in an urban area compared to adjacent rural regions (Grimmond, 2006; Oke, 1987), is a good example of urban climate change. It occurs primarily as a result of anthropogenic modification of environments due to the replacement of native vegetation with engineered materials that increase thermal storage capacity and radiative properties (Golden, 2003). Characteristics of rapidly urbanizing areas include population growth, land-use/land-cover (LULC) change, and intensive material and energy use. These factors are closely related to the causes and effects of climate change.

Because of the complexity of the urban built environment and specifically the climate–energy system, we developed our *Sustainable Urban Systems Framework* (Fig. 1) with which to appraise mitigation strategies to the adverse effects of climate change in the built environment at different scales. The framework will be applied to the city of Seoul as a case study for examining urban climate change and used to suggest ways to enhance the city's existing

* Corresponding author.
E-mail address: jay.golden@asu.edu (J.S. Golden).

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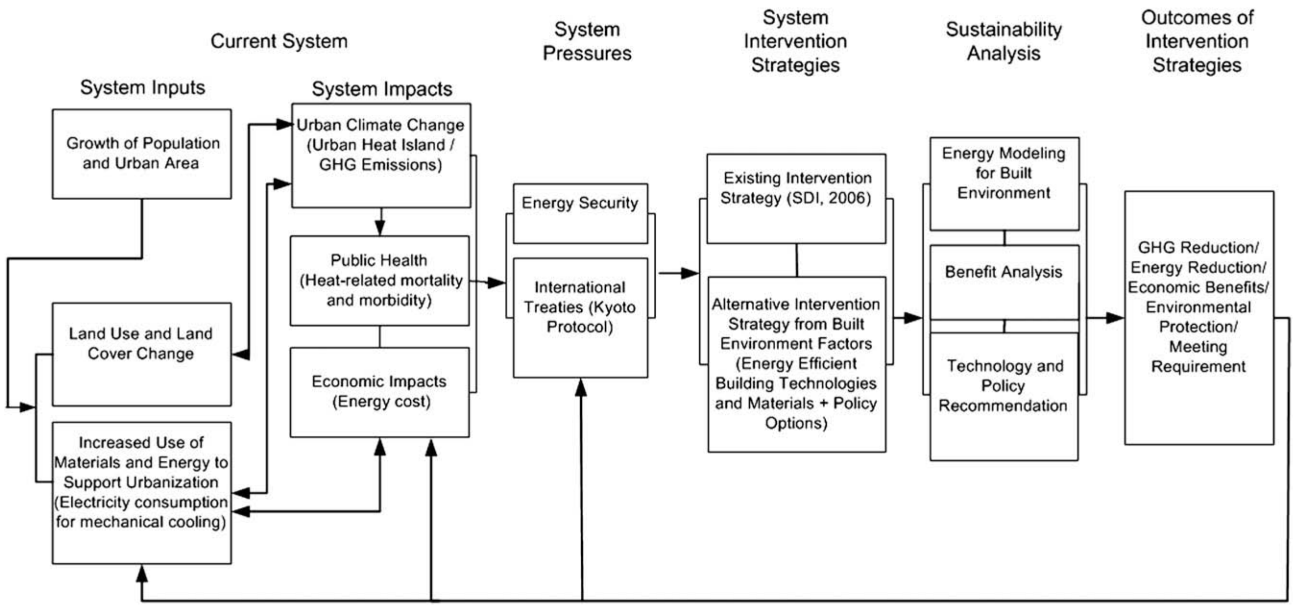

Fig. 1. Sustainable urban systems framework for energy, climate, and the built environment in Seoul, South Korea.

mitigation strategy for global climate change. Our preliminary results indicate that the Seoul government can strengthen its CO_2 reduction strategy by incorporating built environment factors from the Sustainable Urban Systems Framework. As part of this study we calculated the reduction in CO_2 emissions that could have been achieved if green building standards, particularly regarding energy efficiency, had been utilized for all new construction in Seoul from 1995 to 2005. The results of this calculation indicated a potential CO_2 reduction ranging from 0.52 to 1.34 million metric tons per year, a major contribution to meeting the city's Kyoto Protocol GHG-reduction requirement.

Methodology

Researchers in a range of disciplines have attempted to construct models based on complexity frameworks that are capable of addressing the causes and effects of global climate change. Although current models are necessarily imperfect due to a lack of information, they do provide useful insights into trends and outcomes of potential effects of climate change (Tester, Drake, Driscoll, Golay, & Peters, 2005) and it is now possible to analyze the system through these models and estimate possible outcomes.

The first of these models, the World3 System Dynamics model, simulates the feedback among population, cultivated land, and industrial capital and how these factors interact to affect levels of pollution (Meadows, Meadows, & Randers, 1993). The second model, the MIT Integrated Global System Model (IGSM), simulates global environmental changes that might result from natural and anthropogenic causes, the uncertainties associated with the projected changes, and the effect that different policies may have on such changes (Prinn et al., 1999; Tester et al., 2005). The IGSM computes anthropogenic emissions of the key GHGs from twelve economic regions and organizes them into distributions by latitude, providing an understanding of the potential outcomes of different decision-making scenarios (Tester et al., 2005).

Our new framework was designed to create a platform that would allow policy makers to qualitatively explore the broad social, environmental and economic imperatives that influence public policy regarding urbanization and climate change. As presented in Fig. 1, the Sustainable Urban Systems Framework addresses the relationship among impacts and pressures on the system and the characteristics of the urban built environment. Rapid urbanization and population growth drive significant LULC changes as well as intensive material and energy use in the built environment. The framework also takes into account the additional complexity due to the UHI effect and its influence on the climate–energy–built environment system. Considering built environment factors as part of the urban system makes it possible to suggest novel intervention strategies that would support the City of Seoul in meeting its GHG and energy reduction goals.

Evaluating the system

The Sustainable Urban Systems Framework was applied to the city of Seoul to examine system inputs and impacts, system pressures, and system intervention strategies. The current status of population growth, energy consumption, public health concerns, and economic impacts were evaluated using official data from government documents and reports. Satellite images were utilized to quantify the physical growth of the region, urban climate, and LULC change over time. A gap analysis between current conditions and future requirements for the city suggested alternative strategies to support the existing intervention plan for climate change mitigation. In the following sections we will present the results from our evaluation of the system.

System inputs and impacts

Population

Treating population growth as an input of the urban system implies that most urban activities affect both energy and materials intensity and are accompanied by changes in LULC. In the latter half of the 20th century, following the Korean War, the population of South Korea increased 130%, from approximately 20 million in 1950 to 46 million in 2000. In 1960 there were only 3 cities in South Korea with a population of over a half million, but as of 2007 there were 19 such cities (KSIS, 2007a). Similarly, in 1960 less than 30% of the population lived in urban areas of the country, whereas by 1990 more than 75% resided in urban areas (Fig. 2) (SKLG, 2006).

Seoul, the capital of South Korea, is located 50 km south of the border with North Korea and is home to more than 10 million people, 22% of the nation's total population. The city covers an area