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A geospatial approach of downscaling urban energy consumption density in mega-city Dhaka, Bangladesh

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ABSTRACT

Lack of energy consumption data limits resource optimized urban structure and energy planning in developing countries like Bangladesh. Focusing on mega-city Dhaka as a case, this study applies a geospatial approach of using multi-source national and regional datasets and visual analytics to downscale and estimate energy consumption at a local scale (such as ward and gridcell). The energy consumption density (ECD), as a measure of end energy use in a unit area, was estimated and mapped by linking building floorspace data with residents' energy use indicators such as per capita energy consumption, household energy expenditure, and mobility (transportation) pattern. This study also evaluated the ECD modelling outputs, and their sensitivity to distance from central business district (CBD) and total building floorspace. Results found a positive correlation between the residential building floorspace and estimated ECD. Regression and sensitivity analysis also identified and mapped significant spatial clusters and outliers in estimated ECD pattern of Dhaka city. This approach and methodology could help similar cities in other developing countries adopt and implement energy focused urban development.

1. Introduction

Energy consumption and generation are key considerations in optimizing urban planning and constructing urban infrastructures. Evidence suggests that there is a strong connection between urban development process and energy consumption behavior and needs (Singh et al., 2015). According to Marique and Reiter (2014), a well-planned feasible form of urban structure can influence energy efficient behavior and even enhance cleaner energy production in growing urban environment. On the other hand, unlike rural settlements, the urban areas can also offer more energy-efficient means of housing and transportation systems (Schubert et al., 2013) if planned with data-driven process. However, lack of local level energy consumption data often limits resource optimized energy and urban planning in mega-cities. Literatures on energy-efficient urban forms emphasize the challenges of urban energy planning for growing megacities. Prominent research areas varies from the impact analysis of energy consumption pattern to the integrated urban planning nexus (Owens, 1985, Ewing and Rong, 2008, Liu and Shen, 2011, Madlener and Sunak, 2011; Makido et al., 2012, Wilson, 2013, Gudipudi et al., 2016). The recent global study on 40 mega cities (Kennedy et al., 2015a, 2015b) has reported positive correlations between the end use energy consumption and urban form (building floorspace). However, there are evidences of critical discussions about data availability and their quality, statistical methods, contexts and levels of uncertainty. In response to rapid

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urbanization in growing megacities, this is becoming an emerging challenge for urban development planning.

Better understanding of spatial and causal relationships between urban buildings and infrastructures, energy consumption behaviors, and lifestyle of the residents is crucial - (Madlener and Sunak, 2011; Howard et al., 2012; Wilson, 2013; Marique and Reiter, 2014; Resch et al., 2016). The resource efficient urban planning and design could be better promoted by use of detailed spatio-temporal data at a higher resolution (Howard et al., 2012; Allen et al., 2016). Deeper data-driven computational approach can explore more dynamics of cities and test new ideas although preferred method and data for advancement of the traditional urban knowledge is still uncertain (Townsend, 2015; Voskamp et al., 2016).

The energy data related constraints are especially severe in the context of mega-cities of developing countries (Jayasinghe et al., 2017); like Dhaka, Bangladesh. One of the ways to track urban energy consumption pattern is measuring and mapping energy use. One of such measures called Urban Energy Density (UED) which is defined as "the annual total amount of end use energy (kWh) demanded, predicted or consumed in a single or group of buildings normalized by the total building area or its footprint area" (Pereira and Assis, 2013; Vaisi et al., 2015). This UED definition can be applied to a sub-regional scale and called, Energy Consumption Density (ECD) – which is - "the total amount of end use energy (kg oil equivalent: kgoe) consumed in a unit area (e.g. a local administrative unit such as ward or gridcell) normalized by the building floorspace (in square metre: sq.m)". In this study, we focus on residential energy consumption density in mega city Dhaka where ECD (kgoe /sq.m of residential building floorspace) could be used as a metric to compare and conceptualize the level of energy use by residents between two unit areas. The data and information retrieved through this approach can be supported future energy policy – for example, the recently commissioned energy master plan of Bangladesh (GOB, 2015) has included residential energy use as one of the potential sectors for energy efficient development.

Dhaka is one of the highest urban concentrations in south Asia; the resource constraints is very common like in other mega cities of global south. The existing planning and building regulations of Dhaka hardly address the energy dynamics rather focus on density and development control (Parveen, 2012; Alam, 2014; Sikder et al., 2016). Studies have already investigated urban structure phenomenon of Dhaka city by applying various scales and methods, including geospatial approaches (Ahmad et al., 2012; Byomkesh et al., 2012; Raja, 2012; Trotter et al., 2017); however, the dynamic aspect of energy issues are almost missing or were not addressed in a direct manner. To this end, a systematic analysis and visualization of energy consumption pattern and intensity has a potential to add value by stimulating the understanding on energy sensitive urban dimensions particularly at a local scale. To conduct the visualization of energy consumption pattern and relevant spatial analysis, modelling can be an effective tool. Urban planning models can be classified as three levels namely micro, macro and meso (Robinson et al., 2009). For example, urban mobility investigations could be studied by modelling every vehicle and traffic features at a micro level, or by explicitly modelling major arteries (meso) or at an aggregation of regional level (macro). The level of modelling should be chosen in line with the research objectives. A meso-scale modelling has been widely used in urban planning (Couclelis, 1997; Torrens and O'Sullivan, 2001; Batty, 2009; Martilli, 2014). In this method, a problem under study (e.g. regions of Dhaka city) is represented using two-dimensional lattice or grid of cells. Ideally with access to micro building energy data (e.g. smart meters) and urban mobility data (e.g. smart cards), it is methodologically possible to use empirically calibrated micro simulation modelling approach for policy making (Howard et al., 2012; Kim et al., 2012; Angelidou, 2014; Mwasilu et al., 2014). Energy planning for mega-cities is often focused on a city scale rather than looking at sub-regional scale (e.g. districts, local administrative units - wards) for urban planning and infrastructure development (Bale et al., 2012; Phdungsilp, 2006). In the developing countries like Bangladesh, lack of micro-data in energy consumption at a building level poses challenge to develop and apply data-driven micro-simulation model and further pose difficulty for empirical data-driven policy implementation. In this context, a methodological approach is needed for ECD estimation at a sub-regional scale by using available energy consumption parameters and building information. The errors in data sources used for geo-spatial models (e.g. Kocabas and Dragicevic, 2006; Yeh and Li, 2006) can propagate further to the output variables and interpretation of results with sensitivity analyses for estimating ECD.

To address the challenges of spatial urban structure components in the context of energy, this study intend to develop a methodology for estimating and visualizing the analytics on urban energy consumption by using the available urban public datasets such as building information (floorspace, use), population census, household energy expenditure and mobility pattern of mega city-Dhaka. This study aims to answer the following research questions:

1. How to estimate urban energy consumption density in a smaller scale using available multi-sourced public sector urban dataset?
2. Which relationships exist between estimated ECD and explanatory variables such as distance from center business district (CBD) and building floorspace?

Estimation of ECD can help addressing many urban energy challenges especially at a local level. A downscaling approach of ECD estimates and further findings related to these research questions would facilitate decision making for spatial land use and energy infrastructure planning. Urban stakeholders including governments are often interested in understanding other energy-use such as transport/mobility issues for better development planning in addition to building energy consumption (Rahman et al., 2012). Although, local authorities are often key stakeholders in energy-efficiency initiatives, they have limited budgetary provisions; therefore, an analysis at local level of a city (e.g. wards, districts) can support the local city officials and policy makers in informed decision-making.