UNIVERSITÄT BONN igg

Institut für Geodäsie und Geoinformation

Schriftenreihe

57

Sujit Kumar Sikder

Exploring Urban Structure to Approach Energy Optimization

Sujit Kumar Sikder • **Exploring Urban Structure to Approach Energy Optimization**

UNIVERSITÄT BONN igg

Institut für Geodäsie und Geoinformation

Schriftenreihe

57

Sujit Kumar Sikder

Exploring Urban Structure to Approach Energy Optimization

Diese Arbeit wurde am 07. Oktober 2016 als Dissertation zur Erlangung des Grades
Doktor der Ingenieurwissenschaften (Dr.-Ing.) der Landwirtschaftlichen Fakultät
der Rheinischen Friedrich-Wilhelms-Universität Bonn vorgelegt.

Referent: Prof. Dr.-Ing. Theo Kötter
Korreferent: Prof. Dr.-Ing. Hans Joachim Linke

Tag der mündlichen Prüfung: 12. Juni 2017

Diese Dissertation ist auf dem Hochschulschriftenserver der ULB Bonn
http://hss.ulb.uni-bonn.de
elektronisch und mit allen farbigen Abbildungen publiziert.

Schriftenreihe des Instituts für Geodäsie und Geoinformation
der Rheinischen Friedrich-Wilhelms-Universität Bonn

Bonn 2017 ISSN 1864-1113

- Institute für Geodäsie und Geoinformation -

Exploring Urban Structure to Approach Energy Optimization

The case of residential settlement development in Dhaka city, Bangladesh

Inaugural-Dissertation

zur Erlangung des Grades

Doktor der Ingenieurwissenschaft

(Dr.-Ing.)

der Landwirtschaftlichen Fakultät

der Rheinischen Friedrich-Wilhelms-Universität Bonn

von

Sujit Kumar Sikder

aus

Barisal, Bangladesch

Bonn 2017

Referent: Univ. Prof. Dr.-Ing. Theo Kötter

Korreferent: Univ. Prof. Dr.-Ing. Hans Joachim Linke

Tag der mündlichen Prüfung: 12.06.2017

Erscheinungsjahr: 2017

Angefertigt mit Genehmigung der Landwirtschaftlichen Fakultät der Universität Bonn

Abstract

The concept of energy optimization in urban development has the potential to address many urban challenges besides local energy concerns. Past research has attempted to combine the cross-cutting issues of urban planning, energy planning, and local urban sustainability. The gaps that collectively remain in scientific progress necessitated the adaptation of different proposals for energy optimization in urban development. This study conceptualized the interrelationships of urban structure and energy aspects. It has established an integrated planning framework and drafted a simple decision support tool for urban professionals, especially in the local context of Dhaka, one of the fastest growing large cities in the developing countries.

Taking both urban and neighborhood scale study units, explorative and empirical approaches have been adapted to conduct a spatial analysis on a large dataset of building structures and a systematic evaluation of the urban planning process. First, cell-based spatial analytics demonstrate that the urban development pattern has less CBD dependency and a more polycentric urban form, dominated by residential land use. Although very small, mixed use areas can facilitate energy-efficient urban development. The residential neighborhood structure was analyzed further — focusing on urban form, electricity consumption, working mobility, resident's lifestyle and renewable energy potential. In this research experience, the physical structure related indicators are possible to measure with minimum effort, but energy aspects are more difficult and need to be addressed by urban stakeholders. Second, the comprehensive urban planning process was evaluated after establishing a conceptual framework called the "EnUp" model. The findings suggest the adoption of the "EnUp" model is both possible and necessary for cities like Dhaka. Finally, the study results directed the design of a "eNoP-DHAKA" tool that could support energy-optimization in urban residential settlement development. The drafted tool demands further work to synthesize thresholds and generalizations in combination with more case studies; however, the methodological approach and research findings have great potential to explain many urban development and energy aspects. The quantification and visualization of a large-scale building structure dataset with the integration of open data could be effectively promoted urban decision-makers formulate better policy and strategies to decide "where to allow or encourage what".

This research initiated a scientific discussion of approaches to energy-concerned urbanization especially in the context of one of the largest cities in the developing countries. The explorative insights evolved on urban spatial structure, workable conceptual framework, stakeholder's participation, renewable energy potential and a simple decision support tool for urban stakeholders.

Zusammenfassung

Das Konzept der energieoptimierten Stadtentwicklung umfasst neben lokalen Energieproblemen viele weitere städtische Herausforderungen. Dabei werden die Querschnittsthemen der städtischen Planung und der Energieplanung mitlokaler Nachhaltigkeit bei der Stadtentwicklung verknüpft. Eine Frage, die insgesamt im bisherigen wissenschaftlichen Fortschritt offenbleibt ist, wie eine energieoptimierte Stadtentwicklung auf der kommunalen Ebene etabliert und verankert werden kann. Daher wird in dieser Arbeit eine verfeinere Raumanalyse der energetischen Wechselbeziehungen und ein Konzept für eine integrierte Planung in Entwicklungsländern entworfen. Darauf aufbauend wird im lokalen Zusammenhang von Dhaka, einer der am schnellsten wachsenden Großstädte ein einfaches Entscheidungshilfetool für städtische Fachleute in Entwicklungsländern entwickelt.

Explorative und empirische Ansätze wurden adaptiert, um eine räumliche Analyse auf einem großen Datensatz von Gebäudestrukturen und einer systematischen Auswertung des städtebaulichen Planungsprozesses auf städtischer und Quartiersebene durchzuführen. Erstens demonstrieren zellbasierte Raumanalysen, dass die Stadtentwicklungsmuster weniger CBD Abhängigkeit besitzen und eine polyzentrischere städtische Form haben, die durch Wohnnutzung beherrscht ist. Obwohl es sehr wenige Gebiete mit Mischnutzung gibt, können diese eine energieeffiziente Stadtentwicklung erleichtern. Die Wohnquartiersstruktur wurde analysiert, wo beide städtische Form, der Elektrizitätsverbrauch, die Arbeitsbeweglichkeit, der Lebensstil des Einwohners und das erneuerbare Energiepotenzial berücksichtigt wurden. Durch diese Forschung war es möglich, mit minimalem Aufwand die physikalischen, strukturbezogenen Indikatoren zu messen. Energieaspekte sind jedoch schwieriger zu erfassen und müssen von städtischen Akteuren berücksichtigt werden. Zweitens wurde der umfassende städtische Planungsprozess nach einem Konzept, genannt das "EnUp" Modell, bewertet. Die Ergebnisse weisen darauf hin, dass die Adaption des "EnUp" Modells sowohl möglich als auch für Städte wie Dhaka notwendig ist. Schließlich helfen die Studienergebnisse, das "eNoP-DHAKA" Tool, das die energieoptimierte städtische Wohnansiedlungsentwicklung unterstützt, zu entwickeln. Das entworfene Tool bedarf weiterer Arbeit, um Grenzwerte und Generalisierungen in der Kombination mit mehr Fallstudien zu synthetisieren. Jedoch haben die methodologischen Annäherungs- und Forschungsergebnisse großes Potenzial, um viele Stadtentwicklungs- und Energieaspekte zu erklären. Die Quantifizierung und Visualisierung von einem großen Gebäudestrukturdatensatz mit der Integration von offenen Daten, könnte städtische Entscheidungsträger in der Politik bei der Entscheidung von Strategien "wo erlaubt man was zu fördern" unterstützen.

Diese Forschung beginnt eine wissenschaftliche Diskussion über die Ansätze einer energiebezogenen Urbanisierung, vor allem im Zusammenhang mit einer der größten Städte in den Entwicklungsländern. Die explorativen Ergebnisse beziehen sich auf die urbane Raumstruktur, ein funktionsfähiges Konzept, die Beteiligung der Stakeholder, das Potential der erneuerbaren Energien und auf ein einfaches Entscheidungshilfetool für städtische Fachleute.

Acknowledgement

The adoring doctoral journey might not be possible without tremendous support of my first supervisor Univ. Prof. Dr.-Ing. Theo Kötter. I am very much thankful for his kind guidance, encouragement and critical feedbacks in every steps of this research. I would like to thank my second supervisor Univ. Prof. Dr.-Ing. Hans Joachim Linke for his expert comments and many clear directions. I wish to acknowledge all members in Professur für Städtbau und Bodenordnung (PSB) family. I cannot avoid mentioning some names – Prof. Dr. Lautenbach, Dr. Weiß, Dr. Kropp, Dr. Schuppe and many more. My special thanks goes to Asad not only as a fellow PhD researcher, but also for listening my puzzle thoughts with enormous attentions.

My special appreciation goes to anonymous mentors, reviewers, respondents, experts, professionals, individual residents, and field survey team members for their excellent cooperation. I am also very grateful to Sojib Vai, Dipu Da, Anik vai, Himel and Manik for helping in data related issues on Dhaka city.

This study acknowledges KAAD, KHG-Bonn, PSB, BIGS for providing scholarship, research funding and travel grants. Thanks to many friends, seniors and juniors who offered enormous supports during many difficulties in this life-long event. Let me mention some names - Maruf Vai, Mahabub Vai, Rafiq vai, Nazmul Vai and Ashish Da.

My deepest gratitude remain with my family and relatives for encouraging and understanding me in every means and difficulties.

In relation to enormous questions about my future academic endeavors, here I take a help from a German Philosopher - Arthur Schopenhauer:

"With people of only moderate ability, modesty is mere honesty; but with those who possess great talent, it is hypocrisy."

I will keep trying to be the first one.

Sujit Kumar Sikder
07.10.2016, Bonn
Germany

Table of Contents

List of Tables

List of Figures

List of Boxes

CHAPTER ONE: INTRODUCTION

1.1 Background, Motivation and Problem

Urbanization is a global trend. By 2050, it is projected that 66% of the world's population will live in urban areas. The population of developing countries is expected to increase 2.27% annually between 2007 and 2025 (UN, 2014; UN, 2008). Urban areas account for approximately two thirds of global primary energy consumption, offering significant potential to optimize renewable energy production and enhance energy efficiency in urban planning. For example, a careful consideration of building site orientation and other passive strategies could lead to energy savings of 20% - 50% (Kanters and Horvat, 2012; Lehmann, 2012; Duvarci and Kutluca, 2008). At the same time, the urban planning world is going through an extraordinary transition. As Wilson (2013) points out, research interest in the domain of urban planning — after a long interval — is having a rebirth, particularly in regard to investigating the relationship between energy consumption and patterns of physical development. However, energy concepts such as effective consumption, efficiency, distribution and generation have not been fully integrated into urban planning, even though great potential exists in the well-established planning process (Lehmann, 2012). Making urban planning and development more comprehensive and efficient requires a major shift from existing government-based, top-down processes to more participatory, interactive and dynamic approaches for optimizing energy and integrating resources.

Since its emergence in the late nineteenth century, urban planning has been considered to be a combination of science and art (Freestone, 2000). The definition of urban planning varies in the academic literature and in the real, practical world; however, complexity theory provides for the possibility of integrating the "science" and "social practice" of planning (Byrne, 2003). At the local level, urban planning overlaps with environmental planning and urban management. It also has non-linear loops with city politics and, therefore, cannot be conceptualized as a purely technical process.

“Optimization” implies using something in the best possible way. Accordingly, one can conceptualize energy-optimization in urban planning as accomplishing the best possible solution for urban and energy planning by satisfying the goal functions, which include the following criteria: (i) maximization of renewable energy, solar gain, comfort and participation; and (ii) minimization of CO_2 emissions, energy demand, cost, and pollution (Hachem et al., 2013; Strasser, 2012). Although there is ample evidence of applying the goal functions in the developed world, significant challenges exist in site-specific and context-specific interrelationships of any given planning project.

Given the ever-increasing complexity of urban energy planning tasks, there is a need for innovative frameworks, methods and tools (Herfray, 2006). Many studies concentrated either on individual energy sources or on life-cycle approach (Yeo, 2013), and several studies revealed that only a few systems are incorporating energy transitional interrelationships in urban planning. While a few topical urban energy issues, including energy efficiency and solar energy integration in urban planning, were studied under different urban configurations and scales (e.g., Amado and Poggi, 2012; Stoeglehner et al., 2011; Vermeule et al., 2015; Wilson, 2013), the energy optimization issue remains an open topic of discussion, especially in the urban planning context of developing countries.

The complexity of efficient energy resource use in urban planning for a developing nation requires an innovative approach to optimize utilization of renewable energy resources and technologies especially in the context of the country's unique profiles. Many developed countries integrate energy in urban development policies at least in principle. The European Commission, for example, recognizes the importance of integrated planning within the broader agenda of sustainable urban development (EC, 2004). The participation of developing countries is also needed to undertake green energy initiatives in order to reduce long term CO_2 emissions without compromising economic prosperity and environmental sustainability (Blanford, 2009; IPCC, 2007). Many developing countries, such as Bangladesh, currently set their priority on green growth trends with a focus on urban energy adaptation to climate change (Harmeling, 2011; Offer, 2011). The matter of concern should be taken care about effective monitoring mechanism of such green growth initiatives.

Table 1-1. Urbanization status of Dhaka city.

Year	Total Urban Population		Urbanization (%)	Ave. Annual growth rate (%)	
	National	Dhaka	National	National	Dhaka
2011	41,943,532	14,171,567	30.45	4.01	7.14
2001	28,808,477	9,912,908	23.39	3.37	5.33
1991	20,872,204	6,487,459	20.15	5.43	6.55
1981	13,535,963	3,440,147	15.54	10.63	7.53
1974	6,273,602	2,068,353	8.78	6.62	8.47
1961	2,640,726	718,766	5.19	3.75	5.74
1951	1,819,773	411,279	4.33	1.69	1.28

Source: BBS (2001), BBS (2003), BBS (2011), Ahmad et al. (2012)

Bangladesh is one of the most densely populated countries in the world and has an increasing demand for energy in urban areas. By 2050, it is estimated 200 million people will live in Bangladesh, with 40 million living in urban areas (Offer et al., 2011; BBS, 2011b). Dhaka city, the capital of Bangladesh, is expected to have one of the highest urban concentrations among all large cities in the South Asian region (Table 1-1). Dhaka city is located in the central part of the country between EL (90°20' and 90°30') and between NL (23°40' and 23°55'). Resource constraints such as land and energy shortages are harming the quality of urban life in Dhaka city, as is happening in many other large cities in developing economies (Sikder et al., 2016). Resource efficient urban development, therefore, could play an important role in achieving local sustainability that would fit well with the MDGs, as well as the SDGs.

Bangladesh is one of the countries where per capita energy consumption remains relatively low, even after 40 years of independence; however, energy demand is growing quickly with the expansion of economic activities and prosperity. As of May 2011, the estimated daily demand for electricity was about 5500 MW whereas the actual average generation capacity was about 4500 MW (BBS, 2011; Islam et al., 2014). The generation gap was due to fuel supply shortages, because locally-available natural gas is used to generate electricity (approximately 86%) by thermal-based power plants (Ahamad and Islam, 2011). The government of Bangladesh has set a target of sourcing 10% of its electricity from renewable resources by 2020; however, the progress in renewable energy initiatives is very slow and the potential for integrating renewable energy in urban planning is often overlooked (GoB, 2008). A good mix of sustainable energy policies and strategies is crucial to address both supply and demand sides of energy management to accomplish development goals.

1.2 State of the Art

Growing climate change and energy security concerns have led to a significant increase in sustainable urban planning discourse, mostly on three different levels — (i) micro scale (individual buildings); (ii) meso scale (groups of buildings, which make up neighborhoods or districts); and,(iii) macro scale (city or region). The urban structure is significantly scale depend; fast growing mega-cities of global south should be measured with multi-scale explorative consideration in order to support decision making on energy integrated sustainable urban future (Taubenboeck et al., 2009). Energy optimization in the form of increasing efficiency and integrating renewable technology is just one dimension of sustainable urban planning (Vandevyvere and Stremke 2012). Similarly, the sector-specific urban project fields comprise: (i) building engineering; (ii) utility services; (iii) urban planning; and, (iv) transportation management (Webster, 2007). However, progress towards low energy or optimized urban systems must simultaneously emphasize both residential building energy consumption and the transport energy consumption of residents (Marique and Reiter, 2012). Given the complexity of urban residential settlement development, appropriate management of such a system requires knowledge of its boundaries, resources, interactions, surroundings and thresholds (Daniell et al., 2005; Perez and Batten, 2006). No specific level (e.g., city, neighborhood and building) can stand alone; rather each must be considered as a part of a broad urban system (Becker and Boschert, 2013). Therefore, a clear multi-dimensional system approach is essential for contributing to further urban development.

Urban systems are understood to be complex open systems. Planning for such systems, therefore is also complex and often must include a long-term vision (Batty 2009; Byrne 2003; Sikder et al. 2015).

In this regard, Dosch and Porsche (2010) identified three major concerns — balance among diverse sectors, complexity of rebuilding, and the inclusion of stakeholders — that need to be tackled in order to achieve efficient planning (see also Table 1-2). The urban energy system is a socio-technical system that combines the processes of production, transportation, processing, conversion, distribution, storage and end-use (Keirstead et al., 2009). One significant challenge within such a process, called the "paradigm change of so-called fossil based energy systems", may be due to the emergence of renewable technologies (REN21, 2013, p. 62). Several authors and experts have stressed that the integration of such a shift demands ''whole-system" thinking. However, the basic features of integrated energy planning are similar to those of the current energy planning and environmental planning practices that include approaches such as integrated assessment, life-cycle assessment and integrated resource planning (Mirakyan and De Guio, 2013).

Table 1-2. The current drivers and related trends (urban and energy planning).

	Current Drivers	Driver Trends
Urban planning	Space constraints – high rises Urban	Space efficiency – taller high rises, more energy efficient designs
	Ageing Infrastructure – decisions to replace or repair (maintain)	Increased focus on optimization of options and expenditures. Debate whether to replace or repair
	Climate Change and GHG reduction – awareness and info gathering	Resilient infrastructure/city: Electric mobility; use of renewable energy for space/water heating; factoring in environmental externalities in economics
	New eco-friendly designs for commercial buildings and residential units	Move towards optimized eco-friendly and more resilient designs
	Public Choices and Participation	Increased public participation in planning and design; offering hybrid solutions; incentivize public response and partnerships
	New Technologies	Use of new technologies for more compactness and modularity
Energy planning	Space constraints – compact and modular design	Use of new technologies for more compactness and modularity
	Ageing Infrastructure – focus on optimization	Real-time monitoring and increased focus on optimization studies
	Extreme weather and GHG reduction	GHG reduction – integration of renewable sources; extreme weather – learning and developing strategy; factoring in environmental externalities in economics
	Public Choices and Participation	Increased costumer control and partnerships in formulating options (even for power system needs) and delivering value to costumer
	New Technologies – pilot projects in new technologies to deliver value	Targeted rolling out of new technologies; increased automation to deliver improved service; smart-grid and micro- grid.

Source: Adapted from Singh et al. (2015)

Accordingly, urban energy planning should follow a holistic approach, which allows for alternative decision making processes by applying optimizations, simulations and suitability measures (Stevanović, 2013). The suitability measures should be evaluated by summarizing key variables of large data sets and facilitating communication, interpretation and decision making (Niemeijer and Groot, 2008; UN-Habitat and ICLEI, 2009). To this end, the vision for sustainable urban settlement development should consider a bottom up approach where urban stakeholders can participate, monitor and negotiate the key planning variables.

One must stress the need to include energy-conscious strategies at every stage of a planning process (Vandevyvere and Stremke, 2012). The first step in achieving a long-term goal and comprehensive planning procedure is to establish a conceptual framework (Mirakyan and De Guio, 2013). Several models and frameworks have been proposed to integrate energy optimization into urban planning.

Centric Austria International (CIA) introduced a methodological framework called Energy Integrated Urban Planning (EIUP) with the intention of helping cities address local-level energy problems with short- and long-term strategies and action plans (Todoc, 2008). This methodology is a very broad vision of urban planning rather than an early design of urban residential settlement planning projects. Similarly, Yeo et al. (2013) proposed an E-GIS based Decision Support System (DSS) concept of energy-optimization during urban planning that integrates, and is built from, several urban databases. Although the system could be applied at the scale of a city district, it was not able to address larger urban systems and also lacked suitable evaluation measures. Mirakyan and De Guio (2013) drafted a generic integrated energy planning procedure, which consist of four main phases of planning activities to be used with respective stakeholders; however, this framework's unit of analysis did not consider the urban meso scale (i.e., neighborhoods) and mainly focused on territorial energy planning.

Amado and Poggi, (2012) proposed a four-step methodological framework called Solar Urban Planning, which has also been tested at the urban meso level; however this framework did not specify different urban stakeholders and excluded a residential mobility analysis. Similarly, Hachem, et al., (2013) proposed a solar-optimized neighborhood design methodology in the context of Canadian cities. Both of these studies have concentrated only on solar urban planning aspects from the designer’s perspective without considering mobility issues. Still other studies proposed other approaches and concepts, variously called Municipal Energy Planning (MEP) (Rad, 2010), Local Energy Planning (LEP) (Beeck, 2003), and Community Energy Planning (CEP) (Huang et al., 2015), but all of these mostly focused on the technical aspects of energy discourse.

After exploring the urbanization process and its impact on developing countries, Madlener and Sunak (2011) proposed a general research framework in relation to urban structure and energy demand. Lefèvre (2009) presented city-scale determinates and strategies for the reduction of urban energy consumption in relation to urban structure. Stewart and Oke (2012) developed a new Local Climate Zone (LCZ) for classifying urban structure, specially designed for Urban Heat Island (UHI) studies. It includes land cover, building height and landscape pattern properties. Larondelle, et al., (2014) has applied such urban structure classification to conduct a cross-city comparison of surface temperatures. Using a case from Munich, Germany, Wurm et al. (2010) quantified urban building structure and conducted correlation analyses of individual urban structure indicators by following an object based image classification method with multi-sensor remote sensing data.

Some studies have already investigated urban structure in the context of Dhaka city by applying varied aspects, scales and methods, including the spatial structure of land use change (Ahmad et al., 2012), raster imagery-based land use change scenario modeling (Islam and Ahmed, 2011), spatial analysis of land surface temperature (Raja, 2012), and urbanization scenario modeling for urban climate change adaption and mitigation (Roy, 2009). To this end, a systematic analysis of urban building structure may add value by stimulate the discussion on energy optimization in urban planning approaches. It can depict an urban scale analysis by focusing on spatial evolution, land use structure change, estimation of building structure intensity, and energy consumption density (ECD). Some investigations also focused on the interaction between ECD and potential explanatory determinants.

Energy optimization is a complex urban planning task within the context of the 3 pillars of sustainable development (i.e., environmental, economical, and social) and would be highly complex within the vision towards a low carbon future (Mohanty, 2012). In fact, most of the assessment frameworks or tools from a broad vision of sustainability include significant components of energy optimization in urban planning. Some of these tools are already in use or under development on the urban and building levels, but there remains a lack of widely applicable Neighborhood Sustainability Assessment (NSA) tools. The application of developed NSA tools like LEED-ND (USA), DGNB (Germany), BREEAM (UK), and Green Township (India), are limited by multiple barriers, such as being voluntary, causing economic burdens for implementers, tool complexity, ambiguity, and their bias towards expert knowledge (Hamedani and Huber, 2012; Riera Pérez and Rey, 2013; Sharifi and Murayama, 2013; Sullivan et al., 2014). However, the frameworks and guidelines provided by these tools could facilitate further progress in the context of energy optimization in urban development.

In summary, the gaps that collectively remain in the scientific progress on approaches to energy concerned urban planning include the issues of dynamic urban infrastructure, sectoral integration, technology, emission reduction, and stakeholder's participation. An adaptation potential of these different proposals is important to conceptualize the interrelationships of urban structure and energy aspects. There is also a need to establish a workable planning framework and design a simple decision support tool for urban professionals, especially in the context of fast growing cities and regions in developing countries.

1.3 Study Objectives and Research Questions

To address urban planning and energy concerns, this study explores the interrelationships of urban settlement structure and the potential of energy optimization in urban development in the case of the megacity Dhaka. With this goal, the specific objectives and questions framing this study include:

Specific Study Objectives

1) To explore the interrelationships of urban structures and energy aspects based on the local context of urban form, mobility and resident's lifestyle.
2) To conduct an evaluation of the contribution of an energy-optimization in urban planning approach in the case of urban residential settlement development.
3) To develop a simple decision making tool at a neighborhood scale to support energy optimization planning.

Research Questions

i) What major parameters should be used to analyze urban structures in relation to energy aspects within a rapidly urbanizing city context?
ii) How far are the parameters measurable in reference to the local context of urban form, mobility and resident's lifestyle at a residential neighborhood scale?
iii) What is the current state of energy optimization in the planning of residential settlement development projects in Dhaka city?
iv) How can an energy-optimization urban planning conceptual framework contribute to energy resource use efficiency and urban planning in Dhaka city?
v) What could be a simplified decision making tool for energy optimization in urban planning?

The targeted spectators of these research outcomes are urban stakeholders and professionals who are involved in energy-concerned urban development. The research has discussed energy related dynamic parameters in two different scales (urban and neighborhood) in the context of Dhaka city; however, the research has not included the whole spectrum of energy-related urban planning issues, instead focusing on electricity and residents’ mobility issues along urban building structure analysis.

Findings related to the research questions will help to formulate future strategies and policy inputs for urban residential settlement development planning, along efficient resource use in Dhaka city and other cities with similar settings in Bangladesh and around the globe.

1.4 Overall Thesis Structure

This thesis began with an introduction key challenges to resource efficient of urbanization and identifies the significant motivations for pursuing energy-optimization during urban planning in the context of developing countries. The state of art in relation to research interest in the domain was explored in detail in this chapter, leading to the formulation of specific objectives and questions, as well as the general study goal.

The second chapter organizes theoretical, conceptual and contextual considerations that could guide smooth study progress. First, it launches a critical discussion of energy concerned urban planning, examining theories of urban system complexity for resource efficiency, emerging urban initiatives, and causal path of energy sensitive urban structure. Second, key concepts are discussed that are discussed that contribute to approaches to energy-concerned urbanism, such as the urban metabolism model, zero energy framework, parametric solar urban planning and the evolutionary optimization approach.

The research method and data related steps are discussed in Chapter Three. The case study based research approach has been applied for this research, where the analytical methods, data collections, and support-tools are discussed in consideration of the scale of the study units. The city-wide (Dhaka city corporation area) spatial analysis and mapping are applied for exploring urban structure and energy consumptions aspects. On a smaller scale, the residential urban cluster level, urban structure interrelationships are explored with a set of indicators resulting from a systematic selection process. In order to evaluate the process of Dhaka city’s residential settlement development system, a methodological framework called the "EnUp" model is applied, along the analytical frameworks of system analysis and grounded theory. Multi-criteria based decision analysis concepts are included with others in focusing on the study goal and developing a context-specific simple decision making tool.

The result of comprehensive empirical findings from the data analysis are presented in Chapter Four through Six. Chapter Four presents spatial data analysis results in the form of building structure intensity, and insights into ECD. Interactive statistical graphs and figures are also presented for significant statistical analytics. Chapter Five compares two types of residential settlement clusters according to the analytical outputs of the selected indicators for measuring energy optimization levels at a residential cluster scale. As the next step, Chapter Six presents a comprehensive evaluation of the energy optimization potential of residential settlement development where local planning practices, methods, tools and barriers also discussed with fact and figures. Chapter Seven discusses empirical findings and interprets them in broader relevance to theories and concepts.

Research findings justified the drafting of a simple decision making tool for enhancing energy optimization planning in the context of residential settlement in Dhaka city. In Chapter Eight, a draft framework of an "eNoP-DHAKA" tool is presented with detail on flow diagram, weighting approach and performance sensitivity analysis.

Last but not least, Chapter Nine presents conclusions and end statements. Study limitations and further research directions are also included in this chapter. A brief overview of the thesis structure is found Figure 1-1:

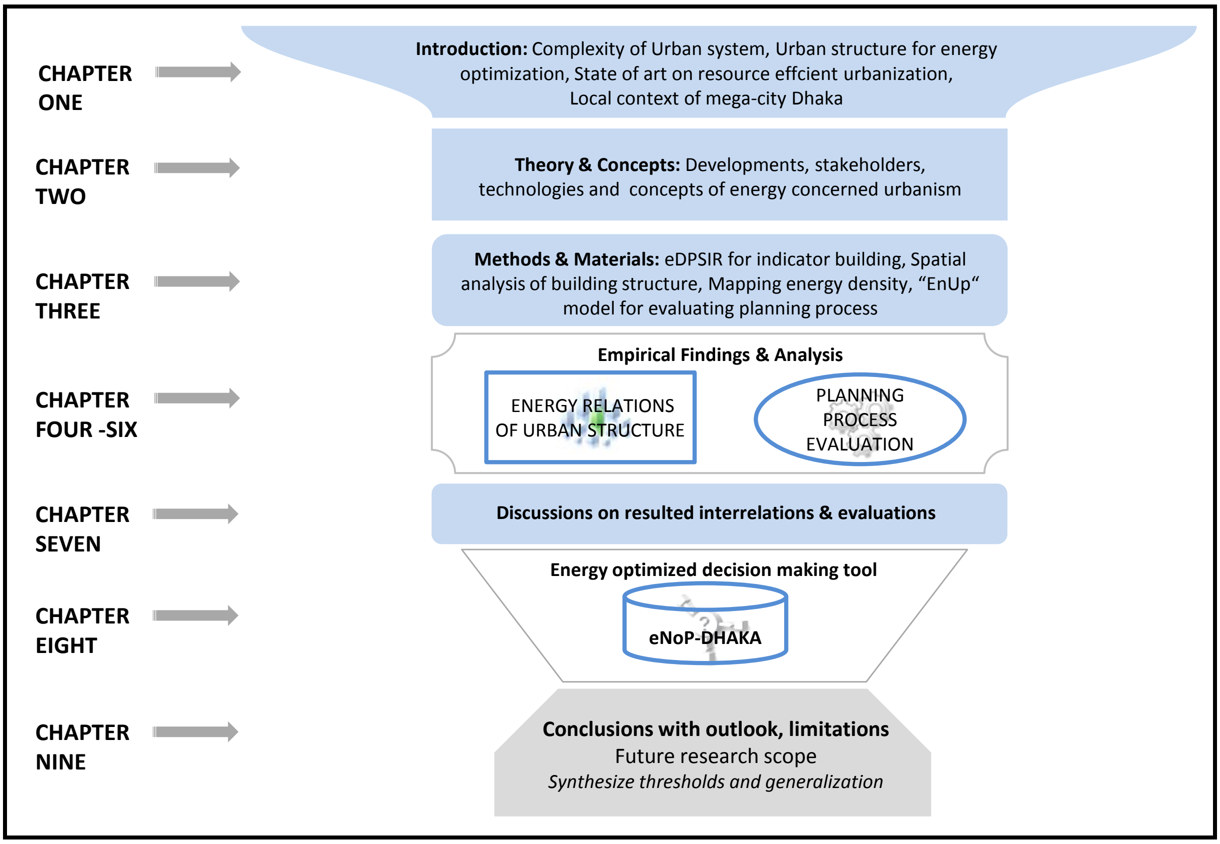


Figure 1-1. Overview on thesis structure.
Source: Author's own

CHAPTER TWO: THEORY AND CONCEPTS OF ENERGY CONCERNED URBANISM

2.1 Understanding Urban Systems: Complexity Era

The community of urban planners and managers are facing a set of complex challenges due to rapid urbanization, extensive globalization, and environmental change. Urban thinkers and scientists are motivated to develop innovative methods that conceptualize of such urban system complexity (Mueller, 2010). The definition of complex systems can be given as:

"...Systems those show surprising and unanticipated or 'emergent' behaviors as shown in patterns that arise at the aggregate level from the operation of system processes at the micro or agent level. Such systems are intrinsically unpredictable in an overall sense but can be fashioned in such a way that makes knowledge of them useful and certain. Cities are the archetypical example, but so too is the economy (Batty, 2009, p. 51) "

Planning and design literatures understand urban systems as a complex open system, and therefore complexity science and planning are not strangers (Byrne, 2003). Although the emerging interactions between individual system elements and non-linearity are showing the characteristics of the complexity topic as reported in research results, but the general theory of complexity is still lacking a clear picture. Time and space are displayed as dynamic variables in the internal system (Dosch and Porsche, 2010, p. 25-28), however, the urban settlements and buildings are often recognized as parts of dynamic complex systems where the basic urban functions and boundaries can be drawn in order to conduct general urban analysis (Figure 2-1).

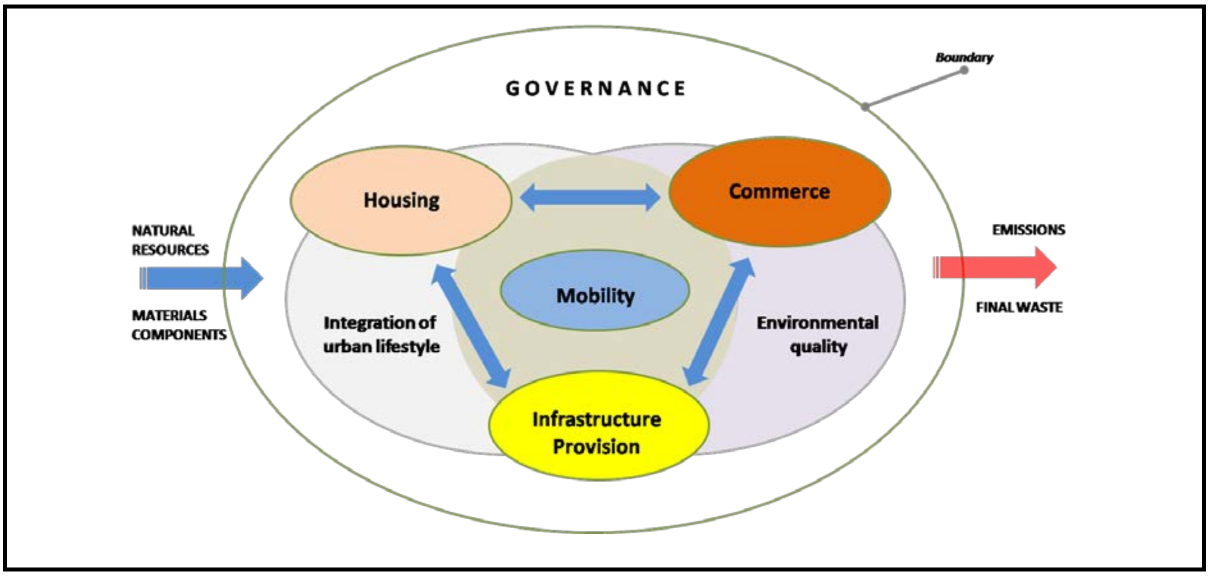


Figure 2-1. Complex functions and boundaries of an urban system.
Source: Adjusted and adapted, following Herfray et al. (2006); Lehmann et al. (2013); Koetter et al. (2016)

"The large cities are facing an exceptional degree of complexity within a network of dynamic ecological, social, economic, cultural, and political interrelations," (Eckardt, 2009, p. 25). Accordingly, the major innovations have to be understood within the institutions that plan for and manage the complex urban settlement system. The climate change community has mobilized some intellectual and financial resources for conducting theoretical and practical city scale case studies.

Based on computer simulations and the urban modeling reviews - urban systems and complexity theory demonstrate a marriage between urban simulation and complex systems analysis (Ruth and Coelho 2007; Geertman and Stillwell, 2009). However, major limitations remain where integration has be confirmed along three dimensions – such as (i) assessment of theoretical, empirical and simulation; (ii) application to location-specific issues with research and stakeholder knowledge; and, (iii) translation of results of complex urban change into a new theory and management approach (ibid). In general, the physical data demand, limited interaction between modelers and users, and assumption related hidden effects are frequently discussed challenges of urban system models. Similarly, the challenges of urban simulation and modeling in the context developing countries can be summarized in general terms: (i) lack of information on the range of options; (ii) lower applicability; (iii) higher uncertainty; and, iv) limited data availability and reliability (OECD, 2011; Beeck, 2003). The possibility to address future urban challenges within the offerings of complexity system theory can be realized after ensuring that "....the planner should be worked within complexity frame and people participation to establish specific future actions rather than technology focused modeling and simulation" (Byrne, 2003, p. 177). Many cities and urban think tanks have already been proposed and have implemented several new initiatives in order to tackle future urban challenges. Of course, there may be overlaps and conflicts in terms of uniqueness and innovative proposition.

2.2 A Multitude of New Urban Initiatives: Anarchy of Terms

Our complex urban system is going through a transition to make the built environment more sustainable by addressing energy and climate related challenges in all over the world. These new urban initiatives and transformative actions are focused on buildings, streets, bridges, neighborhoods, and cities; to become "sustainable", "smart", "resilient", "efficient", "neutral", "passive", "active", "zero", "nearly zero", "plus", "outstanding", "platinum" and many more terms that often create an anarchy of city categories.

Jong, et al. (2015) conducted a systematic survey of web literature published from 1996 to 2013. Using search words, a simplified result was presented after merging of many variations in the data with a single term (category) for each concept (Appendix A: Table 1). The "Sustainable City" category frequently appeared with a co-occurrence search result of twelve (12) categories in consideration of titles, abstracts and key words. "Smart City" often emerged in recent scientific discussion, at least in comparison to other categories, although criticism exists on the contribution of smart growth to social equity and specific environmental progress. The "Resilient City" category seldom appeared and lacked recognition from wide agents of theory; however, the concept "Resilient City" would arise with more optimal harmony between social equity, economic efficiency and environment goals.

2.3 The Discipline of Urban Planning for Resource Efficient Urbanism

In the late 19th century, "Urban Planning" emerged to facilitate massive industrial urbanization and its by-products (Freestone, 2000). The introduction of the urban planning discipline brought with it a variety of definitions, as discussed both in the academic literature and the practical world. The American Planning Association (APA, 2015) defines "Urban Planning" as follows:

"Planning (also urban, city and regional planning) is a dynamic profession that works to improve the welfare of people and their communities by creating more convenient, equitable, healthful, efficient and attractive places for present and future generations."

Urban planning historically borrowed theories and concepts from other academic domains; and therefore, overlaps exist. In fact, it is more a multi-disciplinary field of study than a unique technical or social science. In practice, urban planners deal with hardships quite often along unsteady nature, contradictions, paradox and tensions (Fischler, 2012). However, the dynamic nature of urban planning is recognized as a frontier in global environmental concerns.

Today, we are living in an “Urbanized” world. For the first time in human history, more than 50% of the world’s population is living in urbanized areas (UN, 2008), and two-thirds of the world’s primary energy is consumed by urban areas (IEA, 2008). The consumption of various natural resources besides fossil-based energy resources (e.g., water and land), and the influx of waste generation, triggered the need for providing infrastructure, transportation, supply support and modern urban amenities.

Over time, the conceptualization of urban energy interrelationships is becoming much more complex. The evolution of technological innovations and change are essential in order to leverage possibilities of appropriate action, clean energy integration and improved livability in urban area (Vandevyvere and Stremke, 2012). This also provides a pathway for making a direct connection to urban planning and requires careful review before further discussion.

The historical shifting of human civilizations have had a direct association in the energy source transition from organic sources (i.e., water, wind, sun) to large-scale fossil fuels. From the Industrial Revolution to the 1980s, the modern phase of human history began with an introduction of new energy sources, such as coal. The new form of urban development was influenced by the establishment of industrial cities near coal mining sites, and the invention of the steam engine followed by portable and controllable mechanical energy. The powered ships and locomotives had fuelled for the growth of cities of capitalism and colonialism (Peker, 2005; Newton and Bai, 2008). The introduction to oil-source energy use occurred with the development of the internal combustion engine. Electricity generation and use has been expanded to various processes such as heating, transportation, automobiles, and massive mechanization manufacturing. From World War II to the energy crisis of the 1970s, energy conservation and efficiency were not subjects of discussion, in either scholarly or policy domains (Wilson, 2013). Post-war reconstruction was accomplished in an energy-intensive way because of ample supplies, low prices, and economic prosperity (Lefèvre, 2009). Discussions about urban energy conservation and efficiency (e.g., both energy supply and demand) and the direction of urban development flourished for the first time after the 1970s era.

After the mid-1980s, energy conservation has been discussed together with environmental concerns (e.g., GHG, air pollution, acid rain, deforestation and radioactive waste). In the 1990s, climate change and global warming were highlighted as central topics at the Global Earth Summit in Rio de Janeiro. Since then, the UN-led international platform (i.e., IPCC and UNFCCC) has facilitated discussions on climatic hazards, predictions of loss/damage, and observations on vulnerability and mitigation/adaption options (Zanon and Verones, 2013; IPCC, 2007). Similarly, Our Common Future/Brundtland Report (WCED, 1987) recognized the low energy pathway and importance of renewable energy sources (Manfren et al., 2011). Also, environmental concerns and the fossil-free movement attracted political attention in international, national and local circles from the early 1990s. After the Berlin Climate Conference in 1995, the only legally-binding international commitment (i.e., Kyoto Protocol, 1997) aimed to reduce GHG emission under the provisions of market-based and innovative policy options, such as encouraging renewable energy sources, was adopted. More recently, the Paris Climate Conference of Parties (COP 21, 2015) agreed to phase out fossil-based energy sources and promised to reduce CHG emissions, but the agreement has been criticized due to its voluntary nature.

Many global large cities and local communities have set their visions toward 100% renewable energy futures. In fact, the phenomenon of resource-efficient urbanism is getting additional attention for transitioning to sustainability (UN-Habitat and ICLEI, 2009). Furthermore, future estimations indicate the urbanization potentials are very high in so-called emerging and developing countries. These countries in Asia, Africa and Latin America should be prepared with resilient urban structures that include careful consideration of energy concerns (i.e. supply source, demand and generation).

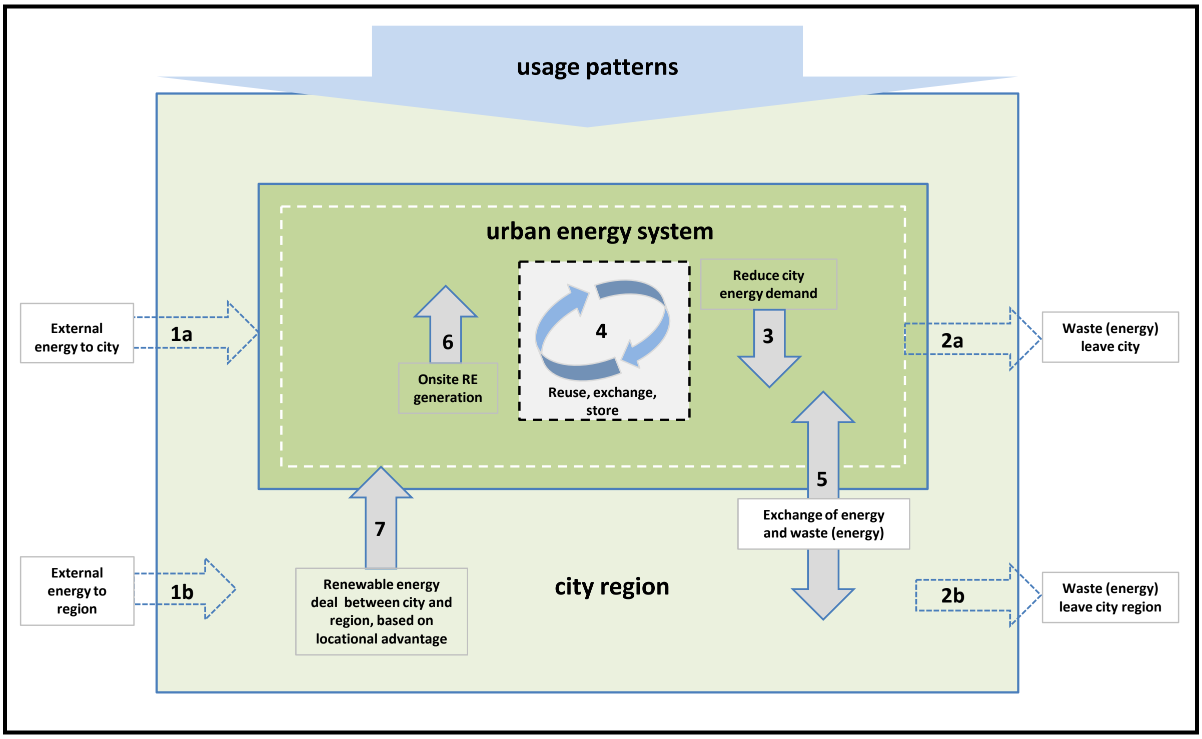


Figure 2-2. Theoretical model with urban energy system components and resilient city vision.
Source: Adjusted and adapted from Dobbelsteen et al. (2012)

Dobbelsteen et al. (2012) proposed a theoretical model for an urban energy system within the vision for resilient cities (Figure 2-2) under certain requirements, such as (i) energy and environmental metabolism; (ii) energy consumption and efficiency potential; (iii) innovative solutions; (iv) optimization of surplus energy use; (v) regional collaboration for energy; and, (vi) local generation (on-site and off-site). However, Dobbelsteen's model is limited as a first step draft in that it does not provide further elaboration in its efforts to test and validate in the context of emerging and developing countries. Some concepts have already been discussed in prior investigations on energy-efficient urban form and structure at varied scales. The high-waved investigations include: mobility energy-related urban density (Newman and Kenworthy, 1989), land use linked energy demand (Owens 1985) and the impact of urban form on residential energy (Ewing and Rong, 2008; Wilson, 2013) and carbon emission related to urban density (Gudipudi et al. 2016). Criticisms have been frequently raised about appropriate data quality, statistical methods, contexts and levels of uncertainty. In particular, Breheny and Gordon (1997) argued that "the density coefficient and its statistical significance decrease when the petrol price and income are included as explanatory variables." After all, Mindali et al. (2004) suggested a research need for detailing theoretical basis in regard to landuse and planning policy.

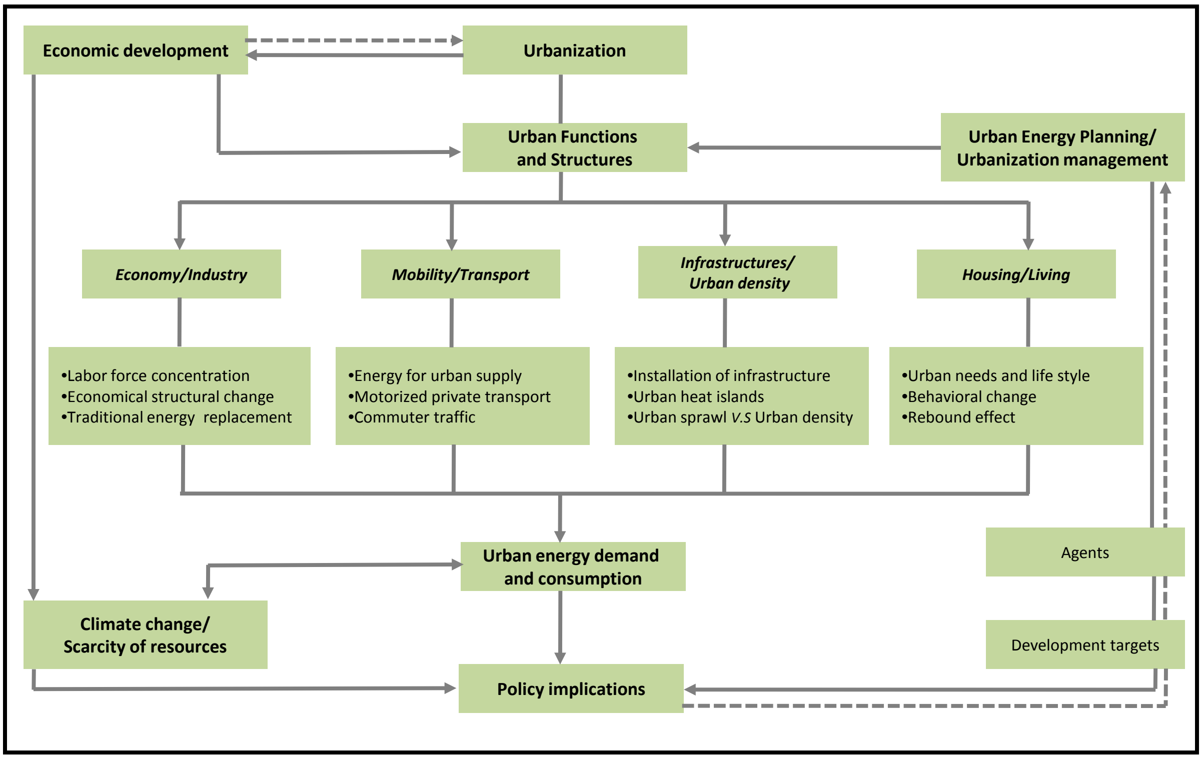


Figure 2-3. Impact of urbanization on urban structures and energy aspects.
Source: Modified and adapted from Madlener and Sunak (2011)

Madlener and Sunak (2011) illustrated a theoretical framework after conceptualizing the multi-scale interrelationships of urban structure that may lead to the multiple goals of the urban planning vision (Figure 2-3). In fact, the prediction of urban structural components has a significant impact that often suffers due to the emergence of uncertainties; however, urban scholars should remember Niels Bohr`s words, "prediction is difficult, especially about the future."

2.4 Causal Paths of Urban Structure vs. Energy Concerns

After a brief introduction to urban structure and energy aspects, this section elaborates a discussion on causal paths between residential form and energy concerns. In general, urban structure is characterized by physical features of the urban environment, such as land use, physical infrastructure, building typology and social infrastructure (Webster, 2007). Urban structures actually enable more energy-efficient means of housing and transportation than do rural structures (Schubert et al., 2013). Specifically, the causal relationships between residential built-up form, energy consumptions, and resident lifestyle patterns can be better elaborated with the physical artifacts, social variables and energy behaviors (Figure 2-4).

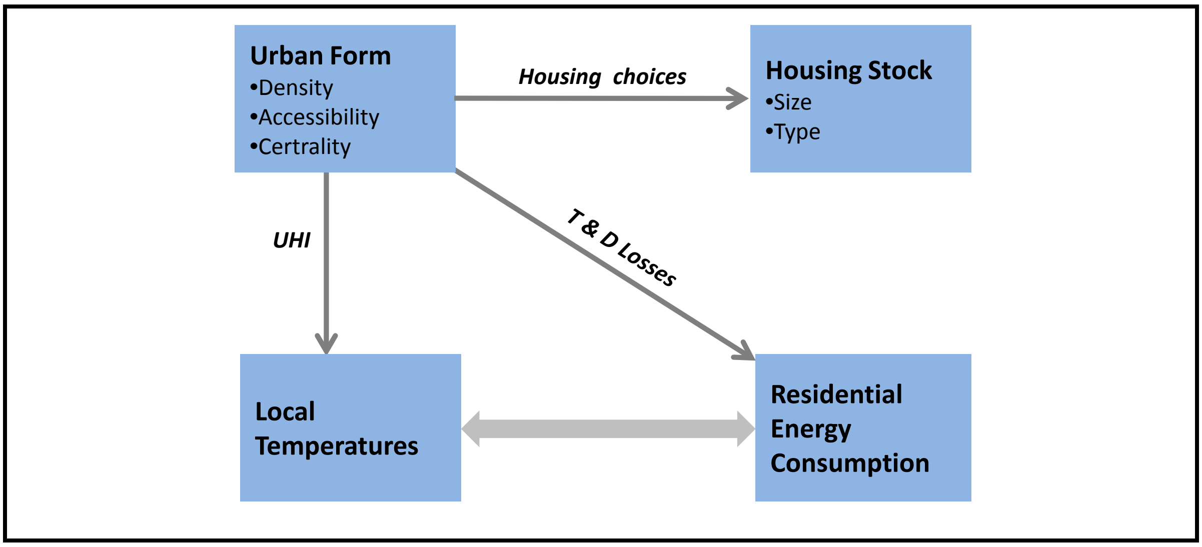


Figure 2-4. Causal path between urban form and residential energy consumption.
Source: Adapted from Ewing and Rong (2008)

At every scale, it is necessary to take a whole-system perspective of energy consumption within residential neighborhoods, and energy-related decisions and variables should be considered (Table 2-1). There are two (2) major decision hierarchies with specific characteristics and degrees of decision implications. They can be categorized as:

i) Landscape and infrastructure (i.e., long-term decision implications) including buildings.

ii) Appliances/equipment (i.e., short-term effects due to rapid upgrading).

Water and waste could be considered as ancillary, because they do not fit in any particular level of the hierarchy. Nevertheless, water and waste matters are highly relevant energy-related decisions that take place within the urban built environment.

Table 2-1. Structural variable at different scale that affects energy aspects.

Structural variable	Region	Individual settlement	Neighborhood	Building
Settlement pattern	⊗			
Communication network (external)	⊗			
Size	⊗	⊗		
Shape	⊗	⊗	⊗	
Communication network (internal)	⊗	⊗	⊗	
Density		⊗	⊗	
Interspersion of land uses		⊗	⊗	
Degree facility centralization		⊗	⊗	
Layout			⊗	
Building orientation			⊗	⊗
Sitting relating to micro-climate				⊗
Design				⊗

Source: Simplified and adapted from Owens (1986, p.5)

The concept of energy remains an abstract issue for planners, and the integration issue depends primarily on political awareness and institutional context. Within the broad vision of sustainable urban development, the internalization of energy optimization potential is gaining popularity in urban planning literature, both to save energy and to create vibrant urban built environments (Table 2-2). Indeed, one of the major obstacles to remain untouched is the inefficiency of laws and regulations to support energy integration (Duvarci and Kutluca, 2008). The energy parameters – particularly renewable energy aspects – have not been established in current planning practice, including assessment of urban development plans.

Table 2-2. Potential energy savings/demand of different urban functions.

Structural variables	Energy link/Mechanism	Effect on energy demand
Urban form	Travel requirements	20%
Land use design's	Travel requirements	150%
Mixed land use	Travel requirements	130%
Density/built form	Space heating	200%
Density/ clustering trip ends	Transit feasibility	20%
Density and mixed use	Neighborhood heat/Cool feasibility	30%
Layout orientation	Solar feasibility	20%

Source: Summarized from Owens (1986, p. 68) cited in Duvarci and Kutluca (2008)

Different parts of cities follow diversified pathways to achieve low carbon urban futures depending on their urban forms (Newton and Newman, 2013). Renewable energy will also have different pathways, meaning a combination of strategies may be necessary for facilitating a smooth transition of urban structure.

Built Environment Fabric		Housing	Transport
	Sub-urban	• Renewable energy technologies for individual buildings, e.g., solar PV • Neighborhood scale technologies	• EVs, hybrid, hydrogen vehicles and associated infrastructures • Smart buses
	Urban	• Neighborhood scale low emission energy technologies e.g., co-generation; tri-generation	• Public transit • Active transport (walk, cycle) • EVs, hybrid, hydrogen vehicles and associated infrastructures

Low/Zero Carbon Technologies

Figure 2-5. Low carbon technology interventions framework of the built environment.

Source: Adapted from Newton and Newman (2013)

The higher potentials of renewable energy resources are context- and scale-dependent (for example, solar or wind potential in the urban built environment) (Figure 2-5). Form-efficient development vision and more compact developments (including density, functional mix, and transit accessibility) can reduce average vehicle travel per capita by 25%-30% (Ewing and Cervero, 2010). Hence, an interdisciplinary and transdisciplinary approach is crucial for sustainable urban residential structure development with principal components such as harmonized subsystem, metabolism, resiliency and environmental impact.

2.5 Concepts to Approach Energy Concerned Urbanism

2.5.1 Urban metabolism (UM) models

Urban metabolism (UM) concept - was envisioned by Wolman (1965) and was further developed by Douglas (1983) - provide an analytical framework to understand the urban development impact with integration of city regions (Kennedy, et al., 2011). The definition of UM: “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste (ibid, p. 1965)". Newton and Bai (2008) illustrated an extended framework of UM concept on human settlement (Figure 2-6) where the trend of desired change are specified along system component and flows.

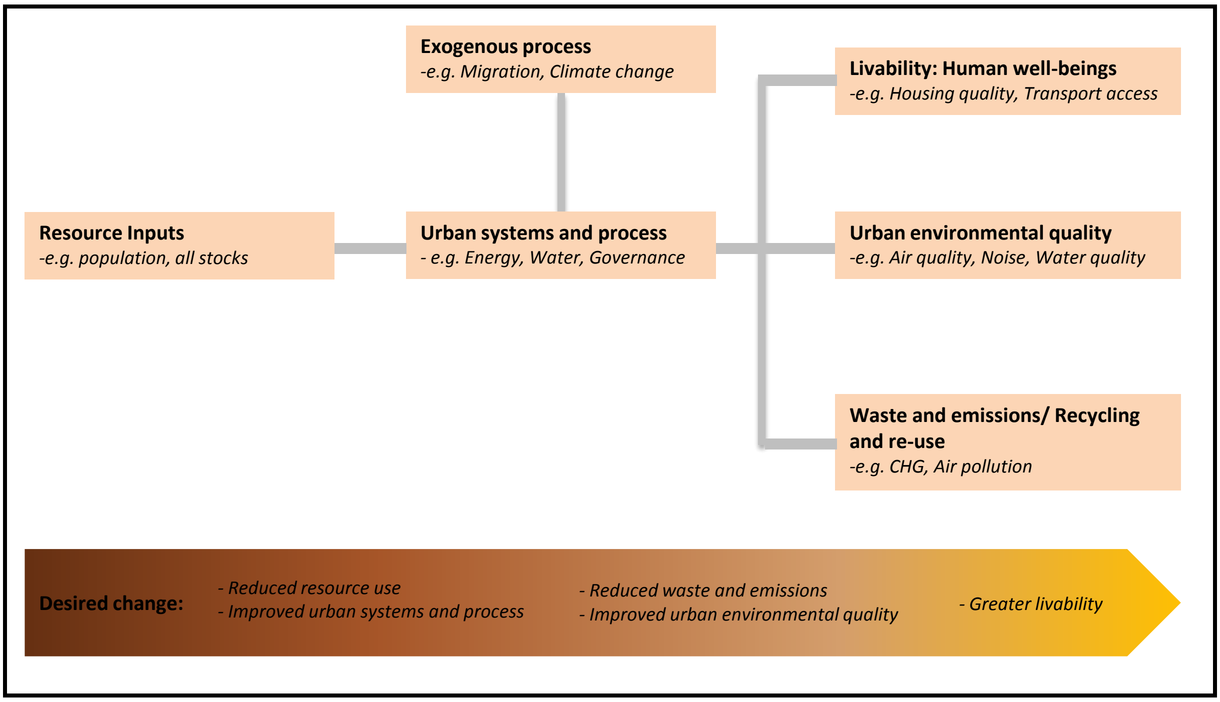


Figure 2-6. Extended urban metabolism model of human settlements.
Source: Modified according to Newton and Bai (2008)

Recently, a variety of analysis tools and decision support system models (DSS) have emerged based on the UM concept (Geertman and Stillwell, 2009), including the IUMAT sustainability assessment tool for an urban district scale (Mostafavi et al., 2014) and a scenario-based DSS tool for European cities (González et al., 2013). Pincetl et al. (2012) proposed an expanded UM framework for assessing urban energy processes and causes, but struggled to acquire and synthesize data. In fact, the potential application of UM is a relatively new development, especially in the urban planning and design context (in review: Kennedy et al., 2011). Challenges remain as to how to design urban metabolism for facilitating sustainable urban development. Similarly, the comprehensive application of the UM concept is quite challenging for many developing countries, because most of them are unable to provide detailed data support that is crucial to feed all components of the framework.

2.5.2 Integrated land use-Transportation energy models

Reality can be simplified with models because they apply abstract theories to represent a system. Over the last 50 years, urban theories have been translated and tested in form or urban model rather than by experimentation on the real world, due to rapid progress in computational abilities of urban functions. The emerged urban models can be categorized into 3 subclasses, apart from the theoretical equivalents under the consideration of the pragmatic structure (Batty, 2009; Reiter and Marique, 2012). The general subclasses are: (i) Land Use-Transportation Models (LUTs); (ii) Urban Dynamics Models; and, (iii) Cellular Automata (CA), Agent-Based Models (ABMs), and micro-simulation.

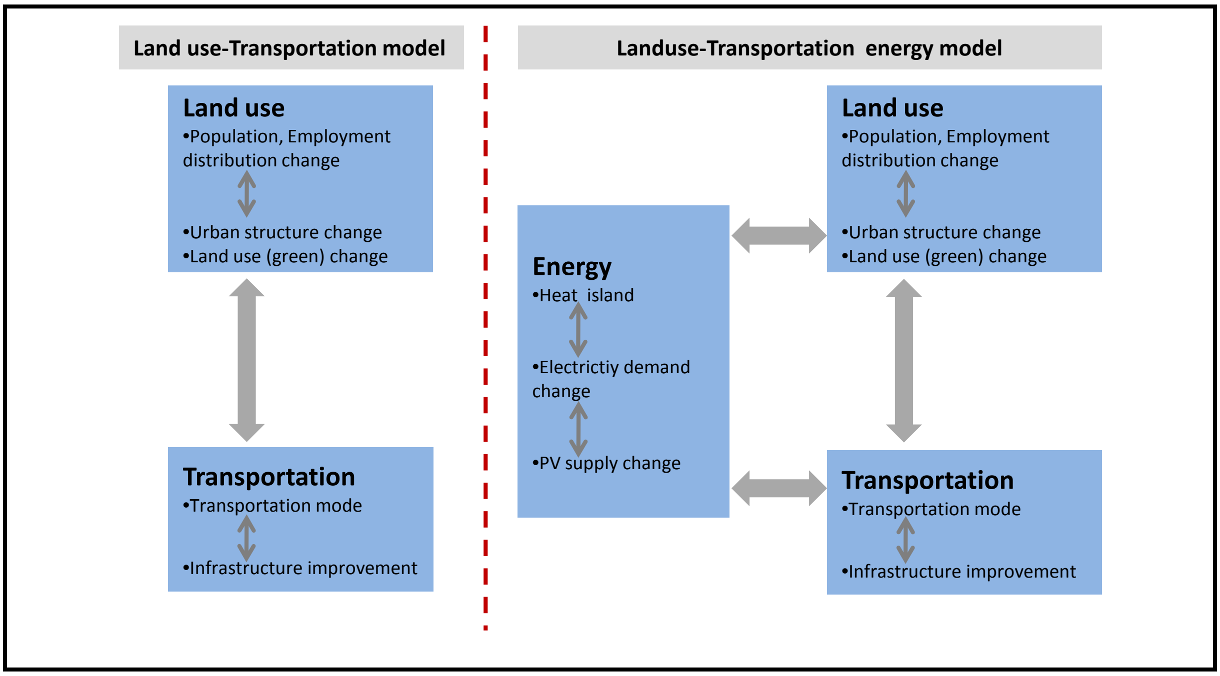


Figure 2-7. Concept of possible interaction between land use-transportation and energy.
Source: Adapted from Yamagata and Seya (2013)

The landuse-transportation models have been continually developing around the static economic and spatial interaction models since the first empirical idea given by Lowry's work in 1965. These days, entire activity patterns of cities have been incorporated within such LUT models – for example, the UrbanSim Model (Batty, 2009). The integrated land use-transportation model has emerged with the addition of energy components, with traditional models (LUTs) including renewable sources (i.e., solar PV). Yamagata and Seya (2013) applied the landuse transportation energy model for designing a future smart city (FSC). Scenario modeling has been adapted to visualize interactions among smart city components, such as compact form, smart grid, solar energy and many more (Figure 2-7). Limitations remain due to data availability for city-scale land use-transportation energy modeling – in particular, for the prediction of dynamic solar energy and transportation modeling.

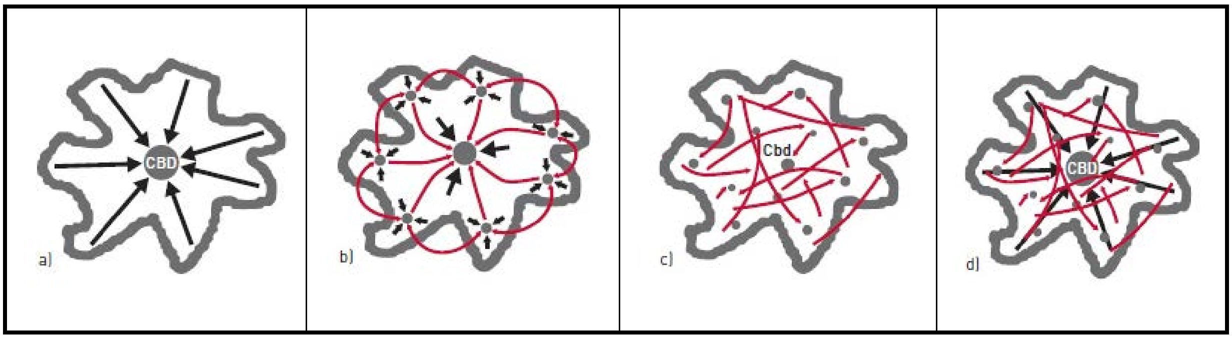


Figure 2-8. Typology of urban mobility in relation to CBD.
Source: Adapted from Lefèvre (2009)

City-scale modeling often deals with two-level energy consumption estimation, such as (i) residential building energy; and, (ii) transportation energy of residents. For determining residential energy reduction strategies, the typology of movement and activity mix also matter, having long-term decision implications (Reiter and Marique, 2012). There are 4 types of basic urban movement or mobility models (Figure 2-8): a) Monocentric; b) Polycentric (i.e., urban village); c) Polycentric model (i.e., random movement); and, d) Mono-polycentric (Bertaud, 2001, cited in Lefèvre, 2009). Given this typology of urban mobility models, various studies argue that more compact urban forms would significantly reduce energy consumption both in the building and transportation sectors (Ewing et al., 2008; Steemers, 2003). Although top-down and bottom-up modeling methods are widely used to predict energy consumption on a larger scale (i.e., national predictions), difficulties exist as to how to generalize the results in order to determine the best strategies on an urban scale.

2.5.3 Zero energy framework: Low carbon technology intervention

The net zero energy frameworks facilitate to find a balance or trade-off among energy consumption and generation. O'Brien, et al. (2010) has illustrated a city scale trade-off between energy production (i.e. solar potential) and energy consumption in varied housing density within the consideration of net zero-energy goal (Figure 2-9). In density term, there is a paradox exist in such relationship - "Per capita solar energy potential decrease as density increase". In fact, the empirical investigation shows that in a low density housing development use almost three times more energy than high density and thus contribute lower net energy.

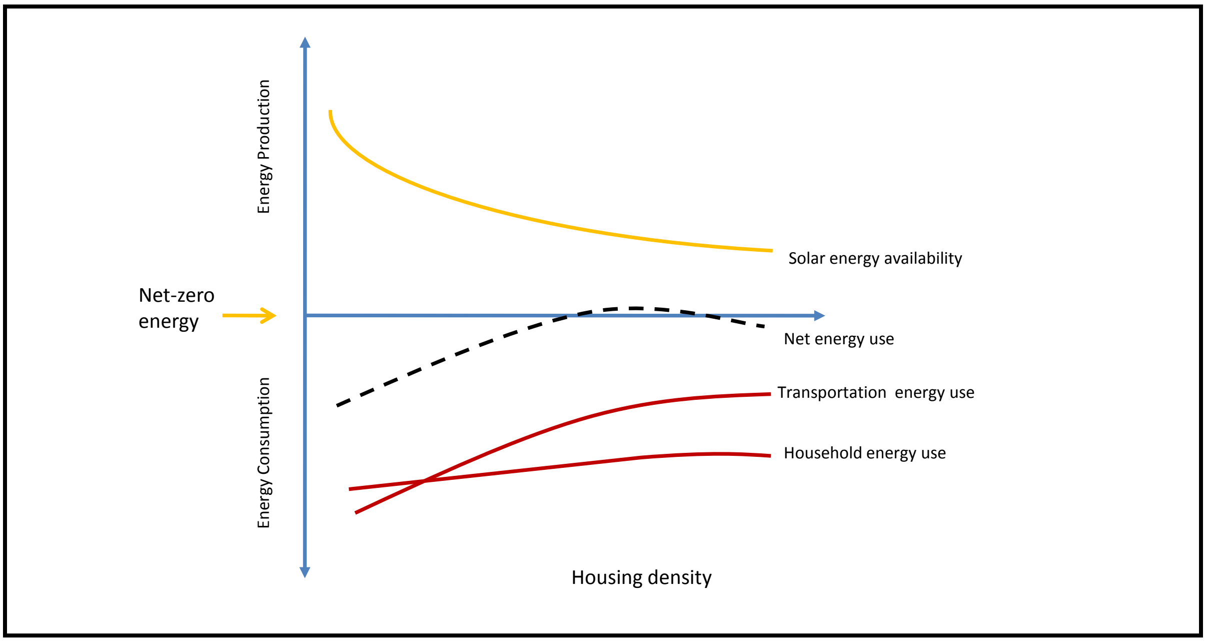


Figure 2-9. Trend in energy use/solar availability vs. housing density.
Source: Adapted from O'Brien et al. (2010)

Zero energy building (ZEB) is already popular in order to mitigate GHG emissions and is receiving growing attention in different parts of the world. There are two types of scale-dependent concepts: (i) net zero building (NZB); and, (ii) zero energy neighborhood (ZEN). NZB is often called zero energy building (ZEB). Marszal et al. (2011) presented a comprehensive review of the concept, definition and calculation method of ZEB. The first challenge to further international massive integration is agreement on a common definition, after addressing issues such as: (i) balance metric; (ii) balancing period; (iii) energy use type included in balance; (iv) type of energy balance; (v) acceptable RE supply options; (vi) connection to infrastructure; and,(vii) energy efficiency requirements. An additional challenge is the development of a set of precise methods for computing energy balance (ibid); however, ZEB accountings do not usually include the resident's transportation energy consumption. Measures are necessary in addition to building retrofitting efforts and interactions linked to a metropolitan as well as an urban planning scale. The location of new or retrofitted buildings and developments are key to the total energy balance, including both building and transportation energy consumptions.

At a neighborhood scale, the zero energy neighborhood (ZEN) concept considers residential transportation or mobility energy use in balance accounting. Marique and Reiter (2014) proposed a simplified "net zero energy neighborhood" (nZEN) framework that defines and computes the balance of annual energy consumption for buildings and residential transportation. The proposed energy balance accounting included all potential sources (i.e., solar, wind, geothermal) for generating on-site renewable energy. The existence of a compatible electric grid is one of the important assumptions of the nZEN framework. Certainly, further efforts are necessary, including exploring the impact of urban form on energy needs in relation to on-site or off-site renewable energy production (Figure 2-10). The challenges has to take in account about locational relations of energy transportation.

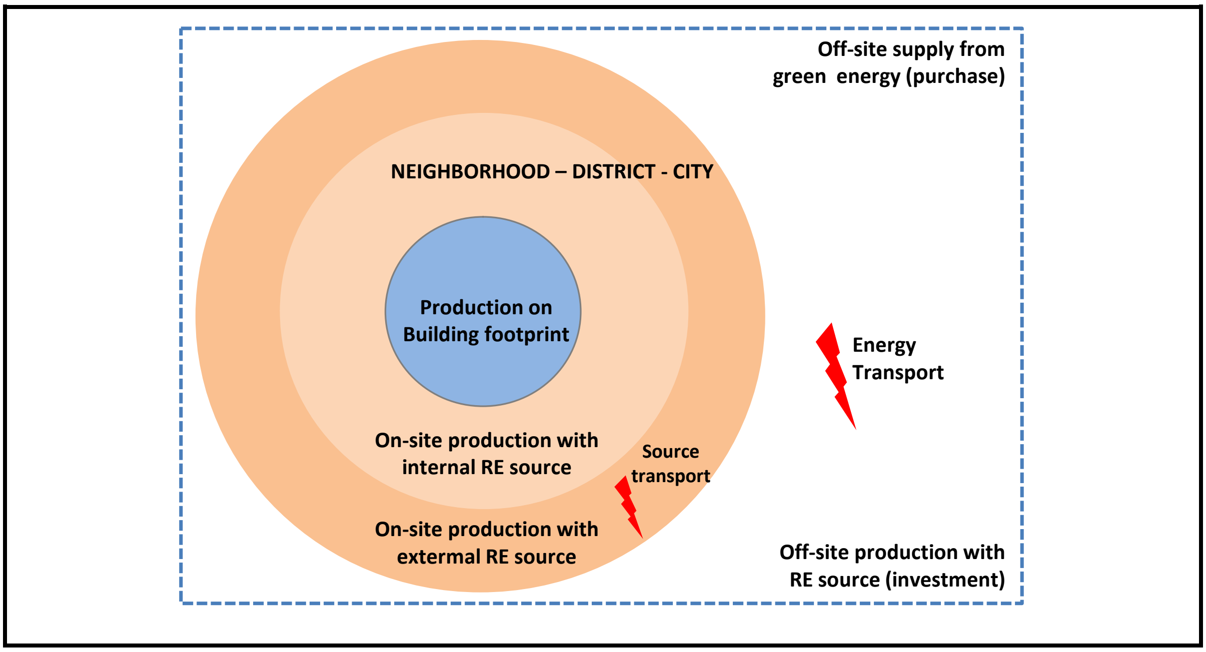


Figure 2-10. Spatial dimentions of potential renewable energy production and supply options.
Source: Modified by following Marszal et al., 2011

There are many innovative technology choice options for renewable energy sources in the combination of off-site and on-site solutions. The International Energy Agency (2009) illustrated detailed visionary urban renewable energy mix options for a municipality transitioning to sustainability (Appendix A: Figure 1). It was an attempt to address the frequently asked question of policy makers, "Which is the optimal choice of technology options, or mix of options?"

2.5.4 Solar urban planning framework: Parametric approach

Apart from holistic sustainability-focused frameworks and concepts, domain-specific approaches are growing in planning literature. For example, in the area of renewable energy (i.e., solar) centered urban planning, Amado and Poggi (2012) proposed a framework for energy-conscious urban planning they named “sustainable solar urban planning”. It stressed the integration potential of energy aspects from top to bottom in the planning process. An empirical case study of an urban neighborhood in Portugal showed that such a framework could facilitate a ZEB vision by maximizing solar access (Figure 2-11). However, one of the major drawbacks of this framework was the exclusion of resident's transport-related energy consumption. The urban planning framework needs to be integrated with residential e-mobility goals that might have strong influences on alternative decision-making during the planning process.

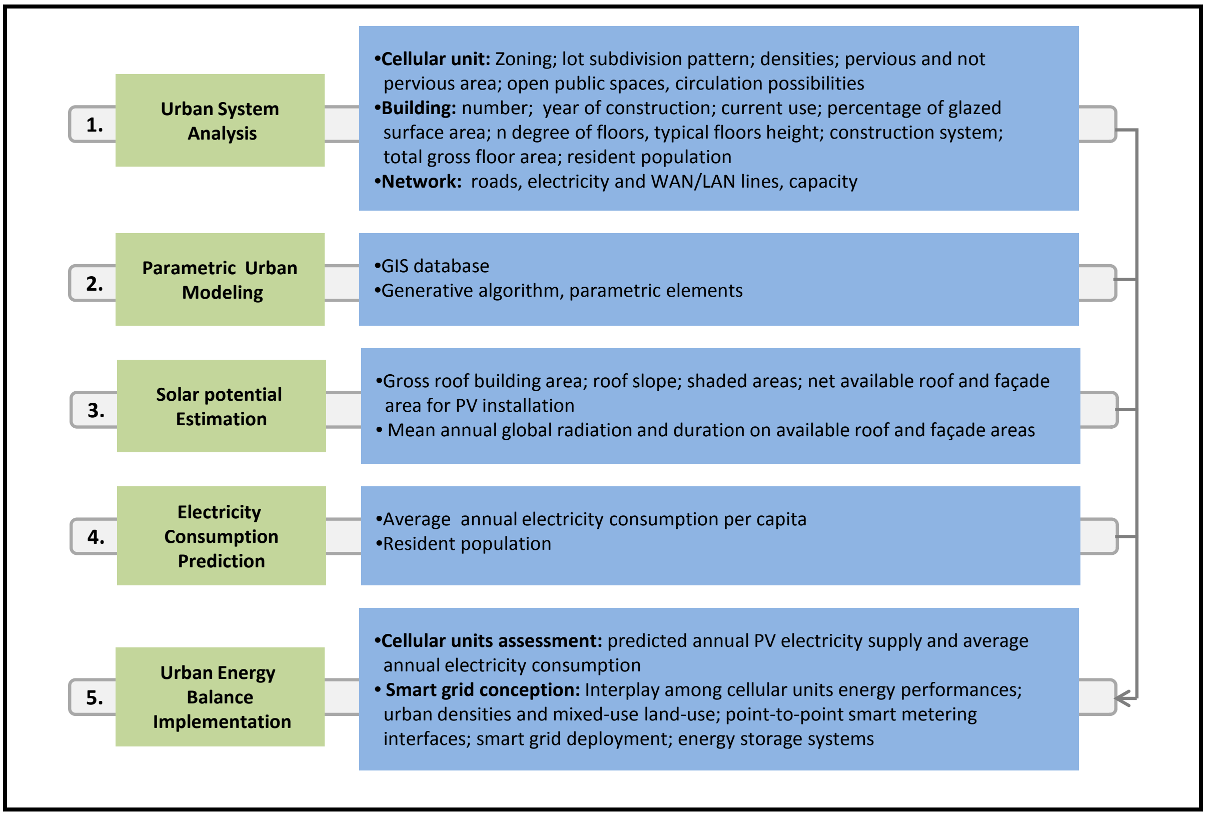


Figure 2-11. Parametric solar urban planning: A methodological framework.
Source: Adapted from Amado and Poggi (2014)

Solar integration into urban planning has two effects: passive and active. For a long time, passive solar issues have been discussed in urban form and building design studies (Cheng and Steemers, 2006; Compagnon, 2004; Košir, Capeluto, Krainer and Kristl, 2014; Martins, Adolphe and E.G. Bastos, 2014; Stevanović, 2013). The discussion of active solar issues (energy generation in the form of electricity or thermal) is a comparatively new development (Amado and Poggi, 2014a; EnergyAgencyNRW, 2008; Hachem et al., 2012; Marique and Reiter, 2014; Wiginton et al., 2010). In fact, many empirical studies suggest solar urban planning can also be influenced by the daylight factor, plot ratio, site coverage, horizontal obstruction and sky view factor (SVF) for harvesting the potential of urban solar resource (Cheng and Steemers, 2006). Apart from urban planning studies, mapping studies of urban renewable resources (e.g., solar, wind, geothermal) are also providing important insights for formulating sustainable urban development strategies and transitions for the urban built environment (Compagnon, 2004; Kabir, Endlicher and Jägermeyr, 2010; Kanters, Wall and Kjellsson, 2014; Santos et al., 2014).

2.5.5 Evolutionary optimization approach: Site scale

The total energy consumption of cities had significant influence on early urban design decisions. In contrast, the decisions could be optimized by balancing minimization and maximization goals. For example, the site scale energy performance should be used to maximize possible solar gains. Similarly, the building site design should be investigated early in the decision process because road layouts can affect the building shape. Furthermore, the primary energy demand can be reduced by optimizing building placement, shape and envelope design (Tereci et al., 2010). Optimization needs to occur at multiple levels, including building planning, site planning, community planning, and urban planning (Figure 2-12).

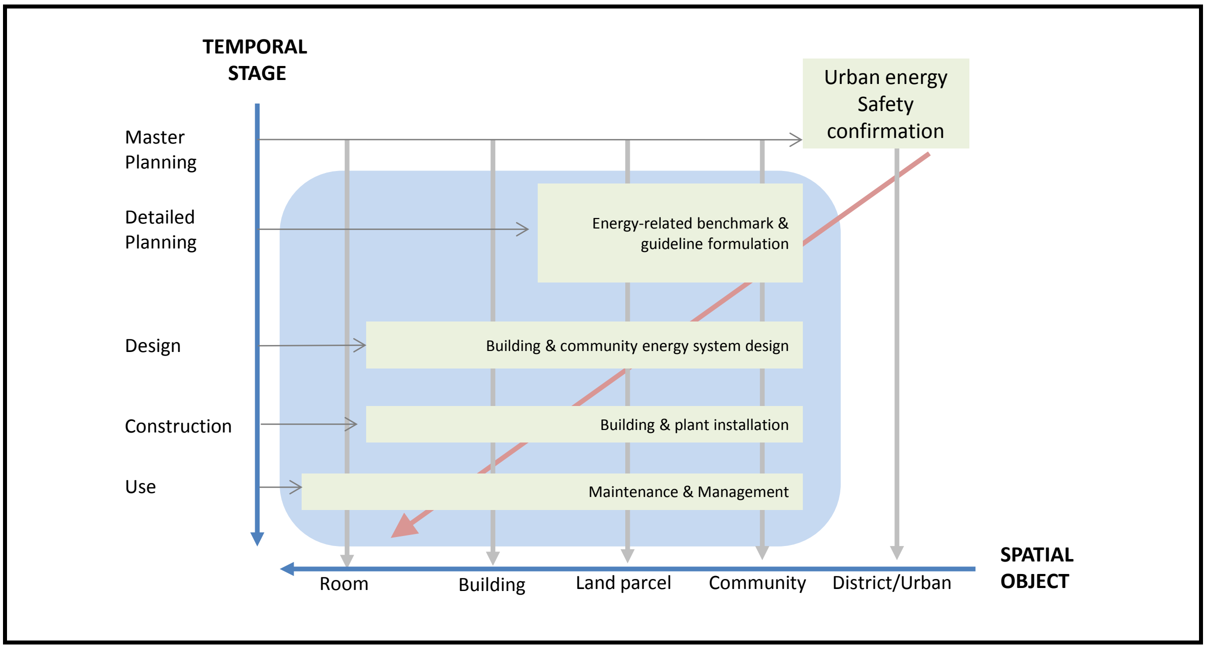


Figure 2-12. Concept and tasks of Community Energy Planning (CEP).
Source: Adapted from Huang et al. (2015)

Huang and Yu (2014) proposed the integrated community energy planning (CEP) framework for supporting a long-term strategic planning process. CEP facilitates a hierarchy structure of energy-related decisions from the community or neighborhood to urban scale. CEP has been validated for optimizing the heating energy footprint of a Chinese city and was found to be valuable in providing assistance and suggestions to system designers.

Many energy integrated urban design studies have also proposed several concepts with empirical applications: passive solar optimization in building design (Stevanović, 2013), building site layout (Ansary and Shalaby, 2014), urban built from optimization (Martins et al., 2014) and urban layout optimization framework (Vermeulen et al., 2015). In fact, critical reviews observed a commonality among studies in using advanced analytical tools, but these tools may be challenged in the urban context of many developing countries.

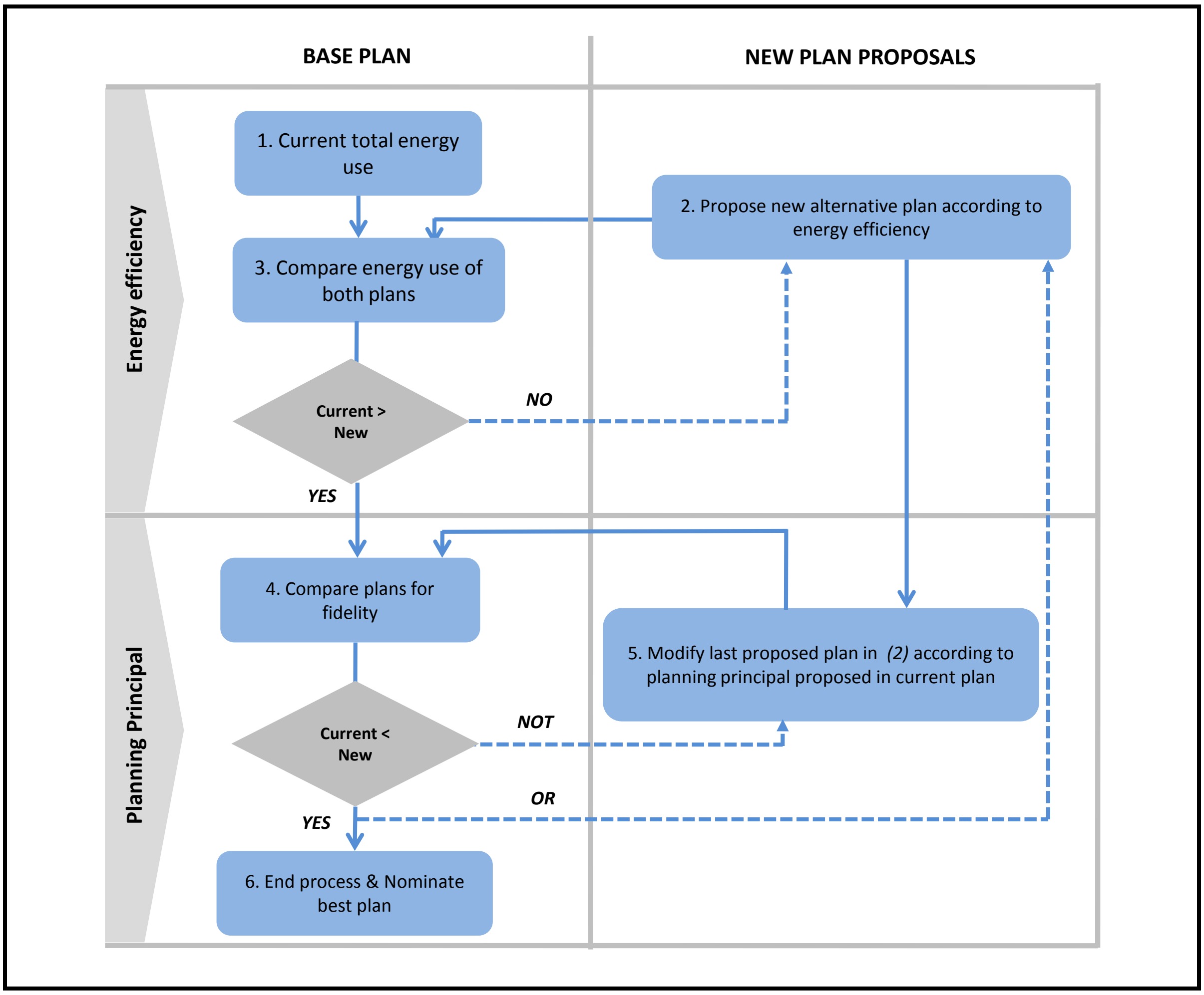


Figure 2-13. Steps of energy sensitive plan evaluation process.
Source: Modified according to Duvarci and Kutluca (2008)

The concept of energy optimization in urban planning has similarities to the energy sensitive urban planning approach. Duvarci and Kutluca (2008) outlined a methodology called "the process of energy sensitive plan evaluation." In logical form, the base plan and new alternatives proposals have to be evaluated under the planning principles and energy aspects (Figure 2-13). The goal can be set as energy efficiency at the first level, but energy optimization aspects can also be added. Urban energy planning, along such issues, needs more research on planning process, methods and tools in the local complexity context of urban system.

2.6 Summary of Theoretical/Conceptual Framework

A theoretical framework includes a generalized set of idea and models on which a study is based. The conceptual framework is the outfitted form of theory. Chinn and Kramer (1999) defined a concept as an "image or symbolic representation of an abstract idea" or a "complex mental formulation of experience". Miles and Huberman (1994) defined a conceptual framework as a visual or written product, one that "explains, either graphically or in narrative form, the main key factors, concepts, or variables and the presumed relationships among them" (quoted from Maxwell, 2005, p. 33).

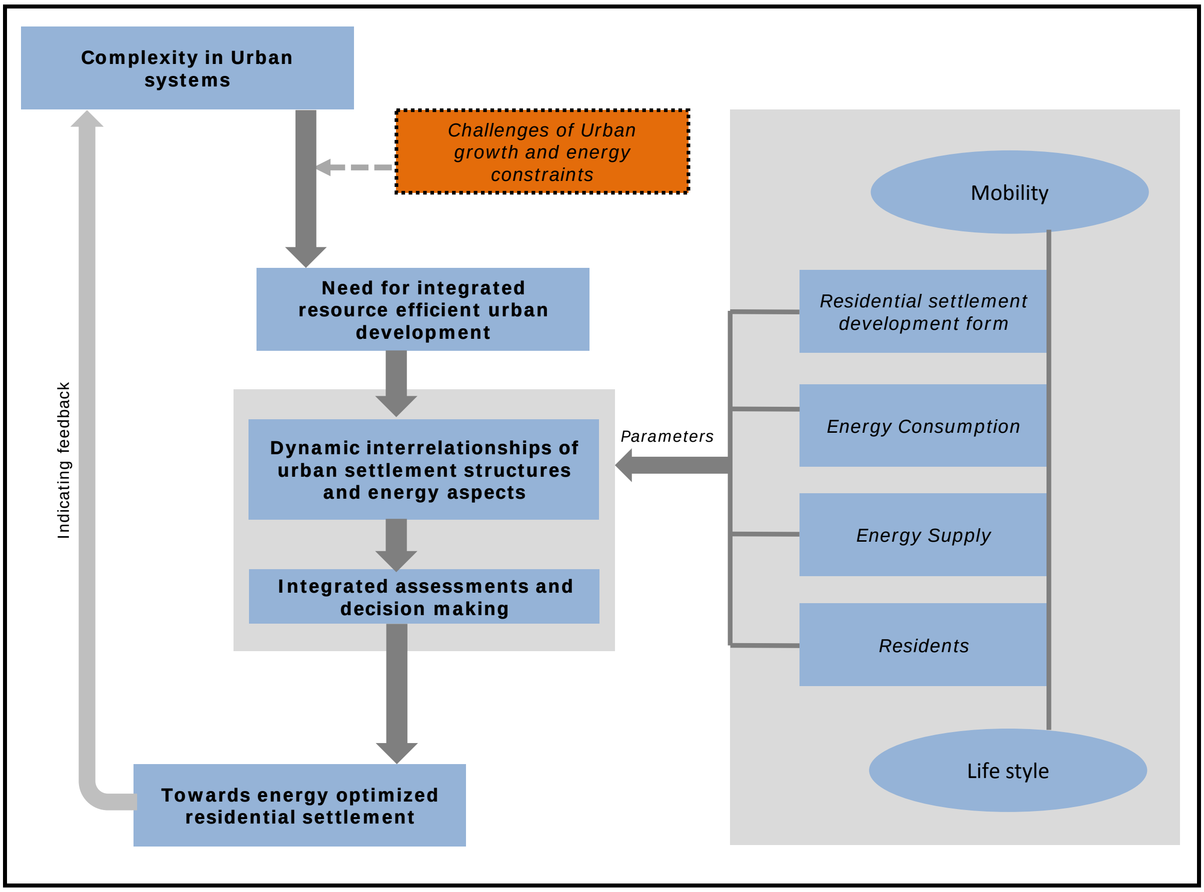


Figure 2-14. Overview on research concepts and contextual considerations.
Source: Author's own

The above theoretical and conceptual discussions represent a scientific overview of energy concerned urban planning aspects. Lengthy discussions were synthesized to guide next steps. A five-stage organizational model has been drafted for analyzing the interrelationships of urban settlement structure in the context of Dhaka city (Figure 2-14). In the first stage, the urban system complexity and need for integrated urban development under the challenges of rapid urban growth and energy constraints have been conceptualized. Second, the interrelationships of urban settlement structure, focused on energy-related parameters, are investigated. Third, the urban and energy planning process has been evaluated with the case of urban residential settlement development. Finally, an integrated decision support tool is proposed to feed energy optimization aspects in the early stages of planning project assessment.

A systematic and logical approach to workflow can guide research towards achievement of its desired goals. A multifaceted research design has been adopted in this study, comprising both qualitative and quantitative methods to answer the research questions. This chapter discusses a step-by-step, complete picture of the research methods, analytical process and data sources used.

3.1 Method of Indicator Identification: eDPSIR Framework

3.1.1 Systematic process of causal network building

One of the major study goals of this study is to select indicators for energy optimization in urban development based on the local context of urban form, mobility and resident's lifestyle. Researching key research domains yielded a large number of indicators in the literature (Appendix A: Figure 3) – the challenge was to decide on a set of significant indicators. In this regard, an integrated method was adopted along a composite and systematic indicator selection process (Figure 3-1). The eDPSIR framework adopted building a causal chain network and used the network to identify concrete indicators (see also Reed et al., 2006, p. 408). In addition, indicators were filtered with the help of expert opinion survey.

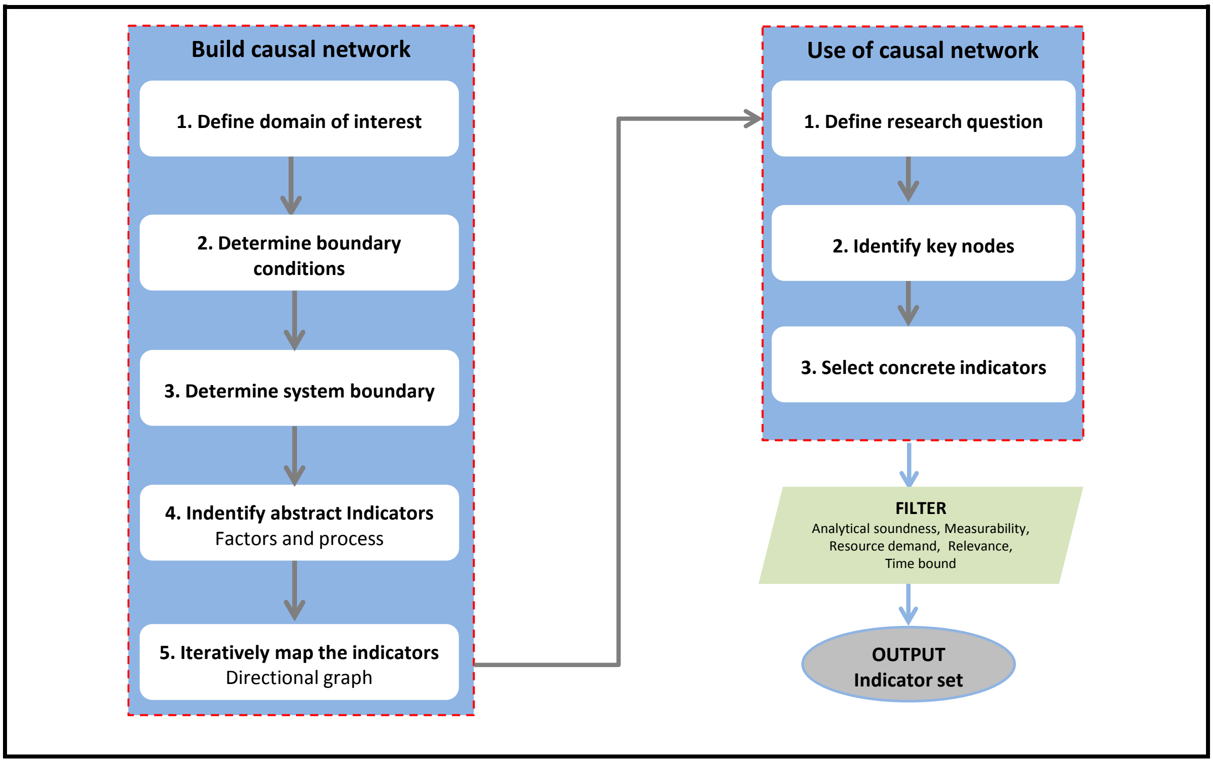


Figure 3-1. Systematic indicator selection process.
Source: Author's draft inspired by Niemeijer and de Groot (2008) and Schetke et al. (2010)

A comprehensive indicator selection framework, based on the causal network concept, was proposed by Niemeijer and de Groot (2008) and named Enhanced Driving force, Pressure, State, Impact, Response (eDPSIR). The main focus of eDPSIR was on the set of indicators as a whole, instead of on individual indicators. The authors strongly argued that the current practice is not transparent enough, over-emphasizes individual characteristics rather the functions of the indicators, and overlooks interrelationships within an analytical problem-solving logic. The strength of the causal network concept was described as follows:"...the concept of causal networks can facilitate the identification of the most relevant indicators for a specific domain, problem and location, leading to an indicator set that is at once transparent, efficient and powerful." (ibid).

i) Build a causal chain network: There are five steps for building a causal chain network. Taking this research context into consideration, each step is briefly discussed below.

a) Define the domain of interest. The specific research issue has to be defined as a domain of interest. The state of art has directed the research interest towards the interrelationships of urban settlement structure and the energy optimization in urban development domain.

b) Determine boundary conditions. The concerned and specific systems need to be identified. This study investigated components of urban structure in light of dynamic energy aspects, within the local context of Dhaka city, Bangladesh's capital.

c) Determine the system boundary. The boundary of the system has to be defined, including the selection of inputs and outputs. The study unit boundary was set as urban scale (higher level) and neighborhood/community (lower scale).The specific topics have been identified as urban spatial form, electricity consumption, on-site renewable energy production and resident's working mobility. Specifically, the system considers: (i) the impact of energy uses and the on-site renewable energy potentials, and (ii) energy consumption for personal mobility in relation to the resident's life style. Outside systems are not included, such as rural settlement structure, effect of natural disasters, environmental migration, life cycle of building materials and others.

d) Identify abstract indicators. This is one of the flexible steps in building a causal chain network. Initially, a very broad conceptual exercise is conducted to align every abstract indicator. It helps to apply the eDPSIR framework by starting with the pressure and then moving forward with state, impact, response and then the driving force. This study limits use of energy by residents as a pressure, whereas response issues are optimization topics such as energy use, on-site renewable energy generation and effective urban planning. The details of significant indicators, process and factors were less important to identify at this level. Nevertheless, it is a preparatory but pre-requisite step to facilitate the mapping process of the causal network.

e) Iteratively map the causal chain network. An end product - a causal chain network map - is drafted at this step. To do so, the previous results are arranged into pressure interface of interest, environmental and social dimension. There are three dimensions: energy consumption, settlement, and society. Afterwards, the sub-components are arranged under appropriate categories and blocks, and finally directional linkages are drawn to link each component. It can be hard to decide on directional lines and the arrangement of abstract indicators among different dimensions, categories and blocks. Besides eDPSIR examples, this study introduced two-directional links to connect dimensions instead of one-direction links (Figure 3-2).

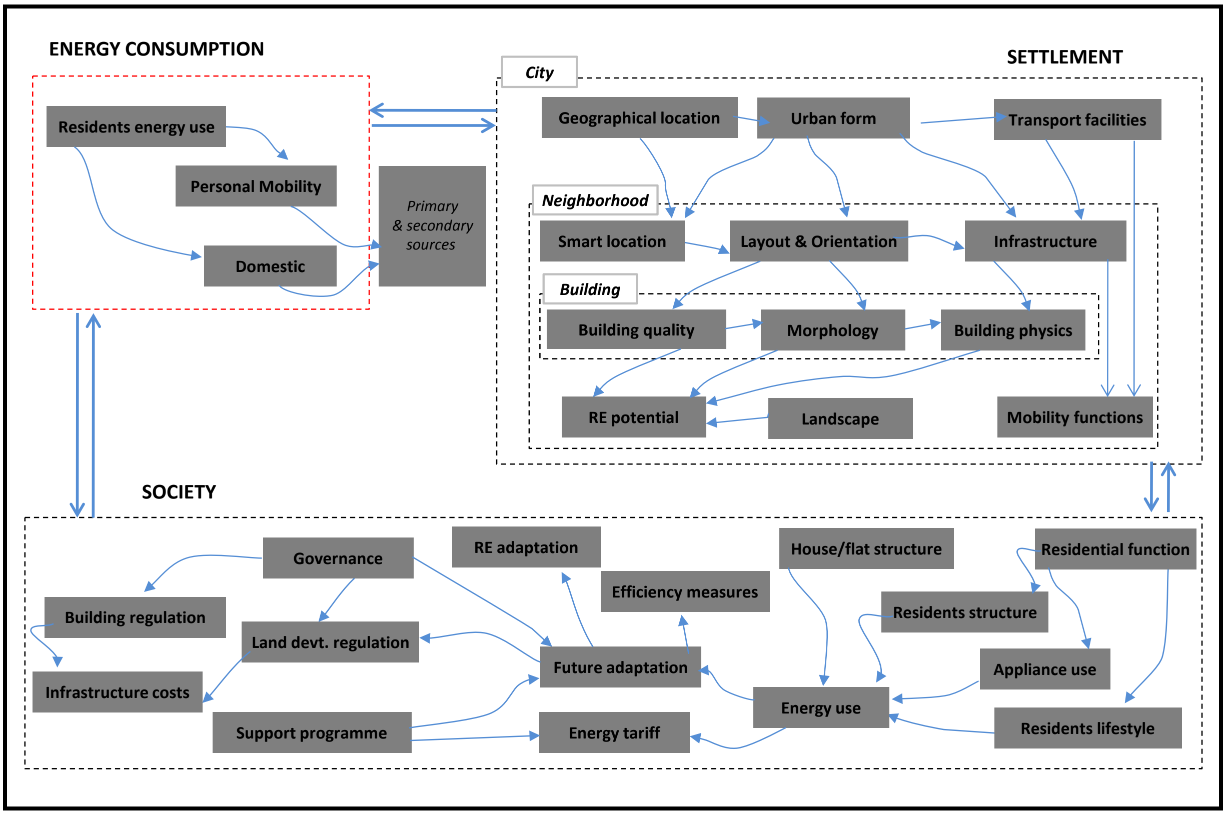


Figure 3-2. A simplified map of causal chain network.
Source: Author's draft followed by eDPSIR framework of Niemeijer and de Groot (2008)

<u>**ii) Use of the causal chain network:**</u> The resulting causal chain network is used from this point forward. The steps followed are:

a) Define research questions. It is necessary to formulate and contextualize the research questions so that the goal to find out a concrete set of indicator will be achieved (OECD 2003). At this point, the domain of research interest also has to align besides other issues such as data collection advantages, quality and scale; in order to answer the general research question - "impact of energy optimization in urban development planning in the context of Dhaka city". However, the systematic brainstorming has been conducted by asking - what is the extent of urban structure and energy aspect related information is available and accessible for achieving research objective.

b) Identify key nodes. This step highlights a significant portion of the causal chain network, leading to the next step of selecting concrete indicators. There are three node types: root, central, and end. Examples include: geographical location (root node), layout and orientation (central node), and renewable energy potential (end node). The end nodes are most useful because they can indicate a domain of interest, such as solar energy potential and energy use for working mobility. The eDPSIR framework suggested two strategies that could be followed: 1) search for additional indicators, and 2) move backward through the network. The second strategy was followed in order to come up with as few indicators as possible.

c) Select concrete indicators. After identifying logical key nodes and abstract indicators, this study was integrated with pre-reviewed indicators and variables that emerged from similar scientific studies (Stoeglehner et al., 2011; Wilson, 2013; Martins et al., 2014; Kötter et al., 2008; Schetke et al., 2012; FFG, 2009). A list of 41 indicators was identified after removing overlaps or similar expressions. In the next step, a filtering process was applied with combinations of typical indicator selection criteria in order to fine tune the indicator list. It should be mentioned here the total scores from the filtering exercise were not blindly taken in consideration; rather, cause and effect relationships played an important role. In fact, the risk of drawing wrong conclusions was kept to a minimum by including even some low-scored indicators under eDPSIR guidelines.

d) Filtering of indicators. The filtering process has a significant impact on the indicator set, especially in practice-oriented research and tools development (Schetke et al., 2012). The application of expert opinions or stakeholder participation during the filtering process may better help to evaluate some key issues, such as local data, regulations, planning standards and other context specific limitations. A filtering operation was performed by means of an expert opinion survey; therefore, the indicators could best reflect on the local context of the research goal (Figure 3-3).

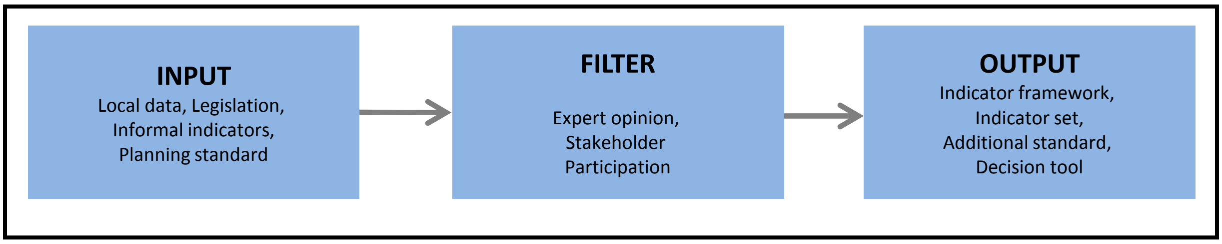


Figure 3-3. Structure of the process for developing indicators.
Source: Modified from Schetke et al. (2012)

A variety of experts facilitated efforts to capture a diverse understanding of urban planning and energy aspects in the context of Dhaka. The snowball principle was adopted to reach experts from different background and skills. First and foremost, key experts were identified and asked to recommend additional experts. Experts contributing to this research included staff from local urban organizations, professionals and academic researchers.

The online survey tool “Survey Monkey” (www.surveymonkey.com), which has good technical compatibility, was used to collect expert opinions. A set of indicators, along with selection criteria, was systematically arranged on the interactive platform of the survey tool and distributed to the selected experts (two rounds) via email communication and social networks (Appendix B). The survey had provisions that allowed the experts to add indicators based on their own judgment and experiences.

Many indicator selection criteria exist in literature. After evaluating 17 studies, Tanguay et al. (2010) aggregated a total of 68 indicator selection criteria with limited descriptions. Similarly, in another review, Niemeijer and de Groot (2008, p. 18) listed 38 indicator selection criteria with detailed descriptions and frequency of use. Only five such criteria have been adopted very frequently in systematic indicator studies. This study used only four selection criteria for the expert opinion survey and a fifth one (e.g., resource demand) was added at the researcher’s discretion. Brief explanations of the five criteria are as follows:

a) Analytical soundness. This expresses the state of theoretical foundation in terms of technical and scientific considerations, where literature and experts determine the scientific strength according to the validity and conceptual basis of an indicator. Damm (2009) suggested integrating the subjective opinion of the researcher as a dependent control factor for the degree of analytical soundness, because the full validity is difficult to guarantee and not easily measurable.

b) Time bound. This refers to the sensitivity to changes within the policy time frames. Particularly, the evaluation of completeness and response to change are matters of certain date and time.

c) Measurability. A crucial one in local context, as there might be some key indicators for which the issue of measurability (qualitative or quantitative) can be almost impossible to address. The accessibility to data is important. For example, there may be public data available, but the barriers to accessing the data may be great due to cost and/or bureaucracy.

d) Relevance. The research issue and target audience have to be justified for an indicator. An indicator can be included despite poor understandability when there is an urgent need for reaching the overall research goal. OECD (2003) stressed user perspective, comparability, and simplicity when conceptualizing relevance.

e) Resource demand. It indicates achievability of research goal in terms of available resources such as budget, time frame and manpower. The researcher has an important role to assess such practical issues without negotiating desired research output.

Table 3-1. Rank value for evaluating potential indicators.

Rank	Very low	Low	Middle	High	Very High
Value	1	2	3	4	5

Source: Adopted from Damm (2009)

Each indicator was evaluated by using the listed ranks (Table 3-1). Each indicator had an equal opportunity to be included in the final list if it satisfied a certain threshold of the aggregated evaluation score. The following formula was used to calculate the aggregated evaluation score:

Box 3-1: Equations for indicator score aggregation

Aggregate score= $\sum AgSC_iI_j$ / NSC ....(Equation 1)

Where $AgSC_iI_j = SC_iI_j \sum ER_r \times V_r$........................(Equation 2)

Here, $AgSC_iI_j$ = aggregated score of each indicator according each selection criteria (i, j = order of individual selection criteria and indicator respectively), NSC = total number of selection criteria, ER_r = frequency of expert response (r = ranks category order), V_r= rank value (where $1< r <5$).

Source: Author's own, following Damm (2009)

The calculation has resulted 26 indicators that achieved above the average score (49.2) according to the experts opinion survey result (Figure 3-5).

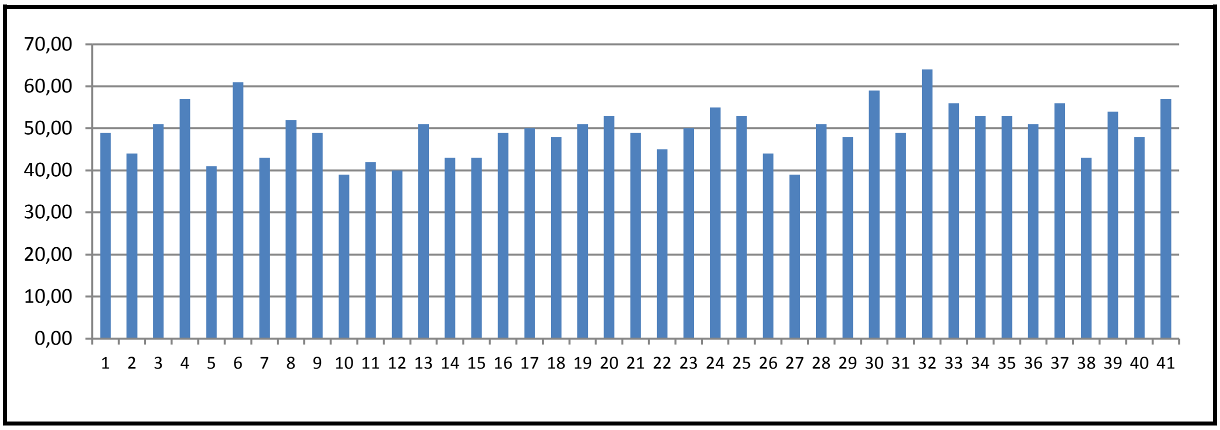


Figure 3-4. Aggregated scores on individual indicators.
Source: Expert opinion survey (2013)

In the end, a draft list of 30 indicators was created, with 4 indicators included even though they achieved lower scores than the standard aggregated value (mean) of expert opinion under the provision of the eDPSIR framework (Appendix E: Table 1). Almost 50% of the indicators were included from the predefined wish list. The results could be further improved with a better indicator filter that would allow comprehensive stakeholder participation through periodic workshops and feedback sessions.

Within the scope of this research, the city-wide analysis included only a few indicators, such as dynamics of land use evolution, spatial urban form (building intensity) and ECD. The neighborhood-level analysis measured all 30 indicators within the two selected residential settlement clusters of Dhaka. The comprehensive step-by-step methods are presented for evaluation of the planning process, which represent abstract indicators of energy aspects such as governance, regulation and RE adaptation focused on both the city-wide and neighborhood levels. The detailed analysis method and data sources are presented in the following sections.

3.2 Spatial Analysis of Urban Building Structure: City-wide

The spatial form of urban structure explains the impact on energy demand and consumption. It is accepted that the feasible form of urban structure can trigger the clean energy production by integrating the renewable technology, modern innovation and alternative solutions (Singh et al., 2015). In fact, the urbanization process and mechanisms could significantly affect the dimensions of urban structure associated with energy consumption behavior and needs. With such motivation, a city-wide spatial analysis of urban building form and ECD was conducted after adopting a compatible and effective method of estimation.

3.2.1 Computation and requirement (Cell-wise)

The cell-based computation method, with the aid of geographical information system software (GIS), is considered a powerful way – especially the Cellular Automata (CA) model – to store and analyze urban structure and spatial growth patterns (Yeh and Li, 2002). The basic concept of the cell-based method is to divide the whole space into continuous square grids after settling on a pre-defined cell size. A careful justification has to be made to decide on the appropriate cell size, which is always a critical step.

The insights of the cell behavior in response to the model and study objectives are commonly referred justifications. In this study, the cell size was settled on (100 × 100) sq.m on the ground by following related studies (Larondelle et al., 2014; Yeh and Li, 2002) and in consideration of two aspects:

i) Balanced between minimum and maximum range. The cell size has to be large enough to contain more than one building structure class. After some sample testing, a cell size greater than 10,000 (100 × 100) sq.m shows significant decreased risk of covering only a single building structure class (i.e., residential or commercial use). However, it can highly affect computation results and communicate wrong information.

To find an optimum size, the coverage area of the largest feature class was taken into consideration- very few building features (8 out of 270,393) in Dhaka city have a coverage area greater than 10,000 sq.m (Figure 3-5); therefore, a cell size of (100 × 100) is able to cover at least 2 different types of building structures or land use classes.

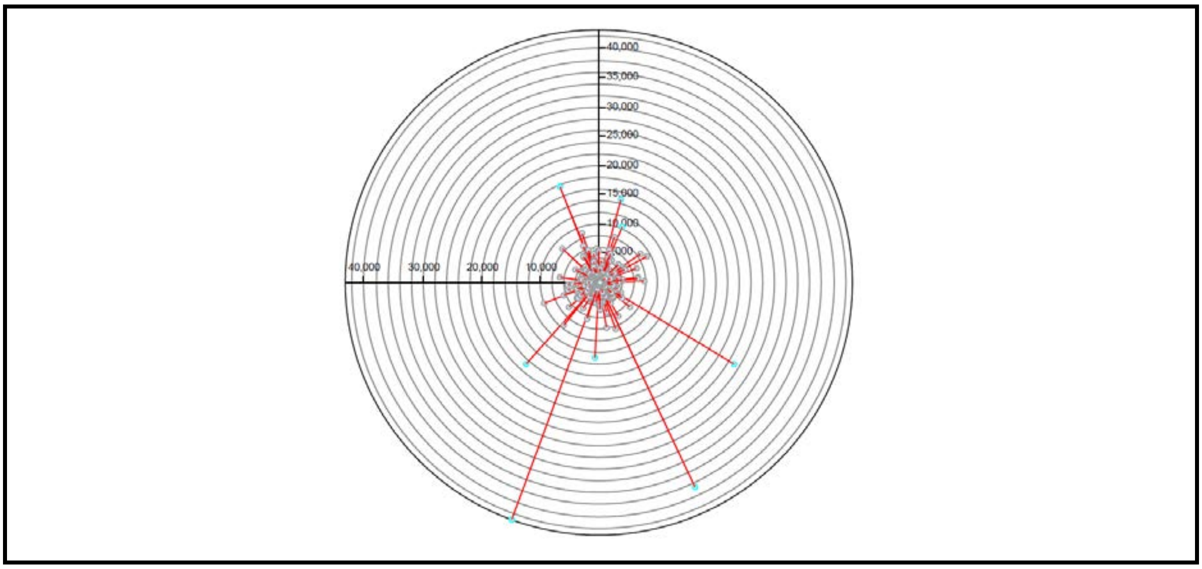


Figure 3-5. Building structure of Dhaka city according to area coverage (sq.m).
Source: Author's using physical survey data of DMDP

ii) Considered trade-off in case of smaller cell size. The variability of spatial density has to be localized as per one of the basic requirements in spatial analysis, so it was assumed that man-made land development decisions vary greatly within a minimum cell size of (100 × 100) sq.m ground area. The possible trade-off that could arise for keeping minimum cell size (100 × 100) instead of (50 × 50) sq.m or (25 × 25) sq.m was ruled out after initial investigation of building size.

Once the cell size was determined, a fishnet (grid polygon layer) was created with unique cell IDs by using GIS-aided software. Afterwards, an overlay operation was conducted on the urban building structure layer to estimate cell-wise information. The extent of area was set as DCC area which was comprised of 90 wards (smallest urban administrative unit). The cell-based computation was conducted with 3 distinct geographical settings, which emerged after overlaying the cellular lattice on the study area boundary and physical features (Figure 3-6). The considered geo-settings were:(i) All features inside the cell boundary (Setting 1); (ii) Features are divided by the cell boundary, falling in-between cells (Setting 2); and,(iii) Cells affected by study area boundary (Setting 3). The computational goal of all settings had to consider the cell-wise proportionate urban building structure and area of interest. The features that fell between multiple cells (i.e., mixed use structure) were divided by the grid line. The ground area outside of the study area boundary (Setting 3: red color) was excluded from individual cell area before storing estimated cellular information.

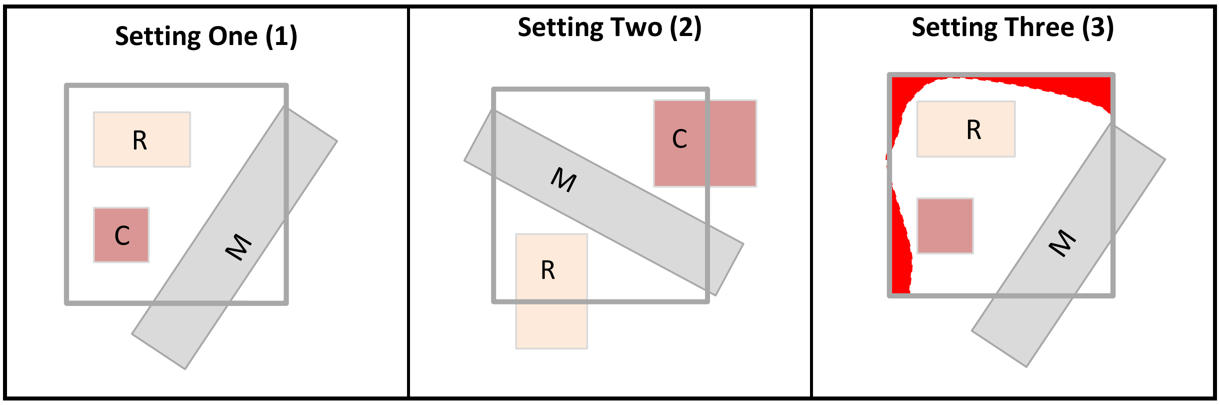


Figure 3-6. Geometric settings in relation to cell and boundary of study area.
Source: Following Saha (2012); Key note: R= residential, C= commercial, M = mixed-use

The urban building structure intensity estimation procedure was conducted in three different parts: (i) horizontal intensity; (ii) vertical intensity; and, (iii) total intensity. The next section explains the associated assumptions, equations and parameters in a comprehensive way.

i) **Estimation of horizontal intensity.** A horizontal intensity for a urban structure class is the ratio of total space or area of a particular use class to the cell area (Zhang et al., 2004). The horizontal use intensity ($HORI_{ij}$) score was computed for each cell; it simply denoted the degree or form of urban structure use (horizontal level) on a specific location (Box 3-2). Similarly, the cumulative horizontal intensity can be derived by accumulating all cell-wise horizontal intensity scores. The total urban built area or the urban land horizontally converted from its natural form can also be estimated by adopting a similar approach. The ratio of built-up space and other soft space can provide important information about city-wide low-energy development, especially for micro climatic-urban heat island and landscape strategies.

ii) **Estimation of vertical intensity.** In any urban structure-related studies, it is very important to identify the location and amount of height-insensitive development patterns (Huang et al., 2007; Stewart and Oke, 2012). The computational equation was formulated according to the popular concept of Floor Area Ratio (FAR). The ratio calculation includes two parameters such as gross building floor area and the building ground or plot area. Urban managers frequently use FAR for determining development control measures at a specific urban location (Kushol et al., 2013). In this study, the numerical score of vertical intensity for an individual cell refers to the state of vertical development in that particular cell area. The vertical intensity score is the ratio of total vertical building space to the cell area (Box 3-2). The vertical space can be estimated as the sum of all floor area being used for a specific purpose. Importantly, the ground floor space had to be excluded so that the double count effect could be avoided with horizontal intensity. Also important, each floor space was calculated separately because all building stories may not have identical floor space.

iii) **Estimation of total intensity.** The total intensity score of a structure class is measured by the simple arithmetic sum of the horizontal and vertical intensities (Box 3-2). It denotes the total concentration of that specific use in each cell. In addition, the total built intensity is also estimated by aggregating all intensity scores of all classes that occupy both horizontal and vertical built space in a cell area.

Box 3-2: Equations for estimating intensity values

Horizontal intensity, $\mathrm{HORI_{ij}} = \frac{\Sigma A_i}{A_j}$ ....(Equation 3)

Vertical intensity, $\mathrm{VERI_{ij}} = \frac{\Sigma F_i}{A_j}$...........................(Equation 4)

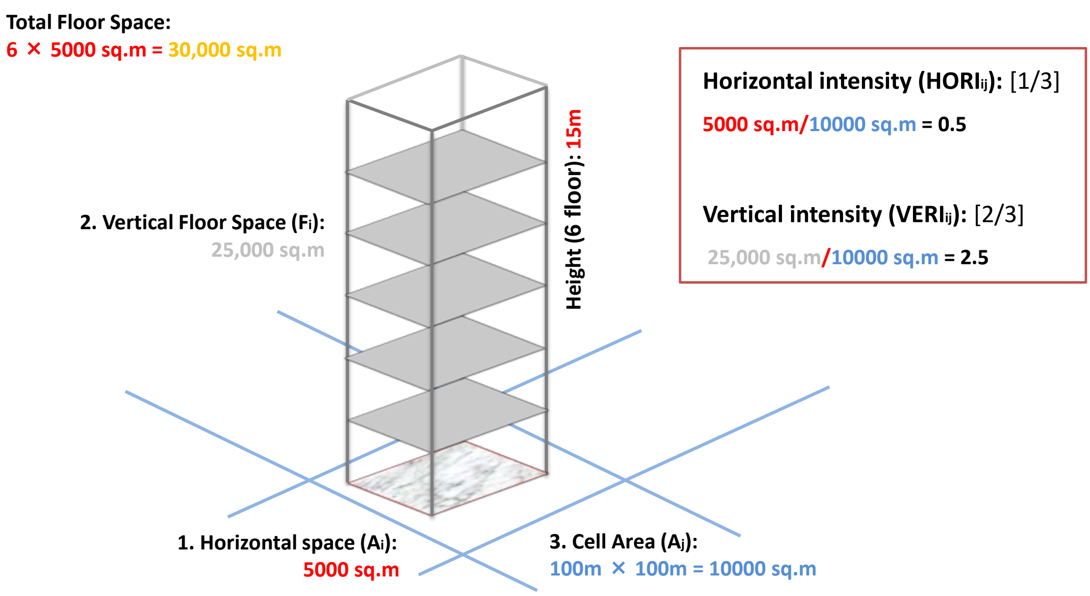
Total intensity, $\mathrm{T_{ij}} = \mathrm{HORI_{ij}} + \mathrm{VERI_{ij}}$..................(Equation 5)

Total built intensity, $\mathrm{B_j} = \sum_{i=1}^{n}(\mathrm{HORI+VERI})_{ij}$.............(Equation 6)

Where, j denoted individual cell and i is an use class, A_i and A_j expressed the ground area of an use class and related cell area. F_i is the floor area of individual storey being used for the class i except the ground floor area. H is the horizontal intensity and V is the vertical intensity of an use class i in the cell j. Finally, n denotes number of use classes.

Source: Author's own following Zhang et al. (2004)

An example estimation of cell level building intensity can be given as:



i = building use type, j = individual cell

3.2.2 Methods of spatial pattern analysis

Tobler first law of geography "everything is related to everything else, but near things are more related than distant things" (Tobler 1970; p.236). In contrast, the two major aspects of spatial urban structure pattern- where and why - were explored after estimating intensity scores of each structure class and the related locations where they were measured. In other words, the urban structures had to be critically analyzed to explore the spatial intensity relations to physical locations as well as use of building structure. The spatial dependency or clustering pattern and degree of distribution were investigated further after estimating the Moran's Index (i.e., spatial auto-correlation analysis methods) and Gini-coefficient.

i) Estimation of Moran Index (Global and Local). The spatial distribution of intensity can be investigated after estimating Moran's Index (Moran's I) values- both Global and Local (Griffith, 2003). Moran's I is one of the frequently-used and established parameters for spatial pattern analysis in a form auto-correlation (Prasannakumar et al., 2011). Some of the settings of spatial auto-correlations are illustrated in Figure 3-7. In this study, the spatial auto-correlation tool in ArcGIS 10.2 was applied to identify the city-wide spatial dependency and clustering pattern of urban structure intensity.

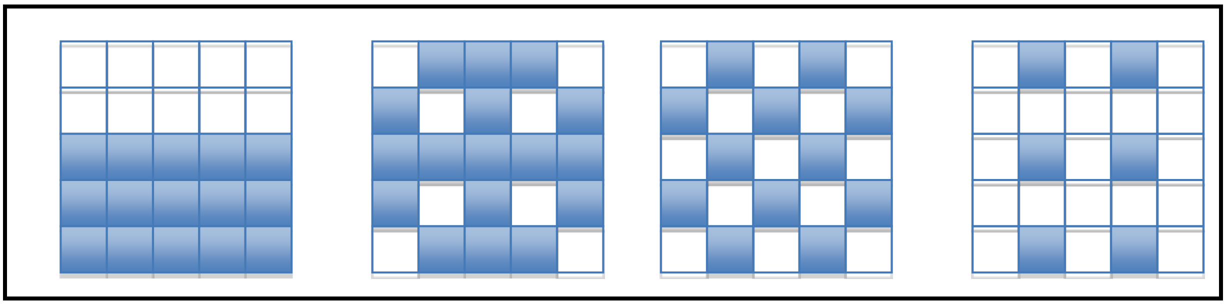


Figure 3-7. Hypothetical settings of clustering in spatial auto-correlations.
Source: Authors own illustrations by following http://gisgeography.com/spatial-autocorrelation-moran-i-gis

Global Moran's I expresses as a single numerical value whether the overall spatial pattern is clustered, dispersed or random. Local Moran's I explores the location of high and low value clusters, given a set of features and associated attribute values (Box 3-3). A positive Moran's I value indicates the feature is surrounded by similarly-valued features (a cluster). Conversely, a negative value suggests a feature is an outlier (Prasannakumar et al., 2011; Anselin, 1995). Typically, Moran's I values range from +1.0 (clustering) to -1.0 (dispersion). A zero value indicates a random spatial pattern.

ii) Calculation of Gini-coefficient. The well-known Gini-coefficient measures the inequality of a distribution, and was developed in 1912 by the Italian statistician, Corrado Gini. Numerical values range from '0 to 1',where '0' indicates total equality and '1' indicates maximum inequality (Groves-

Kirkby et al., 2009). In this case, the Gini-coefficient defines how the building intensities are spatially distributed, and the Local Moran's I identifies the locations of high and low intensities.

Box 3-3: Equations for estimation of Moran's Index and Gini-coefficient

Moran's, $= \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i.j}\,(x_i - \overline{X})\,(x_j - \overline{X})}{S_0\,\sum_{i=1}^{n}\,(x_i - \overline{X})^2}$..(Equation 7)

Aggregated value of spatial weights, $S_o \;= \sum_{i=1}^{n}\sum_{j=1}^{n} w_{i.j}$ ....(Equation 8)

Gini-coefficient, $G_i \;= \frac{\sum_{j=1}^{n}|A_j - S_{ij}|}{2}$..(Equation 9)

Where, n is total number of cells; $w_{i.j}$ expresses the distance-based weight that is inverse distance between cell i to j; x_i is the variable value at a particular cell i, x_j is the variable value at a particular cell j, A_j express a ratio value of cell area to the total study area for j cell; S_{ij} is a ratio of building intensity (i class in j cell) to the total intensity (i.e. whole study area) for the class i.

Source: Described in Prasannakumar et al. (2011); Groves-Kirkby et al. (2009)

3.2.3 Estimation of energy consumption density

Difficulty remains in estimating energy consumption due to lack of detailed data (Pereira & Assis 2013). This study estimated the ECD by following the known principle of population density (Wurm et al. 2010; Yeh & Li 2002; Khatun et al. 2015). The estimation was conducted for each cell (i.e., already introduced for intensity calculation) by using two equations (Box 3-4):

Box 3-4: Equations for estimation of energy consumption density

Total energy consumption density at ward i, $ECD_w = \frac{E_{ti}}{S_t}$ ....(Equation 10)

Energy consumption density at cell j, $E_{jd} = ECD_w \times \frac{S_j}{S_t}$ ....(Equation 11)

E_{ti} express total amount of energy consumption at DCC ward i; besides S_t and S_j denoted the calculated total building floor space within whole administrative unit (e.g. DCC ward) and share at the cell j respectively.

Source: Author's own

An example calculation for DCC ward number 69 can be given as:

Items	Data	Unit
Census Population:	62039	count
Total building floor space i.e. S_t:	563950	Sq.m
Per-capita energy consumption:	214.4	Kg of oil equivalent
Energy consumption at Ward 69 i.e. E_{ti} (E_{t69}):	13301161.6	Kg of oil equivalent
Energy consumption density at ward 69 i.e. ECD_{w69} (E_{ti} / S_t):	23.585	Kg of oil equivalent/sqm

The energy estimation assumes that:

(i) The Dhaka City Corporation (DCC) ward boundary is the smallest administrative unit as per records of the national census agency. It is assumed that a building is completely located within only one ward boundary. The census population number available for DCC wards and used to estimate total energy consumption (E_{ti} = total population at DCC ward i × per capita energy consumption). This study included gross energy consumption per capita but did not specify any individual end-user sector.

(ii) The estimated amount of total space (i.e. S_t and S_j) considered both horizontal and vertical building floor space. There are eight major land-use structures identified by local authorities in Dhaka. Out of which there were only 4 types of building structure classes included in total space estimation namely residential, commercial, services and mixed-use.

The national per capita energy use indicator was taken into consideration to estimate ECD. According to the International Energy Agency (IEA), Bangladesh has a per capita energy use of 214.4 (kg of oil equivalent per capita), which refers to use of primary energy before transformation to other end-use fuels, plus imports and stock changes after deducting exports and fuels supplied to ships and aircraft engaged in international transport (IEA Statistics, OECD/IEA 2012). The estimated unit of energy density is kg of oil equivalent/sq.m, as the calculation was based on unit of building use area.

3.3 Comparative Analysis of Residential Neighborhood Structure

3.3.1 Study unit selection process

An empirical inquiry – an inquiry that investigates a contemporary phenomenon within its real-life context - has to use multiple sources of evidence, including smaller study units, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 1984, p. 23). Similarly, this study adopted a mixed approach, with a significant part of empirical inquiry especially for collecting several unknown urban structure and energy-related variables. In this context, the careful selection of study units was critical for producing convincing research outputs.

In general, the residential settlement development type of Dhaka city can be sorted into two categories, formal/planned and informal development, by following their development process and actors involved (Figure 3-8). At present, there are more than 181 residential settlement development projects within the jurisdiction of the greater Dhaka metropolitan development area considered to be attempts at a formal residential settlement development type called a "planned subdivision" (Alam, 2014, p. 50-51). In this research paper, formal/planned subdivision or land/housing development projects are considered as study units and are referred to as Study Residential Settlement Clusters.

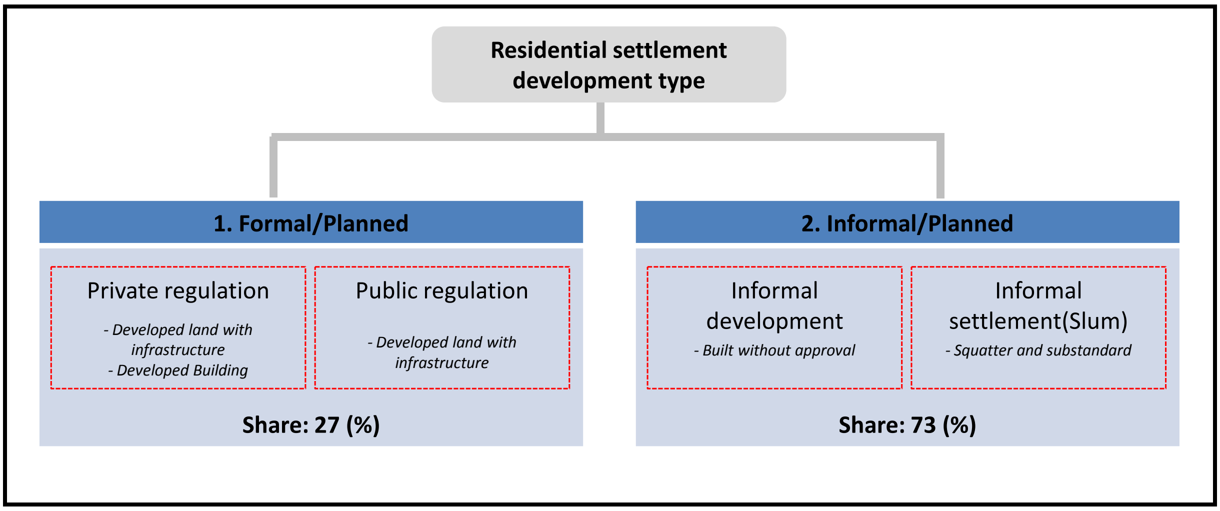


Figure 3-8. Residential settlement development types in Dhaka city.
Source: Author draft based on findings from Masum (2009), Kabir et al. (2010)

A set of pre-defined criteria was settled to find out the representative Study Residential Settlement Cluster (SRC) in following the research objectives.

- Land area more than 5 acres
- Completed and approved by RAJUK
- Located within the DESCO service area
- Formal residential project that developed by public or private sector

After researching on RAJUK database and discussing with local experts, two study units SRC 1: Niketan residential area (Private regulation) and SRC 2: Nikunja (Public regulation) have been selected for comparative analysis (Figure 3-9). These two SRCs meet 4 pre-defined criteria and common characteristics of residential development projects in Dhaka (see also 5.1). The variation in spatial location (central and suburban) has played a role besides some data related advantages. Above all, both primary and secondary information have been collected and processed for conducting a comprehensive analysis at the residential cluster scale.

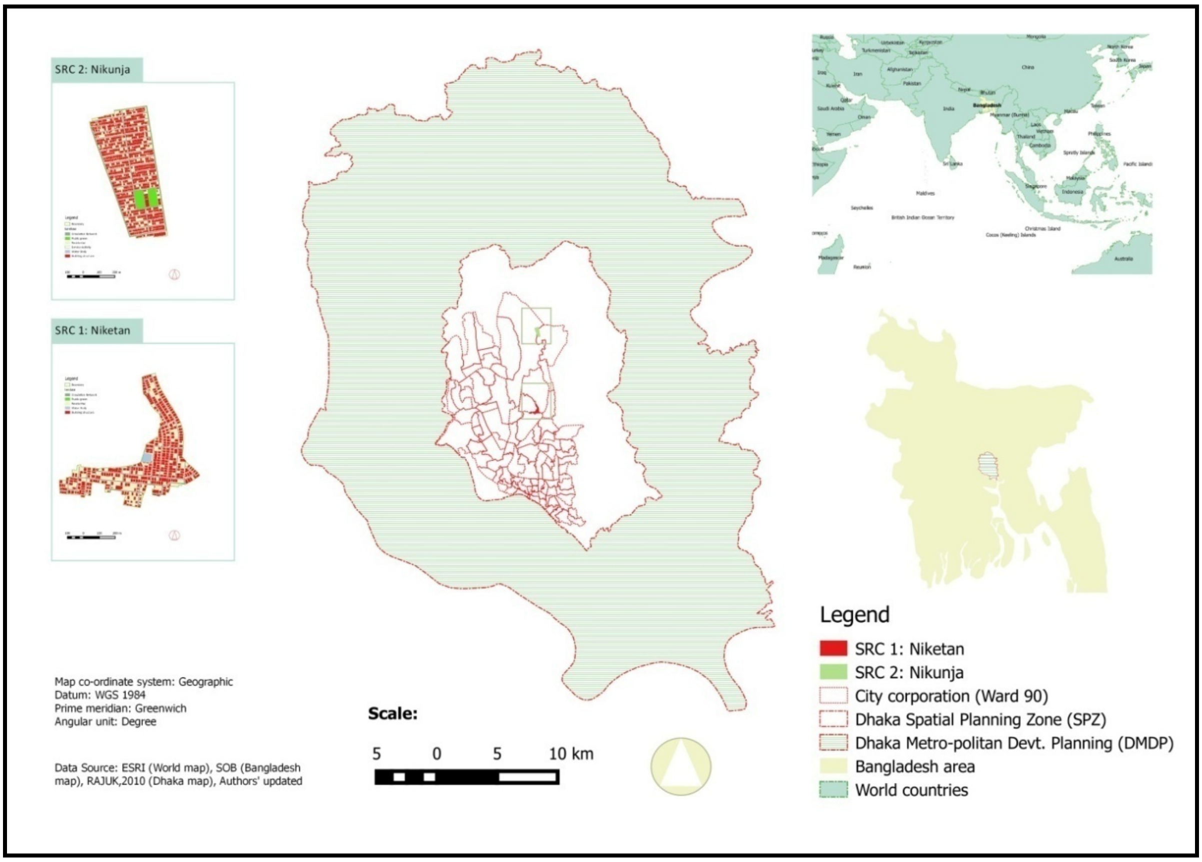


Figure 3-9. Boundary delineation of Dhaka and selected residential clusters.

3.3.2 Measuring selected indicators

The data collected directly from the field is defined as primary information. It was a challenging task to collect the proper information via reliable scientific instruments, tools and techniques. The applied scientific approaches, instruments, tools and techniques were: (i) household survey; (ii) key informant interviews, and (iii) direct observation. The household survey was conducted with semi-structured questionnaires and a sampling technique was applied to select a significant number of residential dwellers.

i) Sampling Technique. Sampling is the process of selecting a subset of individuals from a large population (Sufian, 2009). Simple random sampling (probability group), which is usually taken as a sort of 'ideal' and is an easily-understood model, is more narrowly defined as a method of choosing the population in a way that gives each unit of the group an equal chance (Neuman, 2000; Bulmer and Warwick, 2001). It helped to determine the representative individual residents' for responding specific research questions. The sample size calculation was considered population (residential units), resources, time and nature of the study unit for maintaining statistical significance. The sample size was determined by using the following two formulas:

Box 3-5: Equations for sample size determination

Determination of sample size (ss_1) = $Z^2(p)\frac{(1\text{-}p)}{c^2}$ .... (Equation 12)

Where, Z = Z score (e.g. 1.96 for 95% confidence level), p = percentage picking a choice, expressed as decimal (0.5 used for sample size needed), c = confidence interval, expressed as decimal (e.g., 0.04 = ±4)

Correction for finite HH: Adjusted sample size (ss_2) = $ss_1\,\{1+\frac{1}{\text{Total household}}\}$ ....(Equation 13)

Source: Following Sufian (2009)

In accordance with these two formulas, a total sample size of 256 was selected for administrating the door-to-door household survey (Appendix C: Questionnaires for HH survey), within two residential clusters where the total candidate households numbered 6,433 (BBS, 2011a). The total number of household samples were allocated proportionately among the two residential clusters: SRC 1: Niketan (99) and SRC 2: Nikunja (157); however, the actual household survey was conducted with 307 respondent households in order to meet post-survey data quality checks and adjustments.

3.4 Systematic Evaluation of Development Process

3.4.1 'EnUp-Model' - an evaluation framework

The energy-conscious strategies at every stage of a planning process should start to establish a conceptual framework at the first step (Mirakyan and De Guio, 2013). Several models and frameworks have been proposed to integrate energy optimization into urban planning. In earlier chapters, a few of them briefly introduced and pointed out their strengths and weaknesses, and now introduce a customized conceptual framework called the Energy Optimization in Urban Planning Model (hereafter referred to as the "EnUp" model) that addresses efficiency at the urban residential neighborhood level (Figure 3-10). It has focused on the residential sector because it is the largest energy consumer, both in the context of our study (Dhaka) and in many other developing countries more generally.

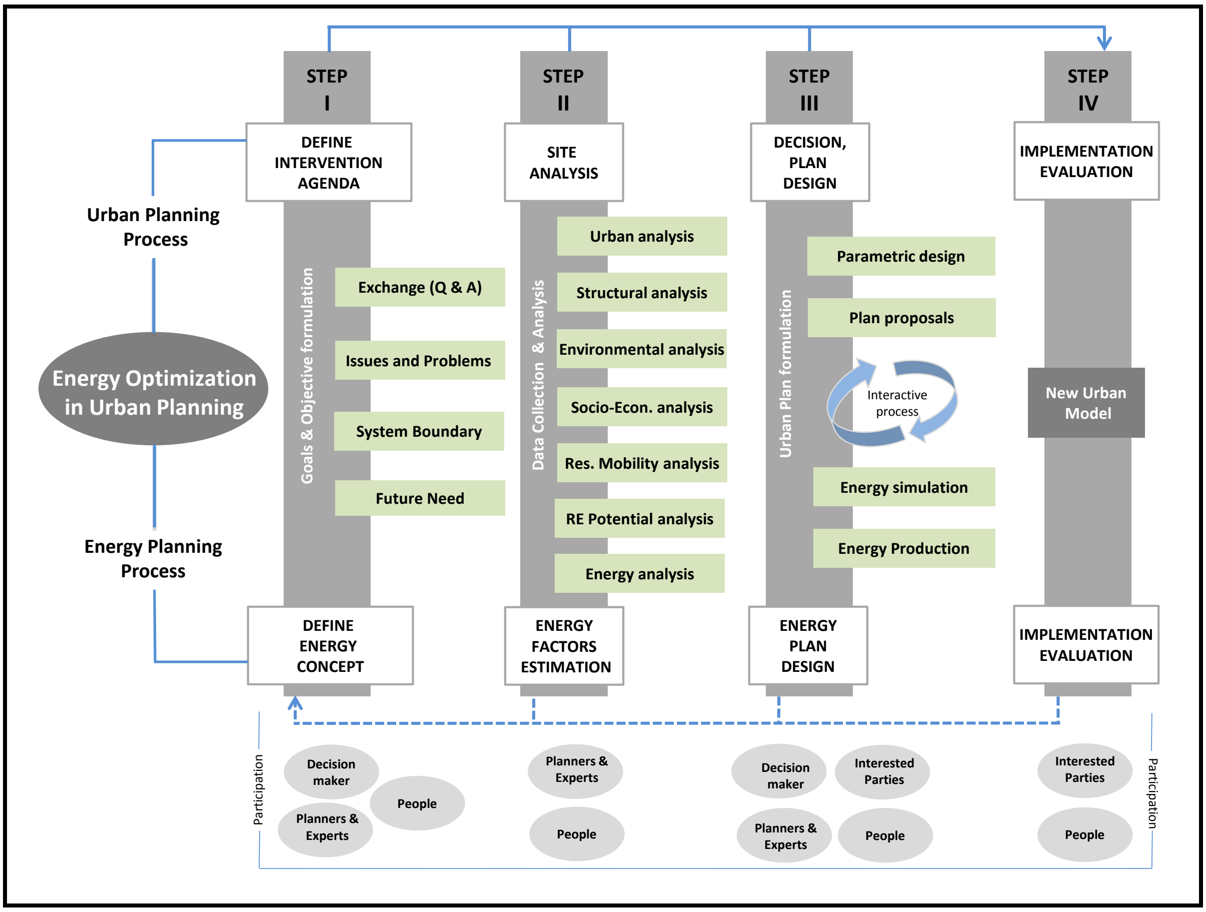


Figure 3-10. "EnUp- model"–A conceptual framework for energy optimization in urban planning.
Source: Author's own

From the conceptual point of view and after extensive discussions of the process of energy-optimization urban planning (Amado and Poggi, 2012) and integrated energy planning (Mirakyan and De Guio, 2013), the "EnUp" model was developed, which adopts a systematic and comprehensive planning approach that can be divided into four main steps:

Step I. Define intervention agenda and energy concept: This is the initial step where the local, context-specific matters (e.g., municipal policy, housing markets) have to be considered. An effective exchange among project-related stakeholders should be facilitated with question and answer sessions. This step is helpful for problem identification, future needs assessments within the specific system boundary, and interactive communication among the stakeholders.

Step II. Site analysis and energy factors estimation: Detailed information on the built environment, socio-economic issues, and other needs have to be collected and analyzed along with energy consumption and renewable energy potentials. The results should be able to critically illustrate the significance of energy optimization needed in the next steps.

<u>Step III. Alternative decision and energy optimized plan design</u>: Based on analyzed results and design requirements, several goal-dependent planning options have to be formulated and simulated. The new plan's provisions, standards, and regulations should also consider urban system functionalities, sectoral linkages, and governance processes rather than only concentrating on the goal of energy optimization. The participation of urban stakeholders is very crucial at this step. Experts and planners should facilitate the whole process in an integrative and interactive way with stakeholders providing critical insights into local requirements, standards and regulations.

<u>Step IV. Implementation and evaluation</u>: Although the new model result should, at this point, be considered as a comprehensive output, the planning process must nevertheless still include implementation and evaluation; therefore, workable implementation and active evaluation measures have to be set up alongside the interactive participation of interested stakeholders.

Notwithstanding the above steps, the "EnUp" model is not functional without appropriate methods and tools for performing both urban- and energy-planning tasks. The "EnUp" model also emphasizes the need for stakeholder participation at every step of planning process. The comprehensive goal function of energy-optimization in urban development could also be addressed within the broad vision of sustainability.

3.4.2 Assessment method of 'EnUp' model potential

The "EnUp" model included several urban system sectors and stakeholders. Therefore, multi-step procedures were used to gather relevant data, including closed- and open-ended questioning with key informants (e.g., officials, urban planners, architects, developers, and researchers) in collecting and analyzing the data (Appendix D). A critical review of several secondary sources was also conducted and includes Rajdhani Unnayan Kartripakkha (RAJUK) planning documents, reports, scholarly articles, and others. In addition, in-person, phone, and mail surveys were administered to respondents in order to quickly gather multi-source information – both on urban planning and energy planning in the context of residential settlement development of Dhaka city. Finally, a total of 15 in-depth, in-person interviews were conducted, composed of two parts: (i) general topics, and (ii) expert assessment on the “EnUp” model potential.

(i) The first part of the key informant interview covered general topics, such as the residential settlement development project approval processes, regulatory frameworks, major challenges, and future efforts needed. The text analysis software package MAXQDA was used to conduct systematic coding of interview transcripts and secondary documents. This research followed the approach of Knigge and Cope (2006) to cluster informant's responses in a code system, which revolve around the research questions. A comprehensive actor analysis was conducted by applying a systematic actor mapping method called "mind tool". Three steps are involved in actor mapping: (i) the first step is to identify all related actors in the residential settlement development business; (ii) the second step is to conceptualize their power, influence, and interest with a focus on energy-optimization in urban planning; and (iii) the final step is to figure out the most important actors and record this analysis on an actor map.

(ii) The second part of the key informant interview gathered expert opinions on each action of the four planning steps of the "EnUp" model. During each interview, it was noted which tools and methods the informant used in practice for performing each planning action (that included in Figure 3-10. Moffatt et al. (2012) provided the guidelines for a structured assessment process that helped to accumulate common understandings among different indicators. Finally, a Spiderman diagram is applied to visualize all aggregated results of the assessment (Section 6.5). In calculating the aggregated value, which expresses the state of individual planning steps, the following formula was used (Box 3-6):

Box 3-6: Aggregation of key informant's opinion

Aggregated value of each step (%), $A_gV = \frac{\sum_{i=1}^{n}\left[\left(\frac{TAS_j}{AN_j}\right)*100\right]R_i}{X}$...............(Equation 14)

Sum of scores of all actions in step j, $TAS_j = \sum_{t=1}^{n}[S]\ A_t$..................(Equation 15)

Where A_t = individual activity identification number (t → '1 to n'), S = individual score of each activity (S → '1 to 5') , AN_j = total number of actions in step j (j → '1 to n'), R_i = respondent identification number, (i→ '1 to n'), X = total number of respondents.

Source: Author's own following Moffatt et al. (2012)

3.5 Method for Energy optimized Decision making: Neighborhood Scale

3.5.1 Approaches to sustainability assessment

Sustainability can be defined from the planning perspective as, '' ... a continuous process of balancing the environmental, economic and social aspects related to the living environment and their systematic improvements" (Rad, 2010). In the early stages, this process should be assessed systematically and while combining different concepts - multi-phase, multi-level and multi-sector - in order to manage a transition towards sustainability (Roorda et al., 2012). Hence, the challenge for the scientific community is to provide reliable assessment methods and tools that will assist professionals and policy makers to choose from many options (Ness et al., 2007). There exist several methods and tools that could feed into the assessments.

Three broad types of sustainability assessment methods and tools (Appendix A: Figure 2) are evident for considering major factors such as: (i) temporal characteristics; (ii) focus (coverage areas); and, (iii) integration of nature and the society system. From a user perspective, sustainability assessment methods can be grouped into two categories: 1) aggregation method, used by economists; and,2) physical indicators, used by scientists and researchers in other disciplines (Singh et al., 2009). However, planning literature suggests three frequently used methods for focusing on energy-concerned urbanism at the neighborhood scale: 1) indicator-based rating index; 2) product-related life cycle assessment (LCA); and, 3) integrated multi-criteria analysis (MCA).

CATSS, a joint project of the International Federation of Landscape Architects and Australian Institute of Landscape Architects (AILA-IFLA), conducted a critical investigation of tools for sustainable settlement development, with consideration of nine (9) standard criteria. They identified four (4) groups of tools: (i) rating tools; (ii) decision support tools; (iii) guidelines; and,(iv) frameworks (AILA-IFLA, 2010). The indicator-based rating approach, or neighborhood sustainability assessment (NSA) tools, are developing and growing quickly (Sharifi and Murayama, 2013; Hamedani and Huber, 2012). The NSA tools are often defined as, "...a tool that evaluates and rates the performance of a given neighborhood against a set of criteria and themes, to assess the neighborhood's position on the way towards sustainability and specify the extent of the neighborhood's success in approaching sustainability" (Sharifi and Murayama, 2013). There are two (2) major categories of NSA tools: (i) spin-off tools, such as LEED-ND (USGBC,2009); and,(ii) plan-embedded tools, such as Ecocity (EU, 2005). Reviewers have argued that the main barriers remaining to the wide adaptation and application of NSA tools are voluntary state, economic burden, complexity and ambiguity (AILA-IFLA, 2010; Nguyen and Altan, 2011; Sharifi and Murayama, 2013; Sullivan, Ridin, and Buchanan, 2014).

The life cycle assessment (LCA) analyzes a whole process as: raw material → construction→ use → demolition. The main phases of LCA study are (i) goal and scope definition; (ii) inventory analysis; (iii) impact assessment; (iv) interpretation; and, (v) result presentation. LCA was introduced in the 1960s and it became a standard (ISO 14040-43) environmental management method (Khasreen et al., 2009). LCA can be performed on a single element or on a whole block of an urban built environment (Vandevyvere and Stremke, 2012). A few examples of LCA applications are multi-scale life cycle analysis (Stephan et al., 2013), ELAS calculator for residential settlement structure (Stoeglehner et al., 2014), low energy neighborhood (LEN)/plus-energy neighborhood (PEN)/Solar-City (Herfray et al., 2006), and residential density comparison (Norman et al., 2006). In short, LCA is becoming a powerful, potential approach recognized internationally for the evaluation of sustainability - but so far almost all studies and development have been limited to the context of so-called developed countries (Khasreen et al., 2009). There are almost no publications applying and learning about the LCA approach in the context of developing countries. The reason could be the lack of useful and accurate information where a high degree of informality and accessibility have major roles.

Decision analysis has had a long existence in planning literature in order to address the promise of multi-objective assessment potential (Figure 3-11). Multi-criteria decision analysis (MCDA) has emerged as one of the forward and well-performed candidates in urban planning decision analysis. MCDA combines a set of methods to support a structured decision-making process with consideration of multiple criteria and a high degree of flexibility.

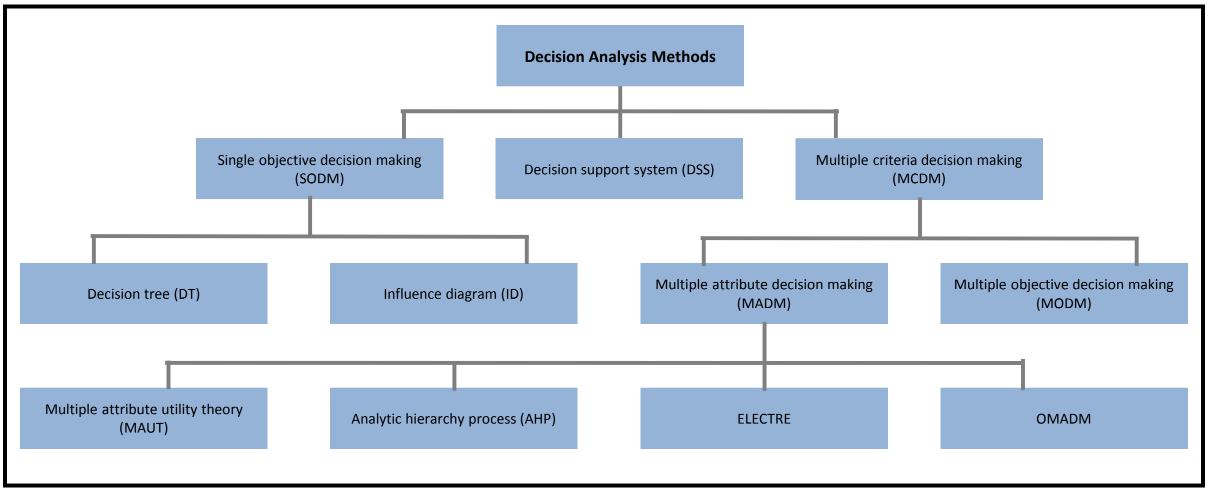


Figure 3-11. Classification of decision analysis methods.
Source: Adapted from Zhou et al., (2006)

Integrated MCDA approaches are widely used to analyze and evaluate the complexity of the urban environment (Qureshi and Haase, 2014). It can manage mixed data and support a life cycle perspective with a number of popular typologies, such as MAUT, AHP, PROMETHEE, ELECTRE and DRSA (Cinelli et al., 2014). Recently, Ali and Al Nsairat (2009) applied AHP to developing a green building assessment tool after employing a three-step cyclic approach: Step 1. Define the context in which items are developed; Step 2. Establish assessment items; and, Step 3. Evaluate assessment items. Nevertheless, there are constraints and demands of MCDA adaptation which need careful consideration, at least for designing an integrated decision making tools such as MCA-DSS (Table 3-2).

Table 3-2. Constraints and demands of the MCA-DSS.

Conceptual demand	Technical demand	Indicator function and task of MCA-DSS
Pay respect to meaning and content of single indicators and are to be developed in accordance to the specific, national targets of sustainable development	Pay respect to data-availability and demands of official statistics	Describe the individual function of each indicator and the MCA within the planning process
Link to practice: Relevance for planning decisions	Data sets	Analysis/communication: Applicable operationalization of complex interrelations
Traceability: Clearness Modular conception	Data quality	Steering, warning and decision support: Steering of planning processes by analyzing and assessing settlement growth
Significance/Adoption of local “Leitbilder”		Monitoring: Awareness-raising of stakeholders
Compatibility of content: “Learning from others”/What is already there?	Data compatibility: To enhance transferability of the MCA between different case-studies	

Source: Simplified and adapted from Schetke et. al. (2012)

This research developed a simple tool for integrated decision making as one of its major study goals. The integration of multi-criteria attributes and decision support system concepts were considered an appropriate approach for such a tool. Investigative findings on urban structure interrelationships and the residential settlement development process in Dhaka city justified the approach. A few major steps have been completed, including defining model settings, standardizing indicators, weighting, and performance analysis. The selected indicators and their measurements in SRC 1: Niketan and SRC 2: Nikunja were used for standard base value estimation and for simulating performance sensitivity. The weighting of indicators included hybrid methods where the expert inputs were collected by adapting the well-known AHP method. The simple Excel-based platform was applied to conduct systematic estimations and design a user interface. A detailed description and resulting outputs are discussed further in Chapter Eight.

3.6 Data Compilation and Processing

The extensive use of several computer-based software packages, such as R programming, SPSS, ArcGIS, QGIS, and EcoTECH, were applied for performing compilation, processing and scientific analytics. The cross-verification and quality check of collected data were ensured during the compilation and processing operations. For example, the energy consumption information was collected during the household survey and adjusted with the official meter readings of the concerned company (i.e., DESCO). The secondary datasets were also updated and restructured with the help of cross-sources.

For example, the geo-databases on physical building structure, land use, roads and water-body were verified, and even updated, with the use of online-based interactive open source platforms: Bing satellite imagery (www.bing.com) and Google StreetView (www.google.com).

Satellite image, Nikunja, Dhaka

Source: www.being.com

Google streetview, Niketan, Dhaka

Source: www.google.com

In summary, the step-by-step key points used to perform the research task were outlined in an organizational diagram (Figure 3-12).

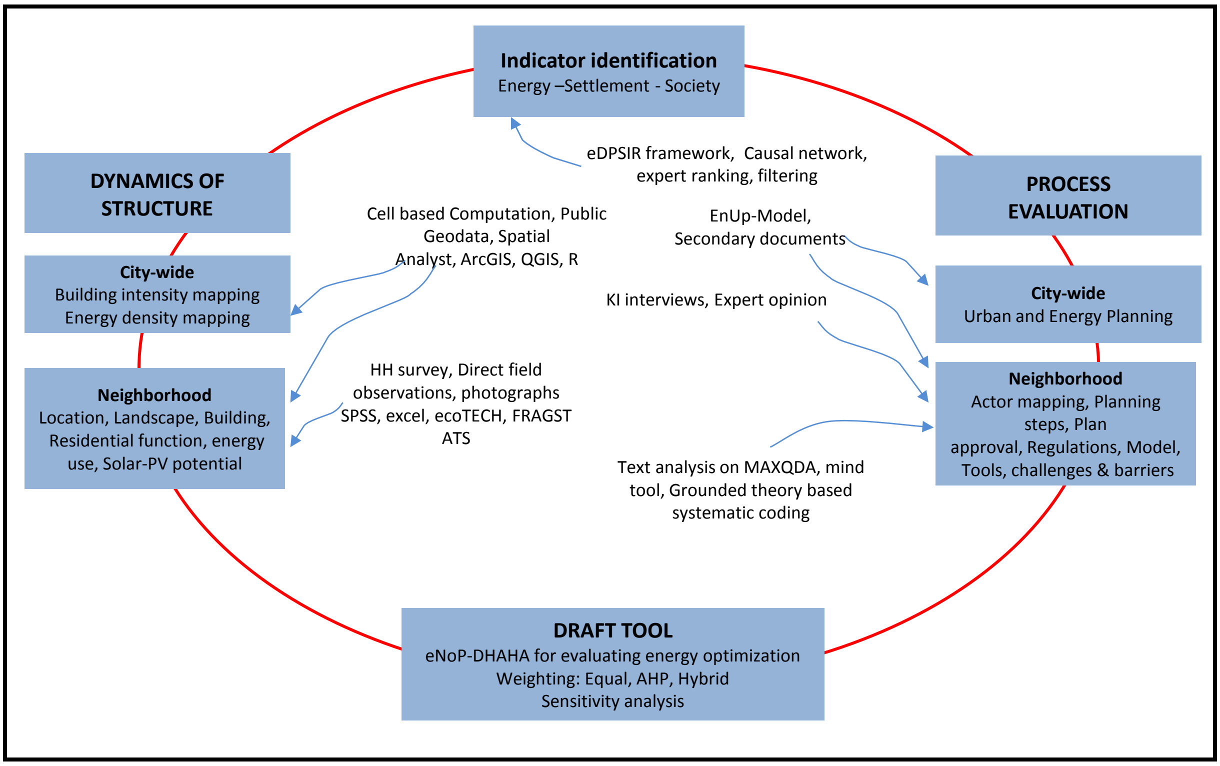


Figure 3-12: Overview on research methodology

After elaborating on research methods and tools, empirical findings are presented in the following pages, in two different scales (e.g., city-wide and neighborhood). The next chapter has a brief introduction of the evolution of urban spatial land use and planning in Dhaka city, followed by detailed results of the spatial analysis of urban structure, especially urban building form and ECD. Some additional variables that are discussed are associated with energy aspect and urban structure.

4.1 Spatial Evolution and Planning

At the end of 15th century, Dhaka emerged as a small army castle with a small river port south of the settlement. Dhaka remained a small rural settlement until the end of the 16th century. During the last 400 years, the city has experienced several urban development and expansion exercises under different governance regimes (Kabir and Parolin, 2010). After the independence of Bangladesh, Dhaka city began to expand in all directions in order to meet the needs of the new capital city (RAJUK, 2012). The spatial expansion of the urban area is most pronounced in the northern and western portions of Dhaka city (Figure 4-1).

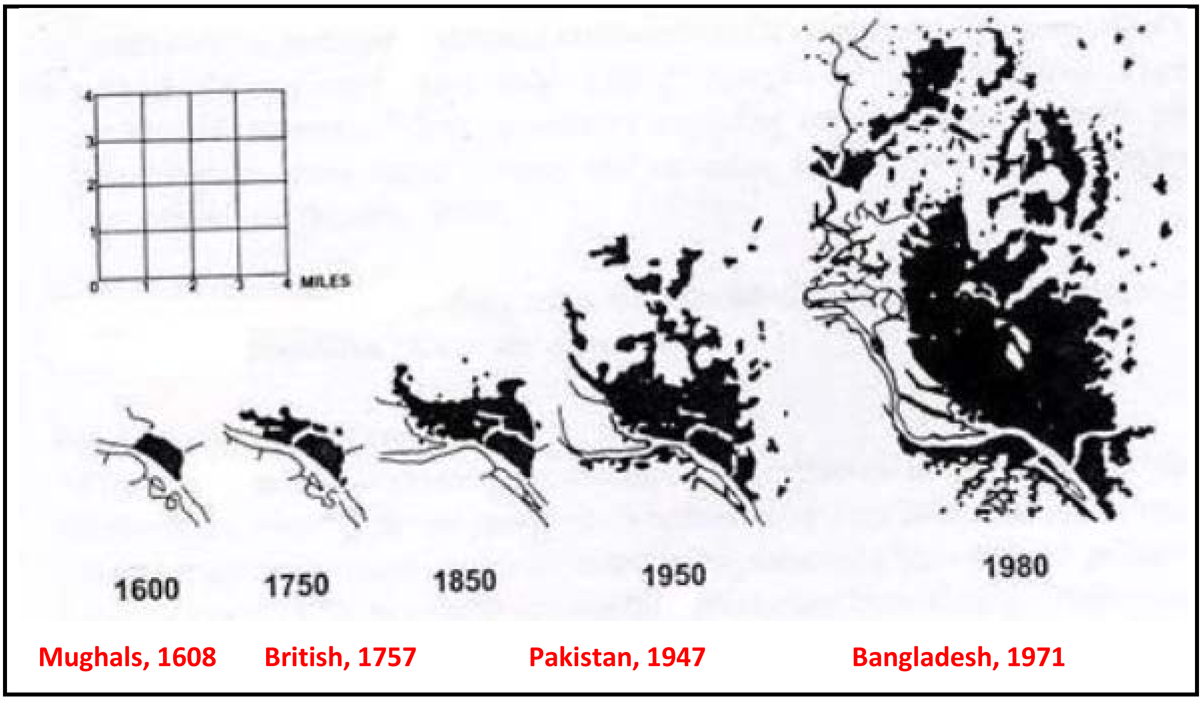


Figure 4-1. Spatial evolution of Dhaka city (1600-1980).
Source: Kabir and Parolin (2010) adapted from (Shankland Cox Partnership and others, 1981)

In 1640 during the Mughal Period, Dhaka was a settlement with an area of only 1 sq. km and an estimated population of 20,000. After the British colonial era (1757-1947) ended, Dhaka occupied 15 sq.km and had an estimated population of 411,279 in 1951. During the Pakistan period, the urbanization level slowly started rising. A rapid rise of urbanization occurred after independence (1971), and Dhaka occupied 40 sq. km and became home to 1,680,000 people (Kabir and Parolin, 2012; Hossain, 2008). The Dhaka Metropolitan Development Plan (2006) was drafted for an area of 590 sq.km and total population of 12,600,000. According to RAJUK projection, the total population could be close to 22,950,000 in the next few years.

Urban planning and development for Dhaka has always been done in a haphazard and almost unregulated way. So far, the most significant efforts in urban planning, spatial development and planning approaches have been:

- Master Plan for Dhaka (1959)
- Dhaka Metropolitan Area Integrated Urban Development Project (1981)
- Dhaka Metropolitan Development Planning - structure plan, urban area plan, and detailed area plan (DMDP, 1995-2015)

4.2 Spatial Land Use Structure and It's Components

Dhaka city is expected to become the world's third largest mega city by 2020, and has 38% of Bangladesh's urban population (UN-Habitat, 2009). Land use conflicts have been an issue because of the topographical disadvantages of low-lying flat and wetlands in the city boundary (BBS, 2011; BBS, 2010). Land conversion has occurred with very little control, and land degradation and urban flooding have been triggered where water-retention ponds and natural drainage networks have failed or been damaged.

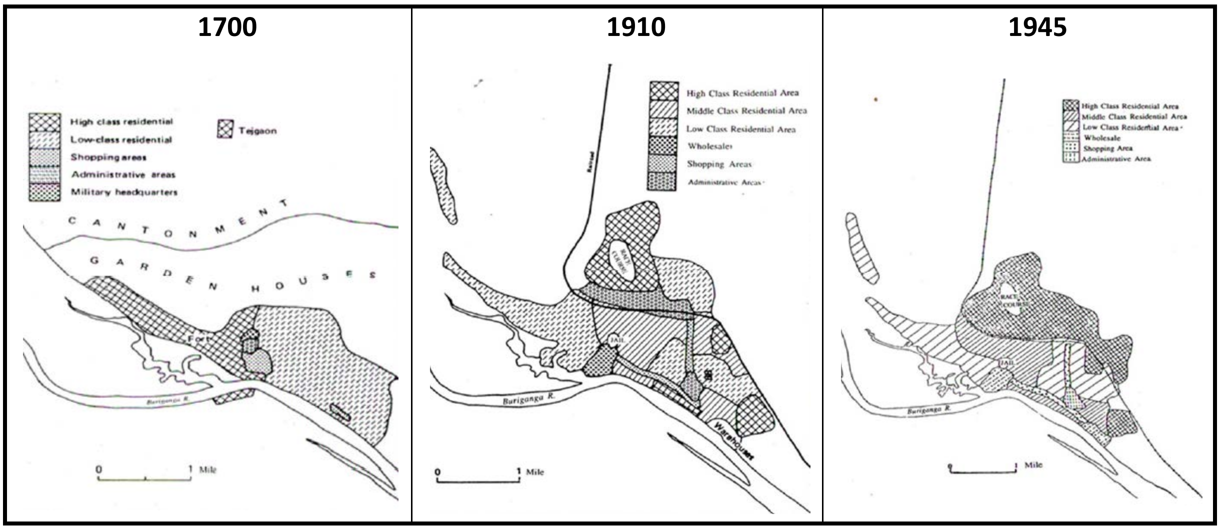


Figure 4-2. Land use evolution of old Dhaka (1700-1945).
Source: Adopted from (Islam, 1996)

Before the 17th century, the land use development of Dhaka city started along the banks of the Buriganga and Turag rivers. The functional use categories included high class residential, low class residential, shopping and administrative uses. In 1910, the middle class residential area appeared as a new sub-category of residential land use (Figure 4-2). The high class residential land use has extended further in the northern direction. The historical change of spatial land use structure (Figure 4-3) shows a trend in general level, but no detail on use variability.

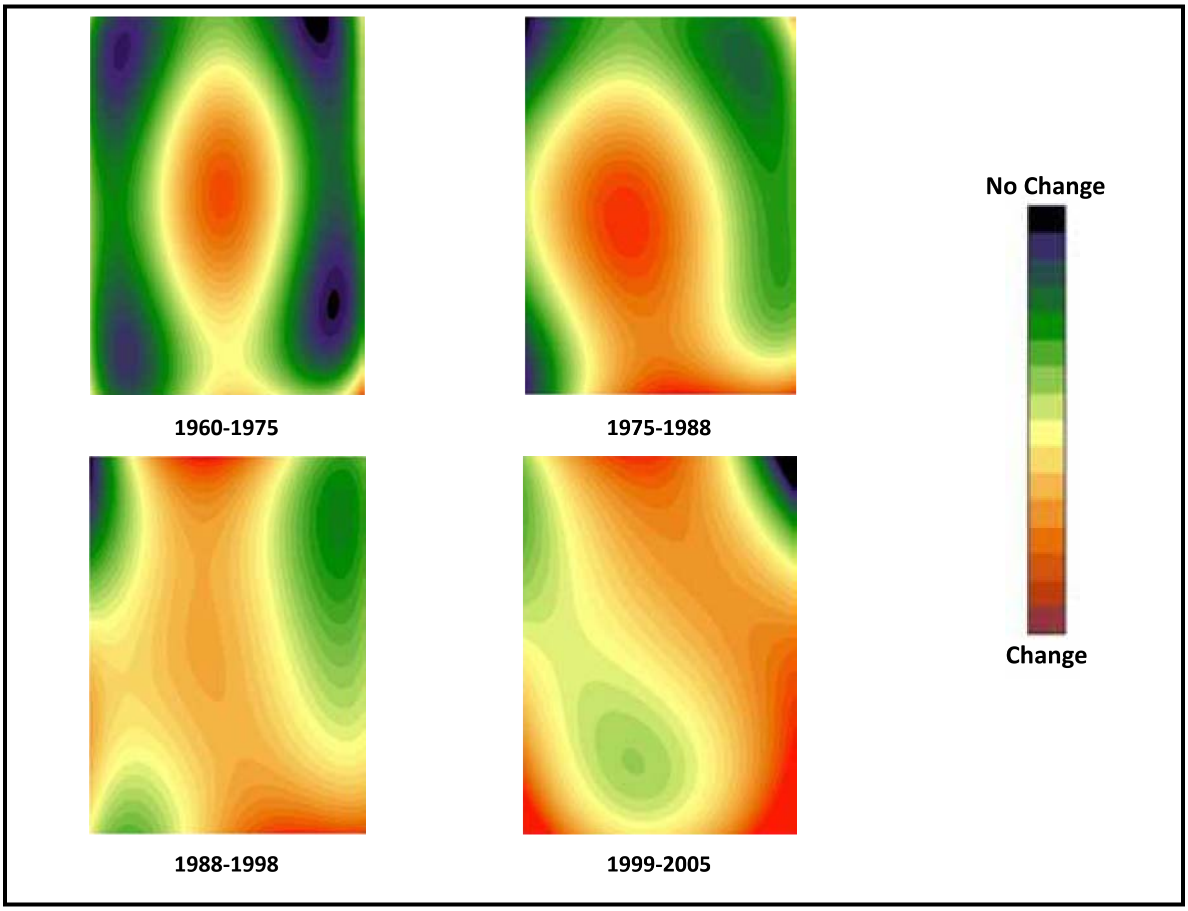


Figure 4-3. Spatial pattern of change in land use structure (1960-2005).
Source: Adapted from Ahmad et al., (2012)

The spatial structure can be analyzed by examining three significant components: (i) Proximity Index; (ii) Cohesion Index; and, (iii) Compactness Index (Ahmed et. al, 2012). The Urban Landscape Analysis Tool (ULAT) has been used to calculate the index values by using satellite image-based raster data sets in combination with other Dhaka city data sources.

Table 4-1. Components of urban spatial structure

Metrics	1960	1975	1988	1999	2005
Proximity Index	0.77	0.65	0.76	0.78	0.82
Cohesion Index	0.74	0.63	0.75	0.77	0.81
Compactness Index	0.74	0.58	0.65	0.66	0.68

Source: Adapted from Ahmed (2012)

The proximity and cohesion indices are showing rapid increases in comparison to the compactness index (Table 4-1). The only exception can be seen in the 1960 index values. This confirms the compact form of Dhaka due to its small spatial size. The average travel distance was also lower until the urban footprint was extended outward after Independence in 1971, when all indices reported lower values. The lower compactness around the urban built area often caused fringe development, which also contributed to the increase in travel distance in Dhaka city.

Ahmed (2013) highlighted some similarities in land cover changes under three unique time intervals (1989-1999; 1999-2009; 1989-2009). They can be summarized as: (i) significant increase in built-up areas, where the net contribution came from fallow land followed by water bodies; (ii) the urban area expansion follows the northern and western directions; and, (iii) the observed haphazard growth patterns indicate the absence of proper planning (Figure 4-4).

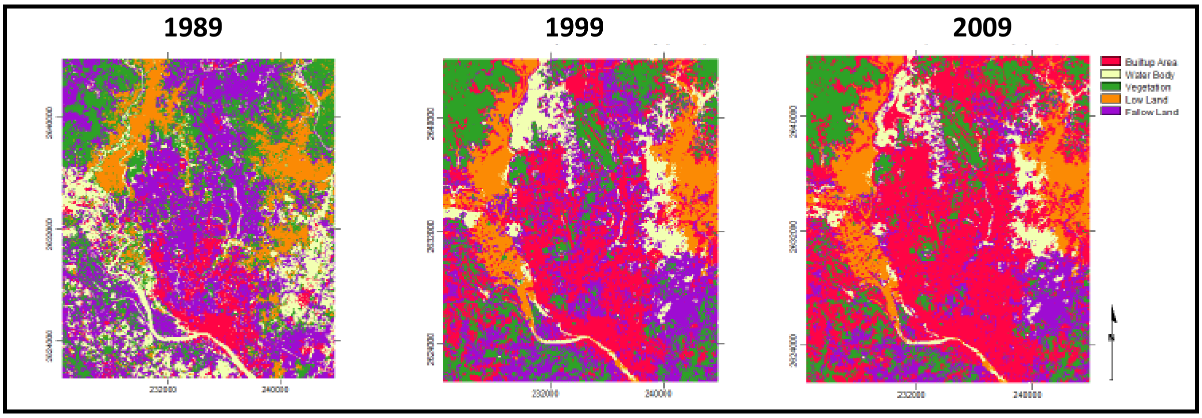


Figure 4-4. Land cover map of Dhaka city (1989-2009).
Source: Adapted from Ahmed and Ahmed (2012)

A detailed investigation of land use changes for Dhaka city for the period 1991-2008 visualized land use change and also quantified the broad land use classifications (Islam and Ahmed, 2011). Within seven categories, five land use classifications were reduced and converted to the remaining two classifications, built-up and transportation/commerce (Figure 4-5). The most significant changes were observed in the water bodies and vegetation classifications.

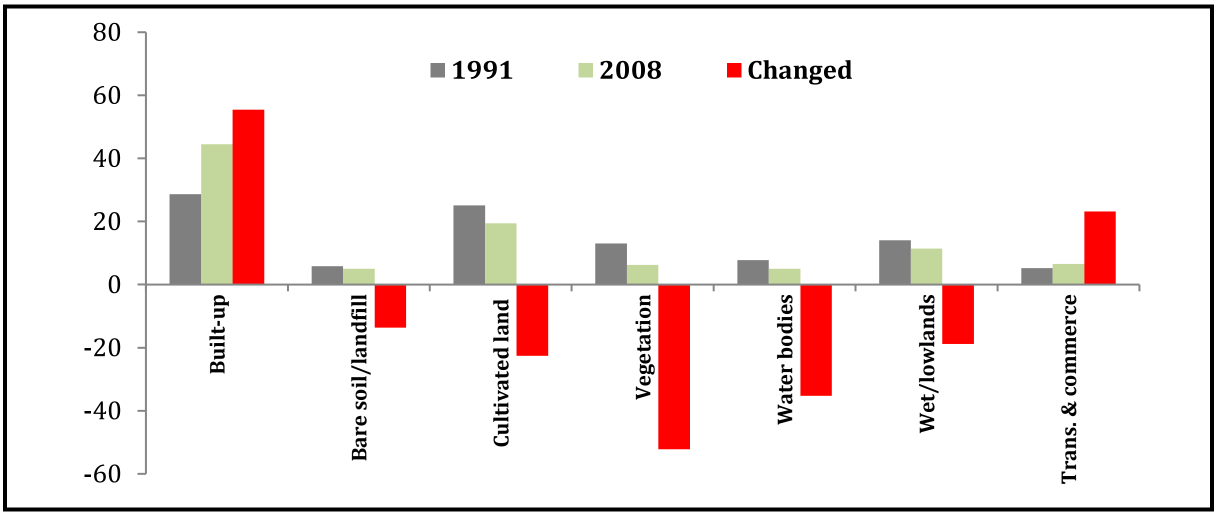


Figure 4-5. Land use classification statistics and change between 1991-2008.
Source: Author's own, based on Islam and Ahmed (2011)

The GIS-aided "Markov Cellular Automata" technique was employed to visualize future scenarios for the years 2020 and 2050, with a lowest accuracy of 57.3 for all types of land use conversion. It is estimated that the compactness of Dhaka city is likely to increase by 2050 due to rapid urbanization. The wet/lowlands will likely be converted to built-up and transportation/commerce type land uses.

4.3 Classification of Urban Structure

A variety of opinions exist in the literature about urban structure classification. Most of them are based on individual research goals, such as local climate (Stewart and Oke, 2012), cross-city landscape vs. surface temperature (Larondelle et al., 2014), urban expansion simulation (Arsanjani et al., 2012), multi-scale analysis (Taubenboeck et al. 2009) and spatial land use patterns (Zhang et al., 2004). Similarly, urban structure classification has often been proposed on the basis of use variables (e.g., residential, commercial, industrial and others) and physical dimensions (e.g., high-rise, mid-rise, low-rise, compact, and scatter). Nevertheless, two broad classifications of urban structure can be identified built type and land cover. Specific subclasses can be defined individually and as combinations of two or more built type/land cover types.

Although we lack a unified classification system for urban structure, a simplified list of 8 major classes can be considered for land use studies in the context of Dhaka city. These were defined in the Dhaka Metropolitan Development Plan (RAJUK, 1995). Description of the 8 urban land use classes are found in Table 4-2.

Table 4-2. Major classes of urban landuse structure.

SL	Class	Definition
1	Residential	Building, structure, space use only residential purpose
2	Commercial	Building, structure, space use only for commercial, business and industrial activities
3	Service use	Building, structure, space occupied by other than (1) and (2). It includes public, office, religious, educational, recreational and community services
4	Mix use	Building, structure, space use concurrently by at least two of above uses
5	Linear network	Surface occupied by urban linear utilities such as road, footpath, drain
6	Water body	All water bodies including wetlands
7	Agriculture	Land use for farming activities such as rice cultivation, nursery, crops
8	Open space	Remaining space (excluding class 1-7) and building bulk-free space, also include - park, playground, garden, urban green, vacant or unused land

Source: RAJUK (1995)

It is observed that among the 8 classes, 4 represent different types of building structures (Classes 1-4),5reflect built up areas (Classes 1-5) and 3 non-built up or land cover types (Classes 6-8). The building structure classes (1-4) have contributions in both horizontal and vertical physical dimension.

4.4 Assessment of Urban Structure

Development density and compactness are well-known energy-related urban form parameters (Besussi et. al., 2006). The design of urban structure in an energy-efficient way benefits from the quantification of use intensity in both vertical and horizontal dimensions. Horizontal intensity, such as urban sprawl, contributes to transportation energy consumption. The micro or local climatic matter (i.e., heat island effect) is also impacted by use intensity of urban structure. The city-wide spatial pattern of use intensities may illustrate the importance of understanding spatial land use planning and utility infrastructure planning. The estimated cell-based databank may facilitate urban and detailed development planning.

The vector data model allows the inclusion of geometry and geographical detail of space more precisely in comparison to raster format or satellite imagery (Crooks, 2010). In this study, it was decided to base the computation of urban structure intensity on the vector data sets. The Capital Development Authority (RUJUK) built an extensive vector dataset (ESRI shape file format) on the urban structure of Dhaka city through direct topographic survey in 2005-2006. This dataset was used for preparing the Detail Area Plan (DAP) and Dhaka Metropolitan Development Plan (DMDP). The attribute information of geographic features, such as building structures, roads, water bodies and other land uses, were included in the dataset. The building structures were also attributed with number of stories and purpose of use. The vector dataset has provided enough advantage to estimate with higher accuracy in each building structure coverage.

4.4.1 State of existing building structure intensity

The Dhaka City Corporation (DCC) has 90 administrative districts called Ward (Figure 4-6). Most of them are covered within the strategic/spatial planning zones (SPZs) that are managing by Capital development authority (RAJUK). The basic criteria were physical characteristics, local administrative boundary, land use identities and future growth potentials. These demarcations have been used for data collection and planning during Dhaka Metropolitan Detail Plan (DMDP).

Urban spatial growth and structure pattern is a great concern for urban thinkers. The land use, building and transport structure classes are subject to huge human modification. Together all structure classes also have direct and indirect impact on urban energy consumption as spatial pattern dominate built environment, human mobility, micro-climate, supply services and many more (Anas, et. al., 1998; Besussi et. al., 2006). It is well-justified to explore the spatial distribution of urban structure especially by measuring building structure intensity.

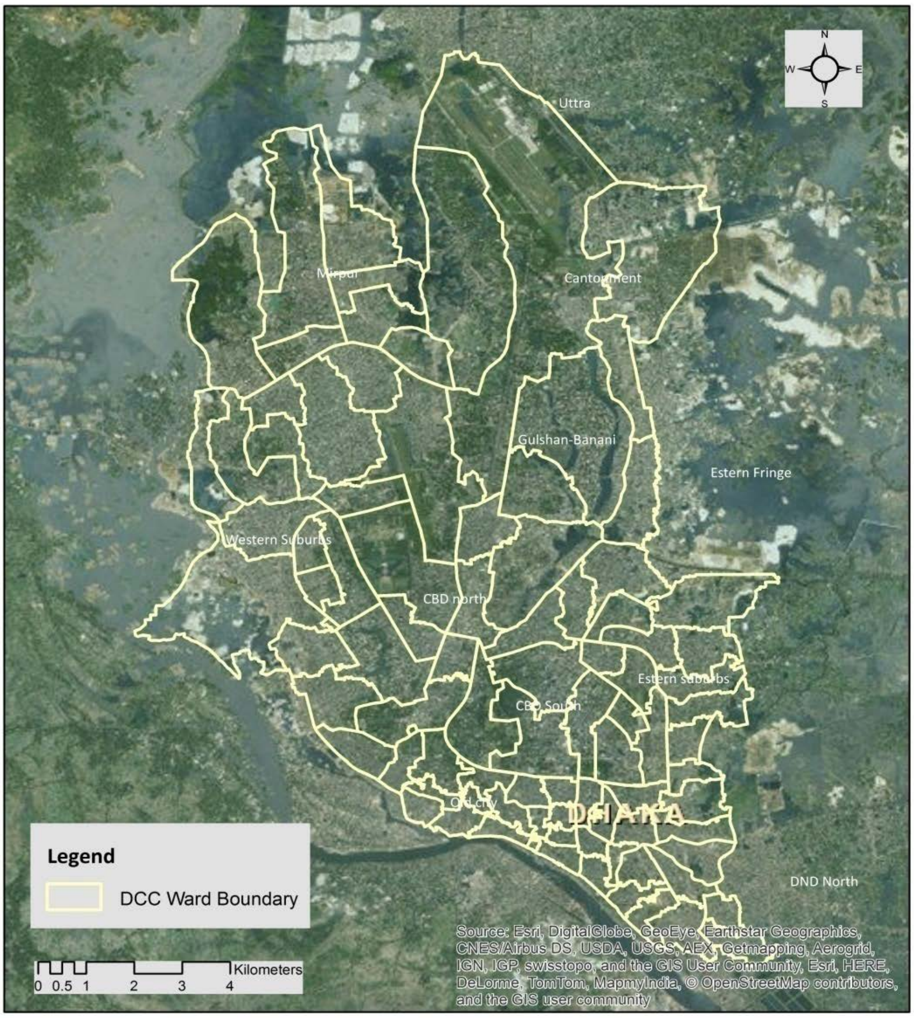


Figure 4-6. Dhaka city corporation (DCC) ward boundary.
Data source: Google (2014) and RAJUK (1995)

Figure 4-7 shows the distribution of mean building structure intensity according to the major four classes in the Dhaka city corporation area. The mean intensity combines both horizontal and vertical intensity. The distribution of mean intensity showed that residential activities (ranging between 0.10 - 0.55) were dominant in comparison to other use classes, such as commercial, service and mixed. Some exceptions were found in the northern city area because of the army cantonment and national airport, which are two major urban community services. The cantonment area is a restricted area and controlled by the cantonment board. After excluding the cantonment area as a restricted zone from the analysis, the central business district (CBD) area (both north and south) showed height build-up intensity. Although the multiple activity mixes are supportive of energy-efficient urban development, the mixed use structural intensity appeared smaller all over the city (~20 percent).

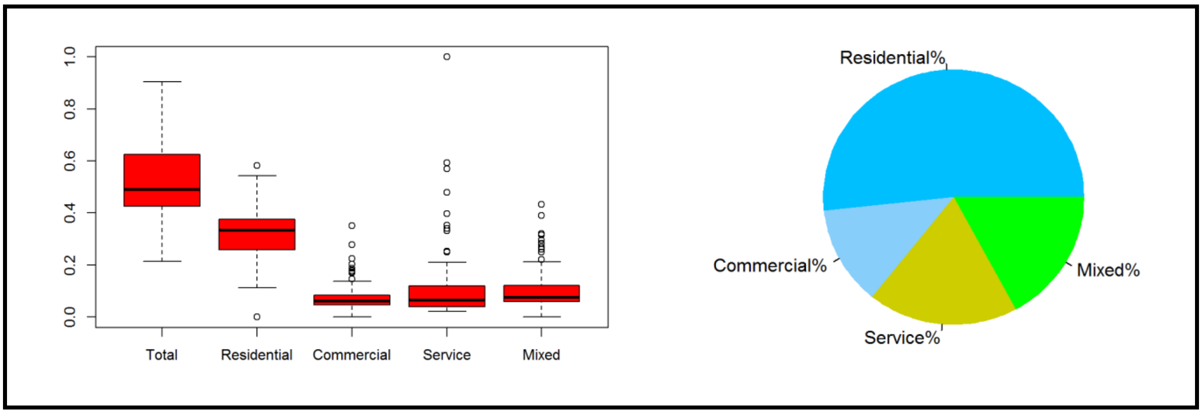


Figure 4-7. Mean intensity of urban building structure and share among landuse classes.

Source: Author's own based on RUJUK-DAP dataset

The average vertical intensity remained higher in the CBD, Old City and Gulshan areas, but suburban areas experienced more horizontal occupancy. The horizontal intensity reached at the peak in the CBD and Old City than all other areas. The total intensity, or built-up intensity, had a relatively higher percentage in the CBD, combining vertical and horizontal, and vertical intercity score. Lower levels of built-up intensity were observed in western and eastern suburbs. The suburbs are also called the fringe area, and urban plans have identified the fringe area for potential development zones.

The spatial distribution of building structural intensity can be better compared with categorized information on a map view (Figure 4-8). The map was prepared with equal intervals of the respective intensity value. The color ramp is representing the degree of intensity combining horizontal and vertical intensities, according to DCC ward-level estimations.

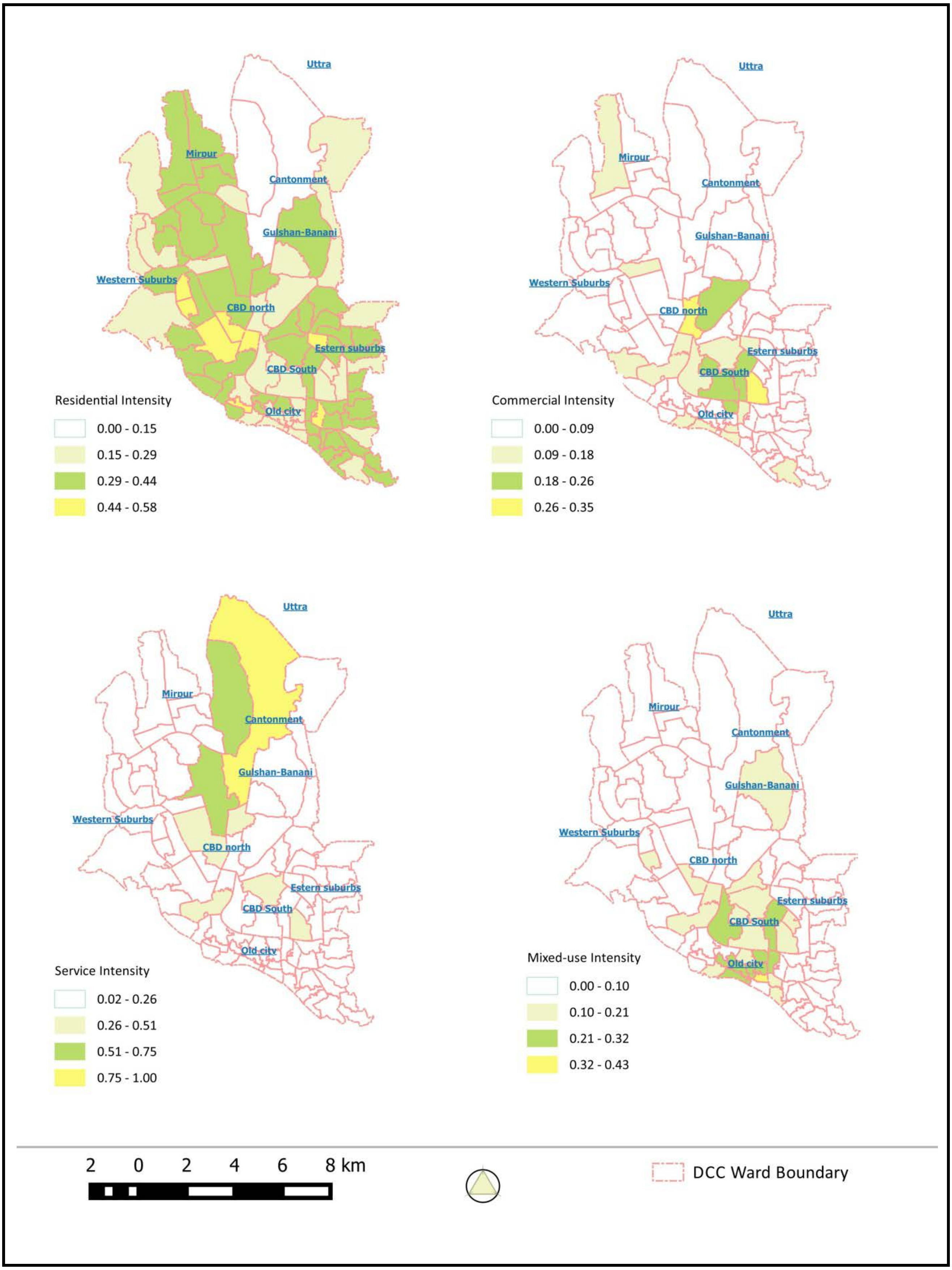


Figure 4-8. Mean land use intensity (classification based on equal interval value).
Source: Author's own based on RUJUK-DAP dataset

4.4.2 Spatial form of building intensity

The form of urban structure may be further conceptualized by interactions and characteristics of intensity distributions. This has been analyzed by applying the well-known spatial autocorrelation (both Global and Local Moran's Index) and spatial distributions of inequality (Gini-coefficient). First, the Global Moran's Index (GMI) measures the level of spatial clustering with a value that varies between positive one (+1 → clustering) and negative one (-1 → dispersion). Second, the Gini-coefficient measures the inequality in a scale of zero (0 → even distribution) to one (1 → uneven distribution). By comparing these two values (Index and coefficient), insight may be provided into the location consequences of land use development over the entire city area (Figure 4-9).

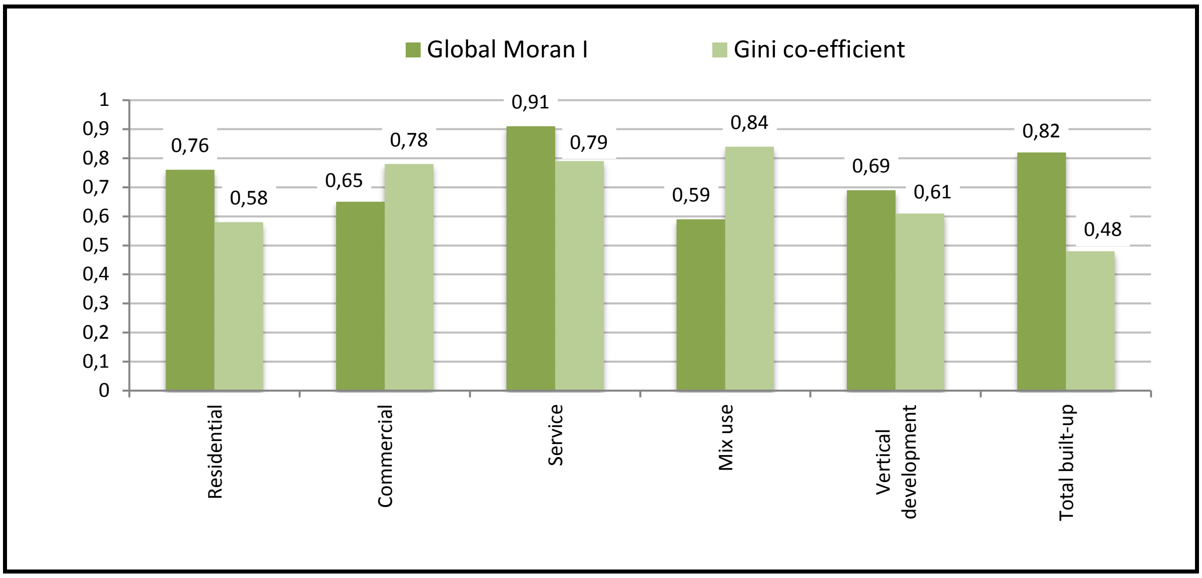


Figure 4-9: Spatial form of urban structure (Global Moran's I and Gini-coefficient).
Source: Author's own based on RUJUK-DAP dataset

Both the Global Moran's Index and Gini-coefficient value were significantly positive, indicating clustering and mostly uneven distribution. The residential building use intensities showed a strong cluster (higher Moran's I: 0.76) and moderate unevenness in its distribution (moderate-higher Gini-score: 0.58). The other classes – commercial, service and mixed-use – exhibited a strong uneven distribution indicating they had some clustering among themselves. The GMI value also supported each relevant Gini-coefficient as the patterns were specially clustered, but the degree varied to some extent. In fact, a "pocket" type of development was evident as the activities had certain location preferences. The vertical development appeared as cluster only and with strong uneven distribution, meaning only a few locations had high-rise building structure development. The mixed-use activity also showed a similar trend. Last, the intensified built-up area (higher Global Moran's I 0.82) where the Gini-coefficient is comparatively lower (0.48) means the structure form in terms of use intensity was more or less evenly distributed over the whole city.

The spatial scenario of building structure form can be better illustrated on a thematic map of structure classes (Figures 4-10 to 4-15). The maps were prepared with categorized Local Moran's I (LMI) values, which are the products of spatial autocorrelation. Based on high and low intensity values, the LMI signifies the clustering and outliers for building structure intensity distribution. Seven different ranges of positive (+) and negative (-) value are classified with red and blue color ramps, respectively. The range value (-0.01 to 0.01) determined as a separate class for better visibility with the assumption that there is no impact of LMI value 0.

The estimation of the Local Moran's Index (LMI) can also help to further analyze urban building structure form, in addition to GMI and Gini-coefficient values (Yeh and Li, 2002). The LMI identifies outliers and spatial clustering, with negative I values and positive I values, respectively. The estimated values of LMI were presented along with related intensity values in a form of a scatter diagram. The horizontal red lines showed the typical value range (-1 to +1) of LMI, and unique symbols showed the type of co-relation or clustering pattern.

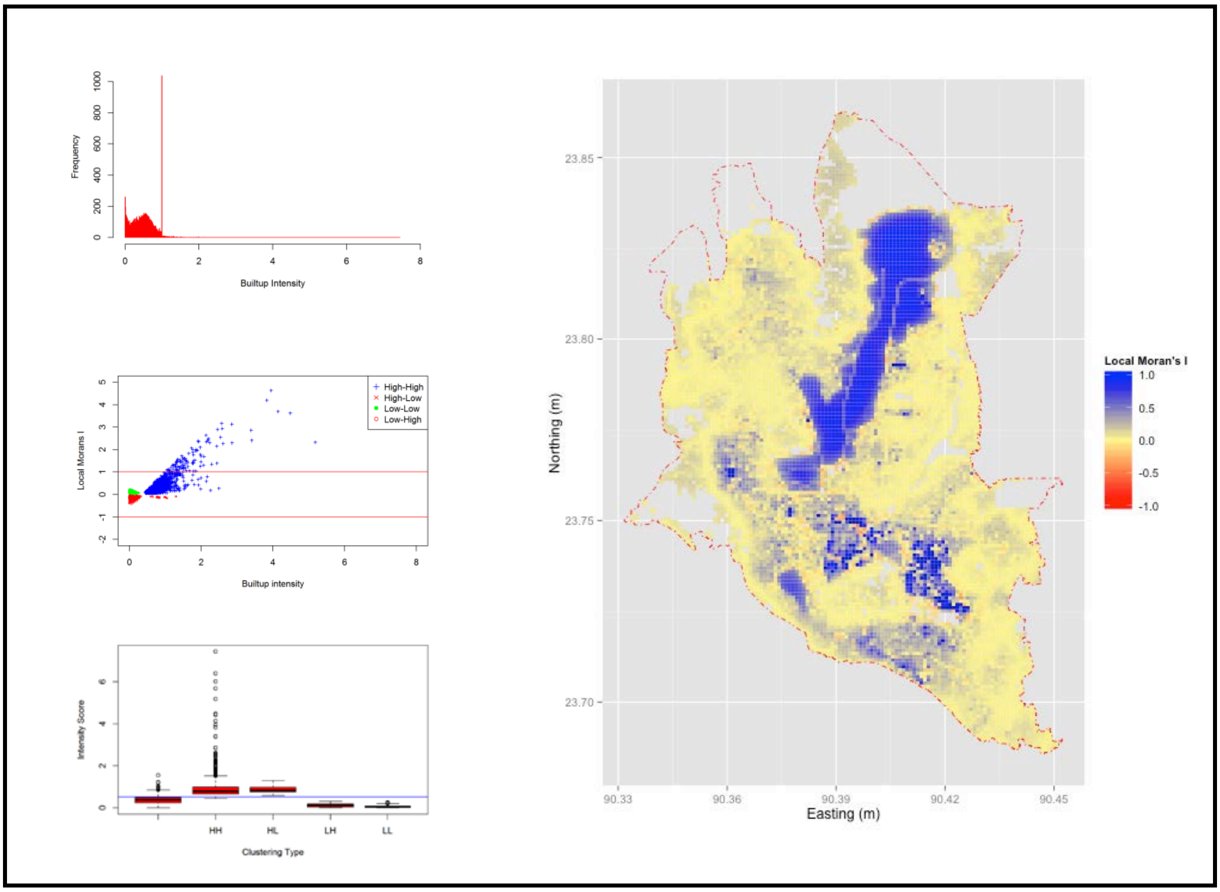


Figure 4-10. Spatial analytics of total build-up form.
Source: Author's own based on RUJUK-DAP dataset
Note: The large blue colored area is under Dhaka Army cantonment (restricted area) and calculated under unique service class

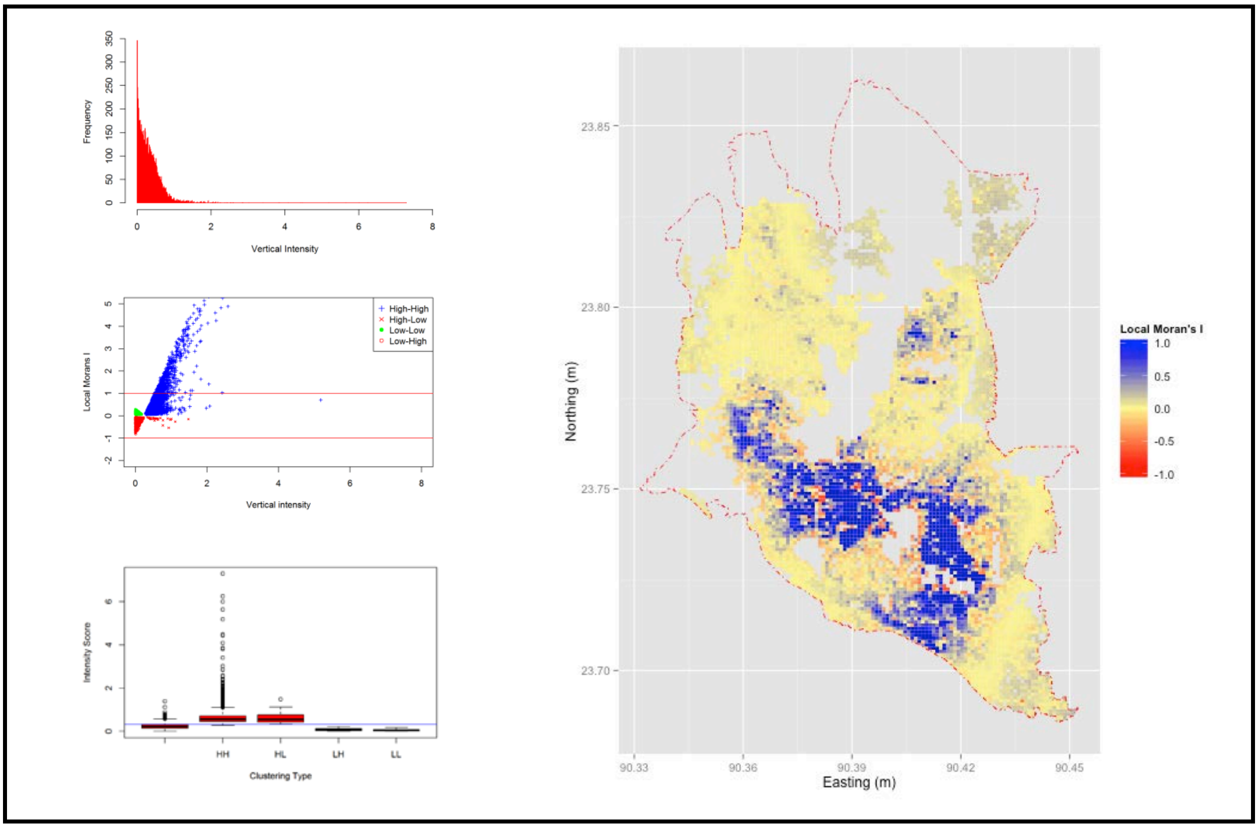


Figure 4-11. Spatial analytics of vertical development form.
Source: Author's own based on RUJUK-DAP dataset

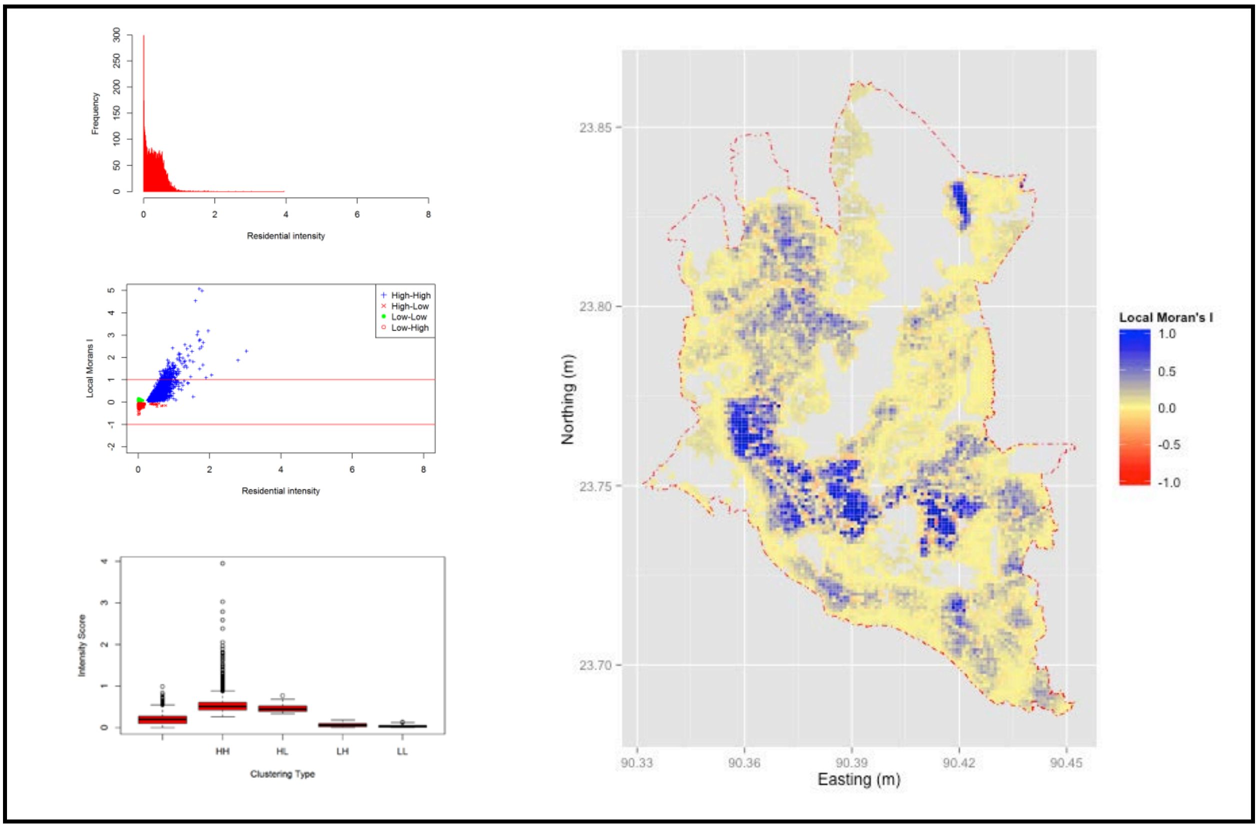


Figure 4-12. Spatial analytics of residential building structure form.
Source: Author's own based on RUJUK - DAP dataset

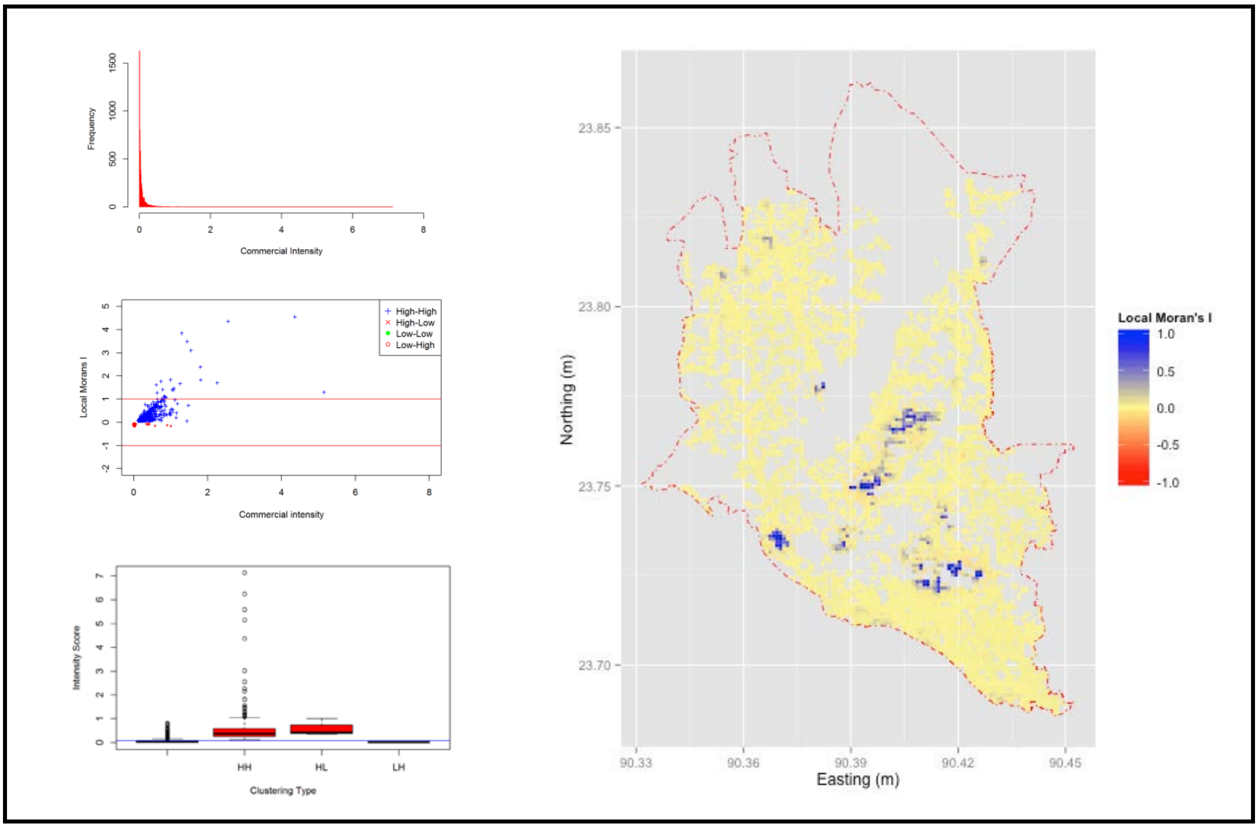


Figure 4-13. Spatial analytics of commercial building structure form.
Source: Author's own based on RUJUK - DAP dataset

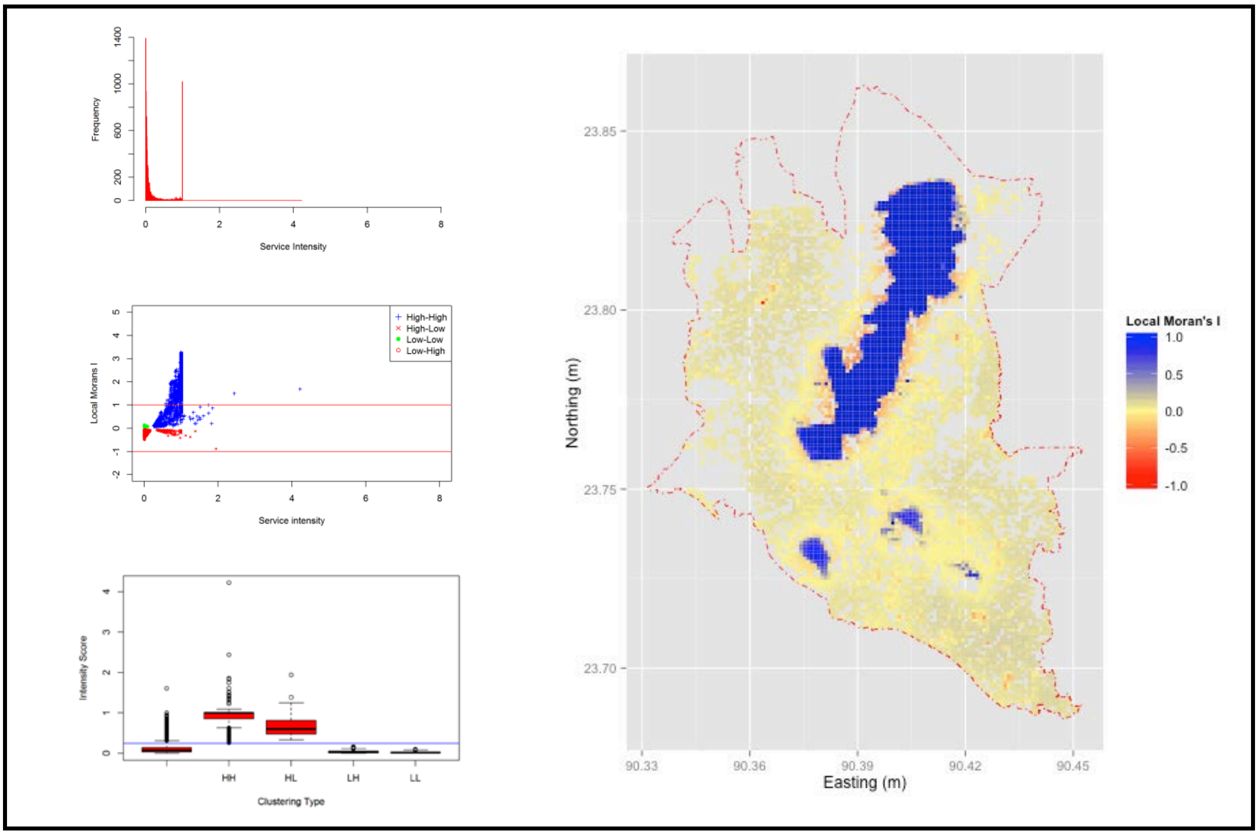


Figure 4-14. Spatial analytics of service sector building structure form.
Source: Author's own based on RUJUK - DAP dataset
Note: The large blue colored part is under Dhaka Army cantonment (restricted area) and calculated under unique service class

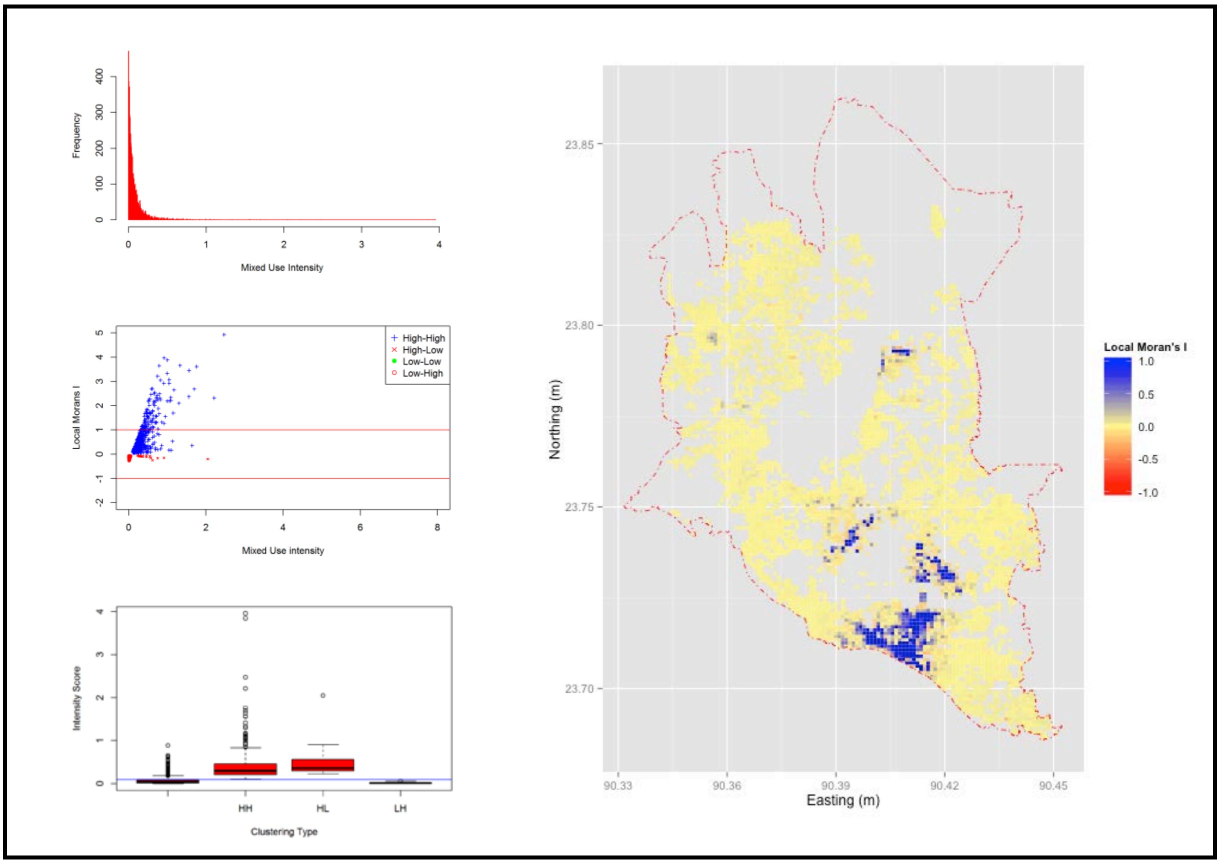


Figure 4-15. Spatial analytics of mix-use building form.
Source: Author's own based on RUJUK - DAP dataset

The scatter diagram showed that most structure classes have few extreme outliers or dispersions (negative LMI values less than -1). It should be mentioned that data points are excluded if there is no co-relation or clustering present. The built-up use intensity (i.e., aggregated for all types of building structures), and both high and low value clusters, demonstrated continuous slow progress of LMI values (max value 20) to intensity scores (maximum value 8). But the vertical use intensities showed sharp progress in relation to LMI, indicating extreme clustering within highly intensified vertical activity. The closeness of the LMI value to -1 indicated the greater existence of outliers. According to the type of structure use, the residential classes are surrounded by similar use (LMI index values above 0), which ultimately indicated the cluster pattern of residential activities with similar value of use intensities. There were a few outliers (LMI value about - 0.50), indicating some sporadic development of residential building structure. The LMI values progressed smoothly (almost with 45 degree slope) towards intensity values. It revealed a continuation among high value clusters and vice-versa; thus expressing a reduced degree of extreme clustering of residential activities. The commercial structures showed a weak clustering pattern over the city, although the LMI index showed much fewer outliers. In fact, the slow change of LMI values to intensity scores suggested a non-continuous clustering pattern. The LMI index for service-related building structures showed clustering of activities, but a scatter pattern existed because little continuity existed among high and low value clusters. The location of the cantonment had a strong influence on the strong clustering among the low value clusters. The mixed-use type building structures had extreme clustering with fewer outliers and were highly impacted by higher intensity scores because high-rise buildings are potentially mixed-use.

The type of co-relations or clustering patterns provided very important information about the form of urban structure, in particular the degree of compactness and influences surrounding landuse. The commercial and mixed-use have almost no low-low co-relations indicating an extreme concentration of activities in some particular area. In fact, the existence of low-high or high-low clustering is indicating some degree of influence on surrounding use decisions by commercial and mixed-use activities. On the other hand, opposite findings were evident in the cases of residential and service type uses of structure. Nevertheless, the service sector activities appeared slightly different from residential, which may have been an effect of the cantonment area in the dataset not having enough building information.

The histogram of cell-wise intensity scores and box-plots according to co-relation type factors is presented to give a better overview of dynamic uses of urban building structure in Dhaka city. The box plots show the presence of an extreme intensity score that contributed to produce Local Moran's Index value above +1.

4.5 Energy Consumption in Relation of Urban Building Structure

4.5.1 Spatial Pattern of Energy Consumption Density (ECD): Residential use in focus

After analyzing the spatial pattern of urban building structure, this section explores significant relationships in terms of urban energy consumption. Urban structure and urban energy consumption are significantly co-related from both physical and spatial dimensions; however, it is often difficult to analyze in the context of many mega cities of developing countries. A simple procedure was applied in this study (Section 3.2.3) to make some initial estimates of energy consumption densities in relation to urban structure. Estimates only included the DCC area due to the availability of ward-wise population census data. The energy consumption information was extracted with an annual per capita indicator. The estimated unit of ECD is kg of oil equivalent/sq.m.

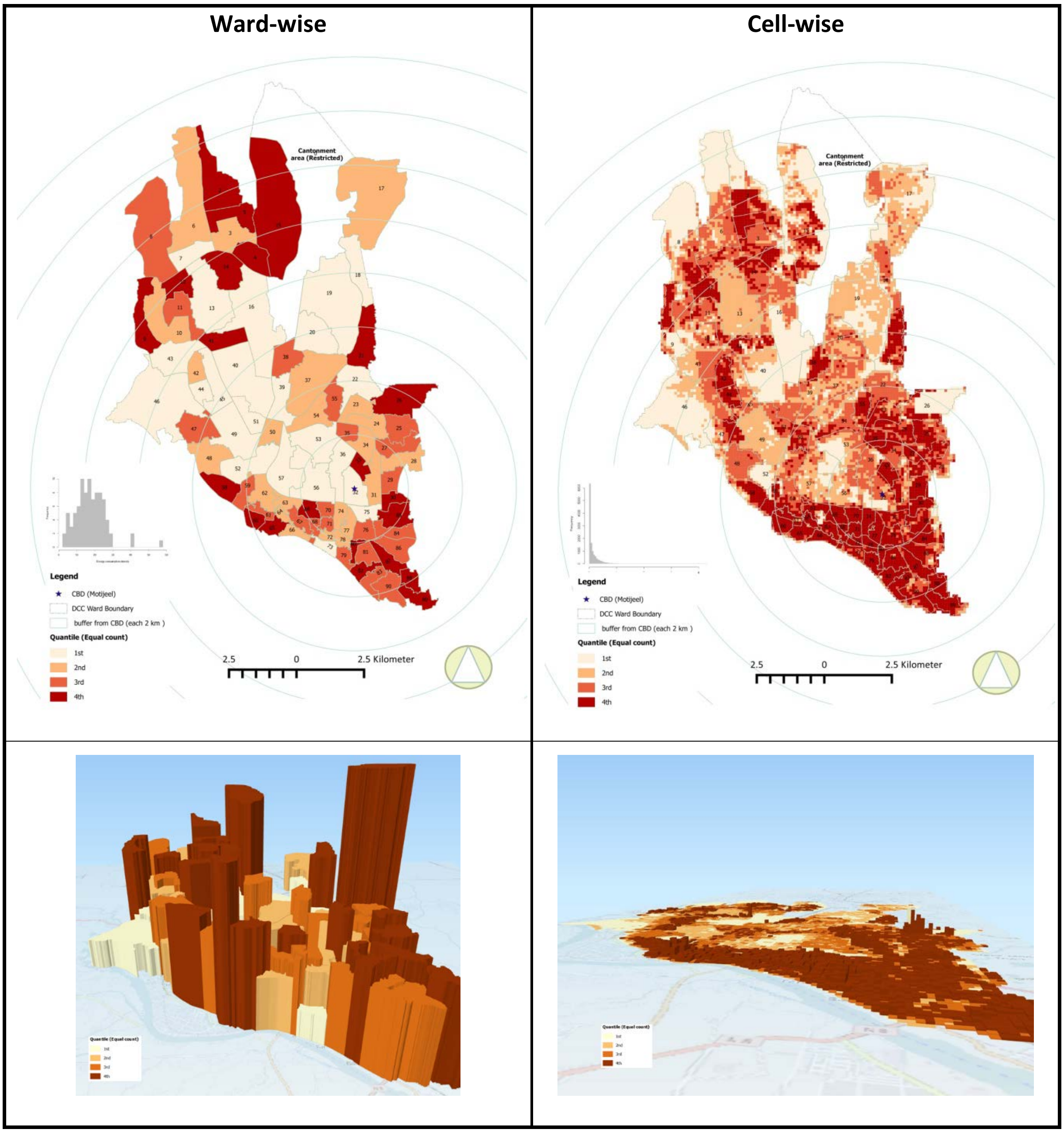


Figure 4-16. Spatial distribution of energy consumption density in 2D and 3D.
Source: Author's own based on RUJUK-DAP dataset

Dhaka city corporation (DCC) has 90 wards. A ward is the smallest administrative and census unit. The estimated ward-wise ECD varied within a range of 3.3 to 56.1 kg of oil per capita/sq.m. Low ECD means high per capita consumption in less intensified or lower degrees of building structure development.

The spatial scenario was illustrated, defining 4 different density classes based on a quantile distribution rule (ward wise Figure 4-16). The cantonment area was removed from the map due to lack of information and restricted status. The suburban wards were classified as higher ECD areas - there could be two reasons for this: higher population density and less building floor space. At this level, a detailed spatial distribution of ECD could be depicted by cell-wise estimation (cell-wise: Figure 4-16). In both ward and cell level detail visualization can be covered better in 3D.

The ECD estimation used the aggregated building floor space from all types of use (i.e., residential, commercial, service and mixed-use). The justification for the aggregation was based on the lack of sector-wise energy consumption information and inter-activity complex relationships. However, the share of building floor space from each type of use had an influence on patterns of sector-wise energy consumption.

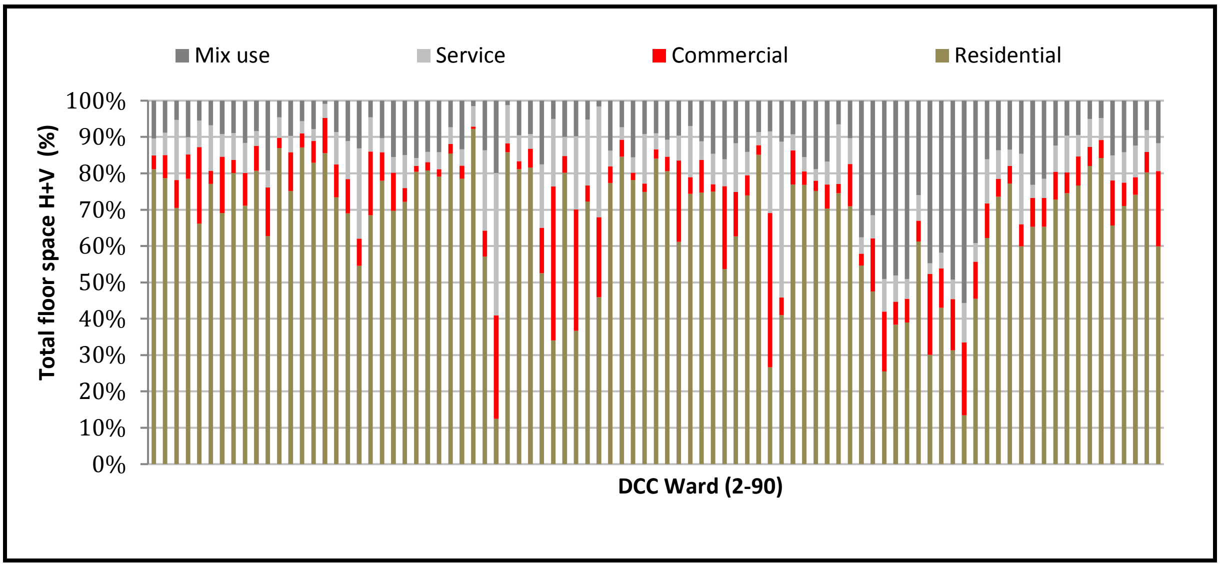


Figure 4-17. Share of building floor space according to use type in DCC area.
Source: Author's own based on RUJUK-DAP dataset

The residential sector had the highest share of building floor space (66.9%) compared to commercial (10.4), service (10.2%) and mixed-use (12.3%) (Figure 4-17). The ward-wise percentile distribution of total building floor space showed that most wards were dominated by residential use. Mixed-use was second priority with higher shares than residential sectors in a few concentrated wards. With few exceptions, the service sector and commercial spaces had even shares in almost all wards.

The relation between ECD and building floor space has to be investigated further with both ward and cell-wise estimations. More insights can be explored with closer looks at both horizontal and vertical space distribution. The comparison among the building use sectors also could be understood by looking at patterns of data points and Pearson co-relation coefficient (ρ) values. Furthermore, the results could be highly significant, especially for conceptualization of the contribution and manipulation need of urban building structure for climate-friendly urban physical development.

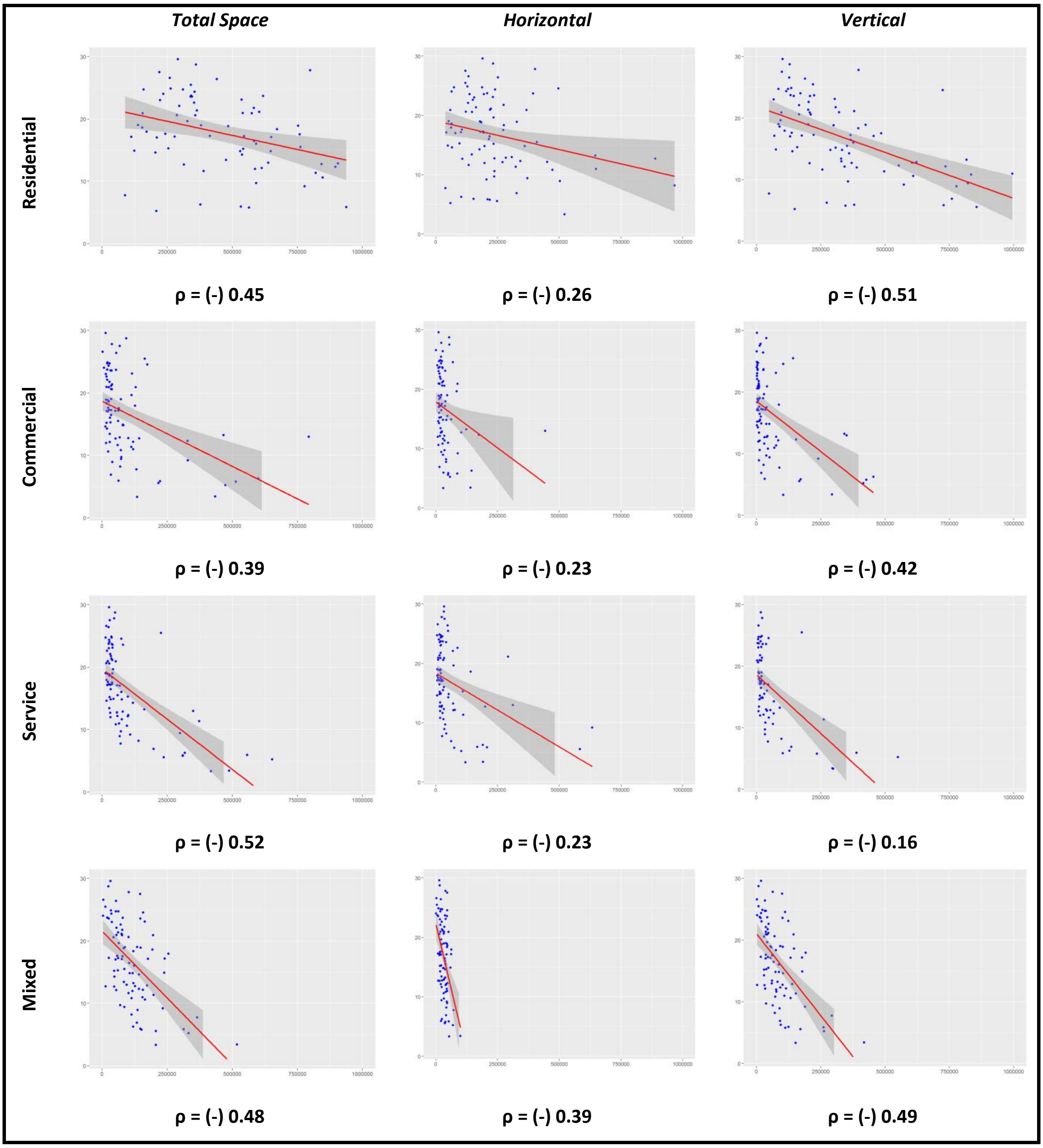


Figure 4-18. Relationships between ECD to building floor space (ward-wise).
Source: Author's own based on RUJUK-DAP dataset

The scatter diagrams (Figure 4-18) show that a negative correlation existed in-between ward-wise ECD and building floor space. More specifically, ECD fell as building space increased, with at least moderate correlations for all types of total space. However, weaker relations were observed for horizontal space than vertical space distributions. The mixed-service use type exhibited weak co-relations in both horizontal and vertical space distribution, but showed a negative trend.

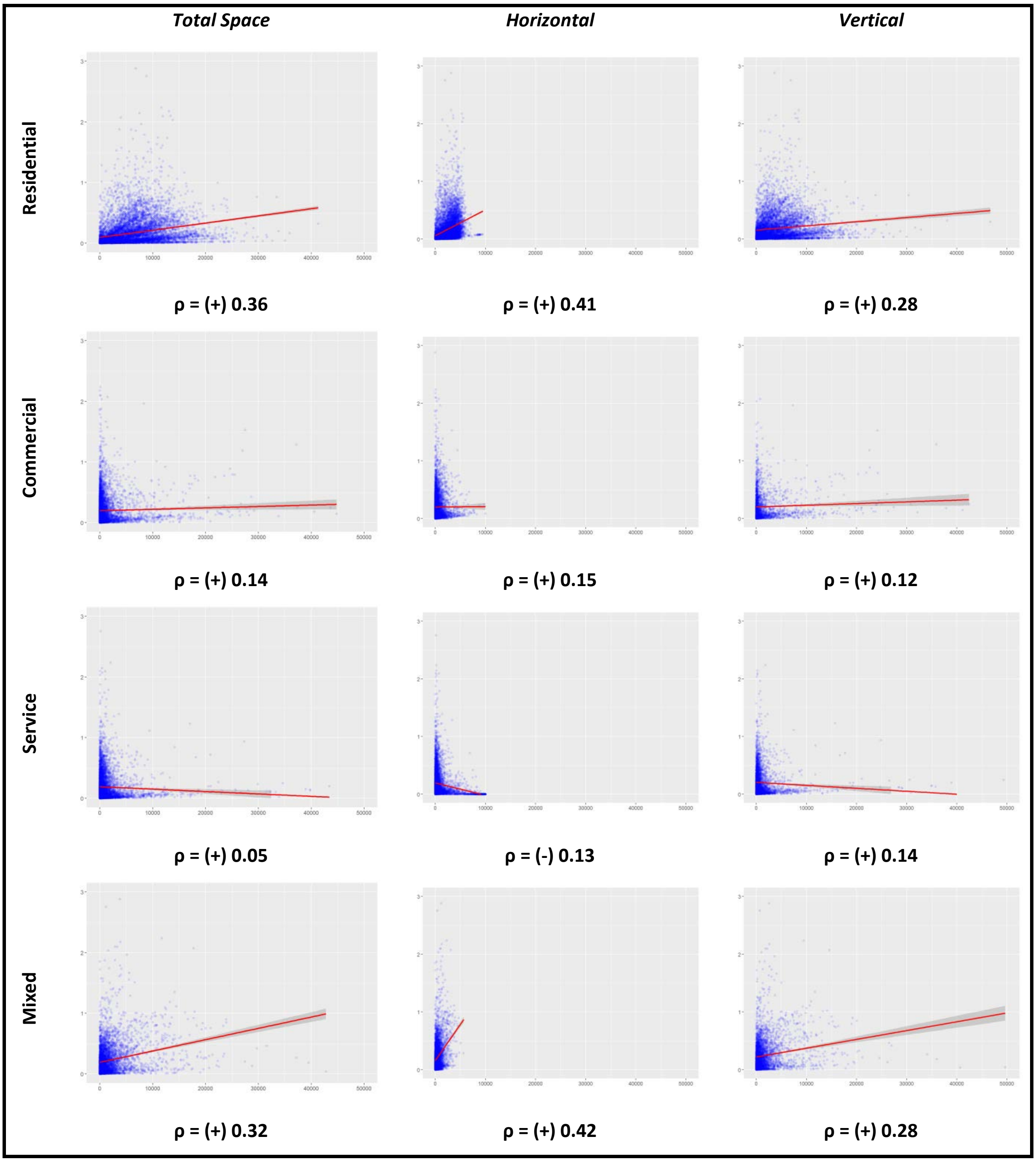


Figure 4-19. Relationships between ECD to building floor space (cell-wise).

Source: Author's own based on RUJUK-DAP dataset

The cell-wise distribution of estimated ECD points had a positive relationship with building floor space (Figure 4-19). A negative relation in service sector horizontal space (e.g. seems even a presence of Simpson's paradox) was the only exception. In fact, the entire scenario confirmed very weak co-relations except residential and mixed use types. In both cases, the horizontal space had a strong relationship with ECD. Therefore, vertical space manipulation may still possible for Dhaka city which could influence intensified and energetic urban development. The carrying capacity of the built environment needs careful considerations apart from meeting low energy goals.

4.5.2 Relationship between energy consumption density and building intensity

Regression analysis was used to examine the relationship between the form of urban structure and ECD. The urban form control variables were structural use intensity estimated for both horizontal (HUI) and vertical (VUI). The dependent variable was identified as ECD. This study formulated a multiple regression equation by following Wilson (2013), where interactions among the control variables were also included.

$$ECD = \beta_0 + \beta_1 HUI + \beta_2 VUI + \beta_3 (HUI \times VUI) \text{.................... (Equation 16)}$$

The regression coefficient was expressed as β, which indicated how the dependent variable (e.g. ECD) was impacted due to changes of one unit in control variables (e.g., HUI and VUI). The data analysis showed that the control or independent variables were weakly correlated (Table 4-3); therefore, the multi-regression equations are helpful.

Table 4-3. Analysis of correlations and variance.

Items	Pearson correlation coefficient, ρ			Variance	SD
	1	2	3		
Horizontal intensity	-	-	-	0.02	0.15
Vertical intensity	0.22	-	-	0.06	0.25
ECD	0.40	0.12	0.29	0.05	0.24

Source: Author's own estimation

After normalization of cell-based estimated data on intensity and ECD, the model predicted a power of approximately 25% with multiple R^2 statistic value at 0.25. The estimated model can be written as follows:

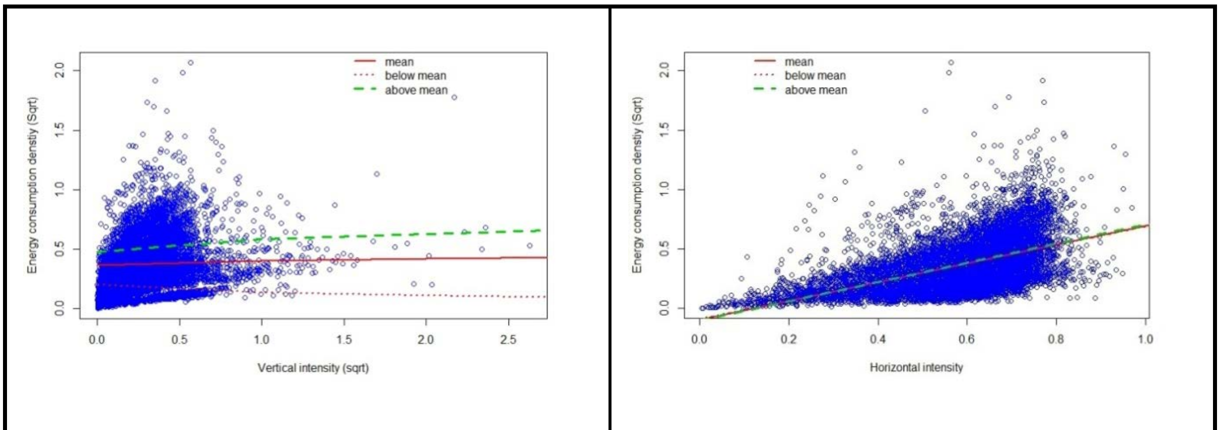
$$E_{cd} = 0.63 (HUI) - 0.20 (VUI) + 0.40 (HUI \times VUI) - 0.018 \text{ .... (Equation 17)}$$

Table 4-4. Linear regression results in interaction terms.

Items	Energy consumption density (ECD)		
	Estimate	Standard error	t value
Intercept	- 0.018	0.012	-1.502
Horizontal intensity	0.637	0.021	29.034
Vertical intensity	- 0.203	0.049	-4.145
Vertical intensity × Horizontal intensity	0.405	0.076	5.272
R^2	0.25		

Source: Author's own estimation

The results showed that the ECD can be described by both horizontal and vertical intensities. The horizontal use intensity had more influence or explanatory power about ECD than did vertical use intensity. The interaction between urban structure use intensity also provided important insights. The graphical explanation of this interaction is plotted with predicted model results by taking both control variables (e.g., HUI and VUI) as moderators.



Note: Predictions with 1 standard deviation above and below the mean HUI | Note: Predictions with 1 standard deviation above and below the mean VUI

Figure 4-20. Interaction plot with HUI and VUI in relation to ECD.

Source: Author's own calculation

The predictions were estimated in terms of mean use intensity values, one (1) standard deviation above and below the mean (Figure 4-21). The interaction plot shows that the constructed regression model showed a large shift for higher horizontal use intensity values compared to lower values. Interestingly, there was almost no shift when the vertical use intensity was considered as a moderator.

4.6 Energy-related Important Variables

In this section, variables such as building age, volume, surface area, and floor area ratio are estimated and analyzed additionally in relation to the importance of urban energy consumption (Keirstead, 2007). The estimation has to be conducted on each individual building, but one may conclude limited relevance to integrate with the cell-based intensity and ECD. Interrelations between the variables are further discussed, highlighting interesting interrelationships about urban structures in the context of Dhaka city.

4.6.1 Building age, volume and floor area ratio (FAR)

The age of a building structure is an important determinant for improving energy efficiency and consumption (Wilson, 2013). Building ages in 2015 were calculated using construction year data available within the DMDP building dataset. The building volume and floor area ratio (FAR) were also estimated with DMDP building data, and the building height factor was extracted from the number of building stories.

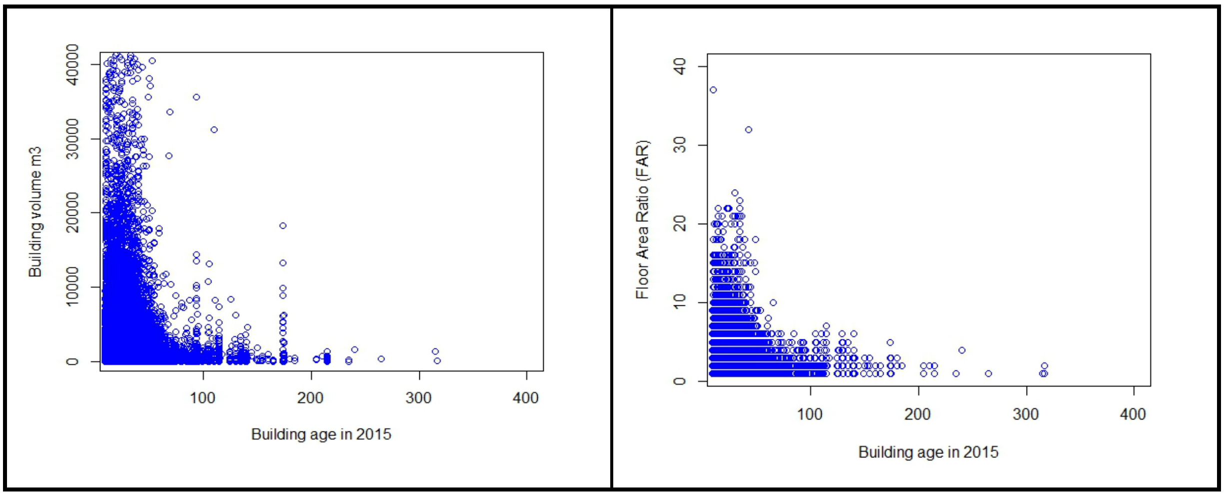


Figure 4-21. Building age in relation to volume and floor area ratio (FAR).
Source: Author's own calculation,
Note: About 19 percent buildings have missing age information

As per DMDP survey data, the buildings of Dhaka city were mostly constructed in the last century, but it should be mentioned that building age information were not available for many buildings (about 19%). The higher volume building structures were mostly constructed during the last 50 years following the increasing pattern of urbanization rates (Figure 4-21). Therefore, the correlation of building age to volume showed a slightly negative trend (-0.0032). The FAR to building age relationship exhibited almost the same pattern as building volume, but the correlation between building age and FAR appeared as positive (+0.0005). It indicated significant high-rise development during recent years. In terms of transportation energy consumption, such densification was suggested by many scholars, but there were also varied opinions regarding quality of urban life, heat island effect and many other factors.

4.6.2 Surface Area to Volume Ratio (SA: V)

The surface-area-to-volume ratio (SA:V) is an important determining factor in relation to energy demand estimations (Schubert et al., 2013). Due to heat loss/gain dynamics, SA:V contributes to the optimization of building thermal comfort, electric load and cooling load savings. It should be mentioned that the precise estimation of SA:V has significant challenges in total surface area calculation due to varied shape building structures of a large dataset. In this study, estimation was done within the platform of GIS in consideration of the relationship between individual building area, perimeter and height. The equation can be written as:

Total building surface area = (Perimeter × height) + (2 × Area)……… (Equation 17)

It was assumed that all buildings had flat roofs. The relationship between the ECD and individual building SA:V ratio could not be analyzed as there wass no building level energy consumption data available.

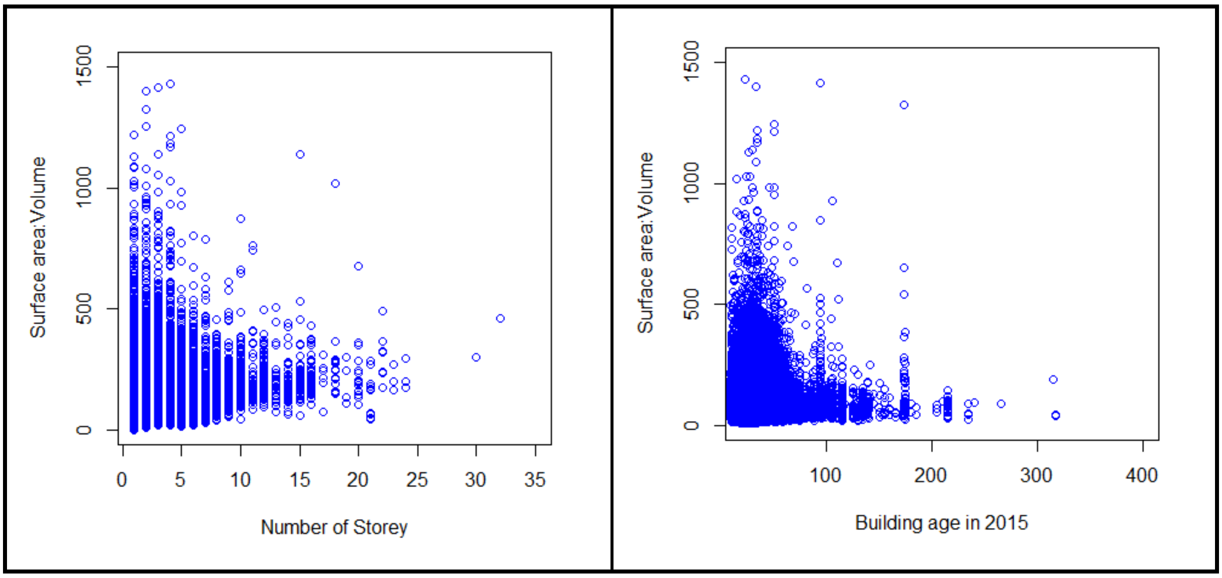


Figure 4-22. Building surface to volume ratio in relation to number of storey and building age.
Source: Author's own calculation
Note: About 19 percent buildings have missing age information

The lower value of S:V ratios indicated minimum heat gain and minimum heat loss (Ko, 2013). In the context of Dhaka city's tropical climate, the S:V ratio should be as low as possible so that the heat gain is minimized. Figure 4-22 shows S:V according to other parameters, such as number of stories and building age. In both cases, S:V ratios remain within the range of 500 . It was observed that the S:V ratio followed a slightly increasing pattern with high-rise buildings (correlation +0.34), but age did not show much effect (correlation +0.03). One reason for this might be that comparatively young high rise buildings had larger volumes that directly affected energy consumption, at least for thermal comfort. Of course, one can argue that the building design and construction materials also had roles to play.

In the next chapter, two case studies are extensively analyzed after choosing representative neighborhood clusters according to the residential development type. The focus on residential neighborhood structure can be justified due to the residential building sector's higher share of overall energy consumption.

CHAPTER FIVE: NEIGHBORHOOD ENERGY RELATIONS OF RESIDENTIAL SETTLEMENT

5.1 Overview of Study Units

Two neighborhood-level study units, called Study Residential Clusters (SRC), were selected to help investigate residential urban structure. A pre-defined set of criteria was applied to identify the two representative SRCs in the context of Dhaka city: Niketan and Nikunja (Table 5-1, Figure 5-1). SRC 1: Niketan was developed by Eastern Housing Ltd., a private sector developer, and SRC 2: Nikunja was developed by the Capital Development Authority (RAJUK), a public agency that is also responsible for physical planning and development control for the metropolitan Dhaka area. Both SRCs are located inside the city local government administrative jurisdiction area (i.e., DCC).

Table 5-1. Basic information on study residential clusters (SRC).

Items	SRC 1: Niketan	SRC 2: Nikunja
Year of approval	2003	1990
Developer type	Private: Eastern Housing Ltd	Public: RAJUK
Target groups	Open for all	Middle income
Total land area (in acre)	55.24	62.41
Total plot	562	923
Total building structure*	392	796
Total household (HH)	2,494	3,939

Source: BBS (2012) and RAJUK (2013)
Note: Including under construction buildings, temporary structures

The site and service approach was used to develop both of these residential clusters. The developer agency conducted earth-filling work and installed basic infrastructure such as roads, drains, electricity, etc. Afterwards, the developer sold the land to buyers in subdivided plots. The private landowners then constructed buildings or hired private developer companies. The land development agency obtained all formal approvals for the residential development projects, such as land acquisition, subdivision planning and more.

Figure 5-1: Perspective view of SRC 1: Niketan (Left) and SRC 2: Nikunja (Right)
Source: Field photography (2013)

The field investigation yielded one of the most important observations: although the initial land development goal was targeted for residential activity only, other activities like commercial and service often deteriorate the residential quality. This observation was reported by other studies (Nahrin, 2008; Shakil et al., 2012) that examined the state of residential quality and regulatory violations in selected residential clusters. Both SRC 1: Niketan and SRC 2: Nikunja are gated communities with private security services financed by residents. The land and building owner are also having welfare society those are working for the betterment of living conditions under governance of elected representatives.

5.2 Measuring energy concerned indicators: Neighborhood scale

A set of selected indicators was measured after collecting multi-faceted information on residential urban structure and energy concerns at the neighborhood scale (Appendix A: Table 2). A brief description of these indicators is presented in this chapter. The selected indicators originated primarily from three dimensions: structural, social and technical. The structural dimension deals with criteria such as location advantages (i.e., in relation to transportation, supply facilities) and road/building orientations, along morphological factors. The social dimension includes housing/flat structure, residents' structure and personal mobility factors. The technical dimension deals with significant energy use factors – in particular, electricity and mobility matters. Renewable energy potential, especially solar potential, is an important criterion in this dimension.

5.2.1 Smart location

Location is a major parameter for human settlement planning. Location can be described as a relative or absolute position on the earth. The smart location criterion refers to either the physical context or the relations of the urban neighborhood to others (Lienau, 1995, cited in Stoeglehner et al., 2009). As per LEED-ND, the desired development objectives, limits and prerequisites can be ensured within these criteria (US:GBC, 2009). From an energy point of view, both the accessibility to employment area and edge contrast impact the energy requirements of the residential settlement.

5.2.1.1 Edge contrast index

The edge contrast index is one of the urban form parameters to determine the dissimilarity among the land uses of a targeted study unit and surroundings area. According to Wilson (2013), the edge contrast index can be estimated by the formula mentioned in Box 5-1:

Box 5-1: Computation formula of edge contrast index

$$\mathrm{EC}i = \frac{\sum_{J=1} \mathrm{PERIMij} * \mathrm{CONTRASTj}}{\mathrm{PERIMi}}$$ ....(Equation 18)

Where i denotes the total perimeter of the case study neighborhood, j represents the length of shared boundary the neighboring parcel.

Source: Author's own

Two landuse classes were considered: (i) Developed (e.g., residential, commercial, industrial, mixed-use, transportation, service) and (ii) Undeveloped (e.g., vacant lots, water bodies, and farmland). The developed landuse class was weighted as zero (0) and the undeveloped class was weighted as one (1) in the calculation of the edge contrast index. The degree of dissimilarity with the developed land use class can be recognized. FRAGSTATS software (a landscape analysis package) was used to estimate the edge contrast index, and QGIS assisted in preparing both vector and raster type datasets.

The edge contrast index has important impacts on integrated urban development and the built environment. Identifying an accurate buffer distance is a critical step to include all significant surrounding land use activity. In this study, a 100m buffer distance was selected, which covered all major land use activities (Figure 5-2).

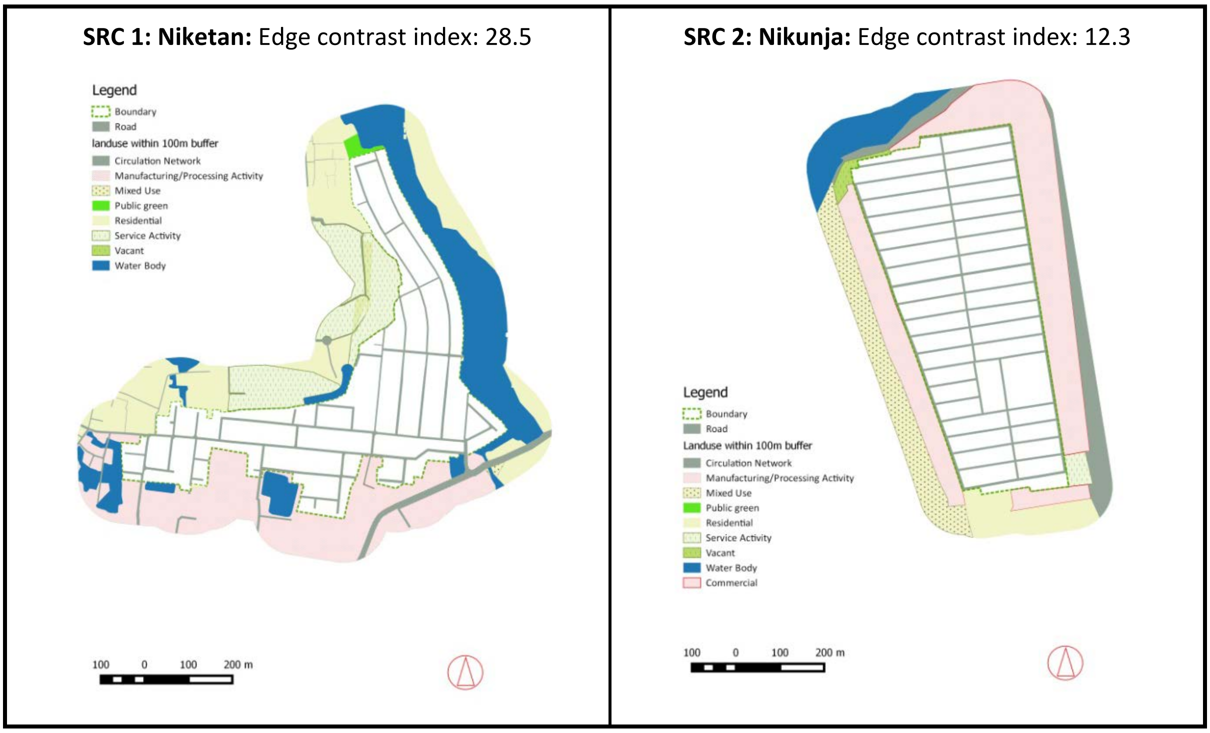


Figure 5-2. Land use within a 100m buffer distance.
Source: Author's own based on RUJUK - DAP dataset.

The estimated edge contrast index value for SRC 1: Niketan was higher than for (double) SRC 2: Nikunja. This indicated a higher degree of dissimilarity in the surrounding landuse in SRC 1: Niketan. The location near to the undeveloped landuse (e.g., water body) may have had strong influence on this result. With the view of energy consumption for cooling comfort, one should support encouraging development near to undeveloped areas. There are other urban structural functions that need careful consideration – for example, functional mix and integrated development concerns.

5.2.1.2 Proximity to employment

The central business district (CBD) is a zone for concentrated employment, - according to traditional urban planning and spatial planning theories. However, in fast-growing cities that grow in an uncontrolled way, there is intermixing of uses and overlapping of employment zones that are difficult to identify (Islam, 2009). Nevertheless, Saha, (2011) identified major employment zones and employment centers across Dhaka city by adopting Euclidean distance method and hot spot analysis.

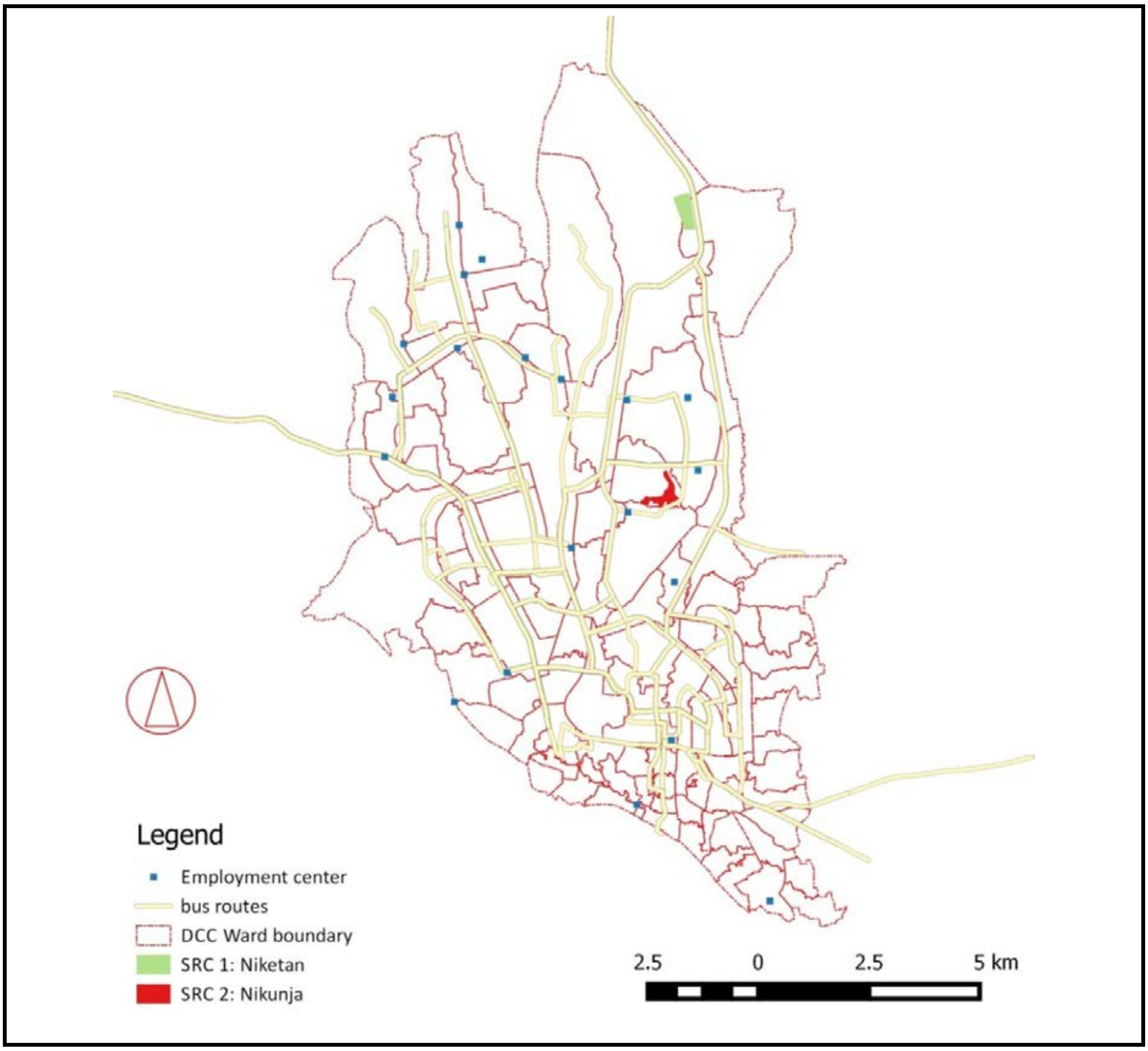


Figure 5-3. Location of employment hot spots in Dhaka city.
Source: Author's own based on RUJUK - DAP dataset and Urban Lunchpad (2013), Saha (2011)

In this research context, such employment zones or centers were recognized in order to identify the proximity of the SRC to major employment areas. The GIS-based analysis tool was used to compute the relative proximity as a simple variable of physical distance (e.g., distance from the centroid point of the SRC) to the employment zones or centers (Figure 5-3). The travel time, transport modal choice, road conditions and comfort level were not considered in the analysis at this level. The distance analysis shows that SRC 1:Niketan is located near employment hot spots (mean 4.9km, with a standard deviation of 2.7; min 0.4 and max 11.4). On the other hand, SRC 2:Nikunja is located far from the employment hotspots (mean 8.3km, with a standard deviation of 3.8; min 4.2 and max 18.1).

5.2.1.3 Transportation facilities

Smart growth policy incorporates the topics of mass transit or transportation facilities –bus and train transit can save energy, reduce pollution, and decrease parking needs. Furthermore, better transportation facilities that decrease commute times can also limit urban sprawl, which has overall benefits to the urban economy, environmental sustainability and public health (UN-Habitat and ICLEI, 2009; Choguill, 2008; Luederitz et al., 2013). Similarly, the service quality is one of the sensitive factors to be considered that includes the frequency of transfers, security, cost, reliability, and comfort. Besides intercity transportation facilities, it is also important to promote connectivity with other nearby local communities (US-GBC, 2009).

i) Accessibility to public transportation facilities

Access to public transportation facilities plays an important role in reducing dependency on private vehicles. In the mega city context of Dhaka, regular formal public transportation often does not exist or remains overcrowded, limited and poor. A variety of informal modes (IMs) or non-motorized transport (NMTs) options have evolved to serve the travel demand (Rahman et al., 2012). The accessibility to such informal transportation facilities is difficult and do not meet any formal planning goals. The distance to public bus routes has to be considered within the broad vision of Bus Rapid Transit (BRT). The distance is defined in planning literature (e.g., bus stop should be within 1.0 km as per Green township India) and local regulatory standards. Urban Launch-pad (2013), an open urban information project, recorded and updated data on the location of bus stops and daily public bus routes for Dhaka city. The GIS-based spatial analysis tool was used to find out the number of bus stations within the catchment area of 1km. Others factors were not considered, such as time and mode to reach the bus stations. Results showed that SRC 1: Niketan and SRC 2: Nikunja have 2 and 3 bus stations within the catchment area of 1km, respectively (Figure 5-4).

SRC 1 Niketan: Bus station < 1km: 3 Nos.	SRC 2 Nikunja: 2 Nos.

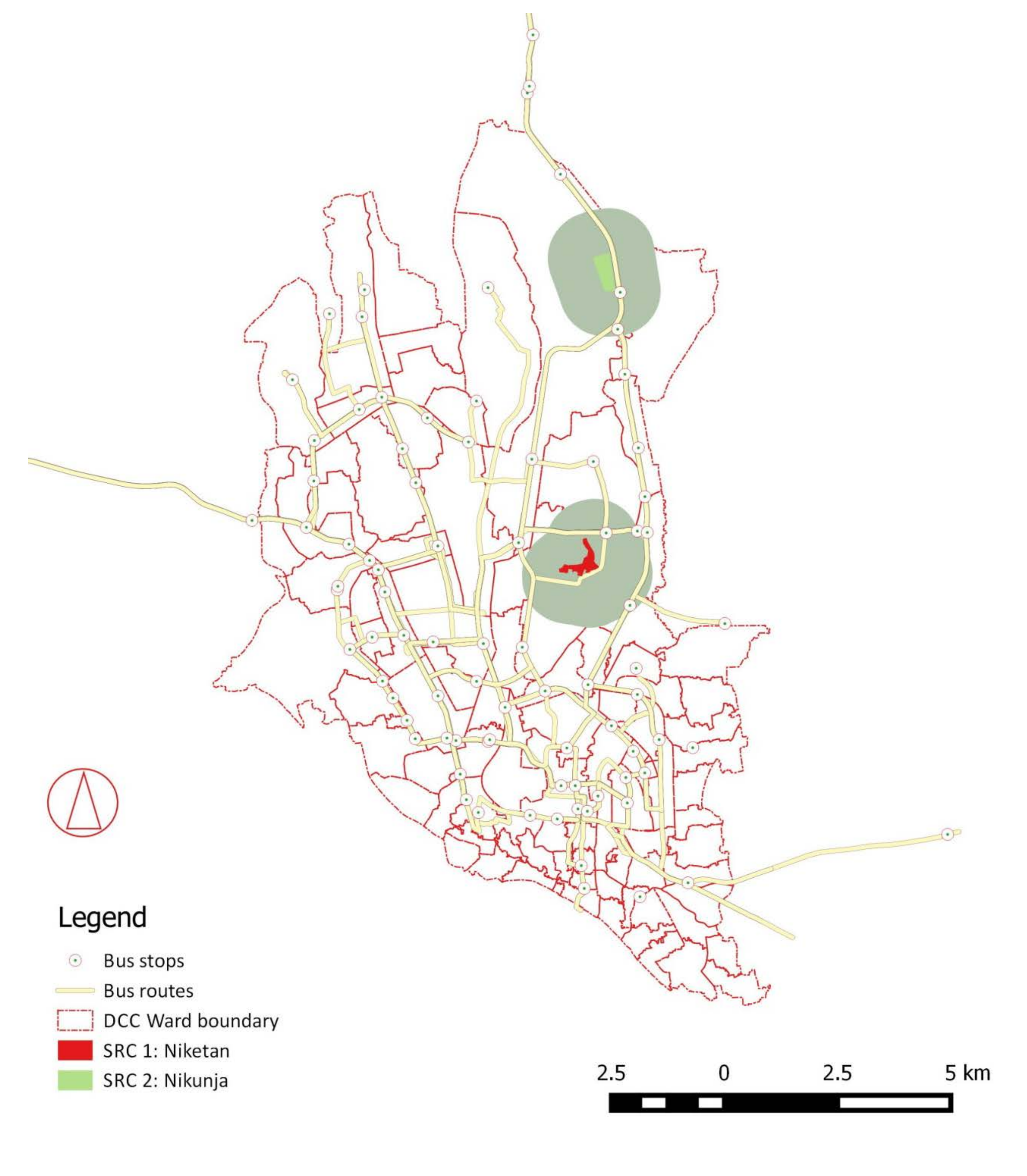


Figure 5-4. Location of bus stations and routes in Dhaka city.

Source: Author's own based on RUJUK - DAP dataset and Urban Lunchpad (2013)

5.2.1.4 Local connectivity

The interconnected road and street networks play major roles in facilitating efficient and multimodal transportation service. The connectivity to the larger community outside the neighborhood area also encourages better accessibility and physical activity (US-GBC, 2009; IGBC, 2010).The road intersections, nodes and surrounding road connections of both SRCs are shown in Figure 5-5.

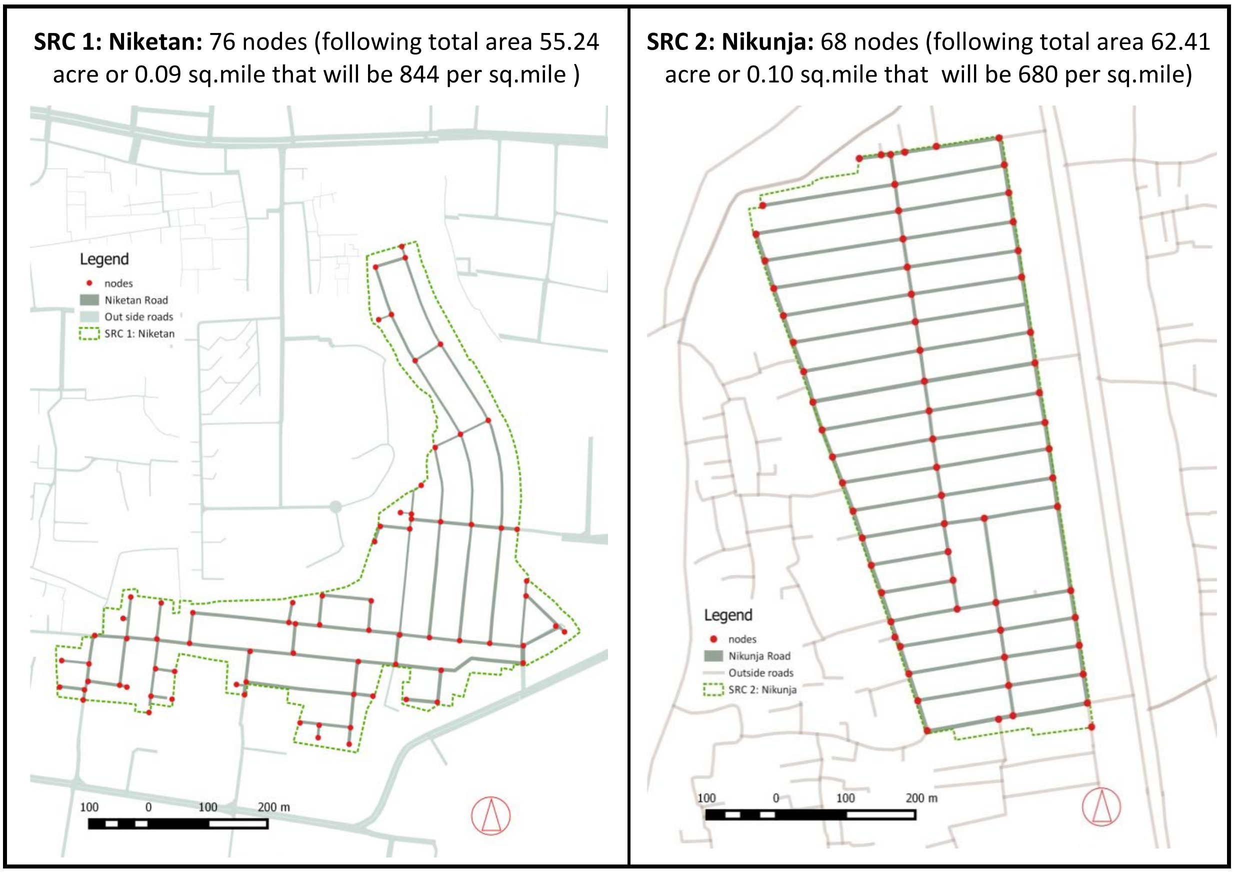


Figure 5-5. State of local connectivity in terms of road intersections and nodes.

Source: Author's own based on RUJUK - DAP dataset

Local connectivity can be conceptualized by measuring distances between street intersections (e.g., Green Township India specified at least 150m) and counting the nodes within a specified area (LEED-ND counts at least 140 nodes per square mile). The Green township India measure (i.e., distance 150m) might be more justified in this study context due to similar regional characteristics. The results showed that the LEED-ND standard is already met by both SRCs in terms of road intersection/node counts (844 and 680 per sq.mile). The government-regulated SRC 2: Nikunja has fewer nodes per sq.mile, which may have an effect, but the LEED standard did not set any minimum or maximum limit.

5.2.1.5 Supply facilities

The integrated principles of sustainable urban development should ensure adequate access to resources and facilities that enable quality of life (Luederitz et al., 2013). As stated in Stoeglehner et al. (2011), accessibility to supply facilities such as electricity, gas, water, and market is essential for a residential neighborhood from the perspective of basic utility provision and quality of life.

i) Accessibility to electricity supply

Electricity is one of the major modern energy sources; an increase in electricity consumption directly affects economic activity in a country like Bangladesh (Ahamad and Islam, 2011). Studies show that approximately one-half of the electricity demand is consumed by the residential sector alone in Dhaka city. In a residential neighborhood context, accessibility to electricity has to be investigated in terms of sources, network, and connections. For promoting clean electricity consumption, this analysis was limited to quantifying the amount of onsite electricity supply from solar sources. A recently abolished local regulation recommended that every new building should obtain at least 5% of its electricity from a solar source.

Table 5-2. Access to electricity supply by their sources.

Electricity Sources	SRC 1: Niketan	SRC 2: Nikunja
Grid feed (% of HH)	93.94	98.09
Solar PV (% of HH)	6.06*	1.91*

Source: Field survey (2013), Note: * additional with grid feed no independent home system

The megacity Dhaka has a total peak electricity demand of about 2000 MW, but the available supply in a typical day is only 1000-1200 MW (Kabir et al., 2010). So far, the SRCs are affected during load shading (blackout) and have to get electricity from alternative sources, including generators and IPS that supply electricity to urban residents (Appendix A: Table 3). Some of the households have solar PV sources, but all are connected to the main electricity grid and alternative arrangements. The reliability of solar PV systems is still very low in Dhaka (Table 5-2). It is often claimed that most of the solar PV systems are not currently operating. Building owners are installing them only to meet the requirements for connecting to the electric grid feed.

5.2.2 Landscape elements

Land uses –at least from a planner’s point of view - should be allocated to various activities for encouraging a better quality of life, and this is essential to achieving the overall local sustainability of human settlements (Choguill, 2008). Land use structures should be considered from the earliest stages of planning. Good planning can result in positive energy benefits along with other supportive build environment elements.

5.2.2.1 State of hard-scape

Hard-scape includes roads, sidewalks, courtyards, parking lots, parking structures, and driveways. The heat island effect is related to hard-scape, which could be reduced by proper strategies (US-GBC, 2009). For example, LEED-ND (US-GBC,2009) suggests that one half (50%) of the hard-scape should adopt appropriate strategies such as the use of trees shade, installing preventive materials and others. The study was only calculated road amount due to limited data.

5.2.2.2 State of public green/open space

The provision of public green or open space is very important for ensuring quality of life in a residential neighborhood (Stoeglehner et al., 2011). It can also contribute to reduced residential energy consumption. GIS tools have been used to calculate the amount of public green space (per person) after analyzing spatial land use data. The local by-laws (e.g., Private Land Development Rule, 2004) provided a standard for residential settlement: "The public green space should be not less than 0.20 decimal per 1000 population". When considering maximum population density standards, 350 persons/acre, the standard for required public green/open space (e.g., parks, playground, etc.) is approximately 7 percent of total land area.

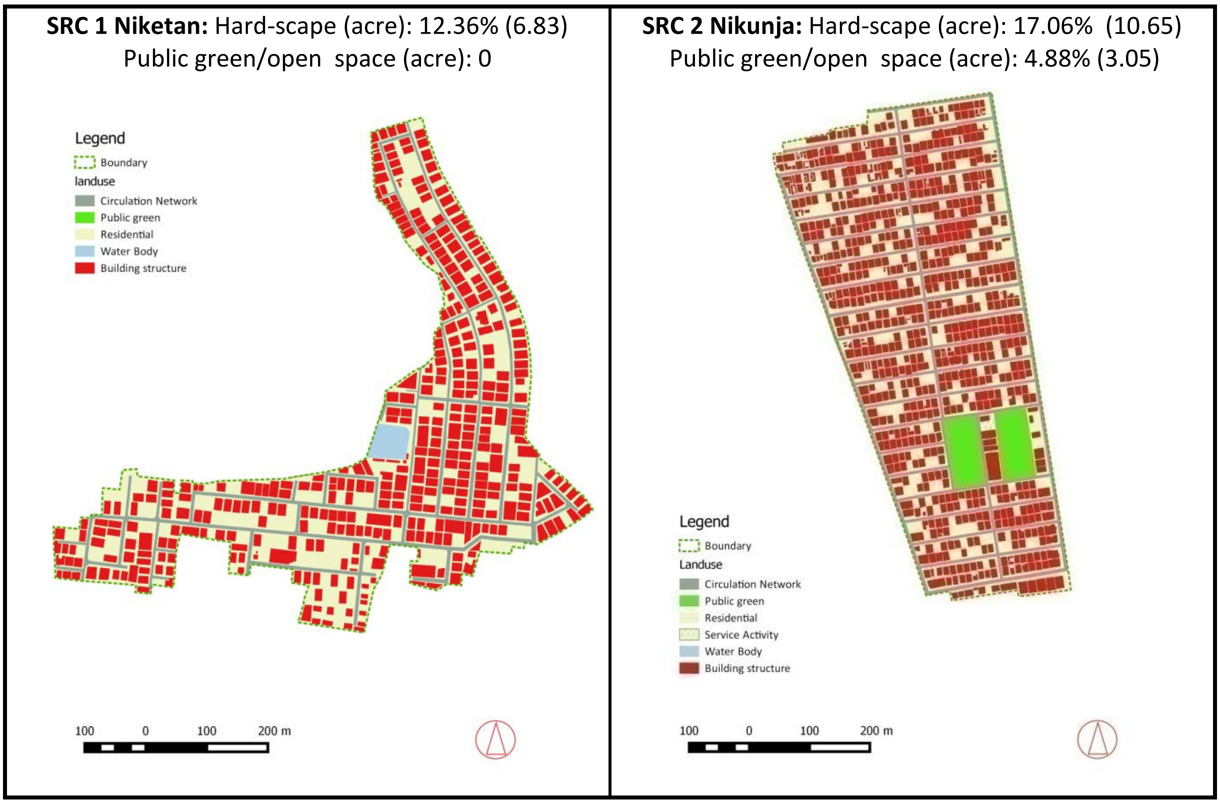


Figure 5-6. Map of land use structures (landscape and public green space).
Source: Author's own based on RAJUK and OSM dataset (2014)

The hard-scape area is a bit greater in SRC 2: Nikunja (Figure 5-6). The two SRCs have similar horizontal building cover (42.2% and 42.6%, respectively), but vary in terms of vertical development. In consideration of individual buildings, the building setback regulations of Dhaka should have a provision to keep a 25% mandatory unpaved portion along E-W roads to optimize comfortable microclimates through the positive canyon-shading effect (Kushol et al., 2013). It would be helpful to measure the state of road orientation, although estimating building setbacks was not possible due to building-level data limitations.

5.2.2.3 State of road orientation

Road orientation is a significant factor for passive solar gain, along with road width, size, shape and tree cover (Zanon and Verones, 2013). For solar access, east-west streets are favorable, but north-south streets are problematic (Kone, 2006; Ahsan, 2009). Parametric urban design methodology suggests measuring road orientation in order to optimize both active and passive energy considerations. Empirical evidence (Hachem and Athienitis, 2013) shows that site-specific characteristics – such as straight road, rows and curved road– strongly influence total energy consumption (-75% to 140%) and solar potential (-12% to 46%). Christensen and Horowitz (2008) developed a computerized Subdivision Energy Analysis Tool (SEAT), which allows users to interactively design subdivision street layouts while receiving feedback on energy impacts, especially roof-top solar collectors, heating, cooling and shading from neighboring houses.

SRC 1 Niketan: Ratio of plots along curved vs. straight road is 3.92 (448:114)

SRC 2 Nikunja: 0 (All straight)

Figure 5-7. Road orientation with layout map.
Source: Author's own based on RUJUK - DAP dataset

The state of road orientation was measured by determining two variables. First, the ratio of plots (along straight roads and curved roads) was calculated along with road layout. Second, the ratio of plots (along east-west and north-south roads) was determined, which only considered plots along straight roads (Hachem et al., 2012). The maximization of solar access is accommodated by this parameter in a neighborhood scale (Ko, 2013). One of the challenges of calculating the two variables is lies in how to define “straight” and “curved” roads. Hachem and Athienitis (2013) provided definitions of straight road and curved road in the context of solar urban planning; however, there are 3 important assumptions in the calculation process: (i) if a plot is bounded by more than one road, then the longer plot axis was considered as a deciding factor; (ii) if a plot shape is square, then the building's longer axis was considered as a deciding factor; and, (iii) plots are excluded that are located at a road's dead end.

The total number of plots is shown in the form of orientation radar for each SRC. Six directions are considered to illustrate a clear overview of all plot orientations, particularly from the front-face (Figure 5-7 and Figure 5-8). One of the significant observations was north-south orientation that dominated for both SRCs. SRC 2: Nikunja had a mix of curved and straight roads that added value to the analysis. In the case of SRC 1: Niketan, all roads are straight, which is a limitation for drawing a firm comparison.

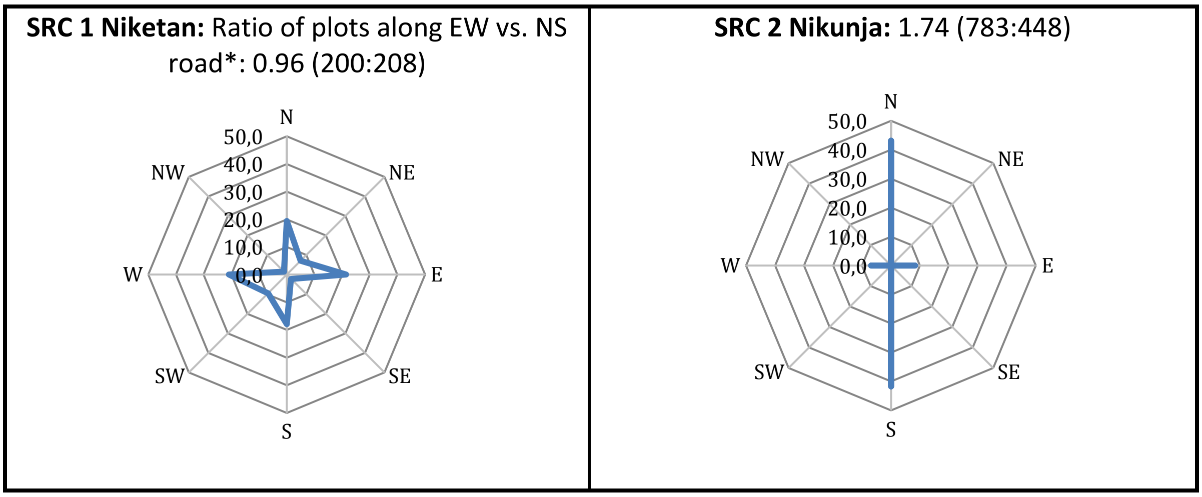


Figure 5-8. Plot orientation (front face) in respect to adjacent road.
Source: Author's own based on NWA (2013), RAJUK data set
Note: * counted only straight roads

The energy relation is not only related to road orientation, but also to building shapes, density and configurations. The height/width ratio of canyons has also been suggested as a significant indicator for the micro-climatic building comfort simulation study (Kushol et al., 2013). Therefore, the study also investigated building quality, often referred to as the built morphology factor.

5.2.3 Building quality

The built morphology factor has a strong impact on overall energy consumption, which is significantly determined by building quality. Martins et al. (2014) defined built morphology as the particular shape and dimensions of the built environment, with the aggregations and configurations of building types. There is a set of 14 energy-related morphological parameters that can help conceptualize solar potential for energy production in the urban configuration context of a tropical city. However, this study measures only a few key parameters.

5.2.3.1 State of building for solar gain

Besides road orientation, the general orientation of buildings and their heights are essential to maximizing or minimizing solar gain, natural ventilation and the urban heat island effect both in winter and summer. A consideration of such issues in urban development control has the potential to result in positive energy benefits (Kavaarpuo, 2014). For example, the city of Boulder, Colorado (USA) adopted a “no shade” building ordinance to maximize solar energy provided by installed solar collectors (IEA, 2009). The current building codes of Dhaka do not guide building placement on a plot. Stoeglehner et al. (2014) stressed the location of single buildings and building blocks to optimize both active and passive energy. Similarly, EnergyAgency.NRW (2008) standardized a critical rotation angle of building from the south direction by +/- 45°.

According to LEED-NB standards, the ratio of a building’s longer axis to the other axis should not exceed 15° (Figure 5-9). Wilson (2013) applied a binary variable-based calculation by determining major axis and azimuth value. This study calculated the average ratio of the buildings’ longer axis to the other axis after estimating all individual buildings. The buildings that were not qualified according to the minimum 15° standard were identified.

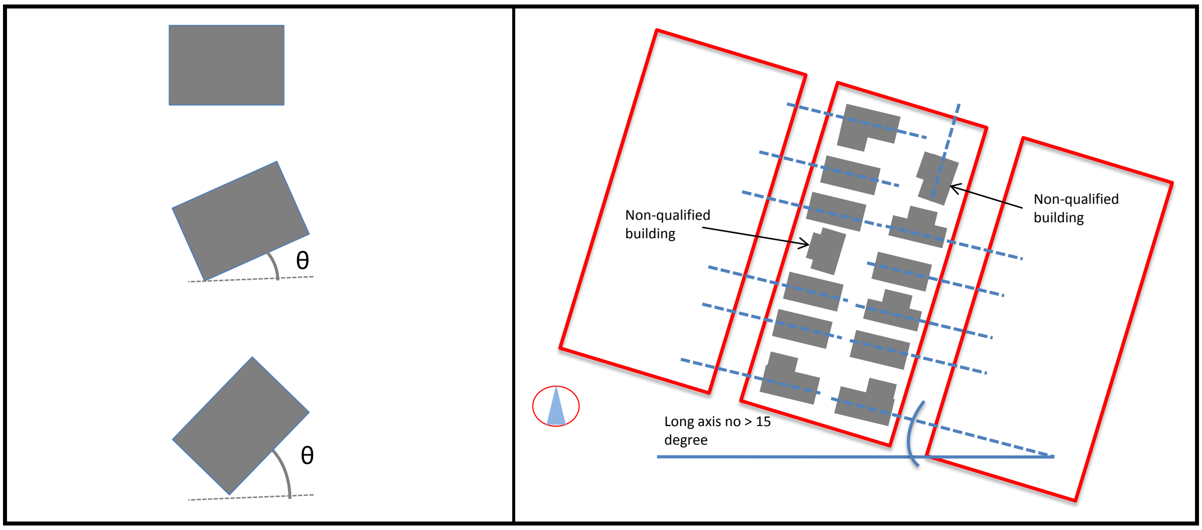
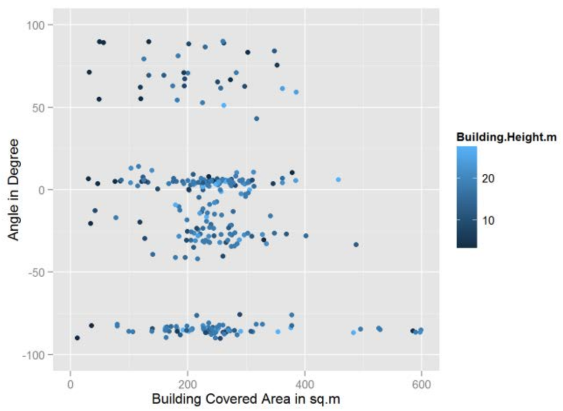


Figure 5-9. Building orientation for solar gain.
Source: Hachem and Athienitis (2013); US-GBC (2009)

Building orientation is largely dependent on plot size and shape, but there is no established reference or standard in Dhaka city. Following Wilson's approach (2013), this study quantified building orientations after calculating polygon main angles in consideration of geographic settings (clockwise with 0° at top/north).

SRC 1 Niketan: Building in between 15 (±) : 44% (174 Nos)



SRC 2 Nikunja: 11 % (93 Nos)

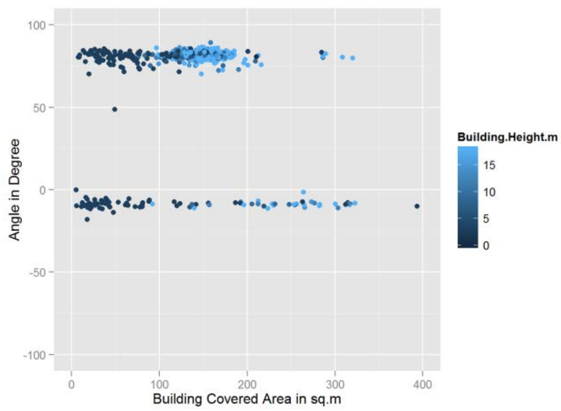


Figure 5-10. Composition of building orientation along east-west direction.
Source: Author's own based on RUJUK - DAP dataset, OSM dataset (2014)
Note: Hachem and Athienitis (2013) suggested ref. value of energy effect and building orientation

Due to irregular building structures, a conversion script was used to convert all buildings to regular rectangle shapes within the ArcGIS environment. Afterwards, the polygon main angle (+/- 90°) was calculated with the geographic rotation option in the cartographic tool "Polygon Main Angle". The results show that SRC 1:Niketan buildings had very scattered patterns in building main angle measurements along with building covered area and building height (color ramp), which may have relations to the majority of irregular building shapes. The dominant main angle values are around negative 25°, which is favorable for better solar access (as per LEED-ND standards). The totally opposite scenario was observed in SRC 2: Nikunja, where the majority of building structures had positive main angles, and showed a linear pattern, along building covered area and building height (Figure 5-10).

5.2.3.2 Building surface and volume relation

The surface-area-to-volume (SA:V) ratio is a significant explanatory parameter to conceptualize settlement structure and energy aspects. This ratio's value shows inverse physical properties in comparison to building size where it is known that after squaring the surface of a given object, its volume increases cubically (Schubert et al., 2013). The energy demand estimation for heating, and cooling are explained better in the context of building physics. The SA:V ratios for both tropical and cold-dry climates should be as low as possible to minimize heat gain and heat losses.

The estimation of the SA:V ratio was conducted with building height and geometrical area data available from the physical building information database. The building volume (V) was simply obtained by multiplying height (H) and geometric area (A). The calculation of building surface area involved multiple steps due to adjustment for irregular building shapes. The initial step of the solution estimated total length of building sides for every building structure. The total surface areas for all vertical sides were obtained after multiplying by building height value. Finally, the horizontal building covered area and roof-top area was added, which gave total cubic building surface area. Flat type roof-tops were assumed for all buildings in the two SRCs.

Table 5-3. Building SA:V ratio along with other building properties.

Items	SRC 1: Niketan					SRC 2: Nikunja				
	H (m)	A (m^2)	V (m^3)	SA (m^2)	**SA:V**	H (m)	A (m^2)	V (m^3)	SA (m^2)	**SA:V**
Mean	16.9	241.1	4,181.1	1,563.8	**0.4**	12.5	135.2	1,881.3	891.3	**0.7**
Min	3.0	11.4	34.6	64.6	**0.2**	3.4	11.7	35.6	69.2	**0.3**
Max	27.4	941.9	18,465.8	536,401.4	**1.9**	18.2	1,006.7	9,180.8	32.6	**2.1**
SD	5.9	96.9	2,312.2	574.6	**0.19**	6.1	61.5	1,186.7	428.8	**0.4**

Source: Author's own calculation

Note: excluded under construction, temporary buildings, building outside

The mean SA:V ratio of in SRC 2: Nikunja was almost double that of SRC 1:Niketan (Table 5-3). This indicated an intense building structure development in SRC 1. The high level of variation can be found in SRC 2: Nikunja because of higher standard deviation of SA:V ratio distribution.

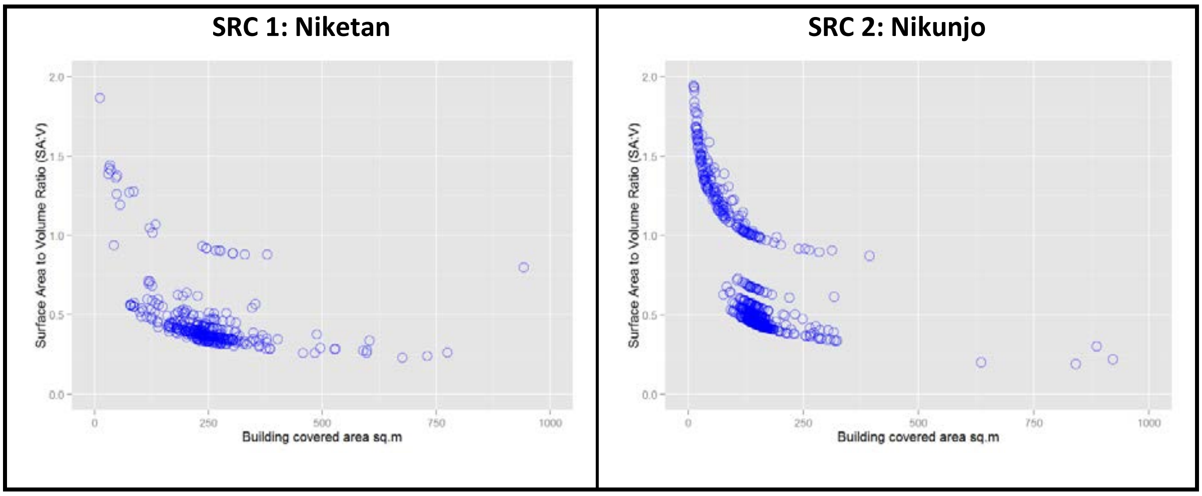


Figure 5-11. Scatter diagram of SA:V and building covered area.

Source: Author's own based on NWA (2013), RAJUK (2007)

Scatter diagrams show the relationship pattern of SA:V ratio and building covered area along degree of overlap. Detailed diversity can be observed in vertical and horizontal built structure. A higher concentration or overlapping data points are significant in SRC 1: Niketan with some exceptions. On the other hand, the observations are arranged in two independent groups for SRC 2: Nikunja (Figure 5-11). These show clear insights into energy aspects in relation to building structure.

5.2.3.3 Building aspect ratio

Building aspect ratio is an output that comes from building length and width for a regular rectangular shape (Li et al., 2015). Passive solar access and comfort can be explained by using the aspect ratio. For example, a building aspect value of 1.3 is often used as a reference in northern climate conditions (Athienitis and Santamouris, 2002).

Figure 5-12. Illustration of aspect ratio in case of convex shape.
Source: Hachem and Athienitis (2013); Li et al. (2015)

The calculated result is highly dependent on building shape. All irregular building shapes were converted to regular rectangular shapes when using the minimum bounding geometry tool of ArcGIS. Afterwards, the simple feature conversion and topological summary functions were used to estimate the aspect ratio for each building.

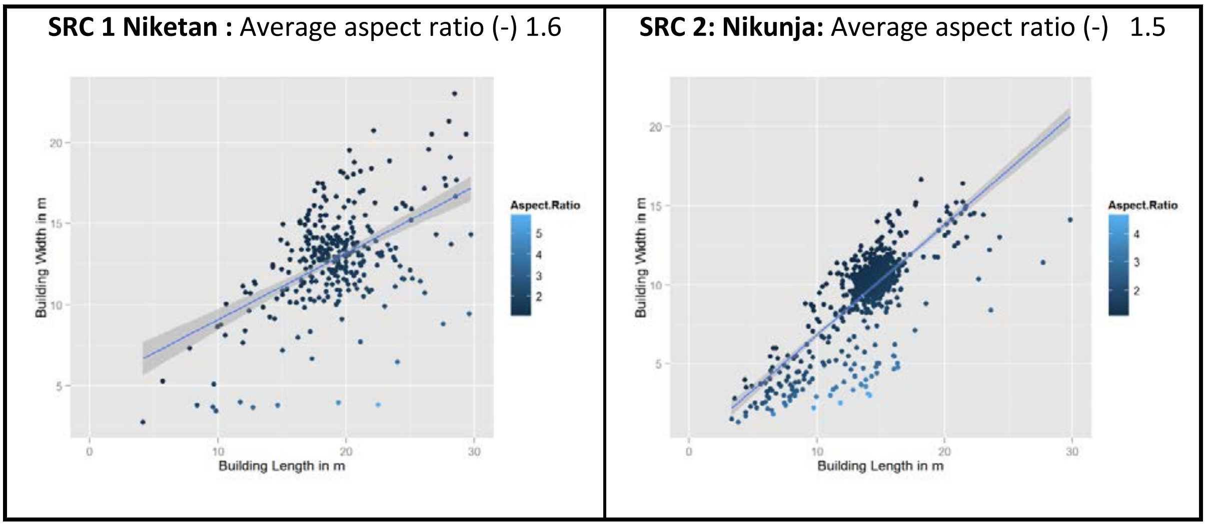


Figure 5-13. Composition of building length, width and aspect ratio.
Source: Source: Author's own after excluded under construction, temporary buildings
Note: Calculation excluded the building under construction, temporary buildings

The data points for aspect ratios are plotted in two-dimensional diagrams with building length and widths (Figure 5-13). The composition shows a scattered pattern in SRC1: Niketan, where the aspect ratio varies between 1 and 5.8. SRC1: Niketan has a higher frequency of the aspect ratio value 1 due to the strong influence of building shape. The building shapes in SRC 2: Nikunja are more regular, and the aspect ratio varies from 1 to 4.7. The average value is slightly higher in SRC 1: Niketan, while the standard deviation remains the same (0.5).

5.2.3.4 Building organization

The spatial distribution of buildings was analyzed with global Moran's I and Local Moran's I. The index values were estimated after converting the centroid points of individual building structures, which were then joined with a regular fishnet. Average building height was joined with the regular fishnet for spatial analysis (for detail method Section 3.2.1). Justification behind the band size (16*16) determination was dependent on the average area of building structure and reflected the main goal to count single buildings within a single cell.

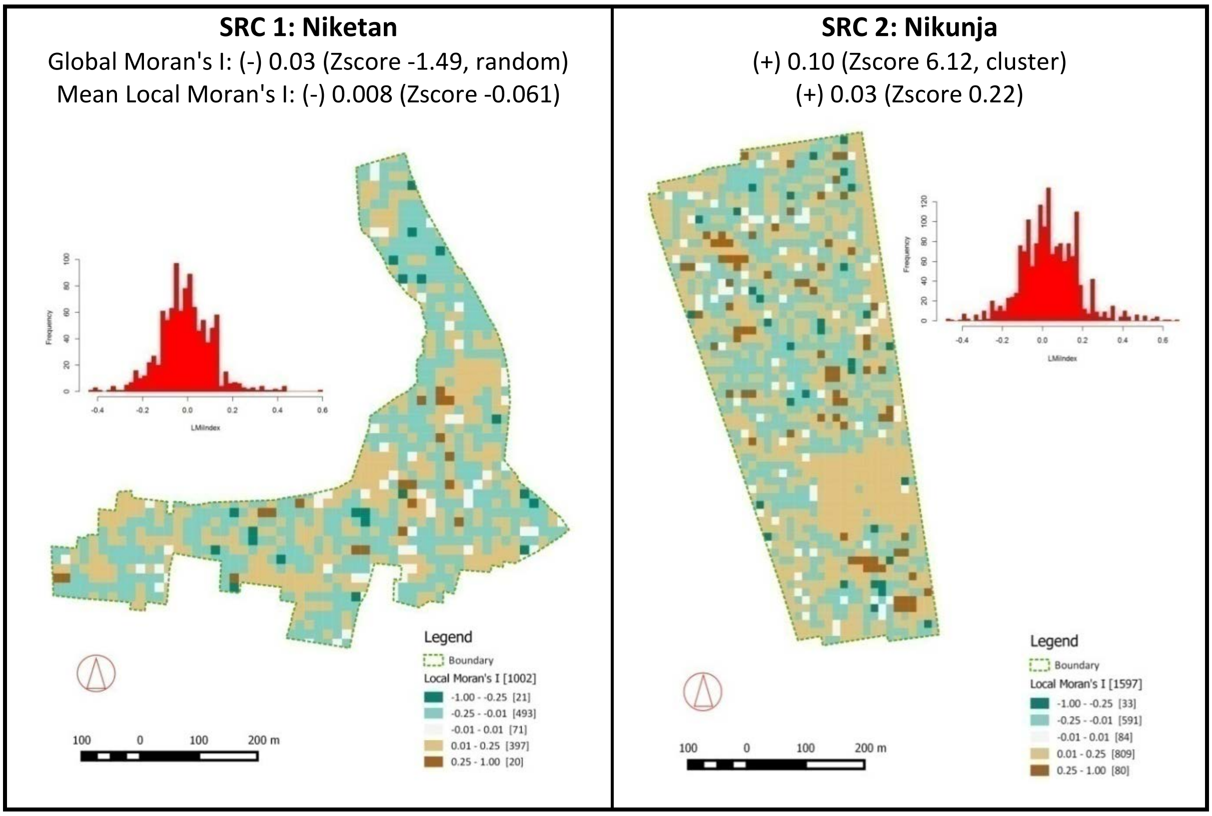


Figure 5-14. Spatial organization of building structures (auto-correlations according to height).
Source: Source: Author's own after excluded under construction, temporary buildings

Typically, Moran’s I values range from +1.0 (clustering) to -1.0 (dispersion). A zero value indicates a random spatial pattern. The Moran's I shows the spatial building pattern after taking building height in consideration. The clustering of high-rise buildings and low-rise buildings were shown according to Local Moran's I value (Figure 5-14). The measured LMI value was presented under a user-defined classification - the range of scale was decided according to the rendering need of intra-case comparison (positive, negative) and also inter-case comparison (between SRC1 and SRC 2).

5.2.4 Housing/ Residential function

5.2.4.1 Housing quality

i) Net housing density

The direct measure of development compactness can be viewed in the form of net housing density, an independent variable mentioned by urban sprawl literature to characterize urban form (Wilson, 2013). It simply expresses the number of housing units per acre (e.g., 0.004 km^2) of developable land (e.g., except water bodies) within each SRC (Table 5-4). It is assumed that total housing units is similar to total number of households, and the developed area was calculated after excluding water bodies.

Table 5-4. Net housing density.

Items	SRC 1: Niketan	SRC 2: Nikunja
Total number of Housing unit	2494	3939
Total area (acre)	54.66	62.41
No. housing unit per acre	46	63

Source: Authors own and BBS (2012)

ii) State of living space

Living space expresses the relationship between the degree of building use and population density. The living area per person is a popular parameter for maintaining structural balance of physical development and residents (Stoeglehner et al., 2014). The resident's lifestyle can also be understood from the state of living space.

Table 5-5. State of living space (Per capita occupancy).

Items	SRC 1: Niketan (sq.m)	SRC 2: Nikunja (sq.m)
Avg. living space/person	37.7	31.4
Minimum	12.3	9.3
Maximum	130	130.1
Standard deviation	17.4	18.3

Source: Field survey (2013)

The mean living space per person in SRC 2: Nikunja was lower than in SRC 1: Niketan (Table 5-5). The resident's socio-economic background can be realized from living space status, but it does not represent the city's overall status. The number of housing units per building varies between2 and 6 in SRC 1: Niketan, and between 1 and 10 in SRC 2: Nikunja. The standard deviations in both distributions are similar (1.22 and 1.28).

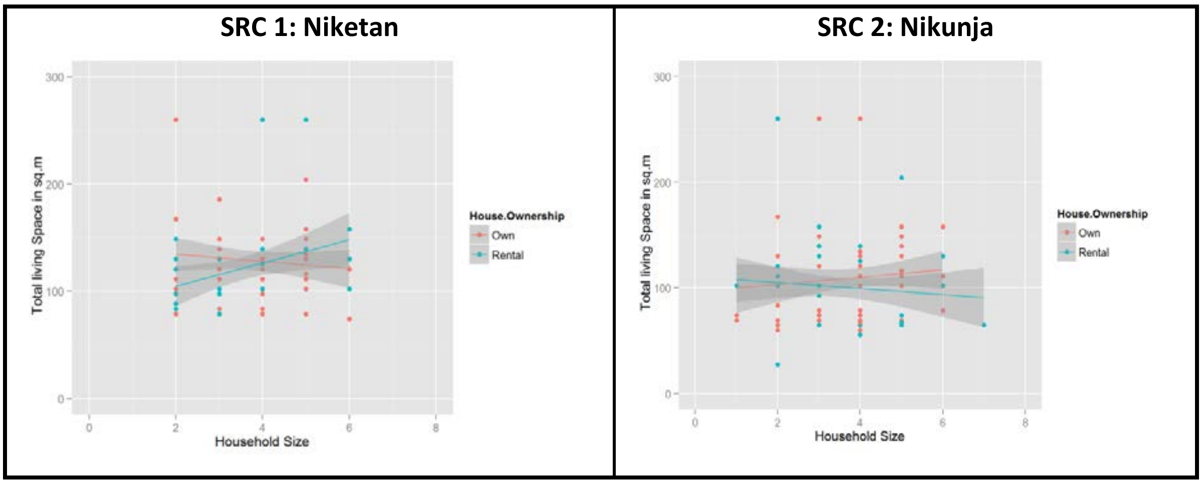


Figure 5-15. Distribution of household size, living space according to home ownership.
Source: Field survey (2013)

The linear co-relation shows an important socio-economic insight relative to living space per household, number of households and house ownership (Figure 5-15). In the case of SRC 1: Niketan, the data points for the house owner group shows a negative trend, whereas the renter group follows a positive trend. The opposite co-relation exists in SRC 2: Nikunja. This supports the higher presence of renters and absentee home owners in SRC 1: Niketan.

iii) Gross population density

Population density is a typical parameter for urban planning and development control. Local planning documents often set standard population density as a regulatory measure. For example, the Private Land Development Rule (PLDR, 2004) selected a gross population density standard of 350 persons/acre in the context of Dhaka city.

Table 5-6. Gross population density.

Item	Population per acre of land area	
	SRC 1: Niketan	SRC 2: Nikunja
Gross population density	168	237

Source: GIS calculation based on BBS (2012) and RAJUK (2008)

The estimation simply considers two variables: (i) total population and (ii) total land area in acres. Total population is obtained by multiplying number of households and average household size (i.e., total HH *average HH size). The final results showed a low gross density in SRC 1: Niketan that is far less than one-half of the local density standard. The local standard was also not met in SRC 2: Nikunja (Table 5-6). There could be several reasons, including the high numbers of empty plots and low-rise developments, higher per capita living space and small family sizes. In fact, there is a lack of balance between population density and building density.

5.2.4.2 Resident's structure

i) Resident's age structure

The age structure of residents has a dynamic influence on energy consumption for both domestic and mobility purposes. For example, residential mobility is dominating by the working age group (30-65) and the young group (15-30). On the other hand, old residents use more energy for domestic purposes. The development character (e.g., newly built, re-urbanization) is a determining factor for resident's age structure.

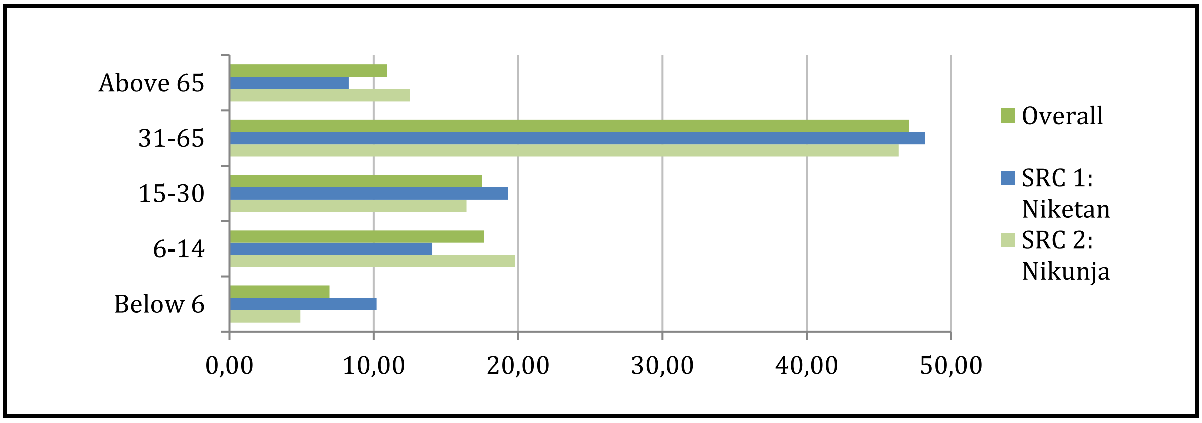


Figure 5-16. Composition of residents' age structure.
Source: Field survey (2013)

The working age population (31-65) dominated in both SRCs, followed by the young age group (15-30) and schooling age group (6-14). There were more schooling age residents in SRC 2: Nikunja than in SRC 1: Niketan, and the same was also true for old residents (above 65). There were more young age residents (15-30) and residents below 6 years in SRC 1: Niketan (Figure 5-16).

ii) Resident's income structure

The income structure of residents provides in-depth information on energy-related dynamic characteristics of a settlement structure. The household income represents the financial ability of energy consumption and investment for energy production (Schubert et al., 2013). The income distribution pattern can explain the socio-economic structure and living quality of a residential settlement.

Table 5-7. Amount of per capita annual income.

Items	Annual Income in BDT /person	
	SRC 1: Niketan	SRC 2: Nikunja
Mean	421,000	259,800
Minimum	192,000	60,000
Maximum	960,000	1,200,000

Source: Field Survey (2013)

STP (2005) classified 4 income groups (low, lower middle, higher middle and higher) to describe the household income distribution and travel behavior of Dhaka city, where approximately 74 percent of households belong to low and lower middle income groups. Higher middle and higher income group people lived in SRC 1: Niketan, according to STP-defined categorization and mean annual per capita income. SRC 2: Nikunja was a lower middle income residential settlement (Table 5-7).

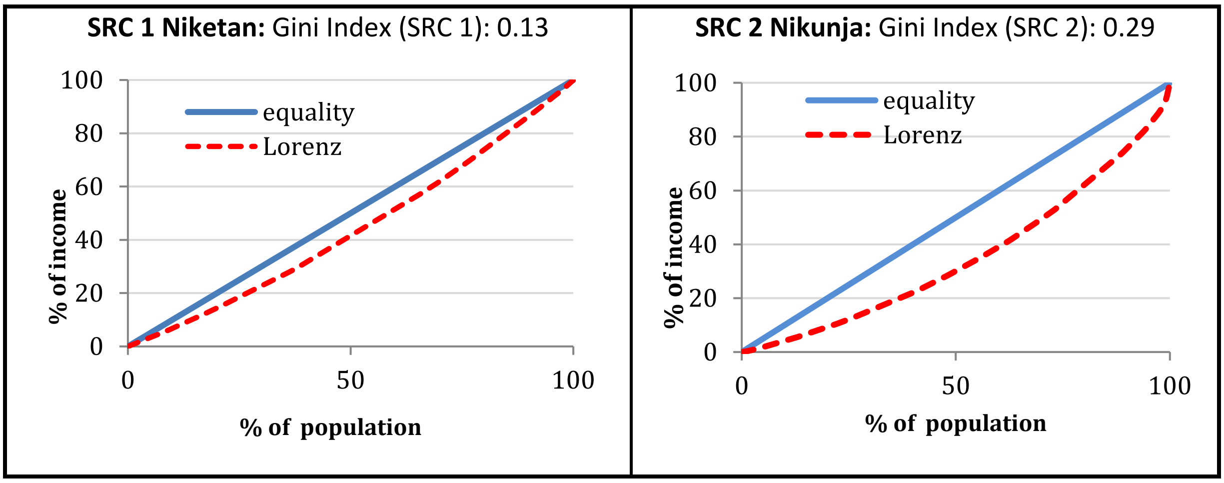


Figure 5-17: Lorenz curve on total household income inequality

Source: Field survey (2013)

For a deeper understanding of income distribution, a Gini-Index and Lorenz Curve were constructed (Figure 5-17). The Gini-index is well-known for illustrating inequality within a distribution, where more values near zero means more equality (Cordonnier and Kunstler, 2015). The results (Figure 5-17) showed that SRC 2: Nikunja had more diverse income groups than SRC 1: Niketan. The estimated Gini-Index also varied twice as much in SRC 2: Nikunja between two sets of income distribution.

iii) Household composition

Household composition is measured with household size. The estimated average household size of Dhaka city is 4.72 (BBS, 2010).A representative sample of household survey data was used to calculate the average household size. The mean household size in both SRCs was lower than the city average (3.72 and 3.76). This is a clear indication of residents' better socio-economic background and higher energy consumption.

5.2.4.3 Resident's mobility matters

The parameters of mobility functions have direct effects on energy consumption where the vehicle ownership pattern has a significant explanatory power about resident's mobility behavior. Nevertheless, the mobility pattern is also very dynamic due to multiple purposes for trip generation: work, education, and recreation. This research only analyzed the working mobility pattern by applying two major sub-indicators: share of private vehicle use for work and annual travel distance for work. All other mobility issues - safety, security, comfort - remain outside the scope of this study.

i) Vehicle ownership status

Updated vehicle registration statistics from the Bangladesh Road Transportation Authority (BRTA, 2015) showed that motor-bikes (40.7%) and private passenger cars (23.6 %) are the most common motorized vehicles in Dhaka city. In this study, the motorized private vehicle ownership pattern analysis only took into account private passenger cars, jeeps, motor-bikes and auto-rickshaws that were owned by individual households. In addition, the information was collected on the type of fuel use and share of vehicle use.

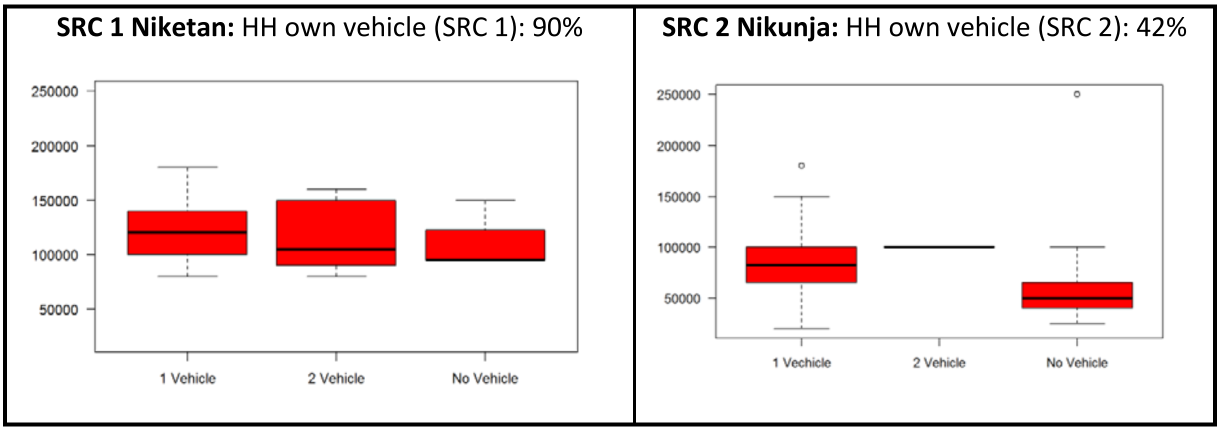


Figure 5-18. Private vehicle ownership pattern and annual HH income.
Source: Field survey (2013)

Box plots reveal some insights into how vehicle ownership and monthly household income impact energy use for working mobility purposes (Figure 5-18). The SRC 1: Niketan people own mostly private vehicles that had a very strong relationship with their financial ability and social status. More than 58 percent of the private vehicles were private passenger cars, where concentrated natural gas (CNG) was the most popular fuel type (about 58 percent). Very low vehicle ownership was observed in SRC 2: Nikunja. Petrol was the most popular fuel type (44 percent), and its use is often related to motor-bike and old model car ownership. One common factor in both SRCs was that the residents had almost twice the number of private passenger cars compared to overall Dhaka vehicle statistics.

ii) Working mobility pattern

Most mobility surveys recognize 4 types of trip, by travel purpose: (i) work; (ii) education; (iii) shopping/recreation; and, (iv) other. Household-generated trips comprise a major portion of all trips (more than 80%) in an urban area. Trips generated by households are classified as home-based and non-home-based (Chatterjee and Venigalla, 2004). In Dhaka city, the home-to-work trip generation system and associated mode choice set is already a complex one with many unusual travel modes

(Figure 5-19). Therefore, only the work base mobility pattern is analyzed in this study to keep the analysis simple and manageable.

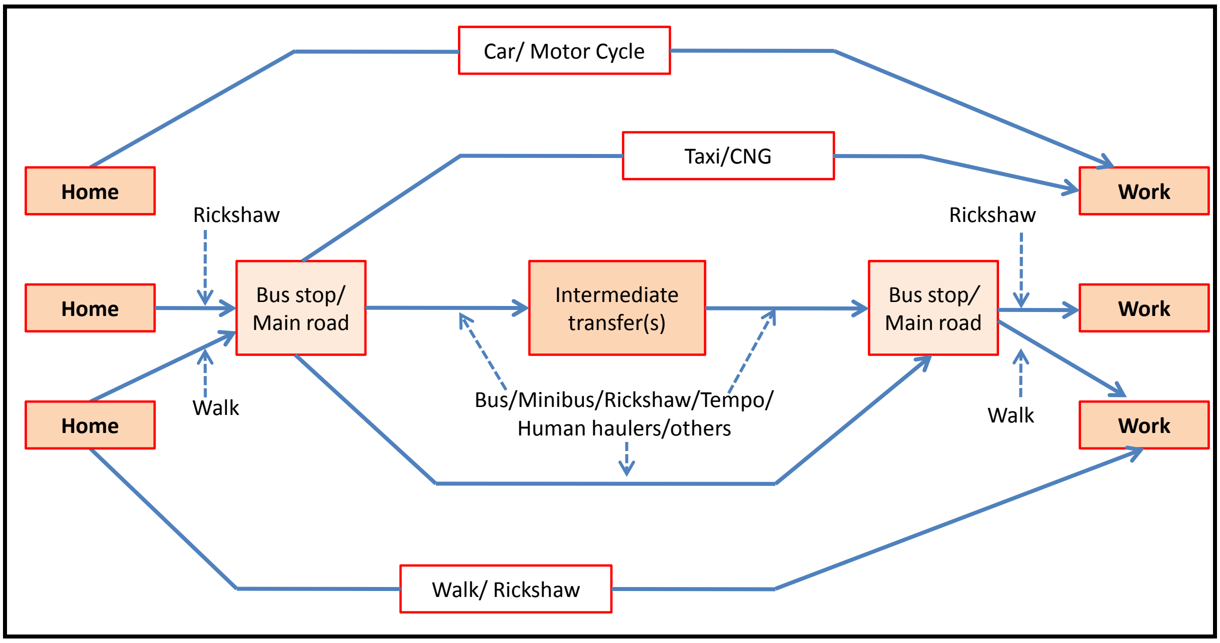


Figure 5-19. The universal modal choice set of individual trip to work in Dhaka (morning).
Source: Updated by adopting Rahman (2008)

The working mobility pattern is investigated with two variables: (i) share of private car-based trips; and, (ii) average annual travel distance motor-based only. The estimation showed that both of the parameters in SRC 1: Niketan were almost double what was found in SRC 2: Nikunja (Table 5-8).

Table 5-8. Car dependency for working mobility.

Items	SRC 1: Niketan	SRC 2: Nikunja
Share of private car based trip (%)	35.3	17.9
Average annual travel distance (km/Capita)	72	42

Source: Field survey (2013)

The household survey included detailed modal shares for working purpose trip generation (Figure 5-20) and travel distance for both motorized and non-motorized transport (Figure 5-21). Although public transportation modes such as bus and trains are not well-functioning in Dhaka city, a good number of working people in SRC 2: Nikunja are using the bus (33%) as a mode of transport. The non-motorized based working purpose comprised almost one-half (rickshaw 44% and walking 5%) of trip generation in SRC 2: Nikunja, while comprising only 19% (rickshaw 15% and walking 4%) in SRC1: Niketan. Bicycle based working mobility is not evident in either SRC.

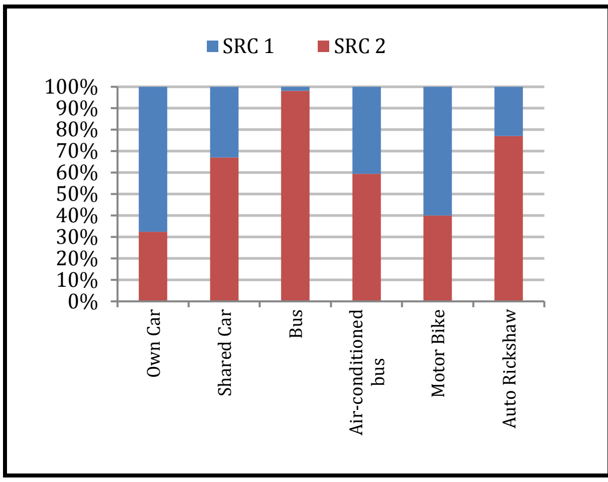


Figure 5-20. Modal share by trip generation.
Source: Field survey (2013)

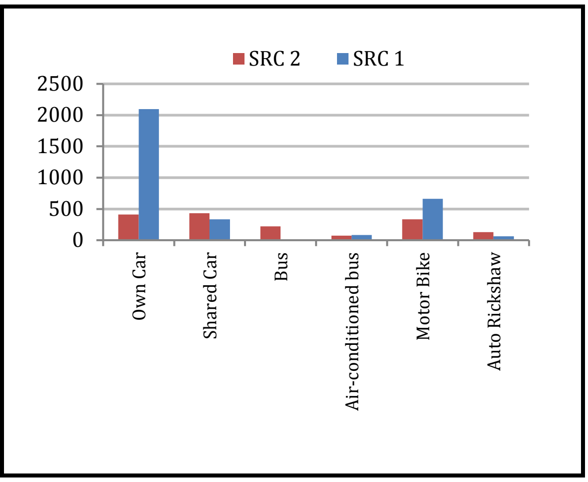


Figure 5-21. Annual travel distance per person.
Source: Field survey (2013)

Figure 5-21 shows average per capita travel distance by motorized modal choose for each SRC. It provides interesting insights about the high car dependency, followed by motor bikes, in SRC1: Niketan. Almost 90% of SRC1: Niketan households owned at least one vehicle.

5.2.5 Energy usage

There are two important challenges for feasible energy solutions at the community scale: (i) on-site energy generation in consideration of urban forms and energy need, and (ii) transportation energy consumption related to location impacts (Marique and Reiter, 2014). The energy need for both domestic buildings and transportation use are discussed beside on-site renewable energy (Solar PV) generation potential.

5.2.5.1 Electricity usage pattern

The central role of electricity has been recognized to achieve sustainable development while meeting ambitious emission targets. The assumptions behind such a statement are: (i) vehicles must be converted to electricity; (ii) electricity generation should be decarbonized; and,(iii) there should be efficient use of electricity within all other sectors (Williams et al., 2012). A residential area uses electricity for a variety of purposes: space heating (E_{SH}), space cooling (E_{CO}), ventilation (E_V), appliances (E_A), cooking (E_C) and domestic hot water (E_{HW}). The annual electricity consumption for buildings can be calculated by aggregating all usages (i.e. $E_{SH}+ E_{CO} +E_V + E_A + E_C + E_{HW}$). In addition, Wilson (2013)suggested including three more parameters: electricity intensity (kWh/area), seasonal diversity (winter/summer), and appliance use.

Household electricity use information was collected during the field survey. The collected data quality was verified and improved by cross-checking with the electricity supply company's billing information, and the Energy Regulatory Commission's (ERC) given rates for residential electricity consumption.

Table 5-9. Electricity consumption pattern along seasonal variations.

Variable	SRC 1: Niketan	SRC 2: Nikunja
Annual electricity intensity (kWh/sq.m)	40.80	34.47
Ratio of summer vs. winter (mean)	1.62	1.73
Avg. Electricity use per HH (kWh)	Summer month: 511.7 Winter month : 302.5	Summer: 344.49 Winter: 193.86
Avg. Electricity use per person (kWh)	Summer month: 149.60 Winter month: 89.33	Summer: 101.40 Winter: 56.83

Source: Field survey and adjusted with DESCO (2013)
Note: * This calculation does not include consumptions from solar source

Most of the electricity use parameters were higher in SRC 1: Niketan than in SRC 2: Nikunja (Table 5-9). The electricity intensities per unit of area were similar, but seasonal uses differed significantly between the two SRCs.

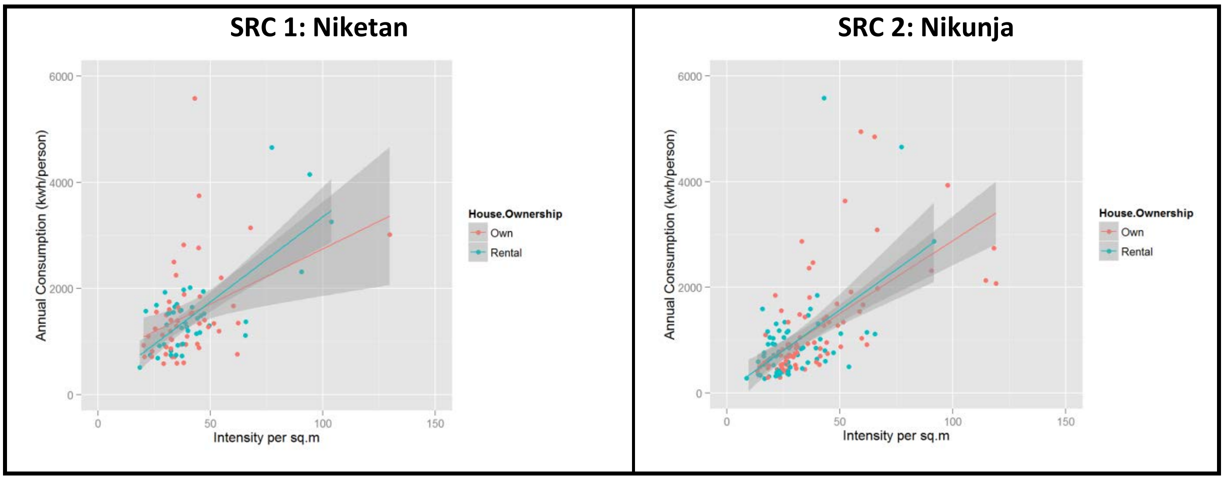


Figure 5-22: Annual electricity consumption pattern along house ownership

Source: Field survey (2013) and DESCO (2012)

A scatter diagram shows the relationship pattern between annual electricity consumption (kWh) per capita and per unit of building floor space (Figure 5-22). The color levels indicate the home ownership status of residents. A positive correlation existed in both datasets, but slight variations in trend lines were observed when accounting for home ownership. The homeowner and renter ratios are 1.2 (SRC 1: Niketan, 54:45) and 1.3 (SRC 2: Nikunja, 90:67). Few owners reported significantly higher electricity use, which may be an effect of other factors (i.e., share contract with renters, use of heavy appliances, combined meters) that cannot be verified at this level.

The number of electric appliances in a household has a strong effect on the amount of domestic electricity consumed (Marique and Reiter, 2014). Some electrical load calculation methods are already in practice for determining different loads and demands of individual appliances, cooling appliances, and lighting loads in the case of housing development projects (Appendix A: Table 3). In this study, there was no intention to conduct detailed estimation; rather, a simple mean was calculated from the aggregated count of household electric appliances. The mean appliances per household were 4.6 (SRC 1: Niketan) and 5.4 (SRC 2: Nikunja). Cooling appliances were counted separately in the estimation of mean household appliances due to their higher profile of electricity use. Dhaka is a tropical city, so the cooling demand is significantly higher during the summer months (February to October). The data point patterns (Figure 5-23) showed the relationships between the numbers of cooling appliances compared to total number of electricity appliances against annual electricity consumption.

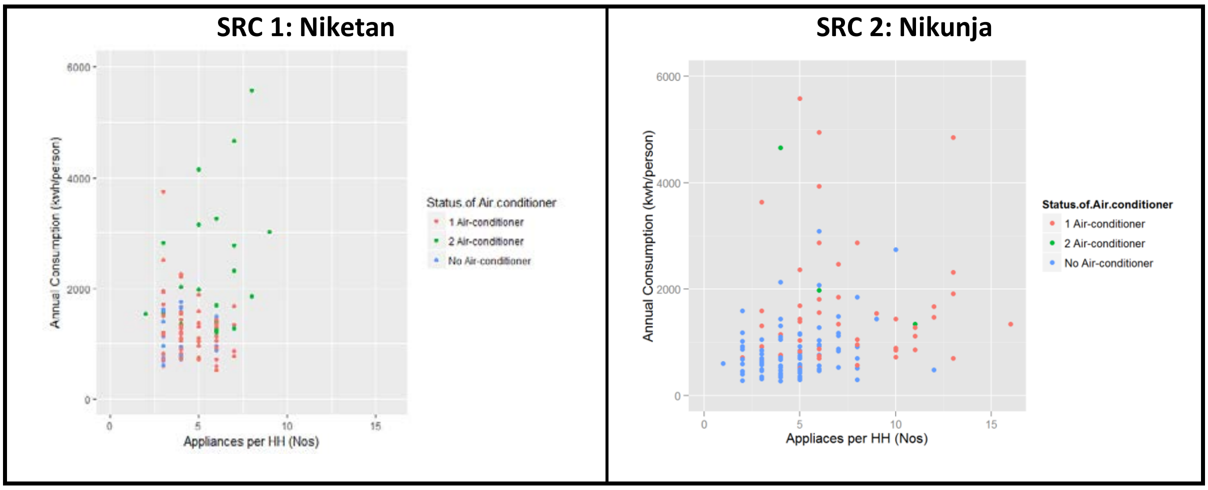


Figure 5-23. Annual electricity consumption by home appliance.

Source: Field survey (2013) and DESCO (2012)

In Dhaka city, air-conditioners are a commonly used cooling appliance. There is a variety of air-conditioner models and brands on the market, and their energy consumption is partly dependent on the quality of installation and maintenance. Most of the households in SRC 1: Niketan had at least one air conditioner, signifying demand for living comfort and the residents' ability to afford one. On the other hand, very few households in SRC 2: Nikunja had air conditioners.

5.2.5.2 Energy consumption for working mobility

The mobility sector has a huge share of total energy consumption in a residential community, where daily commuting for work is one of the major contributors. The commuter energy performance index (CEP) is a known parameter of mobility energy consumption, although there are many others (Boussauw and Witlox, 2009). Challenges arise because Dhaka city has no such performance index. However, based on the empirical home-to-work purpose travel data, this study estimated the annual energy consumption for working mobility (i.e., CO_2 emissions) by following a city-wide transport energy footprint matrix. Labib et al. (2013) summarized a transport energy footprint index, the amount of CO_2 emitted in Dhaka, by using the emission factor model (Appendix A: Table 4).

The collected mobility data did not help distinguish between different types of motorized trips, so this was not included in the analysis, although it would be useful for pollutant criteria. The types of fuel used were also not distinguished where most were fossil fuels. The estimation assumed a standard bus capacity (40 passenger), shared cars (2 passenger), trips with auto-rickshaw, and motor bikes fitted for single travelers. Train-based travel was excluded due to data limitations, but this did not affect results much (because of very few responses).

Table 5-10. Gross energy use for personal working mobility (estimated CO_2 emission).

Variable	SRC 1: Niketan	SRC 2: Nikunja
Annual average CO_2 emission (M. ton/HH)	2.6	1.03
Annual average CO_2 emission (M. ton/Person)	0.7	0.27

Source: Author's own estimation based on Field survey (2013) and Labib et al. (2013)

The annual per capita average CO_2 emission of Bangladesh (0.4 M. ton) is emitted within only 11 days by an EU resident (UNEP, 2015). It should be noted that CO_2 emissions in both SRCs are higher than the national average due to fossil fuel-based residential energy consumption, especially by urban high income residents. The estimated results showed how energy consumption differed in the two SRCs, perhaps indicating a strong relationship with a resident's socio-economic status and preference of lifestyle (Table 5-10).

5.2.6 Renewable resource

5.2.6.1 Solar energy potentials

The assessment of the solar energy potential is essential when proposing any technical and financial solutions for sustainable development. Solar mapping tools are becoming a valuable first step analytical tool for designing and implementing urban planning energy strategies (Kanters et al., 2014). The solar urban planning vision should consider two systems: (i) an active solar system and (ii) a passive solar system. In the case of an active system, identifying buildings suitable for solar PV installation requires 3 kinds of modeling exercises, such as: (i) built environment; (ii) solar irradiation; and, (iii) available area for PV installation (Santos et al., 2014). Several tools and methods have been developed. ArcGIS Solar Analyst Extension (ESRI) is considered one of the more effective tools for local-scale applications.

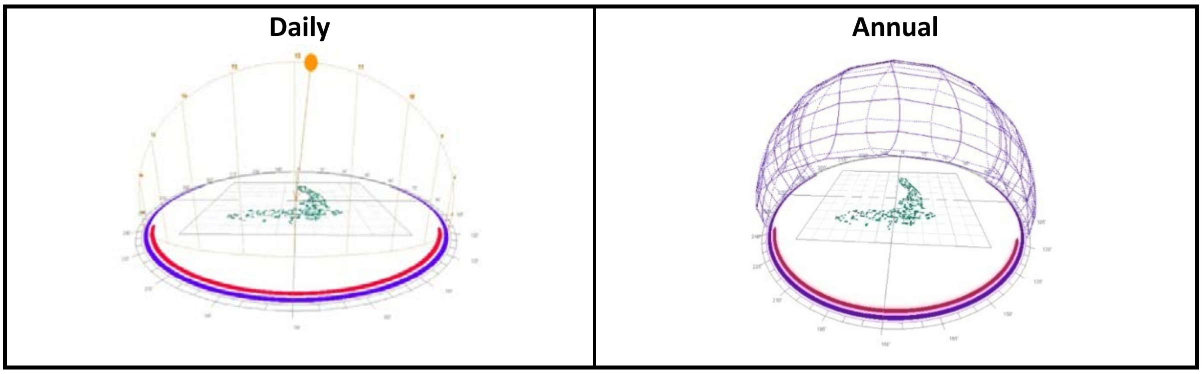


Figure 5-24. Annual and daily sun-path in Dhaka.
Source: Authors' own by using EcoTECH software platform

Solar energy innovations present a limitless opportunity for extracting free renewable energy. In particular, building rooftops present opportunities to avoid a wasted resource in urban areas. During a summer month in Dhaka city, the daily average solar radiation varies between 3 and 6.5 kWh/m^2 per day (Hassan et al., 2012). With that motivation, rooftop solar PV potentials have been estimated for electricity production in this study. The estimation methodology was formulated by integrating two studies primarily: bright top calculation (Kabir et al., 2010) and annual solar PV electricity generation (Amado and Poggi, 2014b). Two assessment scenarios are presented under conservative and visionary criteria (Table 5-11). The following equations are used in the calculation:

Box 5-2. Equations for estimating solar PV potential.

Annual solar PV electricity yield = $(A / A_m) \times E_m \times 365$ ....(Equation. 19)

Each module output, $E_m = W_p \times GHI \times I_e \times B_e$ ....(Equation. 20)

Where, A = Active roof-area for PV (sq.m) , A_m = Area need per PV module (sq.m), M_c= Maximum power capacity (Wp), GHI = Global horizontal radiation (kWh/sq.m/day), I_e = Inverter efficiency (%), B_e = Battery efficiency (%)

Source: Following Kabir et al. (2010); Amado and Poggi (2012)

In the estimation of solar PV electricity, the reduction coefficient was set after including geometric factors, shading effects and other roof uses that can reduce the total roof area. The PV system layouts need additional area to permit installation/maintenance works and spacing among the arrays to avoid shading. The conservative scenario assumed the active roof area was 50% covered by PV, 20% was reserved for PV installation/maintenance, and 30% was reserved for building operation. The visionary scenario assumed up to 80% of the roof area was covered by PV. Both scenarios considered an average 32% reduction factor due to shading effect in the context of Dhaka city. The PV module capacity (W_p)

was assumed in the two scenario to be 75 W_p and 210W_p. Smaller roofs are a challenge for solar PV installation, so that was excluded from the calculation.

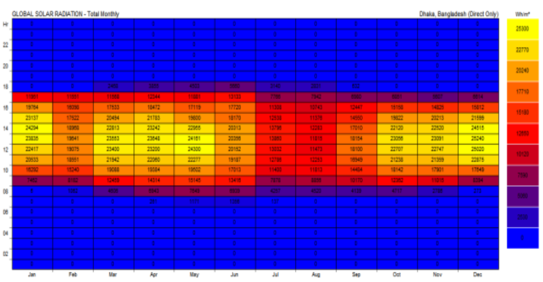


Figure 5-25. Global solar radiation in Dhaka.
Source: Authors' own (EcoTech)

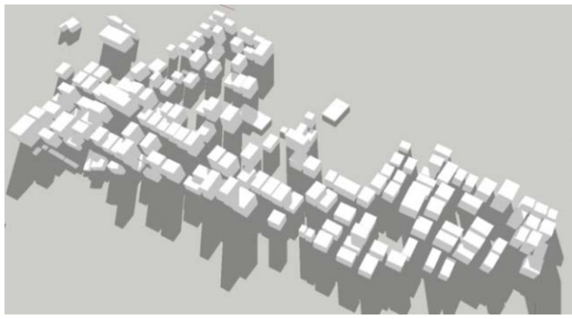


Figure 5-26. Shadow effect at SRC1: Niketan (South).
Source: Authors' own (google-sketchup)

The assessment solar potential revealed that solar PV can contribute in the electricity balance. Under the conservative and visionary scenarios, solar PV contributed 14.2% and 49.8%, respectively, in SRC 1: Niketan, and 16.1% and 56.7%, respectively, in SRC 2: Nikunja. Although these estimations are very straightforward, they need to be improved with further consideration of build forms, metrological requirements and technical know-how.

Table 5-11. Results of Solar PV electricity generation potential.

Items	**SRC 1: Niketan**		**SRC 2: Nikunja**	
	Scenario A	Scenario B	Scenario A	Scenario B
Active roof area (m^2)	41,641	66,625	49,948	79,917
No. of PV modules to be installed	52,051	40,787	62,436	48,924
Annual yield (MW)	2,872	10,084	3,445	12,096
Annual yield (MW) after shadow effect	1,953	6,857	2,343	8,225
Annual electricity / HH (kWh)	783.2	2,759.5	594.8	2,088.2
Annual Electricity / person (kWh)	210.5	739.1	158.2	555.4
Annual balance	14.2	49.8	16.1	56.7

Source: Authors' own, following Kabir et al. (2010); Amado and Poggi (2012)

Note: Yield per PV module (W) for scenario A and B are 151.2 and 677; Area need / PV modules (m^2) scenario A and B are 0.8 and 1.63 accordingly; deducted a shadow effect 32%

In summary, the above results and findings included all 30 indicators measured within the two SRCs in Dhaka city. Some additional variables were also presented with detailed method and data sources. Appendix A: Table-2 presents a complete list of key findings, along units of measurement and data sources. The next chapter contains the major findings of a comprehensive evaluation of urban and energy planning process at both the city-wide and residential project levels. It focuses on the state of energy-optimization in urban development planning, including actors' involvement, planning steps, regulatory frameworks, tools, models, key challenges and barriers.

CHAPTER SIX: EVALUATION OF ENERGY OPTIMIZATION PLANNING PROCESS

6.1 Urban Planning and Development

An emerging megacity such as Dhaka is a prime example of complex and dynamic systems that might be represented by interactions between socio-economic and environmental processes at both local and global scales (Kötter, 2004). Being a former British colony, Bangladesh, as well as Dhaka, is still following the same planning hierarchy of colonial urban planning practices. Since independence, Dhaka has grown both in horizontal and vertical directions, mostly without maintaining any development and planning guidelines (Nahrin, 2008). The first master plan for Dhaka was enacted in 1993. Recently, the government introduced the Dhaka Metropolitan Development Plan (1995–2015) based upon a target population of 15 million residents. However, the projected metropolitan population of 15 million has already been surpassed. Due to huge pressure from urbanization, the city development patterns are dominated mostly by informal characteristics including substandard structure, narrow/irregular streets, poor utility infrastructure networks and inadequate basic services (Parveen, 2012). In this regard, comprehensive action is required to recognize the urban issues of Dhaka and to allocate or control its growth activity in a sustainable manner (Kabir and Parolin, 2012).

Formal urban development projects follow similar patterns, whether they are carried out by the public or private sectors. Most common initiatives include land development or residential township projects, which are often followed by site and services development (Parveen, 2012). The land area is simply divided into roughly symmetrical plots with the provision of a gridiron road layout, and allotted for residential and commercial activities. Apart from site development, the private sector also develops individual apartment buildings sporadically in negotiation with the landowners.

6.2 Residential Settlement Development and Energy Concerns

The residential settlement typology in Dhaka city is dominated by an informal system. Only about 27% of the total residential settlement is developed under the provision of formal private and public sector land/housing development regulations (Masum, 2009). A recent study identified 181 residential settlement development projects in the greater Dhaka area (Figure 6-1), initiated by both the private and public sectors (Alam, 2014). Several sources confirm that only a few projects would meet formal planning standards and development regulations.

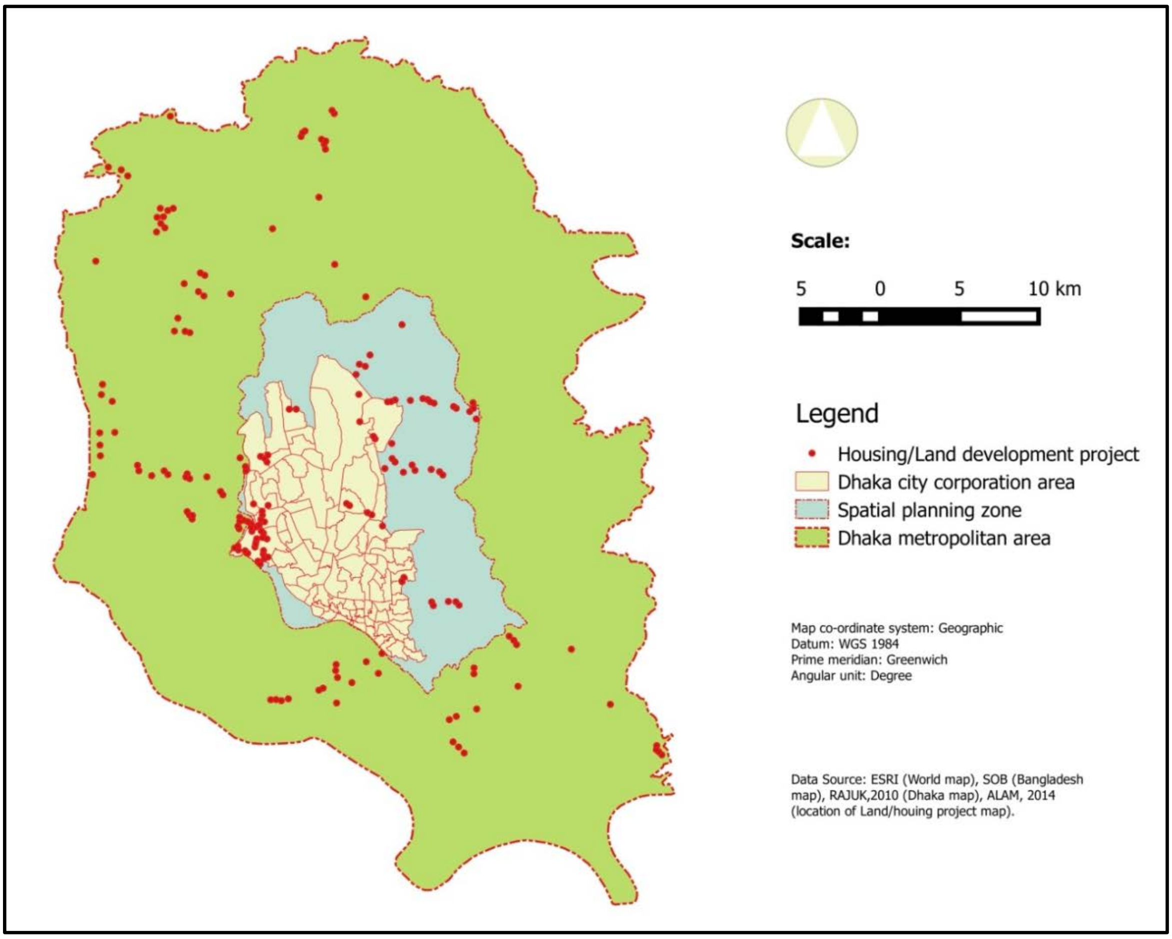


Figure 6-1. Location of residential settlement development projects.

Dhaka city is facing acute housing demand due to continuous urbanization. As a result, the housing business has grown progressively over the last 20 years (Figure 6-2). Since 2006, the main reasons for the exponential growth of the real estate business are mostly related to land market issues, such as vacant land scarcity, higher land values, land speculation and remittance inflow for land purchases. The increasing number of nuclear families and growing public confidence about living standards in apartment buildings have also played significant roles (REHAB, 2012). Studies have estimated that the housing demand may persist or even rise in coming years. For instance, by 2020 more than five million new residents will need to be accommodated in Dhaka (Parveen, 2012). At the same time, however, the transformation of residential settlement quality in the existing planned residential settlement schemes of Dhaka city has mostly deteriorated due to huge violations of predefined land use, illegal plot subdivisions and increased building heights (Nahrin, 2008; Nilufar, 2010). The changes and violations in terms of building use, land use and population density also have had serious impacts on utility service facilities (e.g., electricity, water) and transportation in both inter-neighborhood and other surroundings. For instance, an urban planner, involved in a private sector residential settlement development project, mentioned during a key informant interview "…the current population density threshold for residential areas is only 350 persons/acre, but in reality you will find far more than that."

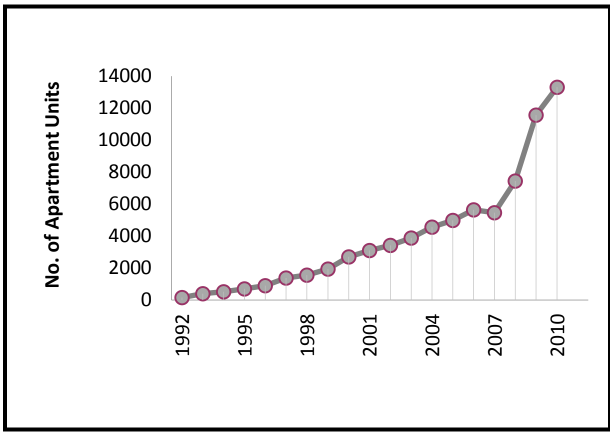


Figure 6-2. Trend of housing business.
Source: Authors own illustration based on housing statistics of the Real-estate and Housing Association of Bangladesh (REHAB). A comprehensive database has been compiled by REHAB which has been confirmed in REHAB (2012)

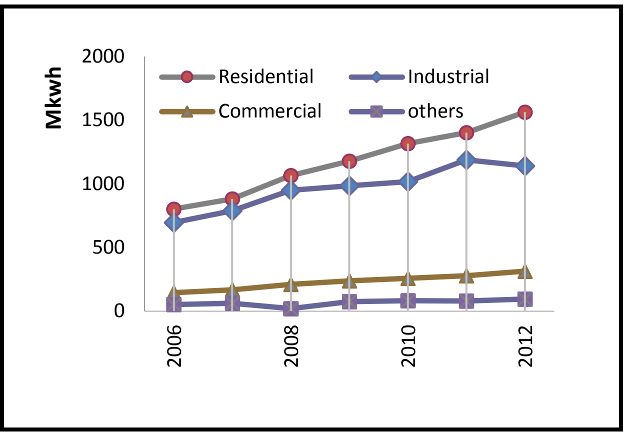


Figure 6-3. Electricity consumption trend.
Source: Authors own illustration according to the electricity consumption data of Dhaka Electric Supply Company (DESCO) Limited. DESCO is one of the largest electricity providers

In addition to growing housing demands, the national energy demand increased by 10% from 2009 to 2011. Compounding this challenge, the buildings of Dhaka city show an unsustainable and inefficient energy consumption portfolio (Ahsan, 2009). One of the electricity providers of Dhaka city (e.g., DESCO) reported that the residential sector alone accounts for 48% of total electricity consumption (Figure 6-3). The city has a total peak electricity demand of about 2000MW, but the available supply in a typical day is only 1000–1200 MW (DESCO, 2012). Therefore, power blackouts are a common phenomenon that causes inconveniences for urban inhabitants (Kabir, 2010).

Apart from many factors of energy generation, one should realize that existing planning and building regulations hardly address the energy efficiency measures and consumption aspects, focusing instead on density and development control. There is, in fact, no building energy code in Dhaka (Parveen, 2012; Alam, 2014). In addition, residential mobility in Dhaka city is highly dependent on private vehicles due to insufficient public transportation options (Rahman et al., 2012). Consequently, enormous traffic congestion and malfunctioning traffic management systems often cause massive delays in covering small distances, resulting in both higher travel time and energy use.

6.3 Actors Involved in Residential Settlement Development

The emerging complexity of urban systems has already indicated that interdisciplinary efforts are necessary, along early integration of stakeholder participation in decision-making at every level and scale (Duvarci and Kutluca 2008; Becker and Boschert 2013). After a critical review of 58 pilot cities, the EU (2014) noted that "An integrated urban planning process should involve significant experts of various urban departments from the very beginning.” Accordingly, the "EnUp" model demands an assessment of stakeholder participation at every step of the planning process. An assessment of actor relationships can be summarized for residential development in Dhaka city (Table 6-1).

Table 6-1. Actor's dynamics for energy optimization in residential settlement development.

Actors	Interests and expectations	Potentials	Deficiencies
Capital Development Authority (e.g. RAJUK)	Planned urban development and control; Develop large housing project; Regional development control; Infrastructure provision	Involve more with energy planning process and negotiation with developers; Demonstration in their own housing project	Hardly can bring all stakeholders together, Limits bargaining power due to different drawbacks of own housing development projects
Local Government (e.g. DCC)	Develop tools for energy supply improvement; Reduction of energy costs; Environment progress; Quality of living improvement; Support programmes	Support energy planning; Conduct awareness campaign; Facilitator of implementation activities which identified in the Action Plan	Very limited involvement in residential development projects and energy planning process
Electricity companies (e.g. DESCO)	Provide un-interrupted power supply; Infrastructure development; Secure financial benefit	Independent to planning and develop of infrastructure and can influence developers to integrated energy issue in planning stage	Only concentrate on distribution and revenue return maximization
Transport authority (e.g. DTCA)	Advice, co-ordinate and planning for integrate and safe traffic and transport system	Transport sector energy concerns could be integrated as a major mandate	Newly established, may introduce innovative policy and strategy
Developer	Lowering development investment and profit maximization; Quick and easy approval of proposed schemes	Branding new business models with modern ideas, skills and new technology adaptation	Often ignore regulatory provision and use organized power but maximize profit due to huge market demand
Central Govt. Line Ministries	Monitor implementation of other or related government policies	Provide common platform with improved administrative and regulatory support	Lack of coordination between the city and central government agencies; Lack of support to implementation
Customers	Access to affordable urban housing with basic infrastructure, utility services and lowing cost	Potentials to invest in energy sensitive measures regarding building construction and renewable	Limited negotiation power due to higher housing demand and power governance
Residents	Compensation in terms of developed land, basic infrastructure, reliable and affordable energy supply	Ambassador for future residents to communicate energy concerns	Lack of awareness and capacity on energy conservation, renewable energy resources

Source: Author own according to Field survey (2013)

Both the public and private sectors are involved in residential settlement development projects (Figure 6-4). While the public sector mostly acquires land, subdivides it and installs some basic infrastructure, and then allocates lots to individual buyers, the private sector purchases (or grabs), develops, and subdivides large amounts of land into plots and then obtains approval from the Capital Development Authority (RAJUK) to sell them to the end users (Masum, 2009; Alam, 2014). According to the RAJUK registry, the total number of private land and housing developers in Dhaka city in 2012 was 108. Although more informal developers are doing small-scale informal land and housing development projects, they are not registered in the RAJUK record book. There is a separate list of registered private developers who are constructing only apartment buildings.

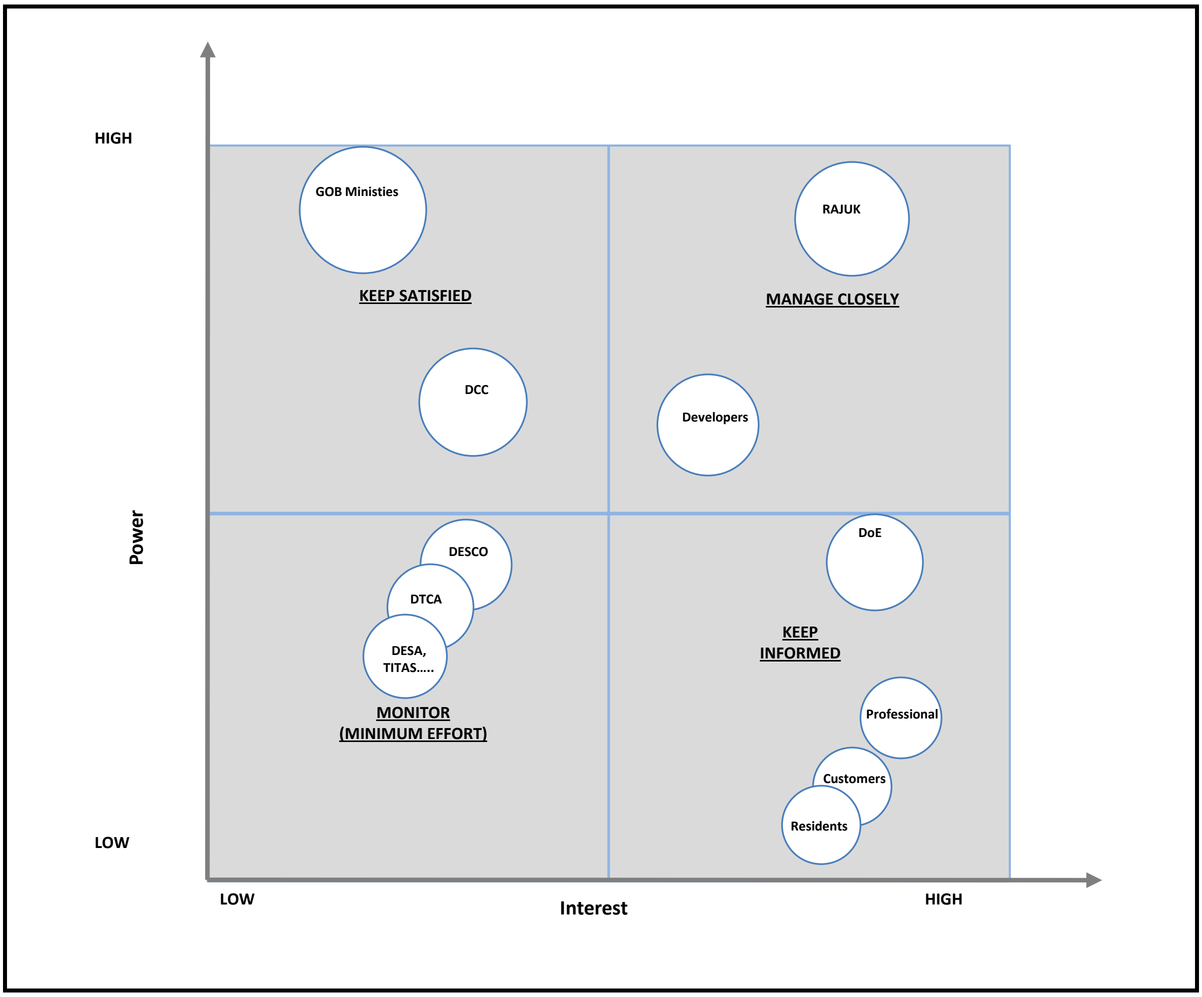


Figure 6-4. Actor map of residential settlement development business.

Source: Author's own, the detail description on procedure of Actor Mapping can be found in http://www.mindtools.com; The actors participation has been discussed from the perspective of good governance in urban residential settlement development projects In: Masum (2009).

Note: The actors name should be read as GOB (Government of Bangladesh), DCC (Dhaka City Corporation), RAJUK (Capital Development Authority), DESCO (Dhaka Electricity Supply Company), DTCA (Dhaka Transport Co-ordination Authority), DESA (Dhaka Electricity Authority), TITAS (Gas Supply Company), DoE (Directorate of Environment).

RAJUK is the main government entity responsible for administrating the approval process of residential settlement development projects, but under the provisions of existing regulatory requirements there are 16 additional organizations that are also involved in the approval process of these projects. Therefore, due to varied interest and power relations among of different agencies, the approval process has become a complex one. The management strategies and working approaches make it difficult for the developers to meet all the requirements of urban agencies. The absence of a one-stop service or common platform is perhaps one of the main reasons hampering the governing of residential settlement development projects. The complexity of the approval process, particularly for utility services (*e.g.,* electricity, water, transportation), is frequently noted due to the absence of prescribed steps; agencies, accordingly are free to administrate according to their own management and development policies (Figure 6-5). In many case, the developers failed to fulfill all the requirements of approval, and as a results, some projects (managed by both the private and public sectors) are simply handed over to the end-user with only very limited or no provision of utility services.

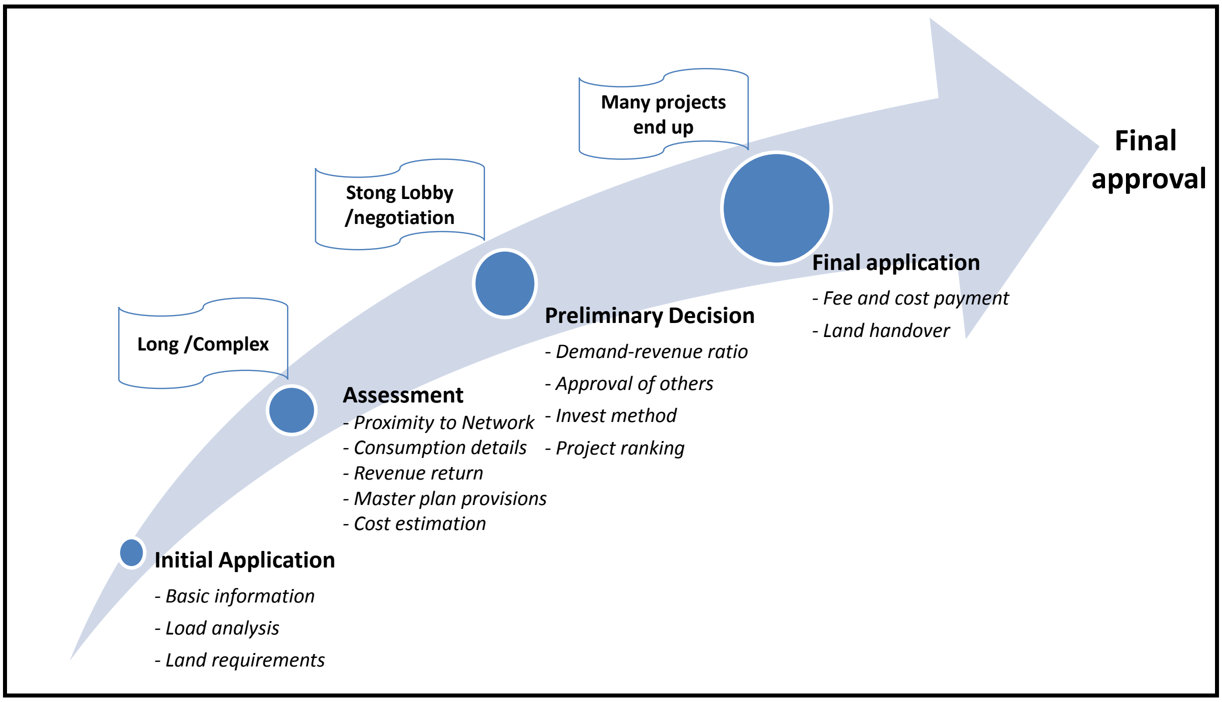


Figure 6-5. Residential settlement development project approval process by electricity authority.
Source: Field survey (2013)

In total there are more than 181 residential settlement development projects that can be identified in greater Dhaka, but only a few projects have been approved by the electricity and transportation authority (Alam, 2014). Unfortunately, even responsible electricity and transportation regulatory agencies do not maintain or share any records about applications and approvals of residential settlement development projects (Figure 6-6).

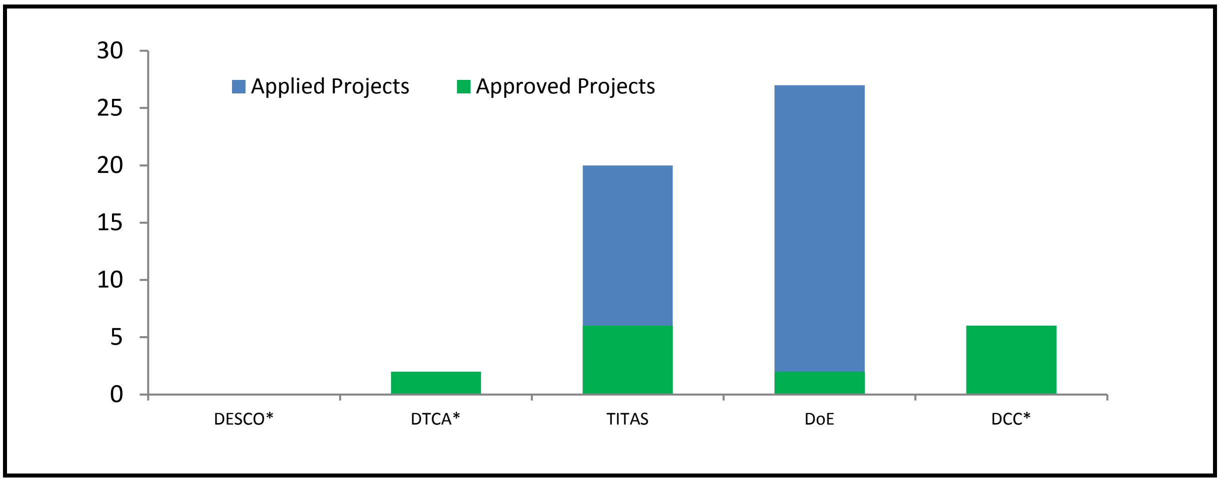


Figure 6-6. State of project approval by urban regulatory agencies.
Source: Authors own illustration based on data from Alam (2014)
Note: (*) keep almost no record on applied residential settlement development projects

Moreover, this complicated process tends to discourage altogether urban stakeholders' participation in any form of energy-optimization in urban development planning. Apart from the organizational actors, the targeted customers and affected residents express increasing interest in affordable housing, but they have almost no negotiation power due to the huge demand for, and limited supply of, housing. Unsurprisingly, their level of participation in the planning and development process remains relatively low.

Evidence from several advanced countries shows that local government is one of the major actors in energy efficiency and management activities. In the context of Dhaka city, one can observe a relatively weak position of municipal authority in terms of energy-optimization in urban development. This is common in other cities of Bangladesh and is largely the result of a top-down governance system.

6.4 Regulatory Framework in Place

One major area that remains under-researched is that of the inefficiency of law and regulation to support energy aspects (Duvarci and Kutluca, 2008). Evidently, sufficient energy-optimized parameters have not been established in current planning regulations and practices, especially for developing countries' urban residential settlement development plans.

Box 6-1: A short story of command-control based aggressive regulation

In 2011, the power division of Bangladesh Ministry of Power, Energy and Mineral Resources issued an office order as- ''all new building required 3% own electricity generation from solar PV for getting approval of grid connections''. One should count such officer order as a positive step towards promoting a supportive environment for diffusion of solar technology in Urban Bangladesh. However, some individuals building owners had invested to install rooftop solar systems to get quick grid connections. But it is also widely claimed that many building owners and housing developers have even rented solar PV system do not function any more after getting an approval of grid connections. Moreover, the housing developer's association-REHAB has continuously complained and did strong lobby with government. Afterwards, the government has abolished such office order in 2013.

Like many other developing countries, Bangladesh is also struggling with insufficient and ineffective regulations for ensuring a better living environment (Mahmud, 2006). In Dhaka city, the present planning and building regulations are mainly focused on the control of density and development control-related issues rather than urban development and building construction practices (Parveen, 2012). The approval process for new individual building construction involves only two steps, land use/planning clearance and building permits, but the approval process for residential settlement development projects involves more regulatory measures. A brief review of the regulations is presented in Table 6-2.

Table 6-2. Potentials and weaknesses of legal framework.

Law/Policyand Enactment Year	Potentials	Weakness
Town Improvement Act (TIA Act 1953)	Basis for building code and land use clearance	Prescribed land use enforcement is optimized in case of privately owned land
Dhaka Metropolitan Development Plan (1995–2005)	Identified suitable areas for residential settlement development	Lack of detailed guidelines and even created conflicts with other regulations; need to address energy parameters
Environmental Conservation Act, 1995	Legal basis for environmental assessment at least for large scale residential settlement projects, the small scale project also should be realized	Mostly focused on industrial and transport pollution control; soft punishment of violation (<5 years imprisonment or fine <1500USD or both)
Private Housing Project Land Development Rule, 2004	Focused on social, physical and environmental standards; Keep approval provision by several urban authorities including energy agencies and transport authority	Almost no provision of punishment imposed other than old legal provisions; Lack of common understanding among different urban stakeholders. No project has approved under this rule yet
Public–Private Partnership Flat Housing Policy (2008) on public vacant land	Encourage innovative solutions to control land supply, mobility and urban form	Increase gentrification and flood risk
Metropolitan Building Construction Rules, 2008	Introduced FAR which to enhance environmental, social and aesthetic values	Limited focus on energy efficiency issue in terms of building design, material use and construction management
National Renewable Energy Policy, 2008	Promote renewable energy with an objective to meet 5% of the total power demand by 2015 and 10% by 2020	Urban sector has all most ignored whereas more focused on rural electrification
Real Estate Development and Management Act, 2010	Basis to impose innovative energy related strategies as it is dealing with management of property transfer and registration	No punishment provision due to violation, no price control mechanism; No concerns about conservation of ecological sensitive area
National Green Building Code, 2012	Instrument to reduce energy consumptions, water use and environmental impact by regulating building design and constructions	Still under consultation which subject to government approval; No significant punishment assigned for violation

Source: Author's own review, KI opinions survey (2013) and Alam (2014) Sikder and Koetter (2015).

An urban planning professional described the state of the regulatory framework for approving residential settlement development projects accordingly: “Even for going through all the processes could be a long and difficult one as there are many open overlaps and loopholes in the regulations. There are almost no prescribed steps or process how to evaluate the public sector housing/land development projects. It should be mentioned here that the Capital Development Authority (RAJUK) itself doing major public sector residential settlement development projects.”

6.5 State of individual planning steps

The "EnUp" model contains a comprehensive set of actions that need to be performed in order to achieve energy-optimization in urban development planning. In the context of Dhaka city, this study conducted a systematic assessment to realize the current state of planning, with particular emphasis on residential settlement development projects. In what follows, feedback from key respondents is presented, which has been aggregated after translating all individuals’ accumulated actions into scores by following the four different planning steps of the "EnUp" model (for detail on the method see also Section 3.4). The final result shows that the site analysis and energy estimations (Step 3) have gained an average aggregated rating of 50%, whereas the remaining 3 steps did not exceed a 40% rating (Figure 6-7). Collectively, these results highlight the need for further initiatives.

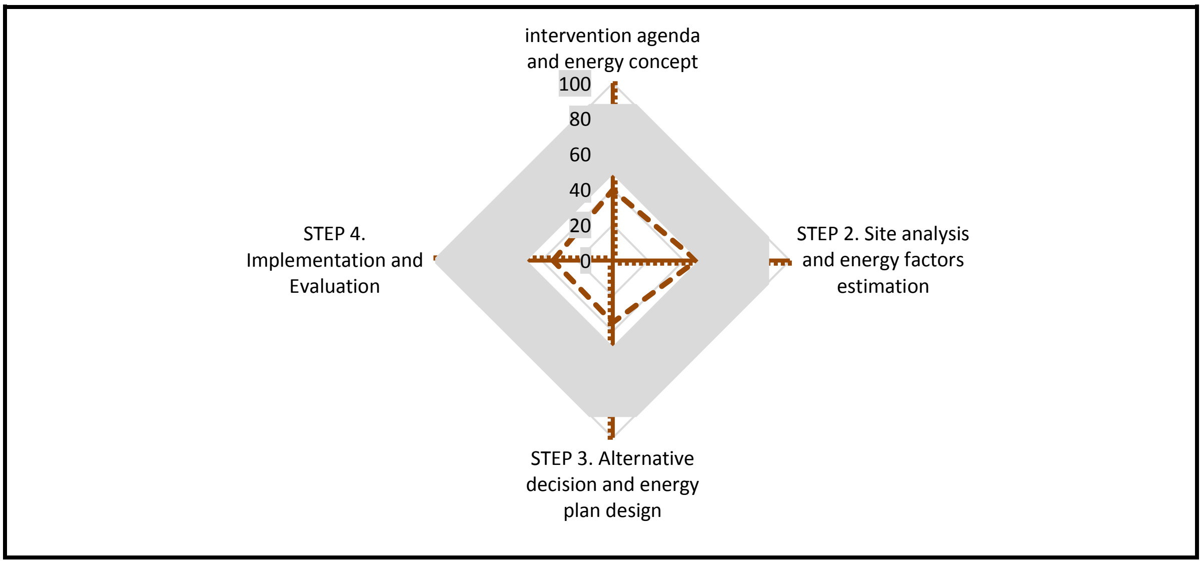


Figure 6-7. Status of major steps of "EnUp" model.
Source: Field survey (2013).

In current practice, the urban site analysis activities for urban residential settlement projects are commonplace in Dhaka city. The energy estimation capabilities perform only on a very basic level without considering any impact of innovations or technologies. The existing methods, models, and tools for conducting different activities will be discussed in the next section.

6.6 Planning Elements that works for the City

A good number of planning elements (e.g. methods, models, and tools) are available for realizing energy-optimization in urban planning and development. EnergyCity, a central European project, has identified 8 modeling tools for reducing energy consumption and CO_2 emissions at the micro level of planning (EnergyCity, 2013). In addition, some integrated models and tools have also been applied and established in consideration of land use, transportation, and energy dynamics (Yamagata and Seya, 2013). After analyzing survey data and published sources, this study argues that the poor use of different methods, models, and tools is one of the significant challenges for adapting an energy-optimization planning framework in the context of Dhaka city, and Bangladesh more generally.

Most modeling and analytical tools demand extensive and/or updated database support (Stevanović, 2013). In the context of Dhaka, control over development is hampered by insufficient exercise of regulations, shortage of skilled manpower, absence of database management (DBM) systems, and lack of new technology/tools adoption (Mahmud, 2006). The urban planning and management agencies reported they are using few methods and tools such as Geographical Information System (GIS) or Remote Sensing (RS) for development planning and topographic surveys. Additionally, most of the initiatives are active on a temporary project-by-project basis, and may disappear after the end of any given project. Urban planners, architects, and other environmental professionals are using some advanced methods and tools, but only on an informal and voluntary basis. They should be supported with more modern and updated tools in order to deliver high quality professional services.

In Dhaka, the local government has limited technical and financial capabilities and, therefore, mostly seeks support from the central government. Municipal capacity building must be built by improving expert knowledge and by providing effective tools and support programs to implement the issue of energy in urban planning.

Though the electricity supply companies continue to progress towards digital database management and the adaptation of energy planning tools (e.g., Windmill, Equipment Record Card software), their efforts remain insufficient for performing urban energy planning at the neighborhood level. The transportation regulatory authority is mostly dependent on traditional models, methods, and tools, except for some very basic traffic modeling and GIS applications. The informal and weak public transportation system adds further challenges for estimating transport-related parameters through the use of well-established models and tools.

Despite these challenges, progress can be seen in the case of individual new building construction. The Institute for Building Efficiency (2013) factsheet shows 11 registered or certified LEED projects in Dhaka city. Additionally, REN21 (2014) reported developing countries like Bangladesh have continued to implement methods/tools and capacity building for future shares and amounts of renewable energy generation in recent years.

6.7 Challenges and Barriers

There are many challenges and barriers for implementing energy-optimization urban development planning in Dhaka city. The challenges and barriers revealed from the empirical data analysis can be grouped into three broad categories: governance, technical, and regulatory. Some cross-cutting issues resist exclusive categorization (Figure 6-8). Governance-related challenges are dominant (46%). These include general issues such as corruption, coordination, evaluation, and stakeholder participation. There are also some exceptional factors, such as ignorance of developers and complexity in the approval process. For example, an urban researcher commented, “Urban agencies are very segregated and mostly do not have any common and clear understanding in their activities. Residential land and housing development is a process where at least 16 authorities are involved directly and all of them have their own mandate and end of the day it is very become complex. “An executive official who works for one of the energy authorities mentioned, “Energy planning is becoming an interdisciplinary task but yet in Dhaka city the authority does not have the culture of integrated work. The electricity sector is not out of that. We think that if the urban planning decisions are well established and manageable it could help energy planning task a lot.”

The technical challenges and barriers (23%) include issues such as traditional energy subsidies, cheap grid electricity, high initial investment for renewable energy system installation, integration complexity for renewable energy, huge housing pressure, boundary-related complexity, and the dilemma of energy distribution and production. Illustrating this are the comments of a RAJUK official, who said, “Dhaka city is a densely populated city such that the known energy measures that are adopted in many other countries in the world–are not feasible here.'' The electricity companies, however, are conducting some digitalization and database management in order to plan better customer services. The government has some programs for encouraging renewable energy and energy efficiency issues in Dhaka, but often faces difficulties due to the interagency generation and distributions dilemmas.

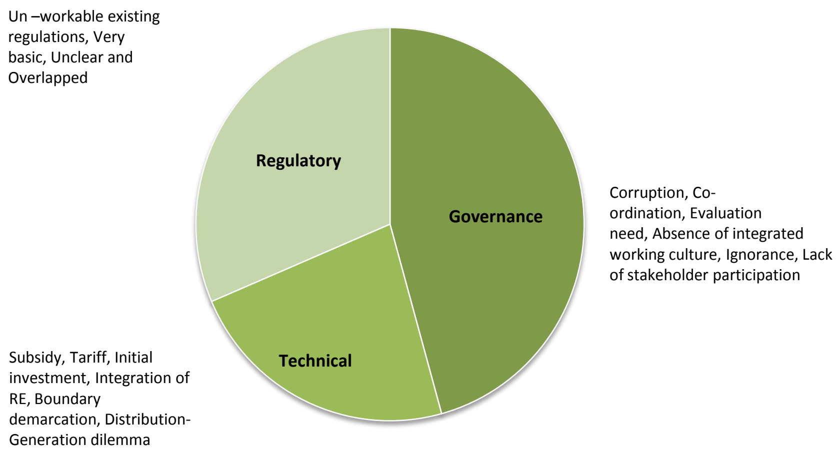


Figure 6-8. Assessment result about challenges and barriers.

Source: Field survey (2013)

Finally, the regulatory-related challenges and barriers (31%) include existing regulations that are frequently unworkable, very basic, unclear and overlap with each other. For example, a land and housing developer mentioned, “There is a need to have clear regulations to include energy issues and other utility services in case of housing and land development projects. The private sector is doing a lot to tackle housing need of the citizens but the public agencies should help by offering easy provisions of infrastructures.” The interagency coordination, furthermore, are not well-functioning within the current regulatory framework - RAJUK (as a leading agency) is not capable of bringing all stakeholders together. In fact, no specific practice in RAJUK exists yet to systematically integrate energy issues into urban planning. Recently, the Floor Area Ratio (FAR) was introduced for density control, but complaints often emerge due to the huge housing pressure.

6.8 Where Further Efforts are Needed

The estimated solar PV potential is very significant in Dhaka city even when only considering building rooftops. The city offers more than 10 sq.km of bright rooftops on which nearly 1000MW electricity can be generated with stand-alone PV applications (Kabir and Parolin, 2012). The feasibility of wider deployment of alternative options for energy-optimization in urban development, such as energy-plus buildings, is significant in the context of Dhaka city. This is because a huge amount of new construction and urban development activities are going to take place in the coming years (Parveen, 2012). The empirical survey data analysis also found a good number of responses indicated the need to address technical issues (41%) is more important than addressing either governance (36%) or regulatory (23%) issues (Figure 6-9). Such technical efforts include the determination of thresholds, recognition of energy aspects, consideration of neighborhood contexts, innovations in new technology adaptation, and integration of energy concepts at the early design stage in urban residential settlement development projects. The needs for capacity-building, strong local government, a supportive private sector, and balance between the public and private sectors are frequently mentioned as areas for potential governance improvement. There are also some comments on regulatory efforts, such as clear regulations for housing projects, review of planning-control instruments, and re-adjustments of laws and rules.

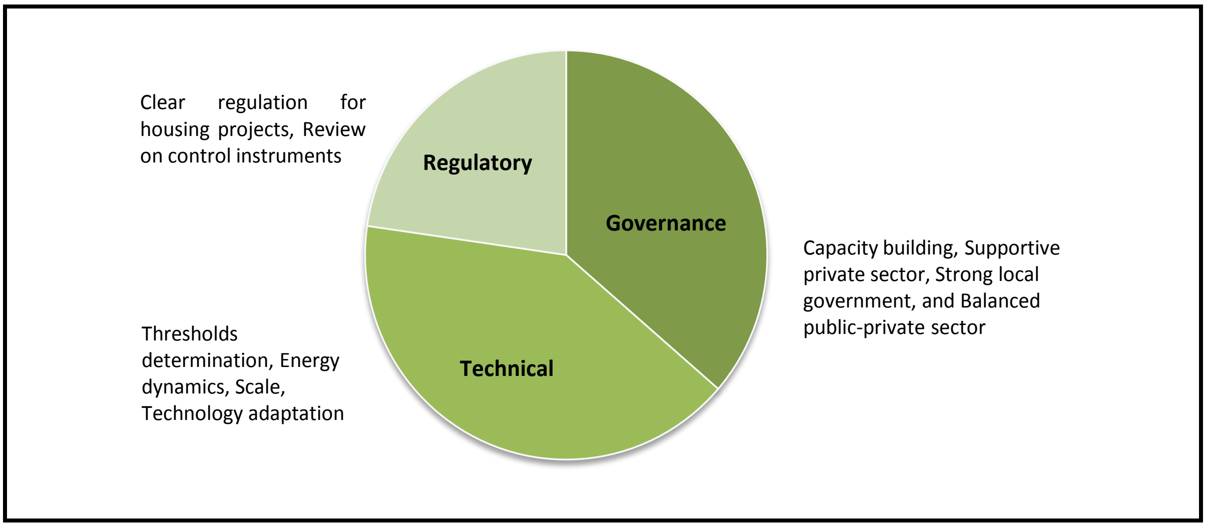


Figure 6-9. Assessment result about needs for further efforts.
Source: Field survey (2013)

The need for an integrated approach can be observed in the statement of an urban planning professional who said, “The hard principal is to fulfill all legal provision and negotiation with the urban and environment management concerns.”

The renewable energy potentials of urban areas deserve a close look in terms of policy concerns. Renewable technology, such as solar PV, is one of the most feasible options throughout the country, but most efforts to install solar technology are concentrated in rural areas. Apart from solar energy, there are other technologies that are also mature enough to support energy efficiency measures and energy production in urban Bangladesh, but they generally are not getting attention from decision-makers. Future urban energy efficiency and renewable energy production initiatives should be able to deal with related challenges, such as grid integrations, management, subsidies, and market issues.

CHAPTER SEVEN: DISCUSSIONS ON RESULTED INTERRELATIONSHIPS AND PROCESSES

7.1 Discussions of Key Findings

The major domain of this study rests on the state of integration between urban planning and energy aspects, in particular in the context of large cities in developing countries. An explorative research approach was adopted to understand the interrelationships of urban settlement structure and the potential of energy optimization in urban development with an empirical case study of the megacity, Dhaka (Bangladesh). In this chapter, the key findings are explained with additional comments and general interpretations. Unexpected results are also highlighted and explained step by step.

7.1.1 Interrelationships of urban structure and energy aspects

The analytical study approach considered two different scales to explore the comprehensive interrelationships of urban structure and energy aspects in the context of Dhaka city. Two research questions guided the discussion: (1) what major parameters should be involved? (2) How far are they measurable? Initially, the urban scale that included the entire municipal area of Dhaka was used. Later, neighborhood level insight was used to "zoom-in" on two representative residential clusters.

7.1.1.1 Spatial pattern of building structure: Urban scale

Physical development density and compactness - in urban scale - are widely-accepted urban form parameters in relation to energy matters (Besussi et al., 2006). Urban structure was quantified after estimating the intensity scores of both vertical and horizontal building use. The powerful cell-based geospatial methods were adapted to measure and visualize urban building structure intensity. The spatial pattern of intensity distribution was explored further after integrating spatial autocorrelation (i.e., Moran’s Index) and spatial distributions of inequality (Gini-coefficient) estimation procedures (Yeh & Li 2002; Islam et al., 2009). In general findings, the residential sector dominated in terms of overall mean intensity share in urban scale. The mixed-use building structure appeared in a very small amount, in comparison to other unique sectors (i.e., residential, commercial, service), although mixed-use should be encouraged to facilitate energy-efficient urban development. The estimated mean vertical intensity was higher than the horizontal intensity in all DCC ward level estimations. On the other hand, the central business district (CBD) area showed a higher percentage of total built intensity (i.e., in combination of horizontal and vertical building use). In particular, vertical development showed a strong but uneven cluster, explained in part by high-rise building structures built close together in some specific urban locations.

The comparative intensity analysis showed interesting findings that support the old school of urban planning theories. For example, the CBD had a higher residential intensity score. Such findings are subject to a land use activity conflict, as stated in some urban structure theories: the high residential density should be discouraged in or near the central business district area in order to maintain better living quality (Huang et al., 2007; Madlener and Sunak, 2011; Schubert et al., 2013). Nevertheless, the low energy city literature sometimes argues about the state of accessibility and proximity to CBD in terms of resident's mobility for work and shopping (Reiter and Marique, 2012). Therefore, the development control and urban management measures of Dhaka should be addressed with appropriate checks and balances, along other concerns besides use density.

The thematic maps of spatial pattern of urban building structure showed better continuation among high value clusters (i.e. Moran's Index value ranged between -1 and +1). The exceptional degree of extreme clustering also existed in intensity pattern that can be observed with LMI values above positive (+ 1). A very weak clustering pattern is appeared in commercial use, but the residential sector had very strong clustering (especially high-high intensity values). The service related building structures seemed to be clustered but with an uneven pattern, while the location effect of cantonment (at the city's heart) should be considered with care in realizing clustering patterns. The mix-use type building structures had extreme clustering with less low intensity values but more in intensity value. This indicated that the mixed use activities most likely occurred in high-rise building structures. In addition, the historical trend of Dhaka's land use structure indicated that the city had residential dominated landuse from the beginning; however, today the mixed use type high-rise building are located in the oldest part of the city, the so called CBD.

Several energy concerned urban scholarships had explicitly pointed out that the urban densification shows great potential towards low energy urban development (e.g. Dienst et al., 2013; Mindali et al., 2004; Norman et. al., 2006; Reiter and Marique, 2012). Urban-scale findings demonstrate that densification has already taken place in Dhaka city. Spatial analysis showed evidence of less CBD dependent urban expansion trends, and a more polycentric development form in Dhaka. In fact, it may make sense to adapt an urban mobility model like the one proposed by Lefèvre (2009) in relation to CBD that fits a polycentric pattern of development. Additional in-depth investigations that focus of transportation components are necessary in order to better recommend a specific type of model.

7.1.1.2 Spatial density of energy consumption: Urban scale

Lack of energy consumption data remains one of the limitations for energy concerned urban studies in the context of many developing countries. Using per-capita energy indicators, this study has been estimated an overall ECD that considered total floor space (i.e. horizontal and vertical) of urban building structures. The population density calculation approach was followed using aggregated building types (i.e., residential, commercial, service and mixed-use). One of the important assumptions of the aggregation was that it is often hard to separate one type of energy use or consumption from another (Marique and Reiter, 2014). The estimation considered only the administrative area of Dhaka city corporation (DCC) because of the availability of data regarding ward-level population and degree of physical development.

The results showed that residential building floorspace has a significant influence on total energy density estimation because the residential use has highest share of total landuse. Similarly, it should be noted that the residential sector is one of the highest energy consumers in comparison to commercial, service and mixed use activity in Dhaka and beyond. The spatial pattern of ECD was visualized on thematic maps. Low energy consumption densities indicated a high per capita consumption in a less intensified or lower degree of building structure development.

The estimated ECD was validated further. There are various validation approaches, but can be five categories can be identified: (i) face, (ii) internal, (iii) cross, (iv) external and (v) predictive validation (Eddy et al. 2012). Cross validation, a commonly-used technique, applied in this research with reference to population density. Khatun, et. al., (2015) published a population density map of Dhaka using a GIS based density gradient method. The ECD mapping showed higher degree validity in representing the real world situation of both density scenarios. The scatter diagrams showed the relationship between population density and ECD scenario, at both the ward and cell level (Appendix A: Figure 5). The cell-wise estimation had a slightly higher co-relation than did the ward-wise estimation.

The population density estimation considered only two-dimensional space (i.e., Khatun et. al., 2015). This research proposed a method of ECD estimation in consideration of three-dimensional building space (i.e., total building floor space), but still followed the same principle of population density estimation. The estimation was conducted at two levels such as ward and cell (100*100). Interesting findings observed in the scatter plot of both density results and their relationship with distance from the CBD (Figure 7-1). The distance from CBD (i.e., Motijeel commercial area - DCC ward no. 32) was estimated as a straight line air distance in consideration of extracted centroid of each polygon feature (i.e., DCC ward and cell).

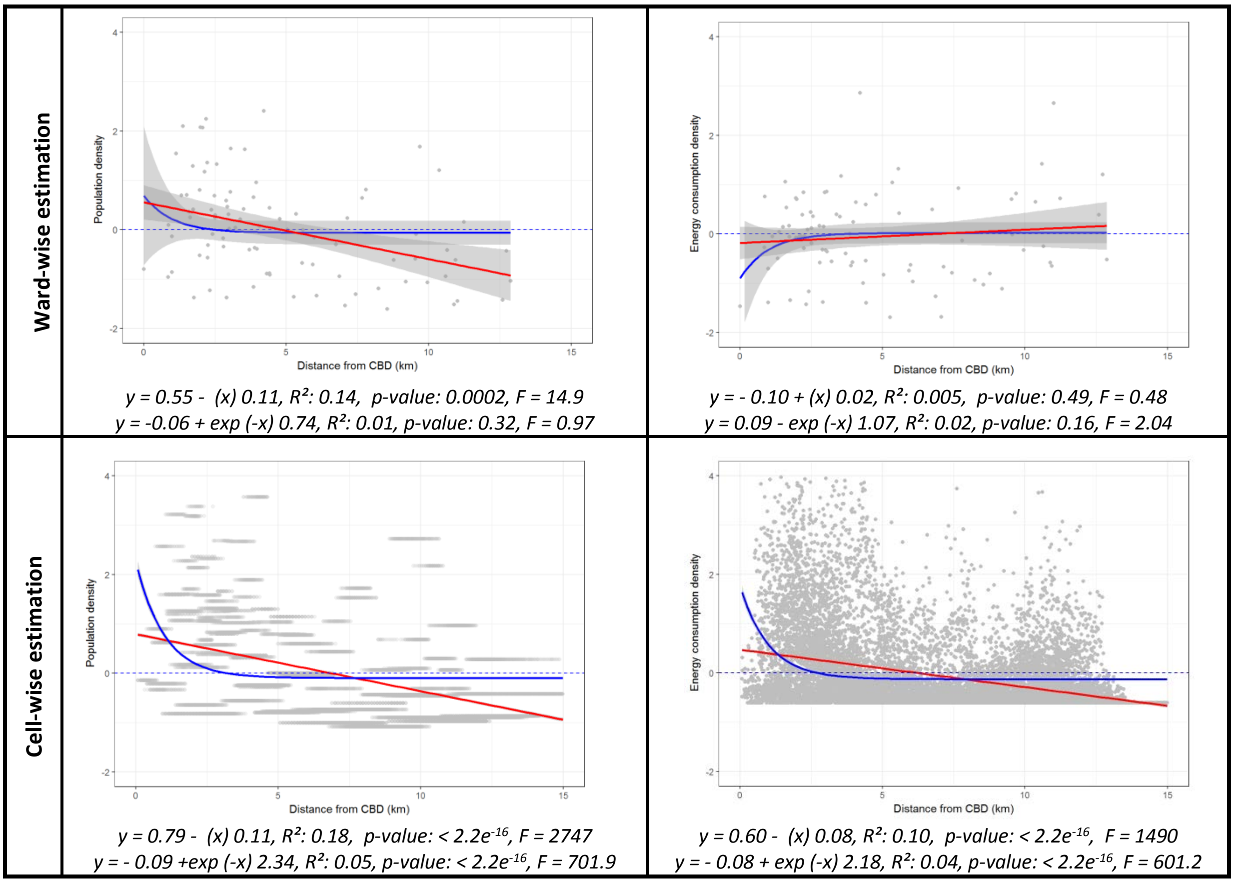


Figure 7-1: Insights of density relations in different scale (ward and cell)

Source: Authors own after GIS based estimations using building information and census data

Note: Population density and ECD was normalized as ratio of distance from the mean and standard deviation (i.e. (x - mean)/SD). The regression lines are shown by red (linear), red (exponential) and blue break line (mean). It is necessary to be mentioned here - according to Chen (2010), most of the real world cities has a negative exponential density function, which is expressed by Clerk (1951). Detail code and statistics can be found in Appendix Figure 9 & 10.

This study concluded that the cell based estimation gives detailed insights about the relationship of density function of urban structure components. In reference to Khatun et. al. (2015), the population density gradient and distance from CBD showed higher degree of validity in three results. By same principle, the cell based estimation provided more detail for explaining urban structure and energy aspects. Nevertheless, the ward-wise estimations showed important findings and could explain the interrelationships of higher transportation energy consumption. On the other hand, the opposite pattern is observed in population density pattern, which is clearly supported in existing theories of urban energy consumption aspects. The cell-based estimation showed same pattern of nearness to the CBD in population density distribution, but only slightly different in the case of ECD. This conflicts with popular urban theory of transportation energy consumption being to distance variation from the CBD.

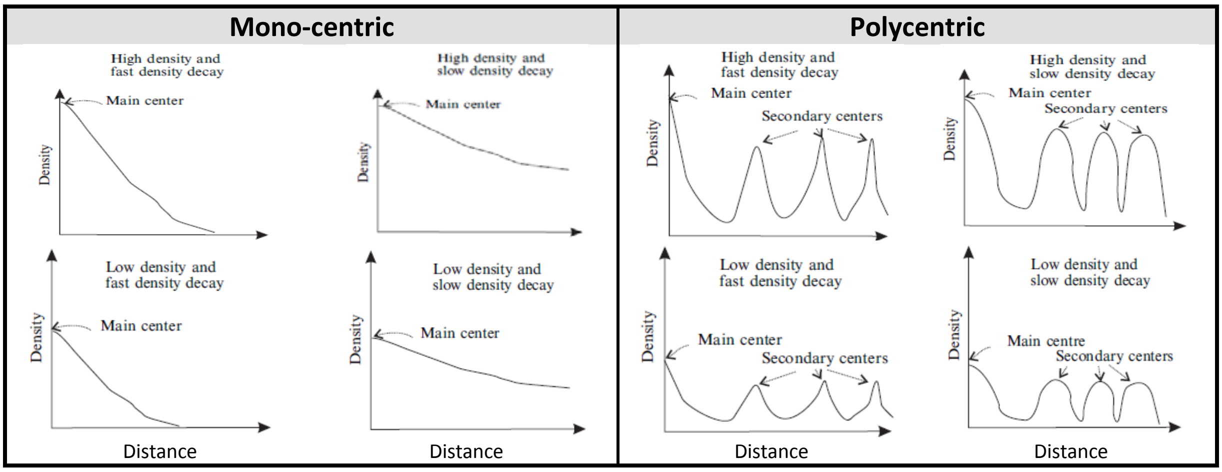
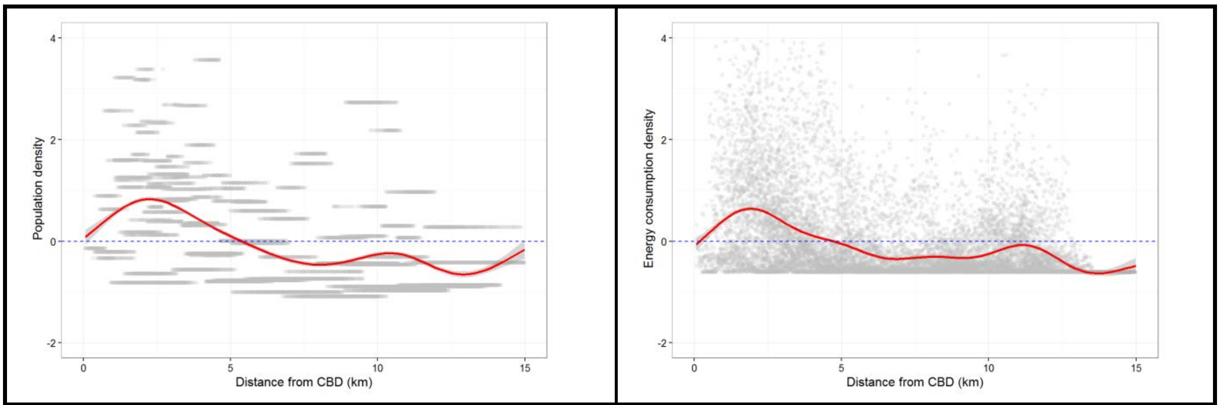


Figure 7-2. Density and decay functions in development scenario.

Source: Adapted from Yeh and Li (2002)

In relation to the urban growth model, the density and decay profile can be conceptualized under two different development scenarios of spatial urban structural: (i) mono-centric and (ii) polycentric (Figure 7-2). High and low degrees of density and decay have significant impacts on the main city center (i.e., CBD) and secondary urban centers (Yeh and Li, 2002). Nevertheless, it is not yet clear whether any density and decay functions are in place and being considered for planning and development control in the case of Dhaka city. In contrast, the location of a secondary center has to be identified before adopting any functional polycentric type of mobility-energy models (i.e. Lefèvre, 2009). Findings could be similar in many megacities like Dhaka.



Intercept: 1.333e-16, R^2(adj): = 0.233, Scale est. = 0.76716 | *Intercept:* 1.622e-16, *R^2(adj): = 0.152, Scale est. = 0.84791*

Figure 7-3. Density and decay relationships in additive terms (Cell-wise)

Source: Authors own after GIS based estimations using building information and census data
Note: Estimated density values were normalized as ratio of distance from the mean and standard deviation (i.e. (x - mean)/SD). The generalized additive model (GAM) formula is: y ~ s(x), Appendix: Figure 11. Detail theory on generalized additive model in Wood (2006).

It is often hard to explain complex urban system components in terms of linear and static models. Therefore, the dynamic non-linear gaps have to be addressed with regard to the urban structure evolution (Chen, 1996). The above discussion pointed out that the polycentric pattern of growth could be investigated in consideration of additive or aggregative approaches. In large cities like Dhaka, the distance from the CBD alone does not have a major explanatory power to conceptualize the function of density and decay of urban structure development. Compare to generalized additive model (Figure 7-3), the local polynomial regression fit (Figure 7-4) showed better performance for estimating in depth relationship between density and distance to CBD. At least, the density and decay functions are confirmed our popular urban theories. Although the regression function of population density is less biased in localized fit (span = 0.75), but the ECD shows an opposite pattern (span = 0.05). This study clearly provided an insight into our understanding of urban structure theory in the context of a large city - Dhaka; however, further work should be done to fine tune the non-linear model fit after including multiple predictors, methods and advance algorithms remain open for conducting further research.

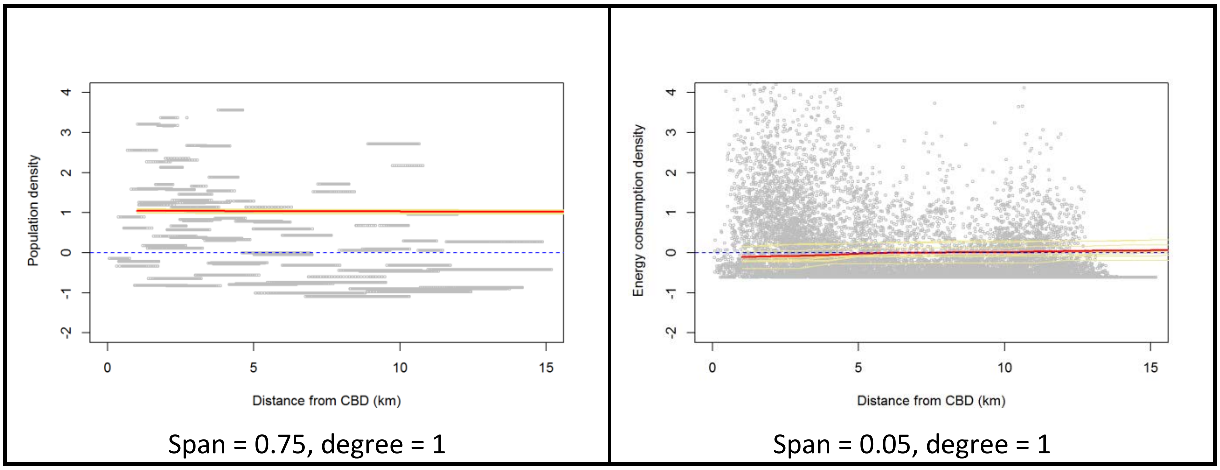


Figure 7-4. Spatial density and distance relation in aggregated terms (Cell-wise).

Source: Authors own after GIS based estimations using building information and census data

Note: Estimated density values were normalized as ratio of distance from the mean and standard deviation (i.e. (x - mean)/SD). Multiple sample sets (10) were taken, in accordance of a statistical machine learning approach called bagging (Breiman, 1996). Finally an aggregative regression (red) line was estimated with all sample regression fit. The LOESS smother fitted after multiple trail of control parameters: span and degree (detail code in Appendix A: Figure 13); follwing Keele (2008) argument that the visual selection of span is ad hoc, but work good in practice.

Details on bagging: www. machine-learning.martinsewell.com/ensembles/bagging/

The co-relation analysis on ECD and building space showed all negative coefficients in ward-wise estimations. Moderate co-relations were observed for all types of use in total space, except mixed-use, but they were weak in horizontal rather than vertical space distribution. Furthermore, the cell-wise estimations indicated mostly positive and weak correlations. Nevertheless, in the case of residential and mixed-use, the horizontal space and energy density relationship appeared to be moderately strong. This indicated the further manipulation potential of vertical intensity for addressing energetic urban development vision in Dhaka city. Such findings were further confirmed by linear multiple regression studies, where the dependent variable is ECD and the independent variables are horizontal and vertical intensity.

The implementation of a net zero energy vision (O'Brien et al., 2010) has a negative function with housing density to solar energy production. The net energy balance calculation included a set of variables in relation to transportation and household energy consumption. This calculation is often criticized due to the omission of some important variables, such as the location function of the main urban center (CBD) or secondary center and their distances. However, it might make a huge difference in implementing an energy-concerned urban development concept in a rich solar resource based megacity like Dhaka. The results of this study can at least start a discussion about zero energy visions for the sustainability transition of an urban system in the context of megacities. Its exploratory findings can feed further advancements at the hands of urban thinkers, professionals and decision makers.

Apart from the cell-based spatial urban structure analysis and ECD mapping, this research explored additional energy-related parameters, such as building age, surface to volume ratio, floor area ratio and others. The results could not be detailed on direct energetic relationships due to lack of building-level energy consumption information. However, the results are offering value for better integration of energy and urban planning research.

The spatial form and degree of development could be better conceptualized after considering use of building space in both horizontal (2D) and vertical (3D) dimensions. The cell-based geo-spatial technology environment has been supported for extensive analysis of vector-based building information. This research found great potential in this approach to exploring in-depth urban structure form for energy-concerned decision-making. However, the quality and reliability of data are acknowledged as limitations in the scope of this study.

7.1.1.3 Measuring energy concerned indicators: Neighborhood scale

The residential urban structure has the highest share of building space and is, therefore, a major energy consumer. After finalizing a set of indicators, a comparative analysis was conducted on representative residential clusters in consideration of residential development type in Dhaka city (i.e., private and public regulation). A comprehensive indicator selection framework called eDPSIR (Niemeijer and de Groot, 2008) and systematic filtering (Schetke et al., 2012) was adopted after systematically gathering indicators from similar scientific studies (Stoeglehner et al., 2011; Martins et al., 2014; Schetke et al., 2012; Wilson, 2013; Marique and Reiter, 2014). In general, three dimensions were considered (physical, social and technical), where a number of categories and criteria were used for a systematic representation of comparative findings at a neighborhood scale in terms of urban form, working mobility and resident's lifestyle.

The private regulation-led residential development (i.e., SRC 1) appeared to be a suitable location due to a higher score in the edge contrast index, nearness to an employment hot spot area, and accessibility to public sector transport facilities (e.g., bus stations). Although a majority of the residents preferred a variety of informal modes (IMs) or non-motorized transport (NMTs) modes, service quality is a sensitive factor that includes frequency of transfers, security, cost, reliability, and comfort. The public regulation-led residential development (i.e., SRC 2) had better connectivity to the local area. Interestingly, LEED-ND (US-GBC, 2009) standards on local connectivity were met by both public and private regulation-led residential development. The supply facilities, especially electricity, had almost no share of renewable sources other than an external fossil-based grid supply in both public and private regulation-led residential settlements. The state of landscape (i.e., state of open/green space), could not meet the minimum regulatory standard in SRC 1, but the share of hard-scape was higher in SRC 2. It would be hard to comment on the standard amount of hard-scape in terms of energy-sensitive goals without further investigation. The state of road orientation findings showed a positive scenario in SRC 1 that had a strong link to the state of plot/building orientation. Opposite findings were found in SRC 2; of course, other parameters, often called morphological functions (building shapes, heights and building quality variables), have to be considered. The minimization of the surface area: volume ratio (SA:V) has a positive impact on energy aspects both from efficiency and consumption aspects. The private sector-led residential development (SRC1) showed a comparatively lower mean score (0.4), with a standard deviation (0.19). The building aspect ratio was estimated and the opposite of findings where SRC 2 has a comparatively lower mean value (1.5). However, this value was still far higher than a proposed reference value. For example, 1.3 was proposed for northern climate conditions (Athienitis and Santamouris, 2002). Furthermore, SRC 2 gains positive impression in state of spatial building organization or clustering (i.e. Global Moran's I and Local Moran's I) based on building height. A strong and even clustering of building heights could be positively influenced in both active and passive forms of energy aspects.

The housing/residential functions have strong influences at a neighborhood scale in both the urban and energy planning domains. The gross urban density observed in both SRCs was lower than the 350 persons/acre regulatory standard of the urban authority. There are still empty plots, which will increase both net and gross densities and, therefore, the population density and building density need to be balanced in future. The household sizes were lower than the city average in both clusters (3.72 and 3.76 accordingly), but the per capita living space was higher in SRC 1. These findings indicated a better quality of living and consequently higher level of energy consumption. The resident's age structure analysis showed that the public-led residential cluster (SRC 2) had more school age (6-14) and older (above 65) persons, but there were more young (15-30) and working age (31-65) persons in SRC 1. The resident's income structure identified a better mix of varied income groups in SRC 2 (Gini index 0.29), but comparatively lower average household income. Therefore, the higher financial capacity can be assumed in the private-led residential settlement cluster (SRC 1).

The transportation-related energy consumption has a direct link to residential mobility functions. In contrast, vehicle ownership indicated the private-led residential cluster (SRC 1) had a higher share of private vehicles (e.g., 58% CNG fuel-based car). The vehicle ownership was much lower in SRC2, perhaps linked to financial ability and social status of the residents. The working mobility pattern developed by analyzing empirical survey data while conceptualizing home to work trip generation system and choice of travel mode is already a complex task due to huge informality in Dhaka city. The annual share of car-based trips and travel distance estimations indicated that residents in the private-led residential cluster (SRC 1) generated almost double the car-dependent trips as SRC 2, at least for annual share in working mobility. The higher income, vehicle ownership and quality of public transport along individual choice could explain this mobility pattern. The nearness to employment hot spots did not show any significant roles (rather remain inverse), which is common to many energy-integrated urban planning theories.

Energy use patterns were explored in this study -in particular, electricity and CO_2 emission for working mobility. Many shortfalls remain unsolved. The findings showed that residents of the public-led residential cluster (SRC 2) consumed comparatively less electricity per capita, but differed only slightly in terms of annual intensity (kWh/sq.m) estimation. Seasonal variations also influenced electricity consumption directly and could be explained by looking at household electric appliance ownership. Air-conditioned use varied greatly between the two residential clusters and indicated variations in residents' lifestyle in general. The private-led residential cluster used twice the energy per household and triple the energy per capita (CO_2) for working mobility. Still, energy use by the private-led residential cluster was low compared to many high income and industrial countries of the so-called developed world. Nevertheless, the findings on energy consumption should be considered for formulating future policy at intercity and national levels.

Besides analyzing many passive energy aspects, this research estimated the potential renewable resource extraction of using active solar technology (i.e., PV). The availability of high amounts of solar radiation is one of the justifications for assessing the solar PV potential, rather than wind, geothermal and other renewable options. A simple method was applied that focused on adaptation possibility, resource needs and data-related limitations. The scenario assessments (i.e., conservative and visionary) reported similar annual energy balances in both residential clusters. However, the amount of electricity generation differed greatly between the two different scenarios. The careful selection of renewable technology is necessary for effective dissemination and rapid adaptation. One should remember the reliability of solar PV system remains low, and those households that have installed rooftop solar PV have not been able to use it to maximum advantage. There are no incentives for the generation of solar PV-based electricity and infrastructure support (for example, tariff or micro-grid solutions).

Along the research goal, the residential study clusters were investigated after adoption of open source and simple methods and techniques to measure a set of indicators. The indicators were assumed to be easily conceptualized by professionals in the context of Dhaka city. The indicator set can be measured and manipulated with minimum effort if the step-by-step methodological descriptions are followed.

7.1.2 Evaluation on residential settlement development process

The growing concept of energy-optimization in urban development planning has great potential to address local energy concerns and urban climate change challenges, such as increased energy demand, clean energy production and the transition towards a green economy. The potential of energy-optimization in urban development planning to use resources efficiently was explored in the development of urban residential settlement, where the questions were framed as: i) what is the current state in the Dhaka city? ii) How can a conceptual framework contribute? This research did not include the entire spectrum of energy-related urban planning issues; rather its focus was on electricity factors and residents' mobility issues. A conceptual framework for energy-optimization in urban planning called the "EnUp" model was developed. The "EnUp" model was applied in a developing country perspective with the potentials of urban energy optimization. Using system analysis and grounded theory approaches, the current state of urban residential settlement development projects along energy planning process was analyzed for Dhaka city. The facts and figures were explored, along key informant interviews and reviews of secondary sources.

The results showed that the adaptation of a comprehensive approach like the "EnUp" model is both possible and necessary to address the urban growth challenges of Dhaka city. The "EnUp" model contains a comprehensive set of actions to achieve energy optimization planning. After a systematic assessment to realize the state of four planning steps, the third step (site analysis and energy estimations) gained an average aggregated rating of about 50%. The remaining three steps did not exceed a 40% rating; therefore, further initiatives are needed. Urban site analysis activities for urban residential settlement projects are commonplace, but the energy estimation capabilities have been modeled with limited innovations or technology interventions.

The "EnUp" model can also serve as a guide for sustainable urban development in Bangladesh by considering current challenges and barriers that need to be addressed. Firstly, governance-related challenges are prominent (46%) - there are needs for capacity building, strong local government, a supportive private sector, and balance between the public and private sectors. Secondly, the technical challenges and barriers (23%) include significant technical issues that need to be solved. Finally, the regulatory-related challenges and barriers (31%) include the fact that existing regulations need to be modified. Our assessment concluded that the need to address technical issues (41% of responses) is greater than the need to address either governance (36%) or regulatory (23%) issues.

The lack of efficient method/tools adoption is one of the technical needs for Dhaka city. Urban agencies are using a few methods and tools for development planning, topographic surveys, and energy planning, but most are project-dependent and may disappear after the project ends. Additionally, there is great dependency on traditional models, methods and tools due to their degrees of informality and lack of available data. Therefore, efforts of professionals such as urban planners, architects and other environmental professionals should be supported in order to deliver high quality professional services.

Both the public and private sectors are involved in residential settlement development projects in Dhaka city. RAJUK is the main government entity responsible for administrating the approval process of residential settlement development projects, but under the provisions of existing regulatory requirements there are 16 additional organizations that are involved in the approval process of these projects. Therefore, due to varied interests and power relationships between different agencies, the approval process has become complex. RAJUK (as a leading agency) is often not successful in bringing all stakeholders together and tackling challenges. Municipal local government is overlooked and is relatively weak in terms of energy-optimization in urban development. Other than institutional actors, the low level of participation of the targeted customers and affected residents is observed in the planning and development process. This is common in other cities of Bangladesh and results largely from a top-down governance system.

A common urban platform is needed that offers a transition to an inter-agency, collaborative working culture, and stakeholder engagement. Additionally, there is a need for regulatory reform, such as improved and stronger policies for housing projects, a review of planning control instruments, and the re-adjustment of laws and rules. From a technical point of view – customized tools, highly-skilled manpower, and high quality data must also be integrated into planning efforts. Findings related to these research questions would help to formulate future strategies and policy inputs for the urban residential settlement development planning, along efficient resource use in the context of Dhaka city and many other cities in the world with similar settings.

8.1 Proposed "eNoP-DHAKA" Tool

The key discussion of empirical findings, specifically the systematic evaluation of the residential settlement development process, suggested the need to design a decision tool that could facilitate energy optimization at the neighborhood scale. There are other challenges, but they remain outside the scope of this research. The question addressed here is “What could be a simplified tool for energy-optimization planning in the context of Dhaka city?”

Multi-dimensional aspects - physical, social, technical and others - have to be considered in urban planning decisions. The multi-criteria based decision approach is a likely candidate. Pre-selected indicators, criteria and categories were used to represent the aspects of energy-optimized urban residential settlement development in the context of Dhaka city. The indicators had already been measured at the existing residential cluster level, so their selection was justified.

8.2 Model Setting and Approach

This study sought to draft a simple tool by following the multi-attribute decision making approach. According to Yeo et al. (2013), this often known as Multi-criteria Assessment Decision Support (MCA-DSS) tool. This study named as "eNoP-DHAKA" and defined as a computer-based decision tool that combines data, modeling, and a user interface. Defined another way, it provides the assistance needed by decision makers to enable them to extract insights and evaluate preferred decision options.

Table 8-1: The pro and cons of popular decision analysis approaches

Approaches	Strengths	Limitations
Delphi	Expert's experience and opinions are solicited by means of brainstorming.	The estimation results are more subjective to evaluators' judgments
AHP	The method combines the qualitative and quantitative merits and provides a multi-dimensional analysis.	Expert's opinions may subjectively affect the results
Principle Components Analysis (PAC)	The statistical methods can summarize the multiple variables to a limited number of synthesized indices, and avoids the correlation among these indices.	The evaluation relies on exigent data quality
BP Neutral Network	The method leads to a mutual evolution process with objective results reflecting the real state.	A large number of training sample data are essential for appropriate evaluation
Mean-Variance Analysis	This method leads to high-accuracy estimation results and the underling rationales are easy for understandings.	The estimation results are sensitive to the quality
ANP	Ideal for deeper understanding	Too complex for practical decision making, verification of inter-relations and feedbacks is not possible

Source: Adapted from Wei et al. (2016)

Urban planning decision tools have to be considered with respect to multi-dimensional aspects, such as physical, social, technical and others. Therefore, an innovative approach needs to be adopted for energy-optimized urban residential settlement development in the context of Dhaka. In order to build a new innovative tool, the advantages and negative aspects of each approach have to be carefully examined (Table 8-1).

The multi-criteria related urban planning decisions require subjectivity to describe the human creative process in assessing something in the absence of mathematical procedures (Munandar and Azhari, 2014). In contrast, this research adopted the AHP approach even though criticism exists about the subjectivity of expert opinions. AHP offer straight-forward process in combination of qualitative quantitative dimensions. Compare to other methods, AHP could be conceptualized easily and therefore flexible to manipulate with minimum efforts. Besides, data characteristics also influenced for choosing the methods that could better adapt to the particular decision assessment task - in our case energy optimization in planning. Additionally, equal and hybrid weighting methods are included for critical comparability of results and provision for human choice from alternatives.

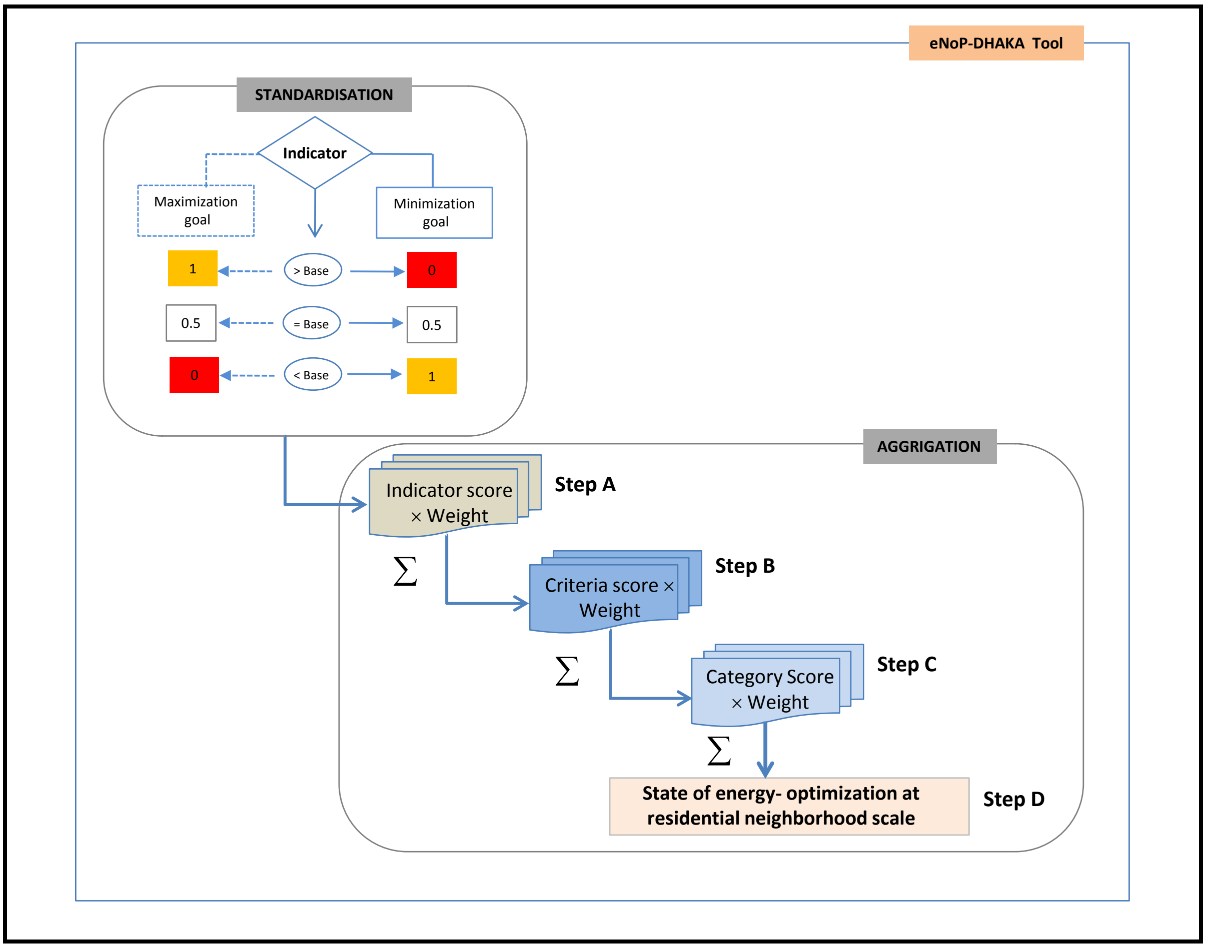


Figure 8-1: Flow diagram of "eNoP-DHAKA" tool calculation process
Source: Author's own draft

First developed by Thomas L. Saaty in the 1970s, AHP has become well-known for analyzing and making complex decisions. There are 4 basic steps are involved in AHP that included all tasks of model building to alternative ranking (Ali and Al Nsairat, 2009). At this level, organizational diagrams of the model may help to conceptualize the overall structure of the decision-making process and components. The assessment items (e.g., indicators, criteria and categories), ordinal scale of standardization and aggregation of weighting steps are shown in the diagram (Figure 8-1).

The decision evaluation process begins with the indicator value (measured for SRCs) at the top, which has to be standardized by following the individual goal functions (minimum or maximum) and progresses towards the category items at the bottom. One of the important given assumptions of this model is that the selected indicators, criteria and categories represent the dimensions of energy-optimization urban residential settlement development in the context of Dhaka city. The result obtained for each item level was calculated according to the following equations (Box 8-1):

Box 8-1: Step-wise formula for estimating of "eNoP-DHAKA" items values

Step A: Indicator result (R_I) = Indicator weighting (W_I) $\times$ Indicator Score ....(Equation 21)

Step B: Criteria result(R_C) = Criteria weighting (W_C) $\times$ Criteria score........................(Equation 22)

Step C: Category result (R_{CA}) = Category weighting (W_{CA}) $\times$ Category score.............(Equation 23)

Step D: Final result = $\sum$ Category result (R_{CA}) ....(Equation 24)

Where, Criteria score = $\sum$ criteria result (R_I) and Category score = $\sum$ category result (R_C)

The final result was estimated 3 ways by using assessment items and three types of weighting approaches. This is simply the use of weighting coefficients systematically and comprehensively that were estimated for each category, criteria and indicator: (i) the weighting coefficients of category are distributed for each criterion, and then indicator (C → A); (ii) the weighting coefficients of criteria are aggregated for each category (B → C) and distributed for indicator (B → A); and, (iii) the weighting coefficients of indicators are aggregated for criteria and then category (A→C).

8.3 Standardizations of Indicators

To perform MCA calculation, several units of indicator values have to be simplified. This study standardized indicator values so that each standardized value fell in the same scale, which facilitated the weighting of indicators in the next step. A scale of ordinal scoring was considered that fulfilled the necessary dimensionless data transformation in the process. The dimensionless indicator score was calculated by assigning an ordinal scale as shown in Table 8-2:

Table 8-2. Definition of Standardizations (ordinary scale) along goal functions.

Goal functions	Ordinal Score		
	Indicator value > Base value	Indicator value = Base value	Indicator value < Base value
Maximum	1	0.5	0
Minimum	0	0.5	1

Besides expert rankings, the minimization and maximization goals are arranged in ordinal scale that confirmed the hybrid nature of relative (pair-wise comparison) and rating model (assumed standards) aspects (Ali and Al Nsairat, 2009). In simple terms, an increasing value of some indicators contributed towards energy optimization. On the other hand, the reducing value of indicators (reverse trend) also influences progress to energy optimization. Here, the base value was used to decide on the ordinal score following goal functions. It should be mentioned that the base value for this study was estimated from SRC indicator results. The arithmetic mean of each indicator was assumed to be representative in the context of Dhaka city. However, there is flexibility to improve them (upon choosing an adjustment factor) according to local regulations and by including more empirical study in the future.

8.4 Weighting Approach

The weighting approach has significant impact on the optimum decision process after standardization of indicator values, and different methods yield different results. There are several approaches that are frequently adopted to calculate indicator weighting, but further investigation is often needed about the justification for non-equal rather than equal weighting approaches (see review in Butler et al., 1997; EC, 2015). In this background, three types of weighting coefficient were estimated to cover comprehensive insights.

8.4.1 No-equal weighting coefficient

The pair-wise comparison under the concept of AHP has been conducted for estimating non-equal weighting of coefficients. An Excel-based structured spreadsheet was developed to collect the expert opinions inconsideration of pair-wise comparison (Appendix E: Figure 1, Table 4 & 5). All categories, criteria and indicators were organized in matrix structure and assigned options for comparing with relative importance. The well-known Saaty's 1-9 scale weights the relative importance in a square matrix structure (Cerreta and De Toro, 2012; González et al., 2013). The values of importance were taken from Saaty’s 1–9 scale, where the number values indicate the following relative importance: (1) equal importance; (3) weak importance; (5) essential or strong importance; (7) demonstrated importance; (9) absolute importance; (2, 4) intermediate vales between the two; and, (6, 8) adjacent judgments. The eigenvector that allows inconsistencies to be checked was employed to calculate the relative weight coefficients of items.

8.4.2 Equal weighting coefficient

Equal weighting feeds into the frequent debate on choosing a specific approach, especially where limitations exist, such as lack of clear causal relationships, no statistical significance and little empirical evidence. Some studies (Lee and Huang, 2007) strongly argue that different assessment items should have equal weights. This study applied the equal weight method for initial integration and analyzing overall trends of assessment items (Appendix E: Table 3). The calculation was very straightforward: simply divide 1 by the number of items.

8.4.3 Hybrid weighting coefficient

The third type of weighting coefficient was calculated in combination of equal and non-equal weighting output (Figure 8-2). This provided an opportunity to amalgamate independent outcomes and subjective expert judgments. The simple arithmetic mean of equal and non-equal weighting coefficient was estimated for each assessment item, such as category, criterion and indicator (Appendix E: Table 5).

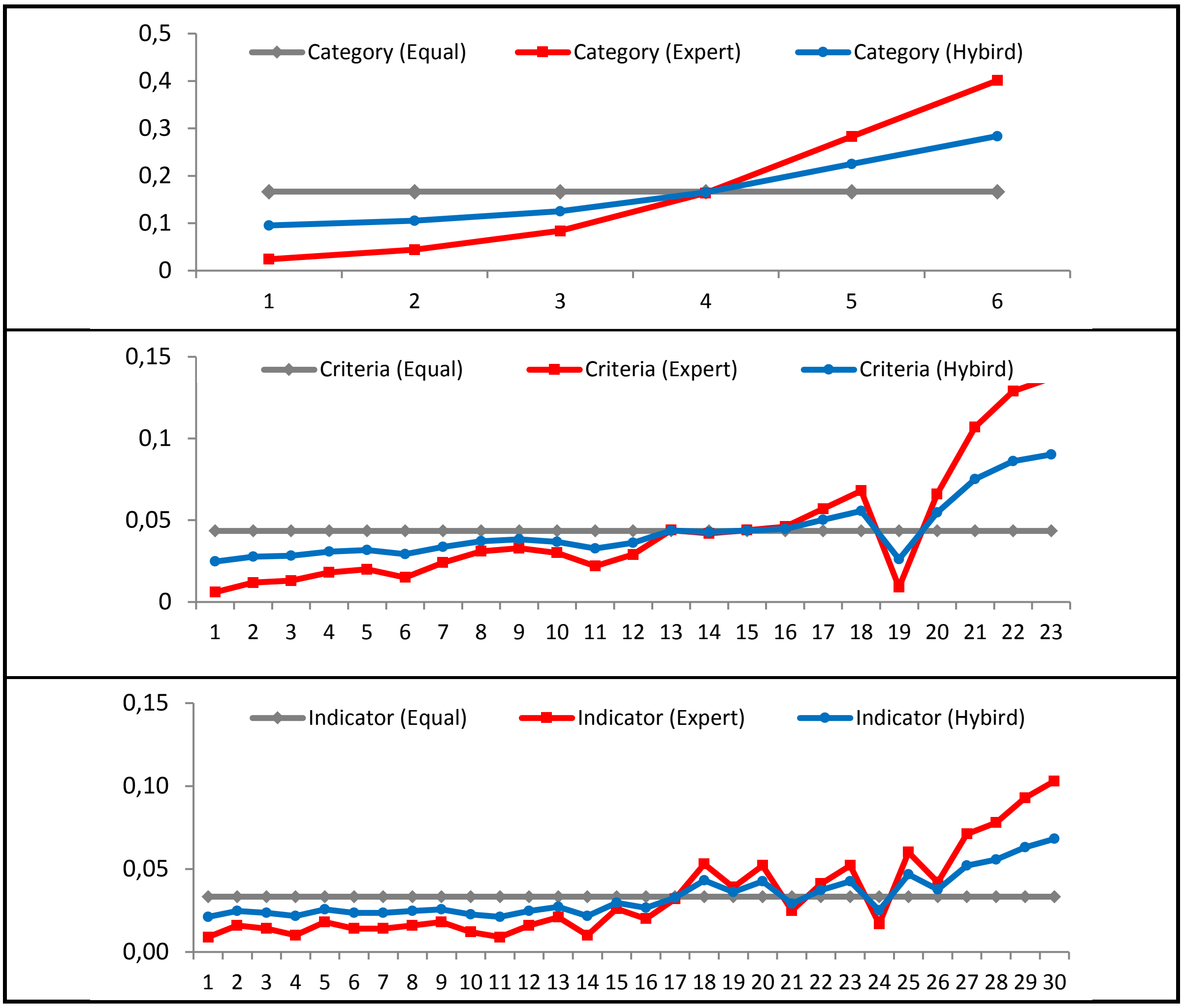


Figure 8-2. Comparison among equal, expert and hybrid weighting coefficients.
Source: Author's own

8.5 Layout of "eNoP-DHAKA" Tool and Application

A tool was created within a computer-based environment to understand of energy optimization state of a residential settlement project. A simple Excel spreadsheet was designed with multiple sheets, with a user input interface (Appendix A: Figure 14), results and a compilation panel. In the user input interface, the user can easily input values for each indicator by following categories and criteria (Figure 8-3).

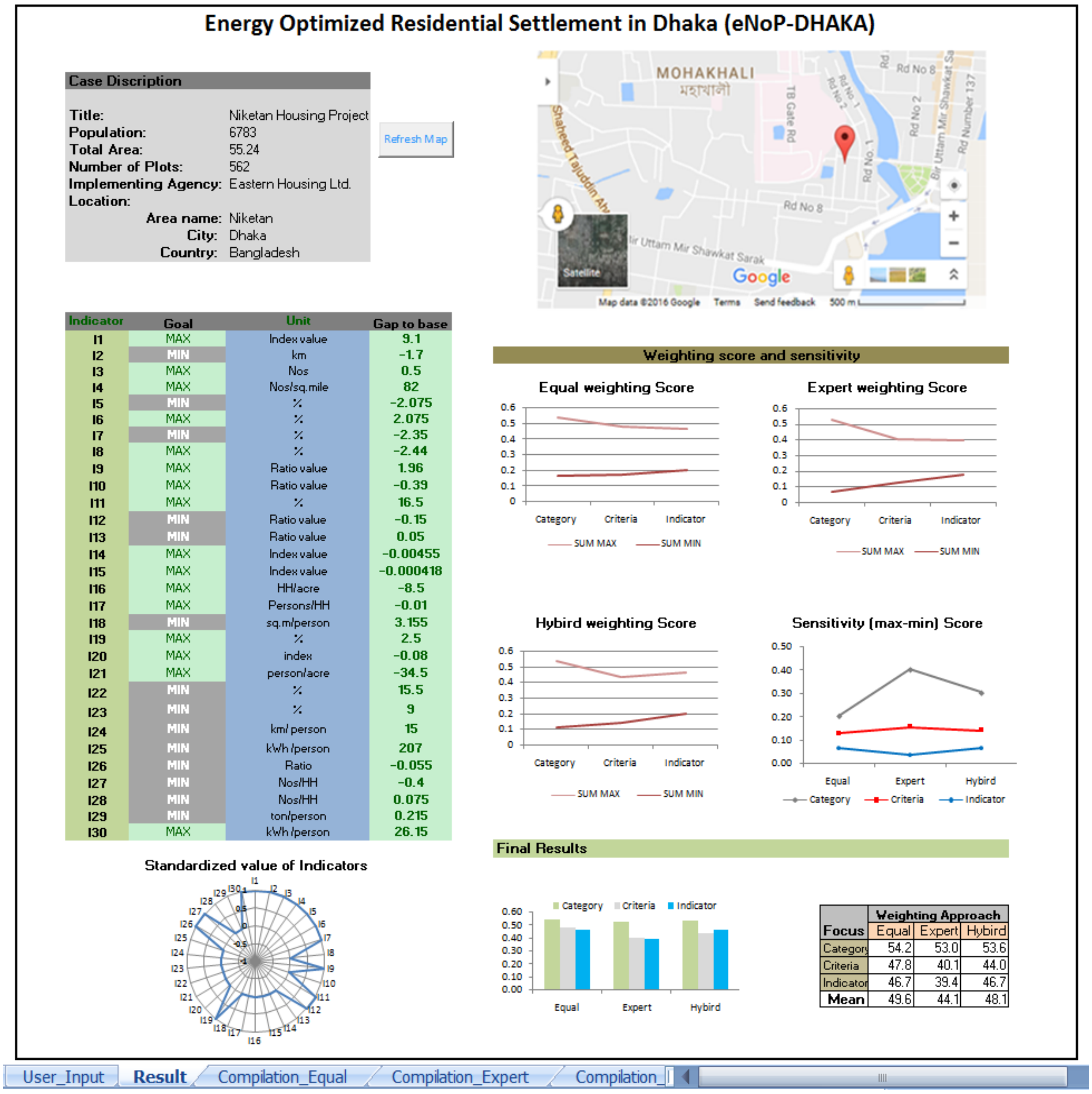


Figure 8-3. Screen shot of final result sheet of "eNoP-DHAKA" tool.

Source: Author's own

The general information and user preference for the weighting method have to be chosen before final results are produced. The results panel summarizes the results in the form of figures, numbers and texts. The indicator-wise detailed results are included in the results sheet. An online link with an automated Google map service is included that shows a location map in the results panel with minimum effort by the user. The compilation panel includes all formulas used to calculate the results after retrieving the inputs from the user interface, and then displays them on the results panel. To maintain compatibility with different versions of Microsoft Office software, spreadsheets are locked except for user input fields. Performance sensitivity results are also included for making the best decisions on the level of energy optimization. Developer access is ensured by providing a passkey for further development. Using the "eNoP-DHAKA" tool, the final results for the two study units showed that SRC1: Niketan achieved a lower energy optimization rank than SRC2: Nikunja (Table 8-3).

Table 8-3. Comparative results of two study residential clusters (SRC).

Item Focus	Weighting approach					
	Equal		Expert (pairwise)		Hybird	
	SRC1	SRC2	SRC1	SRC2	SRC1	SRC2
Category	54.2	41.7	53.0	37.0	53.6	39.3
Criteria	47.8	52.2	40.1	60.5	44.0	56.3
Indicator	46.7	53.3	39.4	60.9	46.7	53.3
Mean score	49.6	49.1	44.1	52.8	48.1	49.7

Source: Author's own, results based on measured indicators values at both SRC (see also Appendix A: Table 2, Figure 12)
Note: The results are shown as percentage which indicated the state of energy optimization at neighborhood scale. More detail on AHP based pair wise comparison and Experts weighting (Appendix E: Table 3 & 6, Figure 1).

8.6 Sensitivity Analysis

The assigned weights are determined based on different approaches and priorities, and the results can easily be affected by different combinations. Therefore, it is necessary to analyze how the final results were influenced by fluctuations in weighting coefficients. In this background, sensitivity analysis was used to study the stability of the results. There are several methods (see review in Butler et al., 1997) of sensitivity analysis; one-dimensional sensitivity to the weights is widely applied where the ratios among other weights are counted as a constant and the final complete results remain unchanged after manipulation of the stability interval. However, this research maintained a standard consistency ratio (≥ 0.1) in the process of expert opinion through a pair-wise comparison that already addressed some level of sensitivity. Performance sensitivity results could provide more insight for better decision-making.

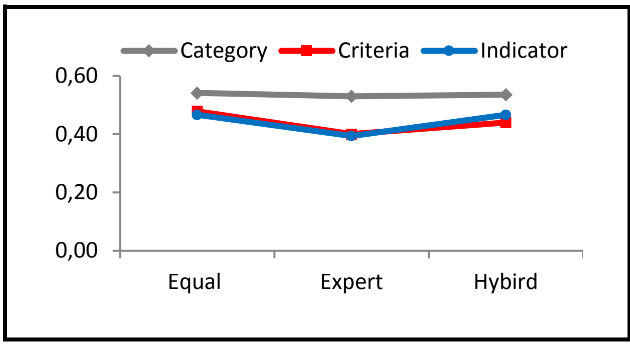


Figure 8-4. Sensitivity on final score (SRC1).
Source: Author's own

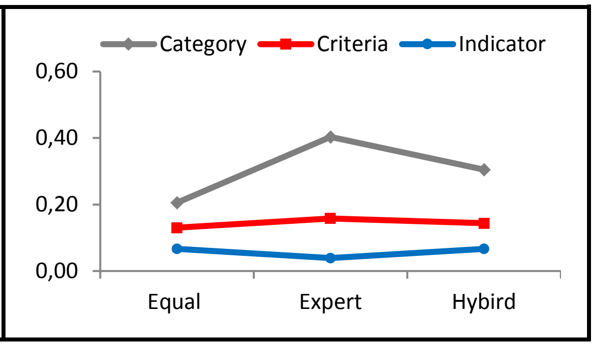


Figure 8-5. Sensitivity on Max-to-Min (SRC1).
Source: Author's own

The first performance sensitivity was estimated on the final completed result of each weighting approach (Figure 8-4). It provided an opportunity for decision-makers to choose from the alternatives under different potentials and limitations of approaches. Secondly, the Max-to-Min distance-based performance sensitivity was calculated by simply considering the aggregated scores of predefined maximum and minimum goal-oriented indicators (Figure 8-5). In comparing the two goal functions, the priority options for further actions could be reflected along sensitivity of weights obtained from the different approaches.

8.7 Discussions on "eNoP-DHAKA" Tool for Energy-optimization Planning

The developed "eNoP-DHAKA" tool was compiled within a simple computer environment where multiple spreadsheets were grouped under different blocks, such as user input interface, results and compilation panel. The inputs and results are represented in the form of figures, numbers, maps and texts. This tool has great potential for evaluating the level of energy-optimization planning, in particular, urban residential planning and development. The categories, criteria and indicators are selected systematically in consideration of human perceptions about complex urban residential systems. The development process maximizes usability potentials of the international scientific relevance and multi-faced input from experienced local stakeholders as well.

The design tool and methods are represented in simple form and context-specific expert-based results, but provide options for hybrid decision-making as well; thus, it can contribute in limited applications of life cycle-based analysis (Herfray et al., 2006; Khasreen et al., 2009; Stephan et al., 2013), urban metabolism analysis (Kennedy, Pincetl and Bunje, 2011; Mostafavi, Farzinmoghadam and Hoque, 2014), and financial obligation based sustainability rating tools (Sullivan et al., 2014; US-GBC, 2009). Subjectivity is frequently criticized in multi-criteria based decision-making. However, urban planning decisions require subjectivity to describe the human creative process in assessing something in the absence of mathematical procedures (Munandar and Azhari, 2014). In that respect, the proposed "eNoP-DHAKA" tool is justified in allowing human judgment by means of expert opinions and choosing weighting methods from alternatives.

Within the scope of this research, only two developed residential units were included to set base or threshold indicator values. In the future, more investigations should be conducted to obtain precise and standard threshold values. The pair-wise comparison under the AHP approach was considered for weighting schemes, which also need to be improved by reaching a wide range of experts and stakeholders. The simplicity of open source software packages has been extensively used for estimation of indicators, so the development authority may engage related stakeholders and continue developing this tool. The indicators were limited to only physical, social and technical dimensions within broader sustainability goals, offering additional scope for further research and development.

CHAPTER NINE: CONCLUSIONS AND OUTLOOK

9.1 Conclusions

Energy-optimization in urban development has the potential to address local energy concerns and urban climate change challenges. The concept should be developed further in moving towards green economy and energy transitions in the rapidly urbanizing city context. This study adopted an explorative approach to understand the interrelationships of urban structure and energy aspects for leading towards the pathway of energy optimization in urban development. It conducted a spatial analysis of urban building structure and systematic evaluations of the urban planning process, and drafted a simple multi-criteria based decision support tool in the context of Dhaka city. The urban structure parameters were conceptualized and quantified in relation to energy optimization approaches of urban development. The scale of investigation has included both urban and neighborhood level study units.

Cell-based computational methods and spatial analytics were adopted to explore the interrelationships of urban structure and energy consumption. First, the spatial pattern of intensity distribution was explored after estimating of spatial autocorrelation (Moran's I) and distributions of inequality (Gini-coefficient). The result showed that the residential sector had the dominant share in terms of overall mean intensity in urban scale, where mixed-use appeared very small, although it could facilitate energy-efficient urban development. Vertical development had strong clustering, but was uneven due to high-rise building structures located close together. The central business district (CBD) area had a higher residential intensity score that may create a land use conflict. Urban densification had already occurred in Dhaka; the spatial growth pattern showed less CBD dependency and a more polycentric development form. Finally, this study estimated overall density of energy consumption by total floor space (i.e., horizontal and vertical) of urban building structure. The estimation density was analyzed and mapped within the administrative area of Dhaka city corporation (DCC). Residential building floorspace had significant influence on total ECD, due to residential use having the highest share of the total land use. The residential sector was the highest energy consumer in comparison to commercial, service and mixed-use activities. The spatial pattern of ECD was also visualized in a thematic map, where low ECD meant high per capita consumption in less intensified or low degree building structure development. The estimated ECD representation was validated with the spatial population density estimation and reported significant co-relation over the urban space. Apart from spatial analytics, a few additional energy-related parameters were also discussed, such as trends of building age, surface volume ratio, and floor area ratio.

The methodological approach used and the research findings have great potential to explain many urban development and energy aspects. The quantification and visualization of large-scale building structure datasets could help urban decision-makers to formulate better policy and strategies, at least in the context of Dhaka city. For example, the quantified spatial distribution of use patterns and energy consumption density could facilitate urban management and help the development authority to decide "where to allow or encourage what." Furthermore, modeling spatial patterns of urban growth is useful in formulating strategies for energy-optimized mobility strategies, along physical development control.

The energy relations of residential urban structure was explored further after selecting a set of indicators. The well-known eDPSIR framework was adopted for selecting indicators along judgment of local relevance, expert opinion, and scientific merit. In particular, two residential settlement clusters (both private and public-lead development types) were analyzed focusing on urban form, working mobility and resident's lifestyle. The selected indicator set will perform better with the additional collection and availability of related data. Upon this research experience, the physical dimension related indicators are possible to measure with minimum effort; however the social and technical indicators (especially energy aspects) posed major challenges that need to be addressed by urban stakeholders. The indicators were able to be conceptualized, measured and manipulated further with minimum efforts after adaptation of described selection methodology.

The comprehensive urban planning process was discussed in this study in light of efficient resource use and a conceptual framework for energy-optimization urban development planning called the "EnUp" model was developed. The developing country perspective of urban energy optimization is a focus of the "EnUp" model. The challenges/barriers and future efforts needed were identified in the adaptation of system analysis. Urban residential settlement development projects were taken into consideration along energy planning for Dhaka city. The key informant opinion and secondary document suggested that adaptation of the "EnUp" model is both possible and necessary for cities like Dhaka and other cities of developing world.

The results of systematic assessments of residential settlement development directed the design of a framework for a decision tool that can support energy-optimization in urban residential settlement development. The multi-dimensional aspects were addressed in the "eNoP-DHAKA" tool approach. The pre-selected items represented the interrelationships of energy-optimization in urban residential settlement development in Dhaka city. The developed "eNoP-DHAKA" tool was compiled and visualized in a simple computer environment in consideration of human perceptions of a complex urban residential system. The development process maximized usability potentials and human perception along international scientific relevance.

This study has contributed to the scientific discussion of approaches to energy-concerned urbanization, especially in the context of a large city in a developing country. Explorative insights evolved on urban structure, technology integration potential, stakeholder's participation, workable framework and a simple decision support tool for urban professionals. The knowledge can serve as a guide for sustainable urban development for other cities in Bangladesh, where current challenges and barriers that need to be addressed beforehand can be considered (e.g., governance viewpoint, regulatory efforts and technical requirements).

9.2 Study Limitations and Further Research Scope

The limitations of this research to address many other relevant issues provide the motivation and scope for further investigations. In urban scale analysis, there are criticisms of using cell based methodologies related to define cell-size, aggregation and rendering processes. In this study, the spatial intensity pattern analysis did not explore any time series building information that could be supported to predictive analytics of future urban growth dynamics in Dhaka city and beyond. Similarly, the scenario-based simulation and mapping could provide deeper insights for evaluating urban development decisions.

A polycentric urban structure development pattern was identified in Dhaka city, but no specific type of mobility model (as given in Figure 2-8) can be recommended without further investigations of key parameters. Micro-scale (i.e. household) spatial analysis and modeling can be conducted after down-scaling urban structure and energy related variables. ECD mapping/analysis could also improve further after including actual energy consumption, appliance use, urban climate, real-time data on building components, transportation and resident's behavior (e.g. Pereira and Assis 2013). Nevertheless, cell-based computational techniques were powerful for easy interpretation as well as the storing of spatial information. A high degree of urban building structure density is already evident in Dhaka, but a threshold should be settled in order to avoid land subsidence risk, soil-load bearing vulnerabilities and poor utility services. This may also be relevant for other cities in Bangladesh.

At the neighborhood scale, it is necessary to include more representatives residential study units (i.e., SRCs) so that more robust and standard threshold value can be gathered for each indicator. Most of the indicators are limited only within three dimensions (i.e. structural, social and technical) and with few variables. In that regard, a huge scope remains - for example, building materials have a strong link with energy aspects. During the household based data collection and analysis, only a few energy issues were included, such as electricity (utility function) consumption and CO_2 emission due to working mobility. The lifestyle-related socio-economic issues were also considered from an energy consumption perspective. Other energy consumption activity should be covered from utility (e.g.

natural gas), mobility (e.g. education, shopping, and recreation) and many more. Also, renewable energy resources other than solar PV based-electricity could be estimated. The comprehensive assessment of many more innovative technologies could add value for conceptualizing local state of a renewable urban future. Further applied research could initiate a web based platform within the goal of sensitizing energy-concerned urban development and renewable energy matters. There could be opportunity to integrate innovative multi-sourced information and smart technologies. It would be helpful to develop guidelines and a user manual (e.g. Chakraborty et al. 2015) for urban professionals on energy optimization planning in use of traditional data source and open materials.

The "EnUp" model could also be tested for the energy-optimization in retrofitting of existing urban built areas or industrial/business areas. However, one must critically analyze the state of local urban planning and the energy context beforehand, as there may be both similar challenges and differences regarding the types of future needs. Local investigations and detailed guidelines are necessary for implementing energy optimization in urban development planning. The components of the "EnUp" model could be explained further along concrete methods and tools for systematic planning and alternative decision making. The future research and development of the "EnUp" model also should consider the emerging topic of vulnerability and resilience of urban systems in general and energy system in particular at the community level.

The proposed "eNoP-DHAKA" tool until now offers a usability for evaluating an existing residential settlement cluster but could be extended for a new settlement assessment. The tool was drafted with a set of indicators that were selected by following a systematic process and considering local context of energy optimization in urban development; however it was assumed to reflect the local issue of significant implementation of energy-optimization goals in the urban planning process. These indicators need to be validated further in relation to the "EnUp" model by including more case studies. This study acknowledges the limitation regarding the discussion of energy optimization from an evolutionary and linear programming perspective.

Last, but not the least, the rapid adoption of energy optimization in urban development can contribute to reduce energy vulnerability and enhance resilience in general. The evolving research methodology would be helpful in exploring multiple dimensions within the local context of energy optimization in urban development and could contribute towards local Sustainable Development Goals (SDGs), as well as larger global issues in a more comprehensive way. The results of this study contribute to the research field by better conceptualizing, documenting and visualizing the possibility of a comprehensive urban planning and energy planning process in big cities of developing countries and useful insights to policy makers, researchers, professionals, developers, urban stakeholders, interested in transition to urban sustainability.

REFERENCES

Ahamad, M.G. & Islam, N.A.K.M., 2011. Electricity Consumption and Economic Growth Nexus in Bangladesh: Revisited Evidences. *Energy Policy*, 39(10), pp.6145–6150. Available at: http://dx.doi.org/10.1016/j.enpol.2011.07.014.

Ahmad, S.J., Bramley, G. & Dewan, A.M., 2012. Exploratory growth analysis of a megacity through different spatial metrics: A case study on Dhaka, Bangladesh (1960–2005). *Journal of the Urban and Regional Information Systems Association, URISA*, 24(1), pp.9–24. Available at: http://www.urisa.org/urisajournal.

Ahmed, B. & Ahmed, R., 2012. Modeling Urban Land Cover Growth Dynamics Using Multi‐Temporal Satellite Images: A Case Study of Dhaka, Bangladesh. *ISPRS International Journal of Geo-Information*, 1(1), pp.3–31. Available at: http://www.mdpi.com/2220-9964/1/1/3/htm.

Ahsan, T., 2009. *Passive design features for energy-efficient residential buildings in tropical climates : the context of Dhaka , Bangladesh*. Thesis. KTH. Available at: http://www.diva-portal.org/smash/get/diva2:353651/fulltext01.

AILA-IFLA, 2010. *Climate adaptation tools for sustainable settlements (CATSS) report*, Canberra. Available at: http://www.aila.org.au/climate/catss/docs/IFLA_AILA-CATSS-Report.pdf.

Alam, M.J., 2014. "The organized encroachment of land developers"—Effects on urban flood management in greater Dhaka, Bangladesh. *Sustainable Cities and Society*, 10, pp.49–58. Available at: http://doi.org/10.1016/j.scs.2013.05.006.

Ali, H.H. & Al Nsairat, S.F., 2009. Developing a Green Building Assessment Tool for Developing Countries – Case of Jordan. *Building and Environment*, 44(5), pp.1053–1064. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132308001868 [Accessed January 20, 2014].

Amado, M. & Poggi, F., 2014a. Solar Energy Integration in Urban Planning: GUUD Model. *Energy Procedia*, 50, pp.277–284. Available at: http://dx.doi.org/10.1016/j.egypro.2014.06.034.

Amado, M. & Poggi, F., 2014b. Solar Urban Planning: A Parametric Approach. *Energy Procedia*, 48, pp.1539–1548. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610214004366 [Accessed April 4, 2014].

Amado, M. & Poggi, F., 2012. Towards Solar Urban Planning: A New Step for Better Energy Performance. *Energy Procedia*, 30, pp.1261–1273. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610212016554 [Accessed July 8, 2013].

Anas, A., Arnott, R. & Small, K.A., 1998. Urban spatial structure. *Journal of Economic literature*, 36(3), pp.1426–1464.

Ansary, A.M. EL & Shalaby, M.F., 2014. Evolutionary Optimization Technique for Site Layout Planning. *Sustainable Cities and Society*, 11, pp.48–55. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2210670713000760.

Anselin, L., 1995. Local Indicators of Spatial Association — LISA. *Geographical Analysis*, 27(2), pp.93–115. Available at: https://www.uni-kassel.de/fb07/fileadmin/datas/fb07/5-Institute/IVWL/Kosfeld/publikationen/LISA.pdf.

APA, 2015. What is Planning? , pp.0–1. Available at: https://www.planning.org/aboutplanning/whatisplanning.htm [Accessed December 18, 2015].

Arsanjani, J.J. et al., 2012. Integration of Logistic Regression, Markov Chain and Cellular Automata Models to Simulate Urban Expansion. *Int. J. Appl. Earth Observ. Geoinf.* Available at: http://dx.doi.org/10.1016/j.jag.2011.12.014.

Batty, M., 2009. Urban modeling. *International Encyclopedia of Human Geography*, pp.51–58. Available at: http://www.casa.ucl.ac.uk/rits/BATTY-Urban-Modelling-2009.pdf.

BBS, 2010. Area, population, household and household characteristics. In *Statistical Yearbook of Bangladesh 2010*. Dhaka, pp. 29–65.

BBS, 2011. *Population & housing census 2011:Preliminary results*, Dhaka.

Becker, T. & Boschert, S., 2013. Complex urban simulations and sustainable urban planning with spatial and social implications. In *ISPRS 8th 3D GeoInfo Conference & WG II*. pp. 27–29. Available at: http://bit.ly/2syYSZD [Accessed September 18, 2014].

Beeck, N., 2003. *A New Decision Support Method for Local Energy Planning*. Tilburg University.

Besussi, E., Chin, N. & Longley, P., 2006. The Structure and Form of Urban Settlements. In *Remote Sensing of Urban and Suburban Areas*. pp. 13–31. Available at: http://discovery.ucl.ac.uk/56130/.

Blanford, G., 2009. *International Emissions Scenarios : The Role of Developing Country Participation Environment*, San Diego, CA.

Boussauw, K. & Witlox, F., 2009. Introducing a commute-energy performance index for Flanders. *Transportation Research Part A: Policy and Practice*, 43(5), pp.580–591. Available at: http://dx.doi.org/10.1016/j.tra.2009.02.005.

Breheny, M.J. & Gordon, I.R., 1997. Urban densities, travel behaviour and the limits to planning. In *Sustainable Buildings*.

Breiman, L., 1996. Bagging predictors. *Machine Learning*, 24(421), pp.123–140. Available at: https://link.springer.com/article/10.1007/BF00058655.

Butler, J., Jia, J. & Dyer, J., 1997. Simulation Techniques for the Sensitivity Analysis of Multi-criteria Decision Models. *European Journal of Operational Research*, 103(3), pp.531–546.

Byrne, D., 2003. Complexity Theory and Planning Theory: A Necessary Encounter. *Planning Theory*, 2(3), pp.171–178. Available at: http://plt.sagepub.com/cgi/doi/10.1177/147309520323002 [Accessed October 21, 2014].

Cerreta, M. & De Toro, P., 2012. Urbanization Suitability Maps: A Dynamic Spatial Decision Support System for Sustainable Land Use. *Earth System Dynamics*, 3(2), pp.157–171. Available at: http://www.earth-syst-dynam.net/3/157/2012/ [Accessed February 26, 2014].

Chakraborty, A. et al., 2015. Open Data for Informal Settlements: Toward a User's Guide for Urban Managers and Planners. *Journal of Urban Management*, 4(2), pp.74–91. Available at: http://www.sciencedirect.com/science/article/pii/S2226585615000229.

Chatterjee, A. & Venigalla, M.M., 2004. Travel Demand Forcasting for Urban Transportation. In Myer Kutz, ed. *Handbook of Transportation Engineering*. McGraw-Hill.

Chen, H.-P., 1996. The simulation of a proposed nonlinear dynamic urban growth model. *Annals of Regional Science*, 30(3), p.305. Available at: https://link.springer.com/article/10.1007/BF01580524.

Chen, Y., 2010. A new model of urban population density indicating latent fractal structure. *International Journal of Urban Sustainable Development*, 1(1–2), pp.89–110. Available at: http://www.tandfonline.com/doi/abs/10.1080/19463131003661025.

Cheng, V. & Steemers, K., 2006. Urban Form, Density and Solar Potential. In *PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture*. Geneva, pp. 6–8. Available at: http://www.usp.br/fau/cursos/graduacao/arq_urbanismo/disciplinas/aut0221/Material_de_Apoio/Cidades/Cheng_Plea2006_Solar_Density.pdf [Accessed April 29, 2014].

Choguill, C.L., 2008. Developing Sustainable Neighbourhoods. *Habitat International*, 32(1), pp.41–48. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0197397507000379 [Accessed February 25, 2014].

Christensen, C. & Horowitz, S., 2008. Orienting the Neighborhood : A Subdivision Energy Analysis Tool Preprint. In *ACEEE Summer Study on Energy Efficiency in Buildings*.

Cinelli, M., Coles, S.R. & Kirwan, K., 2014. Analysis of the Potentials of Multi Criteria Decision Analysis Methods to Conduct Sustainability Assessment. *Ecological Indicators*, 46, pp.138–148. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X14002647 [Accessed July 28, 2014].

Compagnon, R., 2004. Solar and Daylight Availability in the Urban Fabric. *Energy and Buildings*, 36(4), pp.321–328. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778804000398 [Accessed March 26, 2014].

Cordonnier, T. & Kunstler, G., 2015. The Gini Index Brings Asymmetric Competition to Light. *Perspectives in Plant Ecology, Evolution and Systematics*, 17(2), pp.107–115. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1433831915000104.

Crooks, A.T., 2010. Constructing and implementing an agent-based model of residential segregation through vector GIS. *International Journal of Geographical Information Science*, 24(5), pp.661–675. Available at: http://dx.doi.org/10.1080/13658810903569572.

Damm, M., 2009. *Mapping Social-Ecological Vulnerability to Flooding- A sub-national approach for Germany*. University of Bonn, Germany. Available at: http://hss.ulb.uni-bonn.de/2010/1997/1997.pdf.

Daniell, K. et al., 2005. Integrated Urban System Modelling : Methodology and Case Study Using Multi-agent Systems. In *International Congress on Modelling and Simulation*. pp. 2026–2032. Available at: http://www.mssanz.org.au/modsim05/papers/daniell.pdf.

DESCO, 2012. *Annual Report 2012*, Dhaka. Available at: https://www.desco.org.bd/uploads/attachments/Annual_Report_2012_reduced.pdf.

Dienst, C. et al., 2013. On Track to Become a Low Carbon Future City? First Findings of the Integrated Status Quo and Trends Assessment of the Pilot City of Wuxi in China. *Sustainability*, 5(8), pp.3224–3243. Available at: http://www.mdpi.com/2071-1050/5/8/3224/ [Accessed October 30, 2014].

Dobbelsteen, P.A. Van Den, Keeffe, P.G. & Tillie, N., 2012. Cities Ready for Energy Cisis–Building Urban Energy Resilience. In *4th CIB International Coference on Smart and Sustainablle Built Environment*.

Duvarci, Y. & Kutluca, A.K., 2008. Appraisal of energy efficiency of urban development plans : The Fidelity concept on Iymir-Balcova case. *International Scholarly and Scientific Research & Innovation*, 2(12), pp.250–266.

EC, 2015. Composite Indicators Research Group (COIN). *European Commission*. Available at: https://composite-indicators.jrc.ec.europa.eu/?q=content/what-composite-indicator [Accessed February 25, 2015].

EC, 2004. Thematic Strategy on the Urban Environment (COM(2004)60). *Thematic Strategy on the Urban Environment*. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52005DC0718 [Accessed January 1, 2014].

Eddy, D.M. et al., 2012. Model Transparency and Validation: A Report of the ISPOR-SMDM Modeling Good Research Practices Task Force-7. *Value in Health*, 15(6), pp.843–850.

EnergyAgency.NRW, 2008. *Planungsleitfaden. 50 Solarsiedlungen in Nordrhein-Westfalen*, Düsseldorf.

EnergyCity, 2013. *Urban Energy Models - Action Report*, Budapest. Available at: http://www.energycity2013.eu/pages/contact.php.

EU, 2014. *Energy Solutions for Smart Cities and Communities Sustainable Energy Solutions for communities in countries*, Stuttgart. Available at: http://smartcities-infosystem.eu/sites/default/files/concerto_files/concerto_publications/2014-03_concerto-premium_lessons-learnt_sez_en.pdf.

Ewing, R. & Rong, F., 2008. The impact of urban Form on U.S. residential energy use. *Housing Policy Debate*, 19(1), pp.1–30. Available at: http://dx.doi.org/10.1080/10511482.2008.9521624.

FFG, 2009. *Neue Energien 2020: ELAS-Endbericht Arbeitspaket 1*, Wien.

Fischler, R., 2012. Fifty theses on urban planning and urban Planners. *Journal of Planning Education and Research*, 32(1), pp.107–114. Available at: http://jpe.sagepub.com/cgi/doi/10.1177/0739456X11420441 [Accessed October 8, 2014].

Freestone, R., 2000. *Urban Planning in a Changing World: the twentieth century experience*,

Geertman, S. & Stillwell, J. eds., 2009. *Planning Information Systems Best Practice and New Methods* Volume 95., Springer Netherlands.

González, A. et al., 2013. A Decision-support System for Sustainable Urban Metabolism in Europe. *Environmental Impact Assessment Review*, 38, pp.109–119. Available at: http://linkinghub.elsevier.com/retrieve/pii/S019592551200056X [Accessed July 29, 2014].

Government of Bangladesh (GoB), 2008. *Renewable Energy Policy of Bangladesh*, Bangladesh. Available at: http://www.powerdivision.gov.bd/pdf/REP_English.pdf.

Griffith, D. a, 2003. *Spatial Autocorrelation and Spatial Filtering*, Springer. Available at: http://link.springer.com/10.1007/978-3-540-24806-4.

Groves-Kirkby, C.J., Denman, a. R. & Phillips, P.S., 2009. Lorenz Curve and Gini Coefficient: Novel Tools for Analysing Seasonal Variation of Environmental Radon gas. *Journal of Environmental Management*, 90(8), pp.2480–2487. Available at: http://dx.doi.org/10.1016/j.jenvman.2009.01.003.

Gudipudi, R. et al., 2016. City density and CO2 efficiency. *Energy Policy*, 91, pp.352–361. Available at: http://doi.org/10.1016/j.enpol.2016.01.015.

Hachem, C., Athienitis, A. & Fazio, P., 2012. Evaluation of Energy Supply and Demand in Solar Neighborhood. *Energy and Buildings*, 49, pp.335–347. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778812000989 [Accessed March 21, 2014].

Hachem, C., Fazio, P. & Athienitis, A., 2013. Solar optimized residential neighborhoods: Evaluation and design methodology. *Solar Energy*, 95, pp.42–64. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0038092X13002211 [Accessed January 21, 2014].

Hamedani, A.Z. & Huber, F., 2012. *A Comparative Study of " DGNB " Certificate System in Urban Sustainability*, Wuppertal.

Harmeling, S., 2011. Global Climate Risk Index, 2012. *Human Development*. Available at: www.germanwatch.org/cri [Accessed October 15, 2012].

Hassan, A. et al., 2012. Electricity Challenge for Sustainable Future in Bangladesh. *APCBEE Procedia*, 1(January), pp.346–350. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2212670812000589 [Accessed April 3, 2014].

Herfray, G., Vorger, E. & Peuportier, B., 2006. *Life Cycle Assessment Applied to Urban Settlements and Urban Morphology Studies*,

Hossain, S., 2008. Rapid Urban Growth and Poverty in Dhaka City. *Bangladesh e-Journal of Sociology*, 5(1), pp.1–24.

Huang, J., Lu, X.X. & Sellers, J.M., 2007. A global comparative analysis of urban form: Applying spatial metrics and remote sensing. *Landscape and Urban Planning*, 82(4), pp.184–197.

Huang, Z. et al., 2015. Methods and tools for community energy planning: A Review. *Renewable and Sustainable Energy Reviews*, 42(4800), pp.1335–1348. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032114009733.

Huang, Z. & Yu, H., 2014. Approach for Integrated Optimization of Community Heating System at Urban Detailed Planning Stage. *Energy and Buildings*, 77, pp.103–111. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778814002655.

IEA, 2009. *Cities , Towns & Renewable Energy Yes In My Front Yard Cities , towns & Renewable*,

IEA, 2008. *World energy outlook*, Paris. Available at: http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf.

IGBC, 2010. IGBC Green Townships (For Townships and Large Developments). , (November).

Institute for Building Efficiency, 2013. Green Building Rating Systems : Bangladesh. *Fact Sheet/September 2013*, (September). Available at: http://www.institutebe.com/.

IPCC, 2007. *Climate change 2007, Mitigation of climate change*, Cambridge. Available at: http://soilcarboncenter.k-state.edu/originals/IPCC_WGIII_basicpresentation.pdf [Accessed October 9, 2014].

Islam, I. et al., 2009. An Analysis of Spatial Structure of Dhaka : Associated Problems and Issues.

Islam, M. & Ahmed, R., 2011. Land use change prediction in Dhaka city using GIS aided Markov chain modeling. *Journal of Life and Earth Science*, 6, pp.81–89. Available at: http://dx.doi.org/10.3329/jles.v6i0.9726.

Islam, M.T. et al., 2014. Current Energy Scenario and Future Prospect of Renewable Energy in Bangladesh. *Renewable and Sustainable Energy Reviews*, 39, pp.1074–1088. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032114006017 [Accessed August 19, 2014].

Jong, M. De et al., 2015. Sustainable-Smart-Resilient-Low-Carbon-Eco-Knowledge Cities; Making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, p.24. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.02.004.

Kabir, A. & Parolin, B., 2012. Planning and development of Dhaka - A story of 400 years. In *15th International Planning History Society Conference*. Sao Paulo, Brazil, pp. 1–20. Available at: http://bit.ly/2oZCBCR.

Kabir, M.H., Endlicher, W. & Jägermeyr, J., 2010. Calculation of Bright Roof-tops for Solar PV Applications in Dhaka Megacity, Bangladesh. *Renewable Energy*, 35(8), pp.1760–1764. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0960148109004923 [Accessed April 3, 2014].

Kanters, J. & Horvat, M., 2012. Solar Energy as a Design Parameter in Urban Planning. *Energy Procedia*, 30, pp.1143–1152. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610212016438 [Accessed March 31, 2014].

Kanters, J., Wall, M. & Kjellsson, E., 2014. The Solar Map as a Knowledge Base for Solar Energy Use. *Energy Procedia*, 48, pp.1597–1606. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610214004421 [Accessed July 18, 2014].

Kavaarpuo, G., 2014. *Transitions in urban energy systems : Role of urban planning in the Wa Municipality, Ghana*. University of Duesburg-Essen, Germany.

Keele, L., 2008. *Semiparametric Regression for the Social Sciences*, England: Wiley.

Keirstead, J., 2007. Selecting sustainability indicators for urban energy systems. In J. (Eds) Horner, M., Hardcastle, C. , Price, A. , Bebbington, ed. *International conference on whole life urban sustainabity and its assesment*. Glasgow.

Keirstead, J., Samsatli, N. & Shah, N., 2009. SynCity: an Integrated Tool Kit for Urban Energy Systems Modelling. In *Proceedings of the 5th Urban Research Symposium*. Marseille: World Bank. Available at: www.urs2009.net.

Kennedy, C., Pincetl, S. & Bunje, P., 2011. The Study of Urban Metabolism and its Applications to Urban Planning and Design. *Environmental pollution (Barking, Essex : 1987)*, 159(8–9), pp.1965–73. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21084139 [Accessed July 13, 2014].

Khasreen, M.M., Banfill, P.F.G. & Menzies, G.F., 2009. Life-Cycle Assessment and the Environmental Impact of Buildings: A Review. *Sustainability*, 1(3), pp.674–701. Available at: http://www.mdpi.com/2071-1050/1/3/674/ [Accessed March 24, 2014].

Khatun, H., Falgunee, N. & Kutub, J.R., 2015. Analyzing urban population density gradient of Dhaka metropolitan area using geographic information systems (GIS) and census data. , 13(13), pp.1–13. Available at: http://bit.ly/2pWnMOI.

Knigge, L. & Cope, M., 2006. Grounded Visualization: Integrating the Analysis of Qualitative and Quantitative Data Through Grounded Theory and Visualization. *Environment and Planning A*, 38(11), pp.2021–2037. Available at: http://www.envplan.com/abstract.cgi?id=a37327 [Accessed October 20, 2014].

Ko, Y., 2013. Urban Form and Residential Energy Use: A Review of Design Principles and Research Findings. *Journal of Planning Literature*, 28(June), pp.327–351. Available at: http://jpl.sagepub.com/cgi/doi/10.1177/0885412213491499.

Koetter, T., Wiess, D. & Asadzadeh, A., 2016. City-Stress test - How to Live and Plan with New Risk. In *6th International Disaster and Risk Conference IDRC Davos 2016*. Davos, Switzerland.

Košir, M. et al., 2014. Solar potential in existing urban layouts—Critical overview of the existing building stock in Slovenian Context. *Energy Policy*, 69, pp.443–456. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421514000846 [Accessed August 14, 2014].

Kötter, P.T., 2004. Risks and Opportunities of Urbanisation and Megacities. In *FIG Working Week 2004*. Athens, Greece.

Kötter, T., Schetke, S. & Frielinghaus, B., 2008. Assessment of Sustainable Land Use within the Town Planning Process. In *Integrating Generations*. Stockholm, Sweden: International Federation of Surveyors (FIG) Working Week 2008.

Kushol, S.A.S. et al., 2013. Effect of Street Morphology on Microclimate in Residential Areas Following FAR Rule in Dhaka City. In *PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future*. Munich.

Labib, S.M., Mohiuddin, H. & Shakil, S.H., 2013. Transport Sustainability of Dhaka : A Measure of Ecological Footprint and Means for Sustainable Transportation System. *Journal of Bangladesh Institute of Planners*, 6(December), pp.137–147.

Larondelle, N. et al., 2014. Applying a novel urban structure slassification to compare the relationships of urban structure and surface temperature in Berlin and New York City. *Applied Geography*, 53, pp.427–437. Available at: http://doi.org/10.1016/j.apgeog.2014.07.004.

Lee, Y.-J. & Huang, C.-M., 2007. Sustainability index for Taipei. *Environmental Impact Assessment Review*, 27(6), pp.505–521. Available at: http://linkinghub.elsevier.com/retrieve/pii/S019592550600151X.

Lefèvre, B., 2010. Urban transport energy consumption: Determinants and strategies for its reduction. An analysis of the literature. *S.A.P.I.EN.S*, Vol.2/n°3(2.3 (2009)). Available at: http://sapiens.revues.org/914.

Lehmann, S., 2012. Can rapid urbanisation ever lead to low carbon cities? The case of Shanghai in comparison to Potsdamer Platz Berlin. *Sustainable Cities and Society*, 3, pp.1–12. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2210670711000473 [Accessed November 7, 2012].

Lehmann, S. et al., 2013. Supporting urban planning of low-carbon precincts: Integrated demand forecasting. *Sustainability*, 5(12), pp.5289–5318.

Luederitz, C., Lang, D.J. & Von Wehrden, H., 2013. A systematic review of guiding principles for sustainable urban neighborhood development. *Landscape and Urban Planning*, 118, pp.40–52. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169204613001102 [Accessed January 20, 2014].

Madlener, R. & Sunak, Y., 2011. Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management? *Sustainable Cities and Society*, 1(1), pp.45–53.

Mahmud, A., 2006. *Management of Growth and Planned Development of Dhaka City : The Necessity of Proper Enforcement of Planning Standards*,

Manfren, M., Caputo, P. & Costa, G., 2011. Paradigm shift in urban energy systems through distributed generation: Methods and Models. *Applied Energy*, 88(4), pp.1032–1048. Available at: http://dx.doi.org/10.1016/j.apenergy.2010.10.018.

Marique, A.-F. & Reiter, S., 2012. A Method for Evaluating Transport Energy Consumption in Suburban Areas. *Environmental Impact Assessment Review*, 33(1), pp.1–6. Available at: http://dx.doi.org/10.1016/j.eiar.2011.09.001.

Marique, A.-F. & Reiter, S., 2014. A simplified framework to assess the feasibility of Zero-energy at the Neighbourhood/Community scale. *Energy and Buildings*, 82, pp.114–122. Available at: http://doi.org/10.1016/j.enbuild.2014.07.006.

Marszal, a. J. et al., 2011. Zero energy building - A review of definitions and calculation methodologies. *Energy and Buildings*, 43(4), pp.971–979. Available at: http://dx.doi.org/10.1016/j.enbuild.2010.12.022.

Martins, T.A.L., Adolphe, L. & E.G. Bastos, L., 2014. From Solar Constraints to Urban Design Opportunities: Optimization of Built form Typologies in a Brazilian Tropical City. *Energy and Buildings*, 76, pp.43–56. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778814001704 [Accessed March 26, 2014].

Masum, F., 2009. *Land Management Actors and Processes Behind Urban Fringe Development : Mechanism to Guide Urban Land Management . Study on Dhaka , Bangladesh*. TECHNISCHE UNIVERSITÄT MÜNCHEN. Available at: http://d-nb.info/995057648/34.

Mindali, O., Raveh, A. & Salomon, I., 2004. Urban density and energy consumption: a new look at old statistics. *Transportation Research Part A: Policy and Practice*, 38(2), pp.143–162. Available at: http://doi.org/10.1016/j.tra.2003.10.004.

Mirakyan, A. & De Guio, R., 2013. Integrated Energy Planning in Cities and Territories: A Review of Methods and Tools. *Renewable and Sustainable Energy Reviews*, 22, pp.289–297. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032113000646 [Accessed September 5, 2014].

Moffatt, S., Suzuki, H. & Liyuka, R., 2012. *Eco2 Cities Guide: Ecological Cities as Economic Cities*, Washington D.C.

Mohanty, B., 2012. *Sustainable Urban Energy- A Source Book for Asia* B. Barth, F. Cabrera, & R. Rollnick, eds., Nairobi, Kenya: United Nations Human Settlements Programme (UN HABITAT).

Mostafavi, N., Farzinmoghadam, M. & Hoque, S., 2014. A framework for Integrated Urban Metabolism Analysis Tool (IUMAT). *Building and Environment*, (0), p. Available at: http://www.sciencedirect.com/science/article/pii/S0360132314003412.

Müller, B. ed., 2010. *Urban Regional Resilience: How Do Cities and Regions Deal with Change?*, Dresden: Springer.

Munandar, T.A. & Azhari, S., 2014. Comparative Study Of Decision Making Techniques For Multi-Attribute Decision Making Problems. *International Journal of Advanced Research in Computer Science*, 5(5), pp.122–126.

Nahrin, K., 2008. Violation of Land Use Plan and Its Impact on Community Life in Dhaka City. *Jahangirnagar Planning Review*, 6(June), pp.39–48.

Ness, B. et al., 2007. Categorising tools for sustainability assessment. *Ecological Economics*, 60(3), pp.498–508. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800906003636 [Accessed February 19, 2014].

Newton, P. & Bai, X., 2008. Transitioning to sustainable urban development. In P. Newton, ed. *Transitons*. Springer Netherlands, pp. 3–19. Available at: http://books.google.com/books?hl=en&lr=&id=c47nD1k_efgC&oi=fnd&pg=PA3&dq=Transitioning+to+Sustainable+Urban+Development&ots=Q6HghIcl-i&sig=akk6VpK8PvbchJ8yu2flgK7_SDY [Accessed March 28, 2014].

Nguyen, B.K. & Altan, H., 2011. Comparative Review of Five Sustainable Rating Systems. *Procedia Engineering*, 21(0), pp.376–386. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1877705811048636 [Accessed February 19, 2014].

Niemeijer, D. & Groot, R.S., 2008. Framing Environmental Indicators: Moving from Causal Chains to Causal Networks. *Environment, Development and Sustainability*, 10(1), pp.89–106. Available at: http://link.springer.com/10.1007/s10668-006-9040-9 [Accessed July 19, 2014].

Niemeijer, D. & de Groot, R.S., 2008. A conceptual framework for selecting environmental indicator sets. *Ecological Indicators*, 8(1), pp.14–25. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X07000040 [Accessed April 30, 2014].

Nilufar, P.F., 2010. Urban Morphology of Dhaka City : Spatial Dynamics of Growing City and the Urban Core. In *International Seminar on the Celebration of 400 Years of the Capital Dhaka*. Dhaka: Asiatic Society, pp. 1–19.

Norman, J. et al., 2006. Comparing High and Low Residential Density : Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions. , (March), pp.10–21.

O'Brien, W.T. et al., 2010. The relationship between net energy use and the urban density of solar buildings. *Environment and Planning B: Planning and Design*, 37(6), pp.1002–1021. Available at: http://epb.sagepub.com/lookup/doi/10.1068/b36030.

OECD, 2011. *Effective Modelling of Urban Systems to Address the Challenges of Climate Change and Sustainability*, Available at: https://www.oecd.org/sti/sci-tech/49352636.pdf.

OECD, 2003. *Environmental Indicators: development, measurement and use*, Paris. Available at: https://www.oecd.org/env/indicators-modelling-outlooks/24993546.pdf.

OECD/IEA, 2012. IEA Statistics. Available at: http://www.iea.org/statistics/ [Accessed March 20, 2015].

Offer, G., Meah, N. & Coke, A., 2011. *Energy in Developing Economies : A 2050 Approach Enabling a Transition to Low Carbon Economies in Developing Countries Case Study : Bangladesh*, Available at: https://www.imperial.ac.uk/energy-futures-lab/research/our-projects/reports--briefing-papers/low-carbon-economies/.

Owens, S., 1985. Energy demand: links to land-use and forward planning. *Built Environment*, 11(1), pp.33–44. Available at: http://www.jstor.org/stable/23286101.

Parveen, R., 2012. Potentiality of energy-plus urban developments in developing countries . Case study : Dhaka , Bangladesh. In *Annual conference of ANZAScA*. The Architectural Science Association (ANZAScA). Available at: http://anzasca.net/wp-content/uploads/2014/08/p601.pdf.

Peker, Z., 2005. *Intregrating Renewable Energy Technology Technologies into Cities Through Urban Planning : In the Case of Geotherman and Wind Energy*. Izmir Institute of Technology.

Pereira, I.M. & Assis, E.S. de, 2013. Urban energy consumption mapping for energy management. *Energy Policy*, 59, pp.257–269. Available at: http://dx.doi.org/10.1016/j.enpol.2013.03.024.

Perez, P. & Batten, D.F., 2006. Sustainability Assessment of Housing Developments: A New Methodology. In *Complex Science for a Complex World: Exploring Human Ecosystems with Agents*. pp. 1–10.

Prasannakumar, V. et al., 2011. Spatio-temporal Clustering of Road Accidents: GIS Based Analysis and Assessment. *Procedia - Social and Behavioral Sciences*, 21, pp.317–325. Available at: http://dx.doi.org/10.1016/j.sbspro.2011.07.020.

Qureshi, S. & Haase, D., 2014. Compact, eco-, Hybrid or Teleconnected? Novel aspects of urban ecological research seeking compatible solutions to socio-ecological complexities. *Ecological Indicators*, 42, pp.1–5. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X14001472 [Accessed August 14, 2014].

Rad, F., 2010. Application of Local Energy Indicators in Municipal Energy Planning: A New Approach Towards Sustainability. In *ACEEE Summer Study on Energy Effcient Buildings*. pp. 48–59. Available at: http://www.ees.energy.lth.se/fileadmin/ees/Publikationer/2010/ACEEE-2010-FDR.pdf [Accessed October 10, 2014].

Rahman, M.S.-U., Timms, P. & Montgomery, F., 2012. Integrating BRT systems with Rickshaws in developing cities to promote energy efficient travel. *Procedia - Social and Behavioral Sciences*, 54, pp.261–274. Available at: https://doi.org/10.1016/j.sbspro.2012.09.745.

Rahman, S., 2008. *Understanding the Linkages of Travel Behavior with Socioeconomic Characteristics and Spatial Environments in Dhaka City and Urban Transport Policy Applications*. Hiroshima University.

Raja, D.R., 2012. Spatial analysis of land surface temperature in Dhaka metropolitan area. *Journal of Bangladesh Institute of Planners*, 5(December). Available at: http://www.bip.org.bd/SharingFiles/journal_book/20130804140304.pdf.

Reed, M.S., Fraser, E.D.G. & Dougill, A.J., 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. *Ecological Economics*, 59(4), pp.406–418. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921800905005161 [Accessed March 20, 2014].

REHAB, 2012. *A Comprehensive Study on the Real Estate Sector of Bangladesh*, Dhaka.

Reiter, S. & Marique, A.-F., 1997. Toward low energy cities. *Journal of Industrial Ecology*, 16(6), pp.829–838. Available at: http://doi.wiley.com/10.1111/j.1530-9290.2012.00533.x [Accessed May 7, 2013].

REN21, 2013. *Renewables Global Futures Report 2013*, Paris. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:RenewableS+GLOBAL+FUTURES+REPORT+2013#1 [Accessed October 30, 2014].

REN21, 2014. RENEWABLES INTERACTIVE MAP SEARCH RESULTS. , pp.1–28.

Riera Pérez, M.G. & Rey, E., 2013. A Multi-criteria Approach to Compare Urban Renewal Scenarios for an Existing Neighborhood. Case Study in Lausanne (Switzerland). *Building and Environment*, 65, pp.58–70. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132313000978 [Accessed April 3, 2014].

Roorda, C. et al., 2012. Systems analysis for urban sustainability transitions a joint understanding of complexity and dynamics. In *3rd International Urban Research Symposium Belo Horizonte*. Brazil.

Roy, M., 2009. Planning for sustainable urbanisation in fast growing cities: Mitigation and adaptation issues addressed in Dhaka, Bangladesh. *Habitat International*, 33(3), pp.276–286. Available at: http://dx.doi.org/10.1016/j.habitatint.2008.10.022.

Ruth, M. & Coelho, D., 2007. Understanding and managing the complexity of urban systems under climate change. *Climate Policy*, 7(4), pp.317–336.

Saha, D.C., 2011. *Quantification of urban land use intensity: A case of Dhaka city of Bangladesh*. Munster: Thesis, University of Munster, Germany. Available at: http://hdl.handle.net/10362/8266.

Santos, T. et al., 2014. Applications of Solar Mapping in the Urban Environment. *Applied Geography*, 51, pp.48–57. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0143622814000587 [Accessed July 18, 2014].

Schetke, S., Haase, D. & Kötter, T., 2012. Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning. *Environmental Impact Assessment Review*, 32(1), pp.195–210. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0195925511001016 [Accessed January 24, 2014].

Schubert, J., Wolbring, T. & Gill, B., 2013. Settlement structures and carbon emissions in Germany: The effects of social and physical concentration on carbon emissions in rural and urban residential areas. *Environmental Policy and Governance*, 23, pp.13–29.

Shakil, S.H., Kuhu, N. & Rahman, R., 2012. *Ecological Footprint: A Case Study of Dhanmondi Residential Area*. Bangladesh Universtiy of Engineering.

Sharifi, A. & Murayama, A., 2013. A Critical Review of Seven Selected Neighborhood Sustainability Assessment Tools. *Environmental Impact Assessment Review*, 38, pp.73–87. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0195925512000558 [Accessed January 25, 2014].

Sikder, S.K. et al., 2015. Stakeholders participation for urban climate resilience: A case of informal settlements regularization in Khulna city, Bangladesh. *Journal of Urban and Regional Analysis*, 7(1).

Sikder, S.K. et al., 2016. The contribution of energy-optimized urban planning to efficient resource use-a case study on residential settlement development in Dhaka City, Bangladesh. *Sustainability (Switzerland)*, 8(2).

Sikder, S.K. & Koetter, T., 2015. Urban planning in the age of urban energy transition – What is going on in megacity Dhaka , Bangladesh ? In *From the Wisdom of the Ages to the Challenges of the Modern World*. Sofia, Bulgaria: International Federation of Surveyors (FIG) Working Week 2015. Available at: http://bit.ly/2oqaoSV.

Singh, B. (Bob) et al., 2015. *Sustainable Integrated Urban & Energy Planning , the Evolving Electrical Grid and Urban Energy Transition*, Toronto. Available at: http://bit.ly/2pj84RE.

Singh, R. et al., 2009. An overview of sustainability assessment methodologies. *Ecological Indicators*, 9(2), pp.189–212. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X08000678 [Accessed February 20, 2014].

Stephan, A., Crawford, R.H. & de Myttenaere, K., 2013. Multi-scale life cycle energy analysis of a low-density suburban neighbourhood in Melbourne, Australia. *Building and Environment*, 68, pp.35–49. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132313001819 [Accessed February 1, 2014].

Stevanović, S., 2013. Optimization of Passive Solar Design Strategies: A Review. *Renewable and Sustainable Energy Reviews*, 25, pp.177–196.

Stewart, I.D. & Oke, T.R., 2012. Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, 93(12), pp.1879–1900. Available at: http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-11-00019.1.

Stoeglehner, G. et al., 2014. Sustainability Appraisal of Residential Energy Demand and Supply - a Life Cycle Approach Including Heating, Electricity, Embodied Energy and Mobility. *Energy, Sustainability and Society*, 4(1), p.24. Available at: http://www.energsustainsoc.com/content/4/1/24.

Stoeglehner, G., Niemetz, N. & Kettl, K.-H., 2011. Spatial Dimensions of Sustainable Energy Systems: New Visions for Integrated Spatial and Energy Planning. *Energy, Sustainability and Society*, 1(1), p.2. Available at: http://www.energsustainsoc.com/content/1/1/2.

Strasser, H., 2012. *Challenges on the Way to Energy Optimized Communities Challenges on the Way to Energy Optimized Communities*, Salzburg. Available at: http://www.nachhaltigwirtschaften.at/hdz_pdf/events/20121003_ecbcs_annex51_experts_workshop_2_strasser.pdf.

Sullivan, L., Ridin, Y. & Buchanan, C., 2014. *Neighbourhood Sustainability Frameworks - A Literature Review*, London. Available at: https://www.ucl.ac.uk/usar/cdt/wps/USARWPS01-Sullivan-Neighbourhoods-PDF.

SurveyMonkey, Online Survey Tool. , pp.1–3. Available at: https://de.surveymonkey.com/.

Tanguay, G. a. et al., 2010. Measuring the Sustainability of Cities: An Analysis of the Use of Local Indicators. *Ecological Indicators*, 10(2), pp.407–418. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X09001277 [Accessed July 16, 2014].

Taubenboeck, H. et al., 2009. Urbanization in India - Spatiotemporal Analysis Using Remote Sensing Data. *Computers, Environment and Urban Systems*, 33(3), pp.179–188. Available at: http://dx.doi.org/10.1016/j.compenvurbsys.2008.09.003.

Tereci, A. et al., 2010. The impact of the urban form on building energy demand. In *1st International Graduate Research Symposium on the Built Environment*. Ankara, Turkey: METU, pp. 15–16.

Tobler, W.R., 1970. A Computer Movie Simulation Urban Growth in Detroit Region. *Economic Geography*, 46, pp.234–240.

Todoc, J.L., 2008. Integrating Energy in Urban Planning in the Philippines and Vietnam. In *Urban Energy Transition*. Amsterdam: Elsevier, pp. 507–531. Available at: https://www.econbiz.de/Record/integrating-energy-in-urban-planning-in-the-philippines-and-vietnam-todoc-jessie/10003670565.

UN, 2008. *World urbanization prospects: The 2007 revision*, New York. Available at: http://www.un.org/esa/population/publications/wup2007/2007WUP_ExecSum_web.pdf.

UN, 2014. *World Urbanization Prospects: The 2014 Revision*, New York. Available at: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf.

UN-Habitat & ICLEI, 2009. *Sustainable Urban Energy Planning A Handbook for Cities and Towns*, ICLEI, UN-HABITAT and UNEP.

US-GBC, 2009. LEED 2009 for Neighborhood Development Rating System. , (October 2013).

Vandevyvere, H. & Stremke, S., 2012. Urban Planning for a Renewable Energy Future: Methodological Challenges and Opportunities from a Design Perspective. *Sustainability*, 4(12), pp.1309–1328. Available at: http://www.mdpi.com/2071-1050/4/6/1309 [Accessed June 26, 2013].

Vermeulen, T. et al., 2015. Urban Layout Optimization Framework to Maximize Direct Solar Irradiation. *Computers, Environment and Urban Systems*, 51, pp.1–12. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0198971515000137.

Webster, J., 2007. The Canadian Urban Archetypes Project : A Tool Facilitating the Integration of Energy-related Information into Urban Planning Decision Making. In *43rd ISOCARP Congress 2007*. pp. 1–12. Available at: http://www.isocarp.net/data/case_studies/1087.pdf.

Wei, Y. et al., 2016. An Evaluation Model for Urban Carrying Capacity: A Case Study of China's Mega-Cities. *Habitat International*, 53, pp.87–96. Available at: http://dx.doi.org/10.1016/j.habitatint.2015.10.025.

Wiginton, L.K., Nguyen, H.T. & Pearce, J.M., 2010. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. *Computers, Environment and Urban Systems*, 34(4), pp.345–357. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0198971510000025 [Accessed April 29, 2014].

Wilson, B., 2013. Urban form and residential electricity consumption: Evidence from Illinois, USA. *Landscape and Urban Planning*, 115, pp.62–71.

Wood, S.N., 2006. *Generalized additive models: an introduction with R*, Chapman and Hall/CRC.
Wurm, M., Taubenböck, H. & Dech, S., 2010. Quantification of Urban Structure on Building Block Level Utilizing Multisensoral Remote Sensing Data. In U. Michel & D. L. Civco, eds. *SPIE Europe Remote Sensing 2010*. p. 78310H–78310H–12. Available at: http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=725765.
Yamagata, Y. & Seya, H., 2013. Simulating a Future Smart City: An Integrated Land Use-energy Model. *Applied Energy*, 112, pp.1466–1474. Available at: http://linkinghub.elsevier.com/retrieve/pii/S030626191300072X [Accessed January 23, 2014].
Yeh, A.G.-O. & Li, X., 2002. A Cellular Automata Model to Simulate Development Density for Urban Planning. *Environment and Planning B: Planning and Design*, 29(3), pp.431–450. Available at: http://journals.sagepub.com/doi/10.1068/b1288.
Yeo, I.-A., Yoon, S.-H. & Yee, J.-J., 2013. Development of an environment and energy Geographical Information System (E-GIS) construction model to support environmentally friendly urban planning. *Applied Energy*, 104, pp.723–739. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306261913003619 [Accessed May 22, 2013].
Zanon, B. & Verones, S., 2013. Climate change, urban energy and planning practices: Italian experiences of innovation in land management tools. *Land Use Policy*, 32, pp.343–355. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0264837712002372 [Accessed June 6, 2013].
Zhang, L. et al., 2004. A GIS-based Gradient Analysis of Urban Landscape Pattern of Shanghai Metropolitan Area, China. *Landscape and Urban Planning*, 69(1), pp.1–16.
Zhou, P., Ang, B. & Poh, K., 2006. Decision Analysis in Energy and Environmental Modeling: An Update. *Energy*, 31(14), pp.2604–2622. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360544205002264 [Accessed September 30, 2014].

APPENDIX

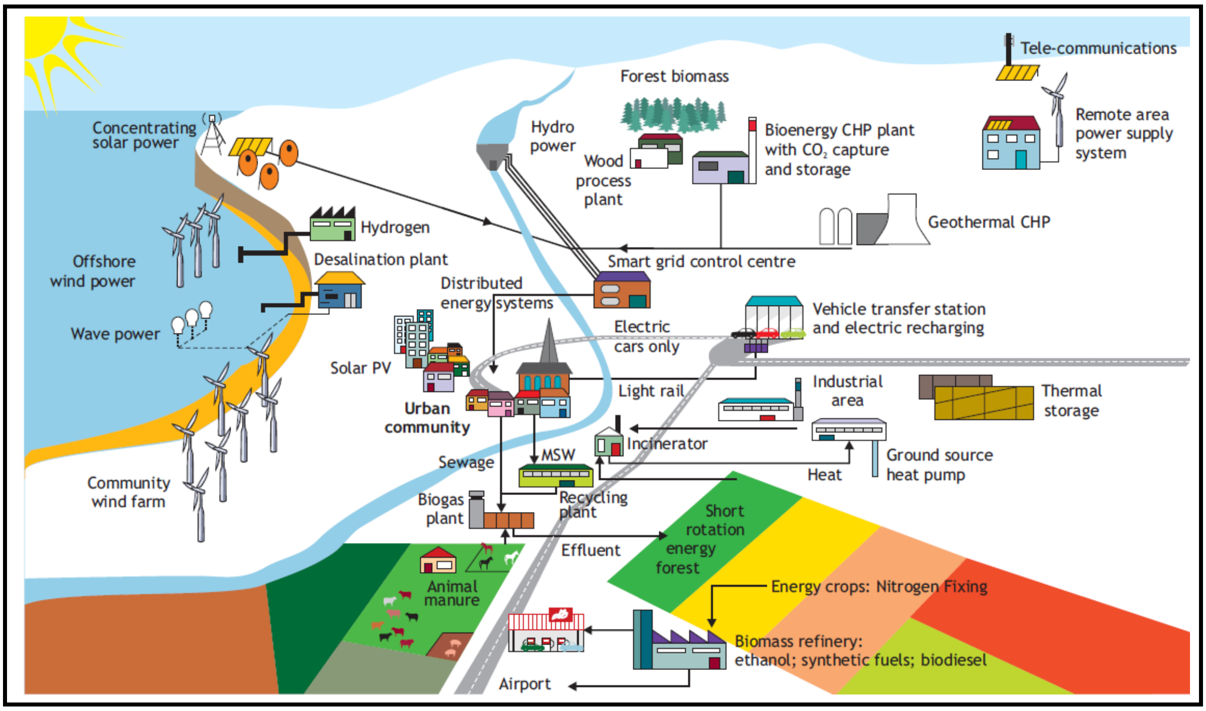
Appendix A:

Table 1: City categories (Single terms) and anarchy in recent literature.

'Eco city' referred to as:	"eco city", "eco-city planning", "eco-city", "sino-singapore tianjin eco-city", "ecopolis (eco-city)", "low-carbon eco-city", "dongtan eco-city", "eco-city index", "u-eco city", "zhong-xin eco-city", "eco-cities", "eco cities under construction", "comparative analyses of eco cities", "chinese eco-cities".
'Sustainable city':	"sustainable city", "sustainable city development", "sustainable city planning", "sustainable city paradigm", "sustainable city plans", "sustainable city management", "sustainable city-building", "sustainable city region", "sustainable cities", "international centre for sustainable cities", "sustainable cities index".
'Smart city':	"smart city", "3d smart city", "amsterdam smart city", "smart city components", "smart city model", "smart city planning and development", "smart city development", "smart cities", "place making smart cities", "smart cities and smart buildings".
'Low Carbon city':	"low carbon city (lcc)", "low carbon city", "shenzhen sino-dutch low carbon city", "low carbon city strategies", "low-carbon city", "low-carbon cities", "healthy and low-carbon cities", "low carbon cities".
'Knowledge city':	"Knowledge city", "most admired knowledge city", "knowledge city index", "knowledge city framework", "knowledge cities", "most admired knowledge cities".
'Intelligent city':	"informative global community development index and intelligent city", "intelligent city", "post intelligent city", "intelligent city-region", "intelligent cities".
'Digital city':	"digital city", "digital city facility", "digital city management system", "digital city planning", "digital cities".
'Ubiquitous city':	"ubiquitous city", "ubiquitous city (u-city) logistics", "ubiquitous city development", "ubiquitous cities".
'Resilient city':	"resilient city-regions", "resilient cities", "disaster resilient cities".
'Green city':	"green city", "low carbon green city", "green cities".
'Information city':	"information city".
'Livable city':	"livable city", "livable cities"

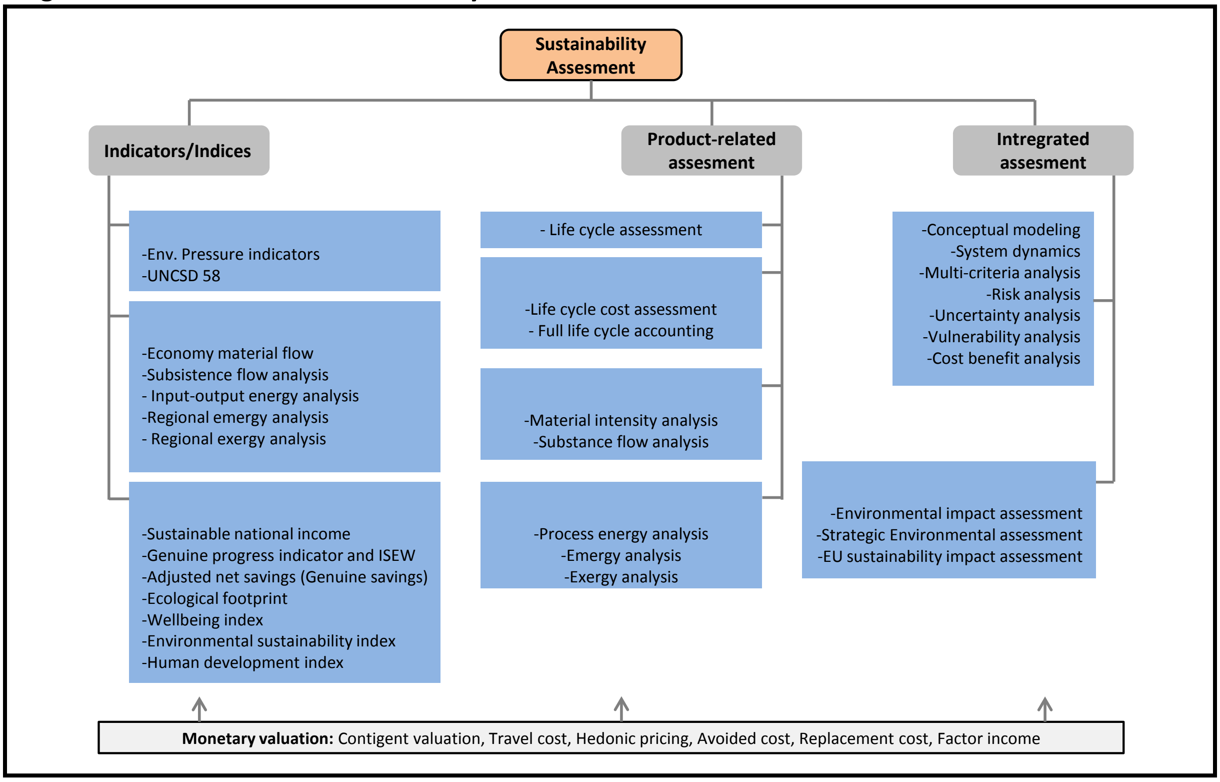
Source: Adapted from the review of Jong et al., 2015

Figure 1: Visionary urban (Municipal) renewable energy mix.



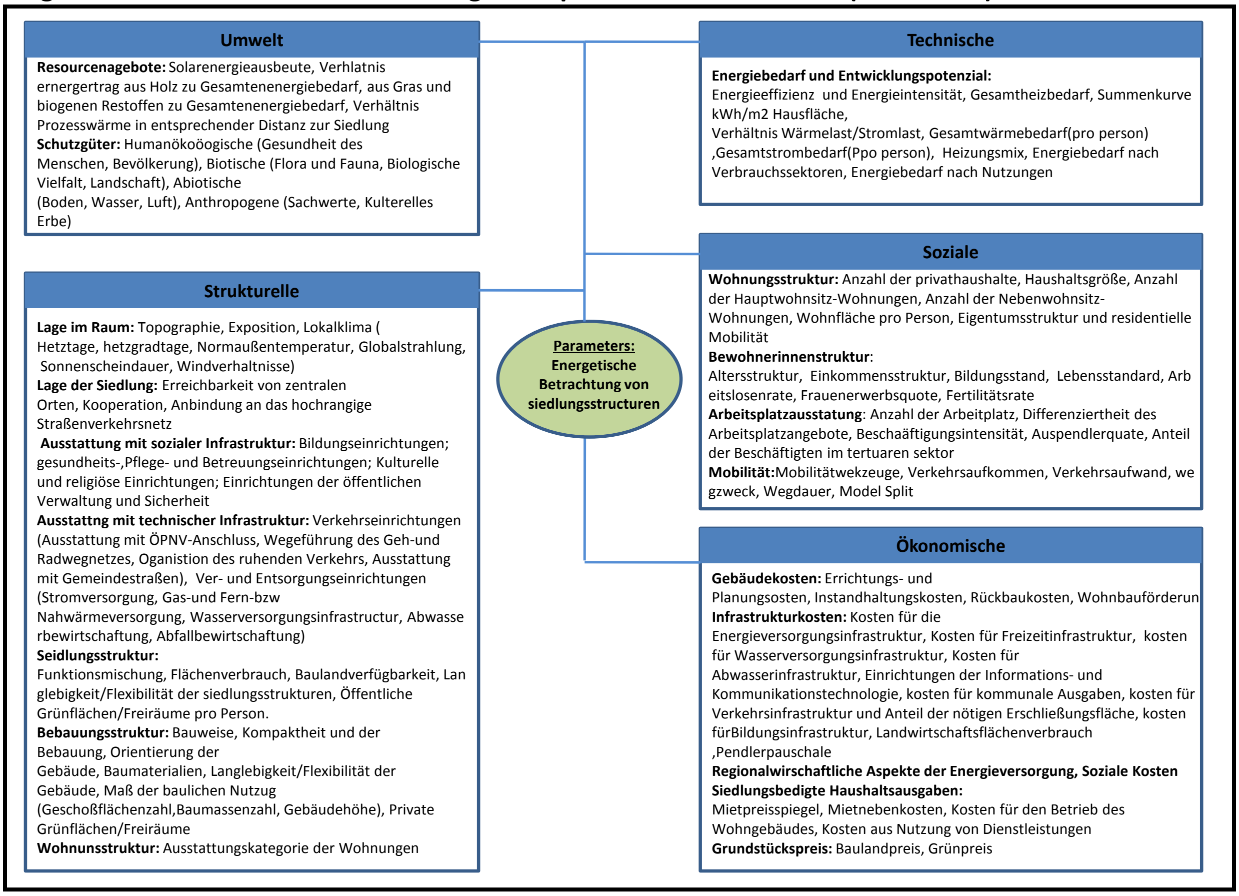
Source: Adapted from IEA (2009)

Figure 2: Framework for sustainability assessment tools.



Source: Adapted from Ness et al. (2007)

Figure 3: Parameters to address energetic aspect of urban structure (in German).



Source: Simplified and Adapted from FFG (2009)

Table 2: Summary results of measuring indicators on two selected residential neighborhoods.

Indicators	SRC 1: Niketan	SRC 2: Nikunja	Unit	Data source
I1: Edge contrast index	28.5	12.3	Index value	RAJUK(2007), DOP
I2: Mean distance to major employment area	4.9	8.3	km	RAJUK(2007), Saha (2010)
I3: Total number of public bus station within 1km	3	2	Nos	Urban Lunchpad (2013)
I4: Total number of nodes per sq.mile	844	680	Nos/sq.mile	RAJUK(2007), DOP
I5: HH connected to grid feed only	93.94	98.09	%	HH survey, 2013
I6: HH connected to solar PV	6.06	1.91	%	HH survey, 2013
I7: Hard scape area	12.36	17.06	%	RAJUK(2007), DOP
I8: Public green and open spaces	0	4.88	%	RAJUK(2007), DOP
I9: Ratio of plots with straight vs curved road	3.92	0	Ratio value	RAJUK(2007), Eastern Housing, DOP
I10: Ratio of plots along EW vs. NS road	0.96	1.74	Ratio value	RAJUK(2007), Eastern Housing, DOP
I11: Amount of buildings within angle to longer axis 15 (±)	44	11	%	RAJUK(2007), DOP
I12: Average Ratio of the building surface to the volume	0.4	0.7	Ratio value	RAJUK(2007), DOP
I13: Average Ratio of buildings length and to the width	1.6	1.5	Ratio value	RAJUK(2007), DOP
I14: Spatial Global Morans'I (Squared)	0.0009	0.01	Index value	RAJUK(2007), DOP
I15: Average Spatial Local Morans'I (Squard)	0.000064	0.0009	Index value	RAJUK(2007), DOP
I16: Housing units per unit of developed land area	46	63	HH/acre	RAJUK(2007), Eastern Housing, BBS
I17: Average household size in the neighborhood	3.72	3.74	Persons/HH	Household survey
I18: Mean living space per residents in a HH unit	37.7	31.39	sq.m/person	Household survey
I19: Residents age in between 15-65	68	63	%	Household survey
I20: Gini index value of annual HH income	0.13	0.29	index	Household survey
I21: Population per unit of gross land area	168	237	person/acre	RAJUK(2007), Eastern Housing, BBS
I22: HH owned private motor Vehicle	90	59	%	Household survey
I23: Share of private car based trip	35	17	%	Household survey
I24: Average annual travel distance for work (motor base)	72	42	km/ person	Household survey
I25: Annual intensity of electricity use	1498	1084	kWh /person	Household survey, DESCO
I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	1.62	1.73	Ratio	Household survey, DESCO
I27: Average appliances in use (except cooling)	4.6	5.4	Nos/HH	Household survey
I28: Average cooling appliance in use	1.2	1.05	Nos/HH	Household survey
I29: Per capita Co2 emission	0.7	0.27	ton/person	Household survey, Labib et. al. (2013)
I30: Annual electricity generation by roof top-solar PV	210.5	158.2	kWh /person	RAJUK (2007), Kabir et.al. (2010), DOP

Note: "DOP" - refers to authors effort for data updating in integration of direct field observations and in use of various open information sources i.e. googlestreeview, bing, openstreetmap.

Table 3: Electrical load calculation matrix for residential building in Dhaka.

SL	ITEM	UNIT LOAD: W	G.F Floor	1St Floor	2nd Floor	3rd Floor	4th Floor	5th Floor	Roof top	TOTAL	TOTAL LOAD: kW	PF	kVA	Amp
1	Light: Tube 36W 1200mm	**50**	5	10	10	10	10	10	2	55	2.75	0.6	4.6	20.8
2	Light: Tube 18W 600mm	30	0	0	0	0	0	0	0	0	0.00	0.34	0.0	0.0
3	Light: Energy Saving 20W	20	2	3	3	3	3	3	0	17	0.34	0.34	1.0	4.5
4	Light: Energy Saving 13W	13	0	2	2	2	2	2	0	10	0.13	0.34	0.4	1.7
5	Light: Incandescent 60 W	60	2	0	0	0	0	0	0	2	0.12	1	0.1	0.5
6	Fan 142cm [56"]	65	2	5	5	5	5	5	0	27	1.76	0.7	2.5	11.4
7	Fan Exhaust 46 cm [18"]	40	1	3	3	3	3	3	0	16	0.64	0.7	0.9	4.2
8	Air Conditioner: 1 ton	1500	0	0	0	0	0	0	0	0	0.00	0.7	0.0	0.0
9	Air Conditioner: 1.5 ton	2250	0	4	4	4	4	4	0	20	45.00	0.7	64.3	292.2
10	Air Conditioner: 2 ton	3000	0	0	0	0	0	0	0	0	0.00	0.7	0.0	0.0
11	Air Conditioner: 3 ton	4500	0	0	0	0	0	0	0	0	0.00	0.7	0.0	0.0
12	Computer	300	1	2	2	2	2	2	0	11	3.30	0.8	4.1	18.8
13	Hair Dryer	500	0	2	2	2	2	2	0	10	5.00	0.8	6.3	28.4
14	Vacuum Cleaner	300	0	1	1	1	1	1	0	2	0.60	0.8	0.8	3.4
15	TV Colour	150	0	2	2	2	2	2	0	10	1.50	0.8	1.9	8.5
16	Washing Machine	6300	0	2	2	2	2	2	0	10	63.00	1	63.0	286.4
17	Refrigerator	160	1	2	2	2	2	2	0	2	0.32	1	0.3	1.5
18	Geyser	2000	0	2	2	2	2	2	0	10	20.00	1	20.0	90.9
19	Iron	1500	0	2	2	2	2	2	0	10	15.00	1	15.0	68.2
20	Socket: 15 A 3Pin	750	3	15	15	15	15	15	0	78	58.50	0.8	73.1	332.4
21	Socket: 5 A 2Pin	250	3	18	18	18	18	18	0	93	23.25	0.8	29.1	132.1
22	Lift 8 Person	8000	1	0	0	0	0	0	0	1	8.00	0.7	11.4	51.9
23	Pump Water:1.5HP	1119	1	0	0	0	0	0	0	1	1.12	0.7	1.6	7.3
24	Pump Water: 2.5HP	1865	1	0	0	0	0	0	0	1	1.87	0.7	2.7	12.1
	Total Connected Load:	**34722**	-	-	-	-	-	-	-	-	**252.1**	**0.83**	**302.9**	**1377.2**
	Load With Demand Factor of (0.7 X 0.7)	0.70									176.5	**0.83**	212.0	

Source: Bestway construction and Engineering Ltd, 2013

Note: 4NO. OF UNITS IN FLOOR, Volt = 220

Table 4: Vehicle CO2 emission in Dhaka (estimated in 2009).

Vehicle types	Vehicle type (%)	Fuel Types	Numbers of Vehicles	Vehicle activity (km/Day)	CO_2 Emission factor (gm/km)	Emission (Ton/Day)
Motor cars	13.8	Petrol	15219	40	**258**	157.06
Motor cars	86.2	CNG	95066	40	**237**	901.22
Buses	24.2	Diesel	3448	130	**847**	397.61
Buses	75.8	CNG	10801	130	**958**	1359.16
Auto-rickshaws	100	CNG	32490	130	**75**	320.67
Motor cycle	100	Petrol	157965	30	**40**	189.55

Source: Simplified after Adapting from Labib et al. (2013)

Table 5: Selected comments of key informants.

Topic	Interviewees	Key Comments
Actors involvements	RAJUK officials	"…. there are no prescribed steps of approval process at the hand of utility regulatory agencies. They are free to administrate according to their own management and development policy. It may sometimes even a problematic issue for the developers in order to fulfill all requirements of approval."
	Independent urban researcher	".... it is also evident that some projects are even ended up and handed over to the end-user with very limited or no provision of utility services. This is even true for both private and public sector residential settlement projects."
	City official	".... learning from several advanced countries show that the local government is one of the major actors in energy efficiency and management activities but in the context of Bangladesh it is not much visible yet."
Method, Model, tools that works for city	City official	".... learning from several advance countries shows that the local municipal government needs to have more expert knowledge, effective tools and programs to implement the issue of energy in urban planning and others. In Dhaka, the local government has limited capacity in terms of financial, technical level- therefore we need more support from the central government."
	Architect	".... there is nothing except some GIS based applications of RAJUK and individual professionals. In private practice, the architects and planners should be supported with more modern and updated tools in order to deliver high quality professional services."
	Transport authority official	".... the public transport system is very weak and mostly informal in Dhaka city so that it is really hard to evaluate any residential settlement development project according to the transport related parameters -for example access to public transport facilities - by using well- established models and tools."
Challenges and barriers	Energy company official	"…. conducting some digitalization, database management to plan service better for our customers but we face it makes huge complexity as the utility area boundary and urban administrative boundary are not the same. Energy agencies and government have some programme for encouraging renewable energy and energy efficiency issues in Dhaka. It is sometimes difficult for us to look on generation of electricity as we are only responsible for distributions and customer services."
	Land and housing developer	".... the law and rules regulation are not enough to co-ordinate the issues among different urban agencies. As a lead agency, RAJUK is not capable enough to bring all stakeholders together. For example, the developers are only negotiating with RAJUK but most of the cases the DCC mandates are not preserved enough."
	Urban planning official	"…. no specific practice in RAJUK yet to integrate energy issue in urban planning. We are only trying to do some small steps such as Floor Area Ratio (FAR) introduction for density control but huge housing pressures.''
	Urban Planner	"…. the current population density threshold for residential area is only 350 person/acre but in reality you will find far more than that".
Where further efforts are needed	Energy technology researcher	"…. renewable energy technology like solar PV is one of the feasible options for all over the country but most of the efforts of solar technology disseminations are only concentrate in the rural area. Apart from solar energy, there are other technologies, which are also very matured enough to support energy efficiency measures and energy production in the urban Bangladesh but still they are not getting enough attention by the decision makers."
	Energy company official	"…. the technological development in Bangladesh and Dhaka city should focus on energy efficiency and renewable energy production but one should realize that how to deal with related challenges such as grid integrations, management, subsidies, and market issues."
	Urban planner	".... even for going through all the processes could be a long and difficult one as there are many open, overlaps and loopholes in the regulations. There are almost no prescribed steps or process how to evaluate the public sector housing/land development projects."
	Developer	".... there is a need to have clear regulations to include energy issues and other utility services in case of housing and land development projects. The private sector is doing a lot to tackle housing need of the citizens but the public agencies should help by offering easy provisions of infrastructures."

Source: Field survey (2013)

Figure 4: Detail codes on interaction terms of HUI and VUI in relation to energy consumption.

```
model_T= lm(sqrt(Edj)~sqrt(Sum_HUI) + sqrt(Sum_VUI) + sqrt(Sum_HUI)*sqrt(Sum_VUI), newML, na.action = na.omit)
```

modified horizontal and predict vertical (one standard deviation above and below the mean)

```
Sum_HUI_1=mean(newML$Sum_HUI)
Sum_HUI_2= (Sum_HUI_1-0.24)
Sum_HUI_3= (Sum_HUI_1+0.24)


p1=predict(model_T,data.frame(Sum_HUI=Sum_HUI_1,Sum_VUI=0:7)) # for mean
p2=predict(model_T,data.frame(Sum_HUI=Sum_HUI_2,Sum_VUI=0:7)) # for lower value
p3=predict(model_T,data.frame(Sum_HUI=Sum_HUI_3,Sum_VUI=0:7)) # for higher value

p1
```

modified verticals over horizontal (one standard deviation above and below the mean)

```
Sum_VUI_1=mean(newML$Sum_VUI, na.rm = T)
Sum_VUI_2= Sum_VUI_1 - 0.03
Sum_VUI_3= Sum_VUI_1 + 0.03


p1=predict(model_T,data.frame(Sum_VUI=Sum_VUI_1,Sum_HUI=0:8)) # for mean
p2=predict(model_T,data.frame(Sum_VUI=Sum_VUI_2,Sum_HUI=0:8)) # for lower value
p3=predict(model_T,data.frame(Sum_VUI=Sum_VUI_3,Sum_HUI=0:8)) # for higher value

p1
```

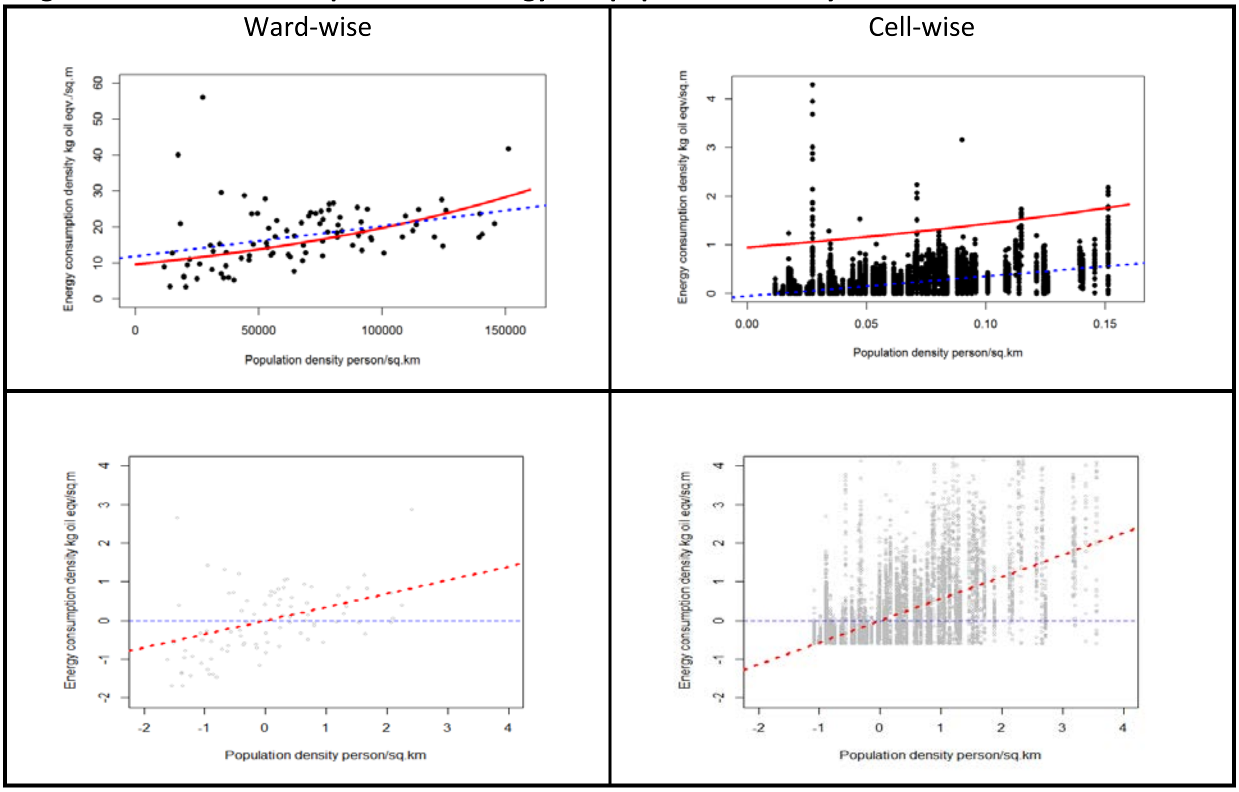
Note: "The **square root**, x to x^ (1/2) = sqrt(x), is a transformation with a moderate effect on distribution shape: it is weaker than the logarithm and the cube root. It is also used for reducing right skewness, and also has the advantage that it can be applied to zero values. Note that the square root of an area has the units of a length. It is commonly applied to counted data, especially if the values are mostly rather small" (Adapted from http://fmwww.bc.edu/repec/bocode/t/transint.html).

Table 6: Linear relationships of density functions.

Linear Functions	Ward-based estimation	Cell-wise estimation
Energy consumption density *vs.* Population density	$y = 84.90x + 1\times 10^7$ $R^2 = 0.12$ $\rho = 0.34$	$y = 4.092x - 0.050$ $R^2 = 0.32$ $\rho = +0.56$
Population density *vs.* distance from CBD	$y = -3996.x + 86912$ $R^2 = 0.146$ $\rho = -0.38$	$y = -0.003x + 0.068$ $R^2 = 0.18$ $\rho = -0.42$
Energy consumption density *vs.* distance from CBD	$y = 18855x + 2 \times 10^7$ $R^2 = 0.005$ $\rho = +0.07$	$y = -0.019x + 0.262$ $R^2 = 0.10$ $\rho = -0.32$

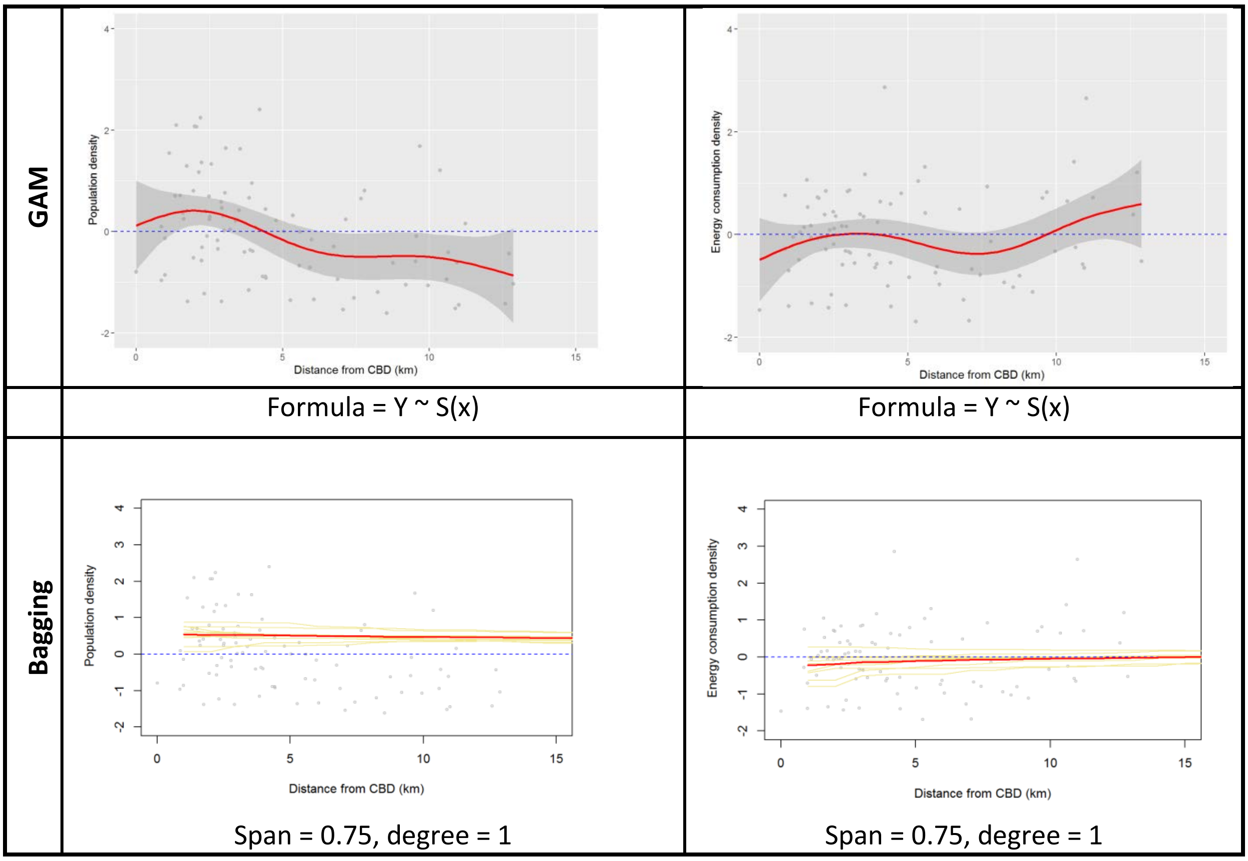
Sorce: Author's own

Figure 5: Inter-relationship between energy and population density.



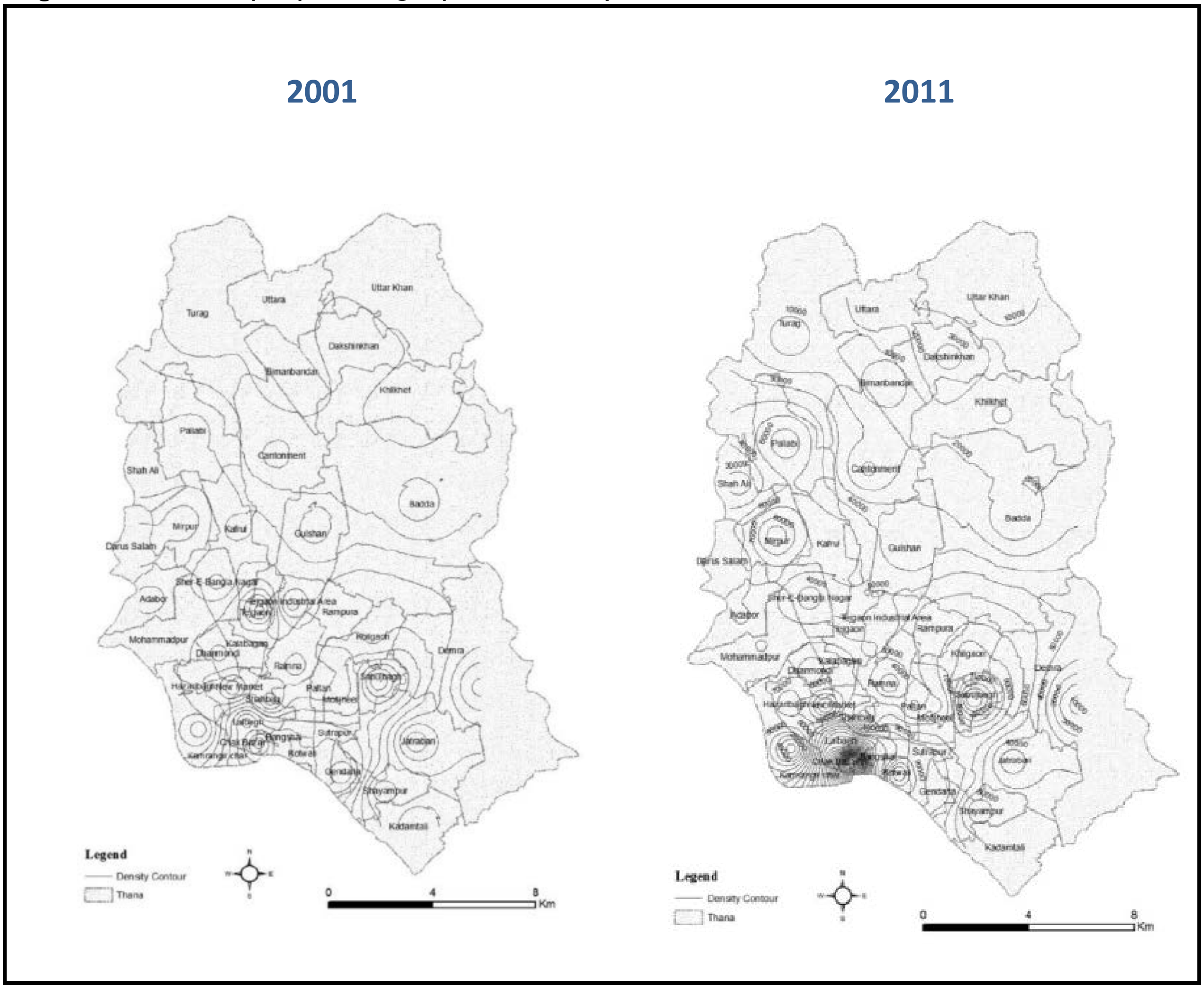
ρ = + 0.34, R^2 = 0.23 ρ = + 0.56, R^2 = 0.32

Figure 6: Insight of density and decay relations (ward-wise).



Source: Author`s own

Figure 7: Contour Map Representing Population Density of Greater Dhaka.



Source: Adapted from Khatun et al. (2015)

Figure 8: Exponential modeling of density functions (Ward-wise estimation).

```
y = mydataset$norm_pop_density
x = mydataset$dist_to_cbd
```

```
# ploting exponential model
exp.model <-lm(y ~ exp(-x),mydataset)
summary(exp.model)
```

```
##
## Call:
## lm(formula = y ~ exp(-x), data = mydataset)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.5490 -0.8393 -0.0267  0.6013  2.4560
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.06015    0.12229  -0.492    0.624
## exp(-x)      0.74653    0.75642   0.987    0.326
##
## Residual standard error: 1 on 87 degrees of freedom
## Multiple R-squared:  0.01107,    Adjusted R-squared:  -0.0002955
## F-statistic: 0.974 on 1 and 87 DF,  p-value: 0.3264
```

```
y = new_sub_ward$norm_ecd
x = new_sub_ward$dist_to_cbd
```

```
# ploting exponential model
exp.model <-lm(y ~ exp(-x),mydataset)
summary(exp.model)
```

```
##
## Call:
## lm(formula = y ~ exp(-x), data = mydataset)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7721 -0.6660 -0.0043  0.5611  4.4944
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.08669    0.12155   0.713    0.478
## exp(-x)     -1.07593    0.75185  -1.431    0.156
##
## Residual standard error: 0.9941 on 87 degrees of freedom
## Multiple R-squared:  0.023,  Adjusted R-squared:  0.01177
## F-statistic: 2.048 on 1 and 87 DF,  p-value: 0.156
```

Figure 9: Exponential modeling of density functions (cell-wise estimation).

Population density

```
y = mydataset$norm_pop_density
x = mydataset$dist_to_cbd
```

```
# ploting exponential model
exp.model <-lm(y ~ exp(-x),mydataset)
summary(exp.model)
```

```
##
## Call:
## lm(formula = y ~ exp(-x), data = mydataset)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.2420 -0.7987 -0.3248  0.6043  3.6390
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.095100   0.009457  -10.06   <2e-16 ***
## exp(-x)      2.343336   0.088450   26.49   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9728 on 12362 degrees of freedom
## Multiple R-squared:  0.05373,    Adjusted R-squared:  0.05365
## F-statistic: 701.9 on 1 and 12362 DF,  p-value: < 2.2e-16
```

Energy consumption density

```
y = mydataset$norm_ecd
x = mydataset$dist_to_cbd
```

```
# ploting exponential model
exp.model <-lm(y ~ exp(-x), cell)
summary(exp.model)
```

```
##
## Call:
## lm(formula = y ~ exp(-x), data = cell)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -2.4219 -0.5159 -0.3490  0.1986 19.2552
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.088359   0.009493  -9.308   <2e-16 ***
## exp(-x)      2.177232   0.088793  24.520   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9766 on 12362 degrees of freedom
## Multiple R-squared:  0.04638,    Adjusted R-squared:  0.0463
## F-statistic: 601.2 on 1 and 12362 DF,  p-value: < 2.2e-16
```

Figure 10: General additive model (GAM) scripts (ward wise estimation).

Population density

```
y = mydataset$norm_pop_density
x = mydataset$dist_to_cbd
```

```
# ploting gam model
library(mgcv)

gam.model <- gam(y~s(x), data = mydataset)
summary(gam.model)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## y ~ s(x)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.869e-16  9.720e-02       0        1
##
## Approximate significance of smooth terms:
##        edf Ref.df     F p-value
## s(x) 3.677  4.585 3.952  0.0034 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.159   Deviance explained = 19.4%
## GCV = 0.88758  Scale est. = 0.84094   n = 89
```

Energy consumption density

```
y = mydataset$norm_ecd
x = mydataset$dist_to_cbd
```

```
# ploting gam model
library(mgcv)

gam.model <- gam(y~s(x), data = mydataset)
summary(gam.model)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## y ~ s(x)
##
## Parametric coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -3.882e-17  1.033e-01       0        1
##
## Approximate significance of smooth terms:
##        edf Ref.df     F p-value
## s(x) 3.655  4.559 1.405   0.271
##
## R-sq.(adj) =  0.0498   Deviance explained = 8.93%
## GCV = 1.0026  Scale est. = 0.95016   n = 89
```

Figure 11: General additive model (GAM) script (cell-wise estimation).

Population density

```
y = mydataset$norm_pop_density
x = mydataset$dist_to_cbd
```

```
# ploting gam model
library(mgcv)

gam.model <- gam(y~s(x), data = mydataset)
summary(gam.model)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## y ~ s(x)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.333e-16  7.877e-03       0        1
##
## Approximate significance of smooth terms:
##        edf Ref.df     F p-value
## s(x) 8.698  8.974 418.3  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.233   Deviance explained = 23.3%
## GCV = 0.76776  Scale est. = 0.76716   n = 12364
```

Energy consumption density

```
y = mydataset$norm_ecd
x = mydataset$dist_to_cbd
```

```
# ploting gam model
library(mgcv)

gam.model <- gam(y~s(x), data = mydataset)
summary(gam.model)
```

```
##
## Family: gaussian
## Link function: identity
##
## Formula:
## y ~ s(x)
##
## Parametric coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.622e-16  8.281e-03       0        1
##
## Approximate significance of smooth terms:
##        edf Ref.df     F p-value
## s(x) 8.887  8.996 247.3  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.152   Deviance explained = 15.3%
## GCV = 0.84859  Scale est. = 0.84791   n = 12364
```

Figure 12: LOESS model and Bagging scripts (ward wise estimation).

Population density

```
# create empty matrix
ll <- matrix(NA,nrow=10,ncol=89)

# iterate 10 times (select the whole function and run)
for(i in 1:10){
    # create sample from data with replacement
    ss <- sample(1:dim(val)[1],replace=TRUE)
    # draw sample from the data and reorder rows based on Distance
    val0 <- val[ss,]; val0 <- val0[order(val0$Dist_KM),]
    # fit loess function through data (similar to spline)
    loess0 <- loess(val0$normDensity_07 ~ val0$Dist_KM, degree = 1, span = 0.75)
    # prediction from loess curve for the same values each time
    ll[i,] <- predict(loess0,newdata=data.frame(val=1:89))
}
# plot the data points
plot(val$Dist_KM,val$normDensity_07,pch=1,cex=0.5, col=8, ylim = c(-2,4), xlim = c(0,15), xlab = "Distance from C
BD (km)", ylab = " Population density")
# plot each prediction model (select whole function and run)
for(i in 1:10){lines(1:89,ll[i,],col= "khaki",lwd=1)}
# plot the average of all models in red
lines(1:89,apply(ll,2,mean),col= "red", lwd = 2)

# add horizontal line of mean 0

abline(h=0, col=4, lty=2)
```

Energy consumption density

```
# create empty matrix
ll <- matrix(NA,nrow=10,ncol=89)

# iterate 10 times (select the whole function and run)
for(i in 1:10){
    # create sample from data with replacement
    ss <- sample(1:dim(val)[1],replace=TRUE)
    # draw sample from the data and reorder rows based on Distance
    val0 <- val[ss,]; val0 <- val0[order(val0$Dist_KM),]
    # fit loess function through data (similar to spline)
    loess0 <- loess(val0$normconEdt_km ~ val0$Dist_KM, degree = 1, span = 0.75)
    # prediction from loess curve for the same values each time
    ll[i,] <- predict(loess0,newdata=data.frame(val=1:89))
}
# plot the data points
plot(val$Dist_KM,val$normconEdt_km,pch=1,cex=0.5, col=8, ylim= c(-2,4), xlim = c(0,15), xlab = "Distance from CB
D (km)", ylab = " Energy consumption density")



# plot each prediction model (select whole function and run)
for(i in 1:10){lines(1:89,ll[i,],col="khaki",lwd=1)}

# add horizontal line of mean 0

abline(h=0, col=4, lty=2)

# plot the average of all models in red
lines(1:89,apply(ll,2,mean),col=2,lwd=2)
```

Figure 13: LOESS model and Bagging script (cell-wise estimation).

Population density

```
# create empty matrix
ll <- matrix(NA,nrow=10,ncol=12364)

# iterate 10 times (select the whole function and run)
for(i in 1:10){
    # create sample from data with replacement
    ss <- sample(1:dim(val)[1],replace=TRUE)
    # draw sample from the data and reorder rows based on distance
    val0 <- val[ss,]; val0 <- val0[order(val0$Dist_KM),]
    # fit loess function through data (similar to spline)
    loess0 <- loess(val0$normPopD_m ~ val0$Dist_KM, degree= 1, span = 0.75)
    # prediction from loess curve for the same values each time
    ll[i,] <- predict(loess0,newdata=data.frame(val=1:12364))
}
# plot the data points
plot(val$Dist_KM,val$normPopD_m,pch=1,cex=0.5, col = 8, ylim = c(-2,4), xlim = c(0,15), xlab = "Distance from CB
D (km)", ylab = " Population density")
# plot each prediction model (select whole function and run)
for(i in 1:10){lines(1:12364,ll[i,],col="khaki",lwd=1)}
# plot the average in red
lines(1:12364,apply(ll,2,mean),col=2,lwd=2)
abline(h=0, col= 4, lty=2)
```

Energy consumption density

```
# create empty matrix
ll <- matrix(NA,nrow=10,ncol=12364)

# iterate 1236 times (select the whole function and run)
for(i in 1:10){
    # create sample from data with replacement
    ss <- sample(1:dim(val)[1],replace=TRUE)
    # draw sample from the data and reorder rows based on distance
    val0 <- val[ss,]; val0 <- val0[order(val0$Dist_KM),]
    # fit loess function through data (similar to spline)
    loess0 <- loess(val0$normEdj ~ val0$Dist_KM, degree=1, span = 0.05)
    # prediction from loess curve for the same values each time
    ll[i,] <- predict(loess0,newdata=data.frame(val=1:12364))
}
# plot the data points
plot(val$Dist_KM,val$normEdj,pch=1,cex=0.5, col = 8, ylim = c(-2,4), xlim = c(0,15), xlab = "Distance from CBD (k
m)", ylab = " Energy consumption density")
# plot each prediction model (select whole function and run)
for(i in 1:10){lines(1:12364,ll[i,],col="khaki",lwd=1)}
# plot the average in red
lines(1:12364,apply(ll,2,mean),col=2,lwd=2)
abline(h=0,col= 4, lty=2)
```

Figure 14: Layout of User input worksheet of "eNoP-Dhaka" Tool.

Energy Optimized Residential Settlement in Dhaka (eNoP-DHAKA)

Please fill all yellow colored cells

Name: Niketan Housing Project
Total Population: 6783
Total Area (in acres): 55.24
Number of Plots: 562
Implementing Agency: Eastern Housing Ltd.
Date: January 16, 2016
Location:
Area name: Niketan
City: Dhaka
Country: Bangladesh

Click on after updating location Create Map

Category	Ctriteria	Indicators	Unit	User defined Indicator Value	Goal	Base value	User defined Adjustment Factor
CA	C	I	U	Vi		Bj	
CA1: Smart location	C1: Proximity of surrounding landuse	I1: Edge contrast index	Index value	28.5	MAX	19.4	0
	C2: Proximity to employment	I2: Mean distance to major employment area	km	4.9	MIN	6.6	0
	C3: Accessibility of public transport facilities	I3: Total number of public bus station within 1km	Nos	3	MAX	2.5	0
	C4: Local connectivity	I4: Total number of nodes per sq.mile	Nos/sq.mile	844	MAX	762	0
	C5: Accessibility to electricity supply	I5: HH connected to grid feed only	%	93.94	MIN	96.015	0
		I6: HH connected to solar PV	%	6.06	MAX	3.985	0
CA2: Landscape elements	C6: State of hardscape	I7: Hard scape area	%	12.36	MIN	14.71	0
	C7: State of public green/open space	I8: Public green and open spaces	%	0	MAX	2.44	0
	C8: State of Road orientation	I9: Ratio of plots with straight vs curved road	Ratio value	3.92	MAX	1.96	0
		I10: Ratio of plots along EW vs NS road	Ratio value	0.96	MAX	1.35	0
CA3: Building quality	C9: State of building for solar gain	I11: Amount of buildings within angle to longer axis 15 (±)	%	44	MAX	27.5	0
	C10: State of building surface and volume	I12: Average Ratio of the building surface to the volume	Ratio	0.4	MIN	0.55	0
	C11: Building Aspect ratio	I13: Average Ratio of buildings length and to the width	Ratio	1.6	MIN	1.55	0
	C12: Building organization	I14: Spatial Global Morans'I (Squared)	Index value	0.0009	MAX	0.00545	0
		I15: Average Spatial Local Morans'I (Squard)	Index value	0.000064	MAX	0.000482	0
CA4: Housing/Residents function	C13: Net housing density	I16: Housing unites per unit of developed land area	HH/acre	46	MAX	54.5	0
	C14: Household size	I17: Average household size in the neighborhood	Persons/HH	3.72	MAX	3.73	0
	C15: State of Living space	I18: Mean living space per residents in a HH unit	sq.m/pers	37.7	MIN	34.545	0
	C16: Residents age structure	I19: Residents age in between 15-65	%	68	MAX	65.5	0
	C17: Residents Income structure	I20: Gini index value of annual HH income	index	0.13	MAX	0.21	0
	C18: Gross population density	I21: Population per unit of gross land area	person/acr	168	MAX	202.5	0
	C19: Vehicle ownership status	I22: HH owned private motor Vehicle	%	90	MIN	74.5	0
	C20: Working mobility pattern	I23: Share of private car based trip	%	35	MIN	26	0
		I24: Average annual travel distance for work (motor base)	km/	72	MIN	57	0
CA5: Energy usage	C21: Electricity usage pattens	I25: Annual intensity of electricity use	kWh	1498	MIN	1291	0
		I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	Ratio	1.62	MIN	1.675	0
		I27: Average appliances in use (except cooling)	Nos/HH	4.6	MIN	5	0
		I28: Average cooling appliance in use	Nos/HH	1.2	MIN	1.125	0
	C22: Energy consumption for working mobility	I29: Per capita Co2 emission	ton/perso	0.7	MIN	0.485	0
CA6: Renewable Resources	C23: Solar electricity potential	I30: Annual electricity generation by roof top-solar PV	kWh	210.5	MAX	184.35	0
							0

User_Input | Result | Compilation_Equal | Compilation_Expert | Compilation_

Appendix B: Questionnaire for ranking indicators (Using Survey Monkey).

EXPERT OPINION SURVEY

Introduction

As part of a acdemic research project, we are looking forward to draft an indicator set that can help us to analyse the interrelationships of urban residential settlement structures and energy aspects based on the local context of urban form, mobility and resident's lifestyle.

In the following section, we are requesting you to rank a number of indicators on the basis of 4 individual criteria.

We are looking forward to receive your valuable opinion on the context of Dhaka city, Bangladesh.

Please do not hesitate to contact me if you need any kind of support.

Lets go.

Best regards,
Sujit Kumar Sikder

How far these following indicators satisfy the given criteria?

1. Analytical soundness: Strong scientific and conceptual basis

	Very low	Low	Middle	High	Very high
1. Edge contrast index	○	○	○	○	○

2. Time bound: Sensitive to changes within policy time frames

	Very low	Low	Middle	High	Very high
1. Edge contrast index	○	○	○	○	○

3. Measurability: Measurable in qualitative or quantitative terms

	Very low	Low	Middle	High	Very high
1. Edge contrast index	○	○	○	○	○

4. Relevance: Relevance for the issue and target audience at hand

	Very low	Low	Middle	High	Very high
1. Edge contrast index	○	○	○	○	○

Source: Screen shot from SURVEYMONKEY: COM

Appendix C: Questionnaire for HH and Personal interview.

A. General information:

Road No: Plot/House No: Floor No:

Name of the HH Head:....................................Profession of HH head:....................................

Monthly approximately family (HH) income :..(BDT)

Monthly approximately family (HH) expenditure :....................................(BDT)

B . Household demographic

1. How many household member in your family?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ More (Specify).............

2. Persons in different age groups

Age group	Number					
Below 6	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ More (Specify)........
6- 14	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ More (Specify)........
15-30	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ More (Specify)........
31-65	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ More (Specify)........
Above 65	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ More (Specify)........

B. House information

3. Housing type:

☐ Single family house ☐ Double family house

☐ Duplex ☐ Row house

☐ Multi-family house

4. House ownership: ☐ Own ☐ Rented

If rented then, Where is your landlord from?

☐ same building/area ☐ Same city

☐ Same country ☐ Foreign country

5. How long do you live in your house? ....years
6. What is the size of your apartment/house? ....sq.m living area
7. How many Bedrooms have in your house? ....sq.m living area

C. Electricity and appliances

8. How much electricity do you consume per month (average)?

In summer (Feb - Oct): ....(kwh) In winter (Nov-Jan): ....(kwh)	**OR**	In summer (Feb - Oct): ....(bill in BDT) In winter (Nov-Jan): ....(bill in BDT)

9. What your arrangement during load-shedding time?

☐ IPS ☐ Commercial generator line ☐ Personal generator ☐ Others............

10. Do you have Solar Photovoltaic (PV) system your house?

If yes, Capacity of the System (KW/KVA): ☐ Total no. of panels: ☐

11. How many electronics appliances do you have in your house (please put numbers)?

☐ Refrigerator ☐ Dishwasher

☐ Computer ☐ Dryer

☐ TV ☐ Washing machine

☐ Air conditioner ☐ Others (Specify).................

If yes, then the capacity .... BTU (or mention about the room size..........sq.m)

Period of use: ....(name of months), Duration of use .... hour/day

C. Mobility

12. How many private vehicles do have in your HH?

☐ 1 ☐ 2 ☐ 3 ☐ More (Specify)........

13. Please give us a bit detail information about your private vichcles:

Vehicle 1

Type of Vehicle: ☐ Car, ☐ Motorbike, ☐ Others (specify).......................

Fuel used for operation: ☐ Diesel, ☐ Petrol, ☐ Gas, ☐ Others (specify)..............

How many km drive in a year? ....km per year

How much fuel does in need? ....litre per 100 km

Does this vehicle used for work purpose? ☐ Yes ☐ No

if yes then how much ☐ 1/4 ☐ 1/2 ☐ 3/4 ☐ Full time

Vehicle 2

Type of vehicle: ☐ Car, ☐ Motorbike, ☐ Others (specify).......................

Fuel used for operation: ☐ Diesel, ☐ Petrol, ☐ Gas, ☐ Others (specify)..............

How many km drive in a year? ....km per year

How much fuel does in need? ....litre per 100 km

Does this vehicle used for work purpose? ☐ Yes ☐ No

if yes then, how much ☐ 1/4 ☐ 1/2 ☐ 3/4 ☐ Full time

Vehicle 3

Type of vehicle: ☐ Car, ☐ Motorbike, ☐ Others (specify).......................

Fuel used for operation: ☐ Diesel, ☐ Petrol, ☐ Gas, ☐ Others (specify)..............

How many km drive in a year? ....km per year

How much fuel does in need? ....litre per 100 km

Does this vehicle used for work purpose? ☐ Yes ☐ No

if yes then, how much ☐ 1/4 ☐ 1/2 ☐ 3/4 ☐ Full time

Vehicle 4

Type of vehicle: ☐ Car, ☐ Motorbike, ☐ Others (specify).......................

Fuel used for operation: ☐ Diesel, ☐ Petrol, ☐ Gas, ☐ Others (specify)..............

How many km drive in a year? ....km per year

How much fuel does in need? ....litre per 100 km

Does this vehicle used for work purpose? ☐ Yes ☐ No

if yes then, how much ☐ 1/4 ☐ 1/2 ☐ 3/4 ☐ Full time

15. Total Mobility of the household for work (count every trip 2 times)

Sex	Age	Education	Distance travel with different mode (km in a week)									
			Car (Own)	*Car (Share)*	*Train*	*Bus*	*AC bus*	*Motorbike*	*Bicycle*	*Auto-rickshaw*	*Rickshaw/Van*	*others*

*** Count week only Sunday to Thursday (5 days)*
Sex: Male = 1, Female = 2;
Age group: Below 6 = 1, 6 to14 = 2, 15-30 =3, 31 to 65 = 4, above 65 = 5
Education: Illiterate = 1, Primary = 2, High school = 3, College = 4, University = 5

16. Future planning about energy aspects (put tick mark please)

	May be	Of course	May not	Of course not
Install Solar PV system				
Use energy efficient appliances				
Connect with central cooling system *				
Use less air-conditioner				
Renovate building structure				
Travel less with own car				
Buy a car which consume less energy				
Relocate to nearby workplace				

**** Willing to connect once available***

Thanks a lot for your kind co-operation.

Name of the Surveyor: _ **Date and Signature: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _**

Appendix D: Questionnaire for Key Informants Opinion Survey.

(Face to Face and online using Survey monkey)

PART ONE (1): General Topics

i) What are the major steps for getting approval of a housing/land development project?

ii) Who are the major actors involved in the process?

iii) Do the housing /land development projects need to get approval by the utility (e.g. electricity) agencies?

iv) What are steps to get approval from utility (electricity and transportation) agencies?

v) What are the basic principles for approving a housing/land development project?.

vi) Where need additional effort for integrating energy in urban planning (e.g law, rules)?

vii) Is there any decision support system in place for integrating energy issue in urban planning? Please explain a bit detail.

viii) Please describes other issues

PART TWO (2):

In this section, you are requested to continue with an assessment that four (4) steps of residential settlement planning process. Please give the scores from your own experiences and perceptions on residential land subdivision planning, development, approval and implementation in Dhaka city.

Step 1. Definition of Intervention programme and energy models which are addressing local policy and sustainable factors

Actions/Issues	**Score** *(Please check only 1 score for each key indicator)*									
Subdivision planning	**Not at all**				**Partially**				**Strong**	
Residential development	1	☐	2	☐	3	☐	4	☐	5	☐
Environmental protection	1	☐	2	☐	3	☐	4	☐	5	☐
Social needs	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Score:	Do not fill				%		Do not fill			
Energy issues										
Electricity on demand	1	☐	2	☐	3	☐	4	☐	5	☐
Renewable available resources	1	☐	2	☐	3	☐	4	☐	5	☐
Reducing Co2 emissions	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Score:	Do not fill				%		Do not fill			

Step 2. Site analysis and energy estimations

Actions/Issues	**Score** *(Please check only 1 score for each key indicator)*									
	Not at all				**Partially**				**Strong**	
Environmental Analysis (a)	1	☐	2	☐	3	☐	4	☐	5	☐
Economic Analysis (b)	1	☐	2	☐	3	☐	4	☐	5	☐
Urban Analysis (c)	1	☐	2	☐	3	☐	4	☐	5	☐
Social Analysis (d)	1	☐	2	☐	3	☐	4	☐	5	☐
Existing Energy Analysis (e)	1	☐	2	☐	3	☐	4	☐	5	☐
Energy potentiales Analysis (f)	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Methods and tools used:										
Score:	Do not fill				%		Do not fill			

Step 3. Plan design (Interactive process)

Actions/Issues	Score *(Please check only 1 score for each key indicator)*									
	Not at all				Partially				Strong	
Parametric urban form design	1	☐	2	☐	3	☐	4	☐	5	☐
Urban residential plan proposals	1	☐	2	☐	3	☐	4	☐	5	☐
Energy simulations	1	☐	2	☐	3	☐	4	☐	5	☐
Energy productions	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Methods and tools used:										
Score:	Do not fill				%		Do not fill			

Step 4. Implementation and Evaluation

Actions/Issues	Score *(Please check only 1 score for each key indicator)*									
Subdivision planning	Not at all				Partially				Strong	
Percient residential functions	1	☐	2	☐	3	☐	4	☐	5	☐
Environmental performance	1	☐	2	☐	3	☐	4	☐	5	☐
Management programme	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Score:	Do not fill				%		Do not fill			
Energy issues	Not at all				Partially				Strong	
Percient energy balance	1	☐	2	☐	3	☐	4	☐	5	☐
Zero energy building	1	☐	2	☐	3	☐	4	☐	5	☐
Renewable technology cost	1	☐	2	☐	3	☐	4	☐	5	☐
Co2 emission reduction	1	☐	2	☐	3	☐	4	☐	5	☐
(*Additional if any*)	1	☐	2	☐	3	☐	4	☐	5	☐
Score:	Do not fill				%		Do not fill			

Information on Respondent:

Institution:	Profession:
Educational Qualifications:	Work Experience in Year:
Contact details:	

Appendix E:

Table 1: Resulted score that are based on expert opinion (Survey monkey).

ID	Indicator	Selection criteria-wise score (Expert opinion)				Total Score
		Analytical soundness	Time bound	Measurability	Relevance	
1	Edge contrast index	15.00	9.00	13.00	12.00	49.00
2	Topography	13.00	9.00	13.00	9.00	44.00
3	Mean distance to major employment area	22.00	10.00	11.00	8.00	51.00
4	Total number of nodes per sq.mile	21.00	11.00	13.00	12.00	57.00
5	Employment rate	10.00	9.00	11.00	11.00	41.00
6	Total number of public bus station within 1km	25.00	11.00	11.00	14.00	61.00
7	Spatial Global Morans'I	17.00	9.00	8.00	9.00	43.00
8	HH connected to grid feed only	20.00	9.00	10.00	13.00	52.00
9	Public green and open spaces	19.00	8.00	11.00	11.00	49.00
10	Road orientation index	14.00	8.00	8.00	9.00	39.00
11	Block orientation index	15.00	9.00	7.00	11.00	42.00
12	Floor Space Index (FSI)	13.00	9.00	8.00	10.00	40.00
13	Average Ratio of buildings length and to the width	19.00	10.00	10.00	12.00	51.00
14	Plot ratio	16.00	8.00	9.00	10.00	43.00
15	Street width	16.00	7.00	10.00	10.00	43.00
16	Average Ratio of the building surface to the volume	16.00	9.00	11.00	13.00	49.00
17	Hard scape area	20.00	8.00	11.00	11.00	50.00
18	Average Spatial Local Morans'I	14.00	12.00	10.00	12.00	48.00
19	Ratio of plots with straight vs curved road	17.00	12.00	10.00	12.00	51.00
20	Amount of buildings within angle to longer axis 15 (±)	19.00	11.00	11.00	12.00	53.00
21	Ratio of plots along EW vs. NS road	18.00	9.00	11.00	11.00	49.00
22	Degree of structure use	16.00	7.00	10.00	12.00	45.00
23	Amount of living space	18.00	8.00	12.00	12.00	50.00
24	Housing units per unit of developed land area	22.00	10.00	11.00	12.00	55.00
25	Average household size in the neighborhood	18.00	12.00	11.00	12.00	53.00
26	Mean living space per residents in a HH unit	17.00	7.00	9.00	11.00	44.00
27	House type	13.00	8.00	9.00	9.00	39.00
28	Residents age in between 15-65	15.00	12.00	11.00	13.00	51.00
29	Average appliances in use (except cooling)	17.00	11.00	9.00	11.00	48.00
30	Gini index value of annual HH income	20.00	11.00	13.00	15.00	59.00
31	HH connected to solar PV	13.00	12.00	13.00	11.00	49.00
32	Population per unit of gross land area	24.00	14.00	11.00	15.00	64.00
33	HH owned private motor Vehicle	17.00	11.00	13.00	15.00	56.00
34	Average annual travel distance for work (motor base)	16.00	14.00	10.00	13.00	53.00
35	Annual intensity of electricity use	18.00	9.00	12.00	14.00	53.00
36	Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	18.00	8.00	11.00	14.00	51.00
37	Average cooling appliance in use	18.00	11.00	13.00	14.00	56.00
38	Number of bed rooms	17.00	7.00	9.00	10.00	43.00
39	Per capita Co2 emission	17.00	10.00	12.00	15.00	54.00
40	Annual electricity generation by roof top-solar PV	15.00	9.00	12.00	12.00	48.00
41	Share of private car based trip	20.00	10.00	14.00	13.00	57.00

Source: Expert opinion survey, 2013

Note: Experts comprised as - officials, urban planners, architects, developers, and researchers

Table 2: List of selected indicators according to category and criteria.

Category	Ctriteria	Indicators
CA1: Smart location	C1: Proximity of surrounding landuse	I1: Edge contrast index
	C2: Proximity to employment	I2: Mean distance to major employment area
	C3: Accessibility of public transport facilities	I3: Total number of public bus station within 1km
	C4: Local connectivity	I4: Total number of nodes per sq.mile
	C5: Accessibility to electricity supply	I5: HH connected to grid feed only
		I6: HH connected to solar PV
CA2: Landscape elements	C6: State of hardscape	I7: Hard scape area
	C7: State of public green/open space	I8: Public green and open spaces
	C8: State of Road orientation	I9: Ratio of plots with straight vs curved road
		I10: Ratio of plots along EW vs. NS road
CA3: Building quality	C9: State of building for solar gain	I11: Amount of buildings within angle to longer axis 15 (±)
	C10: State of building surface and volume	I12: Average Ratio of the building surface to the volume
	C11: Building Aspect ratio	I13: Average Ratio of buildings length and to the width
	C12: Building organization	I14: Spatial Global Morans'I (Squared)
		I15: Average Spatial Local Morans'I (Squard)
CA4: Housing/Residents function	C13: Net housing density	I16: Housing units per unit of developed land area
	C14: Household size	I17: Average household size in the neighborhood
	C15: State of Living space	I18: Mean living space per residents in a HH unit
	C16: Residents age structure	I19: Residents age in between 15-65
	C17: Residents Income structure	I20: Gini index value of annual HH income
	C18: Gross population density	I21: Population per unit of gross land area
	C19: Vehicle ownership status	I22: HH owned private motor Vehicle
	C20: Working mobility pattern	I23: Share of private car based trip
		I24: Average annual travel distance for work (motor base)
CA5: Energy usage	C21: Electricity usage pattens	I25: Annual intensity of electricity use
		I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)
		I27: Average appliances in use (except cooling)
		I28: Average cooling appliance in use
	C22: Energy consumption for working mobility	I29: Per capita Co2 emission
CA6: Renewable Resources	C23: Solar electricity potential	I30: Annual electricity generation by roof top-solar PV

Source: Author's own

Table 3: Weights of category, criteria and indicator (Equal).

Category	Weight	Criteria	Weight	Indicators	Weight
CA	WCA	C	WC	I	WI
CA1: Smart location	0.167	C1: Proximity of surrounding landuse	0.043	I1: Edge contrast index	0.033
		C2: Proximity to employment	0.043	I2: Mean distance to major employment area	0.033
		C3: Accessibility of public transport facilities	0.043	I3: Total number of public bus station within 1km	0.033
		C4: Local connectivity	0.043	I4: Total number of nodes per sq.mile	0.033
		C5: Accessibility to electricity supply	0.043	I5: HH connected to grid feed only	0.033
				I6: HH connected to solar PV	0.033
CA2: Landscape elements	0.167	C6: State of hardscape	0.043	I7: Hard scape area	0.033
		C7: State of public green/open space	0.043	I8: Public green and open spaces	0.033
		C8: State of Road orientation	0.043	I9: Ratio of plots with straight vs curved road	0.033
				I10: Ratio of plots along EW *vs.* NS road	0.033
CA3: Building quality	0.167	C9: State of building for solar gain	0.043	I11: Amount of buildings within angle to longer axis 15 (±)	0.033
		C10: State of building surface and volume	0.043	I12: Average Ratio of the building surface to the volume	0.033
		C11: Building Aspect ratio	0.043	I13: Average Ratio of buildings length and to the width	0.033
		C12: Building organization	0.043	I14: Spatial Global Morans'I (Squared)	0.033
				I15: Average Spatial Local Morans'I (Squard)	0.033
CA4: Housing/Residents function	0.167	C13: Net housing density	0.043	I16: Housing units per unit of developed land area	0.033
		C14: Household size	0.043	I17: Average household size in the neighborhood	0.033
		C15: State of Living space	0.043	I18: Mean living space per residents in a HH unit	0.033
		C16: Residents age structure	0.043	I19: Residents age in between 15-65	0.033
		C17: Residents Income structure	0.043	I20: Gini index value of annual HH income	0.033
		C18: Gross population density	0.043	I21: Population per unit of gross land area	0.033
		C19: Vehicle ownership status	0.043	I22: HH owned private motor Vehicle	0.033
		C20: Working mobility pattern	0.043	I23: Share of private car based trip	0.033
				I24: Average annual travel distance for work (motor base)	0.033
CA5: Energy usage	0.167	C21: Electricity usage pattens	0.043	I25: Annual intensity of electricity use	0.033
				I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	0.033
				I27: Average appliances in use (except cooling)	0.033
				I28: Average cooling appliance in use	0.033
		C22: Energy consumption for working mobility	0.043	I29: Per capita Co2 emission	0.033
CA6: Renewable Resources	0.167	C23: Solar electricity potential	0.043	I30: Annual electricity generation by roof top-solar PV	0.033

Source: Author's own

Table 4: Weights on category, criteria and indicator (Expert based pair wise comparison).

Category	Weight	Criteria	Weight	Indicators	Weight
CA	WCA	C	WC	I	WI
CA1: Smart location	0.024	C1: Proximity of surrounding landuse	0.006	I1: Edge contrast index	0.008
		C2: Proximity to employment	0.012	I2: Mean distance to major employment area	0.026
		C3: Accessibility of public transport facilities	0.013	I3: Total number of public bus station within 1km	0.033
		C4: Local connectivity	0.018	I4: Total number of nodes per sq.mile	0.041
		C5: Accessibility to electricity supply	0.020	I5: HH connected to grid feed only	0.028
				I6: HH connected to solar PV	0.023
CA2: Landscape elements	0.044	C6: State of hardscape	0.015	I7: Hard scape area	0.026
		C7: State of public green/open space	0.024	I8: Public green and open spaces	0.032
		C8: State of Road orientation	0.031	I9: Ratio of plots with straight vs curved road	0.030
				I10: Ratio of plots along EW *vs.* NS road	0.026
CA3: Building quality	0.084	C9: State of building for solar gain	0.033	I11: Amount of buildings within angle to longer axis 15 (±)	0.028
		C10: State of building surface and volume	0.030	I12: Average Ratio of the building surface to the volume	0.032
		C11: Building Aspect ratio	0.022	I13: Average Ratio of buildings length and to the width	0.048
		C12: Building organization	0.029	I14: Spatial Global Morans'I (Squared)	0.030
				I15: Average Spatial Local Morans'I (Squard)	0.034
CA4: Housing/Residents function	0.164	C13: Net housing density	0.044	I16: Housing units per unit of developed land area	0.028
		C14: Household size	0.042	I17: Average household size in the neighborhood	0.018
		C15: State of Living space	0.044	I18: Mean living space per residents in a HH unit	0.029
		C16: Residents age structure	0.046	I19: Residents age in between 15-65	0.035
		C17: Residents Income structure	0.057	I20: Gini index value of annual HH income	0.033
		C18: Gross population density	0.068	I21: Population per unit of gross land area	0.052
		C19: Vehicle ownership status	0.009	I22: HH owned private motor Vehicle	0.028
		C20: Working mobility pattern	0.066	I23: Share of private car based trip	0.041
				I24: Average annual travel distance for work (motor base)	0.028
CA5: Energy usage	0.283	C21: Electricity usage pattens	0.107	I25: Annual intensity of electricity use	0.040
				I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	0.024
				I27: Average appliances in use (except cooling)	0.033
				I28: Average cooling appliance in use	0.037
		C22: Energy consumption for working mobility	0.129	I29: Per capita Co2 emission	0.051
CA6: Renewable Resources	0.401	C23: Solar electricity potential	0.137	I30: Annual electricity generation by roof top-solar PV	0.077

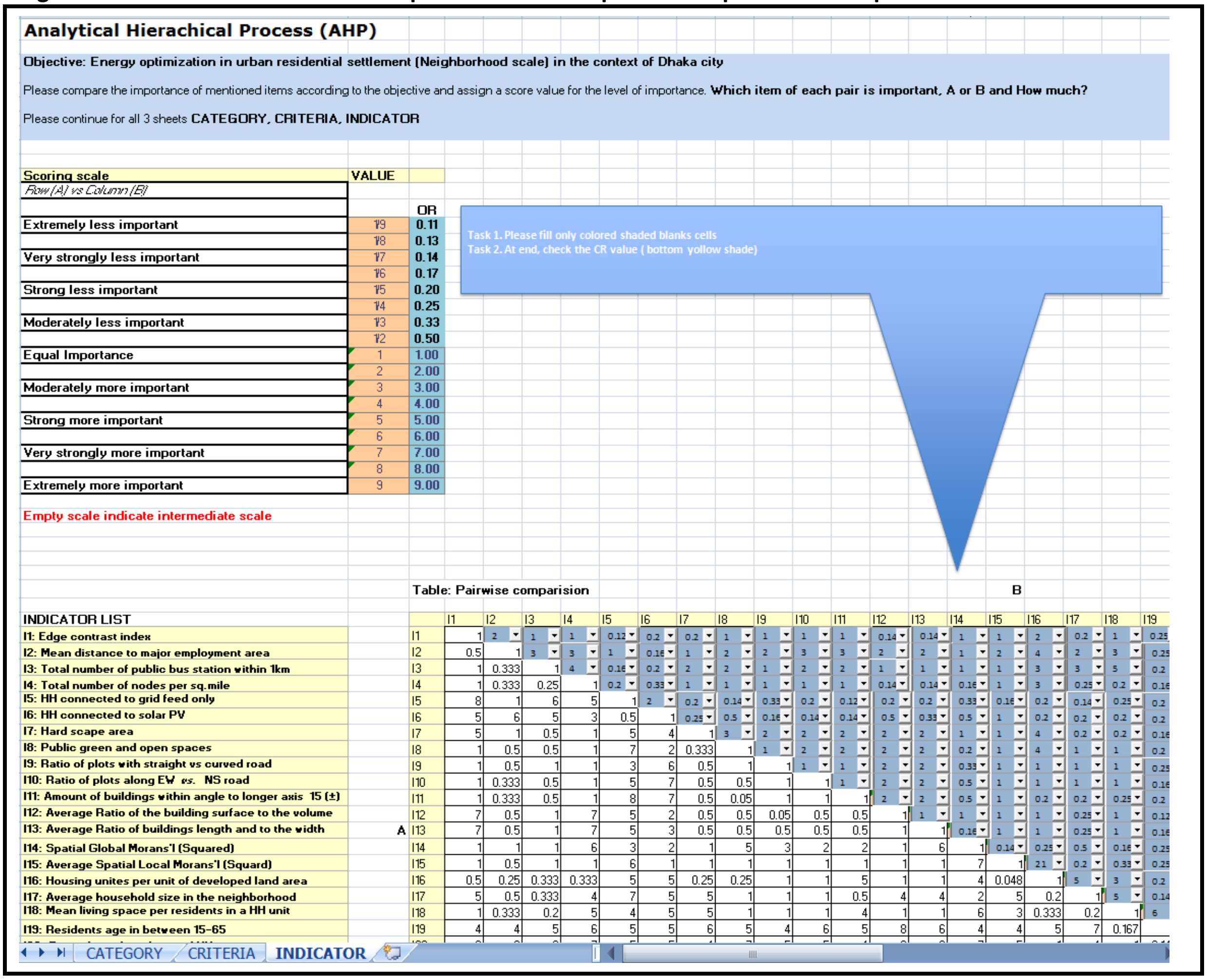
Source: Author's own, estimated based on expert ranking, 2015

Table 5: Weights of category, criteria and indicator (Hybrid).

Category	Weight	Criteria	Weight	Indicators	Weight
CA	WCA	C	WC	I	WI
CA1: Smart location	0.095	C1: Proximity of surrounding landuse	0.025	I1: Edge contrast index	0.021
		C2: Proximity to employment	0.028	I2: Mean distance to major employment area	0.025
		C3: Accessibility of public transport facilities	0.028	I3: Total number of public bus station within 1km	0.024
		C4: Local connectivity	0.031	I4: Total number of nodes per sq.mile	0.022
		C5: Accessibility to electricity supply	0.032	I5: HH connected to grid feed only	0.026
				I6: HH connected to solar PV	0.024
CA2: Landscape elements	0.105	C6: State of hardscape	0.029	I7: Hard scape area	0.024
		C7: State of public green/open space	0.034	I8: Public green and open spaces	0.025
		C8: State of Road orientation	0.037	I9: Ratio of plots with straight vs curved road	0.026
				I10: Ratio of plots along EW *vs.* NS road	0.023
CA3: Building quality	0.125	C9: State of building for solar gain	0.038	I11: Amount of buildings within angle to longer axis 15 (±)	0.021
		C10: State of building surface and volume	0.037	I12: Average Ratio of the building surface to the volume	0.025
		C11: Building Aspect ratio	0.033	I13: Average Ratio of buildings length and to the width	0.027
		C12: Building organization	0.036	I14: Spatial Global Morans'I (Squared)	0.022
				I15: Average Spatial Local Morans'I (Squard)	0.030
CA4: Housing/Residents function	0.165	C13: Net housing density	0.044	I16: Housing units per unit of developed land area	0.027
		C14: Household size	0.043	I17: Average household size in the neighborhood	0.033
		C15: State of Living space	0.044	I18: Mean living space per residents in a HH unit	0.043
		C16: Residents age structure	0.045	I19: Residents age in between 15-65	0.036
		C17: Residents Income structure	0.050	I20: Gini index value of annual HH income	0.043
		C18: Gross population density	0.056	I21: Population per unit of gross land area	0.029
		C19: Vehicle ownership status	0.026	I22: HH owned private motor Vehicle	0.037
		C20: Working mobility pattern	0.055	I23: Share of private car based trip	0.043
				I24: Average annual travel distance for work (motor base)	0.025
CA5: Energy usage	0.225	C21: Electricity usage pattens	0.075	I25: Annual intensity of electricity use	0.047
				I26: Seasonal usage ratio: summer (NOV-JAN)/winter (FEB-OCT)	0.038
				I27: Average appliances in use (except cooling)	0.052
				I28: Average cooling appliance in use	0.056
		C22: Energy consumption for working mobility	0.086	I29: Per capita Co2 emission	0.063
CA6: Renewable Resources	0.284	C23: Solar electricity potential	0.090	I30: Annual electricity generation by roof top-solar PV	0.068

Source: Author's own (mean weight in consideration of Equal and Expert weight)

Figure 1: Screen shot of interactive spreadsheet for expert based pair-wise comparison



Source: Author's own illustrations

Table 6: Results pair wise expert ranking (indicators).

Indicator ID	Weighting by Key Experts								Expert weight (Mean)
	Urban Planner	Researcher	Urban Planner	Engineer	GIS expert	Real-estate Professional	Architect	Planning Offical	
I1	0.009	0.008	0.009	0.009	0.009	0.010	0.010	0.009	0.009
I2	0.014	0.027	0.016	0.015	0.015	0.014	0.015	0.016	0.016
I3	0.012	0.025	0.012	0.012	0.014	0.012	0.012	0.012	0.014
I4	0.009	0.008	0.009	0.010	0.009	0.010	0.010	0.016	0.010
I5	0.017	0.016	0.018	0.016	0.019	0.019	0.019	0.019	0.018
I6	0.014	0.012	0.014	0.014	0.014	0.015	0.015	0.014	0.014
I7	0.013	0.017	0.013	0.013	0.012	0.013	0.013	0.015	0.014
I8	0.020	0.020	0.015	0.015	0.015	0.015	0.015	0.015	0.016
I9	0.017	0.013	0.019	0.017	0.019	0.020	0.020	0.020	0.018
I10	0.012	0.015	0.012	0.012	0.011	0.012	0.012	0.012	0.012
I11	0.008	0.014	0.008	0.008	0.008	0.008	0.009	0.008	0.009
I12	0.014	0.018	0.015	0.015	0.018	0.019	0.015	0.014	0.016
I13	0.020	0.030	0.023	0.023	0.016	0.018	0.018	0.023	0.021
I14	0.008	0.019	0.011	0.008	0.007	0.008	0.008	0.011	0.010
I15	0.019	0.032	0.026	0.026	0.025	0.026	0.026	0.026	0.026
I16	0.025	0.022	0.018	0.019	0.017	0.019	0.019	0.018	0.020
I17	0.031	0.027	0.032	0.033	0.032	0.033	0.033	0.033	0.032
I18	0.059	0.033	0.062	0.060	0.050	0.051	0.049	0.062	0.053
I19	0.037	0.050	0.037	0.037	0.038	0.039	0.037	0.037	0.039
I20	0.045	0.054	0.050	0.050	0.057	0.057	0.049	0.050	0.052
I21	0.023	0.034	0.021	0.025	0.023	0.025	0.021	0.025	0.025
I22	0.050	0.035	0.041	0.041	0.038	0.040	0.039	0.041	0.041
I23	0.053	0.049	0.054	0.055	0.050	0.051	0.051	0.052	0.052
I24	0.017	0.033	0.010	0.010	0.035	0.012	0.010	0.010	0.017
I25	0.062	0.061	0.063	0.063	0.053	0.053	0.063	0.063	0.060
I26	0.041	0.054	0.041	0.041	0.036	0.037	0.042	0.041	0.042
I27	0.075	0.044	0.074	0.075	0.078	0.078	0.075	0.069	0.071
I28	0.082	0.055	0.082	0.083	0.081	0.082	0.082	0.079	0.078
I29	0.088	0.082	0.088	0.089	0.106	0.106	0.099	0.086	0.093
I30	0.107	0.092	0.105	0.108	0.097	0.097	0.114	0.101	0.103

Source: Author's own, estimated based on expert ranking, 2015
Note: Mean Consistency Ratio is 0.39

In der Schriftenreihe des Instituts für Geodäsie und Geoinformation der Rheinischen Friedrich-Wilhelms-Universität Bonn sind erschienen:

Heft 57 2017	Sujit Kumar Sikder Exploring Urban Structure to Approach Energy Optimization
Heft 56 2017	Asad Asadzadeh Conceptualizing the concept of disaster resilience: a hybrid approach in the context of earthquake hazard
Heft 55 2017	Stefan Paulus Potentiale von Laserscannern zur Phänotypisierung von Pflanzen für den Einsatz im Hochdurchsatz-Screening
Heft 54 2017	Proceedings of the First International Workshop on VLBI Observations of Near-field Targets
Heft 53 2016	Christian Eling Entwicklung einer direkten Georeferenzierungseinheit zur Positions- und Orientierungsbestimmung leichter UAVs in Echtzeit
Heft 52 2016	Maike Schumacher Methods for assimilating remotely-sensed water storage changes into hydrological models
Heft 51 2015	Christoph Holst Analyse der Konfiguration bei der Approximation ungleichmäßig abgetasteter Oberflächen auf Basis von Nivellements und terrestrischen Laserscans
Heft 50 2015	Lutz Rolf Roese-Koerner Convex Optimization for Inequality Constrained Adjustment Problems
Heft 49 2015	Jan Martin Brockmann On High Performance Computing in Geodesy Applications in Global Gravity Field Determination
Heft 48 2015	Judith Leek The application of impact factors to scheduling VLBI Intensive sessions with twin telescopes
Heft 47 2015	Thomas Artz Determination of Sub-daily Earth Rotation Parameters from VLBI Observations
Heft 46 2015	Roelof Rietbroek Retrieval of Sea Level and Surface Loading Variations from Geodetic Observations and Model Simulations: an Integrated Approach
Heft 45 2014	Ehsan Forootan Statistical Signal Decomposition Techniques for Analyzing Time-Variable Satellite Gravimetry Data
Heft 44 2014	Erich Weiß Lebensbilder der preußischen Verwaltung des 19. und 20. Jahrhunderts im Wandel Eine Sammlung biographischer Miniaturen
Heft 43 2014	Neysa Jacqueline Setiadi Assessing People´s Early Warning Response Capability to Inform Urban Planning Interventions to Reduce Vulnerability to Tsunamis Case Study of Padang City, Indonesia

Heft 42 Nils Leber
2013 Entwicklungsperspektiven metropolitaner Peripherien im Rahmen Stadtregionaler Planungs- und Entwicklungsprozesse am Beispiel Nordrhein-Westfalen

Heft 41 Sophie Schetke
2013 Socio-environmental impacts of settlement growth under conditions of fostered infill development: a methodological framework for a multicriteria assessment

Heft 40 Ribana Roscher
2013 Sequential Learning Using Incremental Import Vector Machines for Semantic Segmentation

Heft 39 Michael Ying Yang
2013 Hierarchical and Spatial Structures for Interpreting Images of Man-made Scenes Using Graphical Models

Heft 38 Sabine Daniela Bauer
2013 Automatische Detektion von Krankheiten auf Blättern von Nutzpflanzen

Heft 37 Martin Drauschke
2013 Ein hierarchischer Ansatz zur Interpretation von Gebäudeaufnahmen

Heft 36 Timo Dickscheid
2013 Robust Wide-Baseline Stereo Matching for Sparsely Textured Scenes

Heft 35 Alexander Barth
2013 Vehicle Tracking and Motion Estimation Based on Stereo Vision Sequences

Heft 34 Richard Steffen
2013 Visual SLAM from image sequences acquired by unmanned aerial vehicles

Heft 33 Till Rumpf
2013 Finding spectral features for the early identification of biotic stress in plants

Heft 32 Christian Siemes
2012 Digital Filtering Algorithms for Decorrelation within Large Least Squares Problems

Heft 31 Silvia Becker
2012 Konsistente Kombination von Schwerefeld, Altimetrie und hydrographischen Daten zur Modellierung der dynamischen Ozeantopographie

Heft 30 Annette Eicker / Jürgen Kusche (eds.)
2013 Lecture Notes from the Summer School of DFG SPP1257 Global Water Cycle

Heft 29 Matthias Siemes
2012 Ein Beitrag zur koordinatengesteuerten Aussaat von Rübenpflanzen mittels Multi-Sensor-System und Filteransatz

Heft 28 Jörg Schmittwilken
2012 Attributierte Grammatiken zur Rekonstruktion und Interpretation von Fassaden

Heft 27 Markus Rembold
2012 Die Anerkennung und Feststellung von Grundstücksgrenzen
Ein Beitrag zur Entwicklung des Liegenschaftskatasters im Lande Nordrhein-Westfalen in Vergangenheit, Gegenwart und Zukunft

Heft 26 Lihua Li
2012 Separability of deformations and measurement noises of GPS time series with modified Kalman filter for landslide monitoring in real-time

Heft 25 2012
Benedikt Frielinghaus
Ökonomisches Entscheidungstool zur Wohnbaulandentwicklung
Wirtschaftlichkeitsanalysen potenzieller Wohnbauflächen auf der Ebene des Flächennutzungsplanes

Heft 24 2011
Enrico Kurtenbach
Entwicklung eines Kalman-Filters zur Bestimmung kurzzeitiger Variationen des Erdschwerefeldes aus Daten der Satellitenmission GRACE

Heft 23 2011
Sarah Böckmann
Robust determination of station positions and Earth orientation parameters by VLBI intra-technique combination

Heft 22 2011
20th Meeting of the European VLBI Group for Geodesy and Astronomy
Proceedings

Heft 21 2011
Philipp Zeimetz
Zur Entwicklung und Bewertung der absoluten GNSS-Antennenkalibrierung im HF-Labor

Heft 20 2011
Alessandra Roy
Effects on the Geodetic-VLBI Observables Due to Polarization Leakage in the Receivers

Heft 19 2011
Dietmar Weigt
Auswirkungen von Flughäfen insbesondere von Fluglärm auf den Immobilienmarkt am Beispiel des Marktsegments „individuelles Wohnen“

Heft 18 2011
Anno Löcher
Möglichkeiten der Nutzung kinematischer Satellitenbahnen zur Bestimmung des Gravitationsfeldes der Erde

Heft 17 2010
Basem Elsaka
Simulated Satellite Formation Flights for Detecting the Temporal Variations of the Earth’s Gravity Field

Heft 16 2010
2nd International Conference on Machine Control & Guidance
Proceedings

Heft 15 2009
Alexandra Weitkamp
Brachflächenrevitalisierung im Rahmen der Flächenkreislaufwirtschaft

Heft 14 2008
Akbar Shabanloui
A New Approach for a Kinematic-Dynamic Determination of Low Satellite Orbits Based on GNSS Observations

Heft 13 2008
Frank Friesecke
Stadtumbau im Konsens!?
Zur Leistungsfähigkeit und Fortentwicklung des städtebaulichen Instrumentariums unter Schrumpfungsbedingungen

Heft 12 2008
Heinz Rütz
Zur Kostenanalyse der privaten Umlegung als Teil der konsensualen integrierten Baulandentwicklung

Heft 11 2008
Gaby Alexandra Boele-Keimer
Kommunales Kennzahlenmanagement am Beispiel von Vermessungs- und Katasterämtern in Nordrhein-Westfalen

Heft 10 2008
Annette Eicker
Gravity Field Refinement by Radial Basis Functions

Heft 9 2008
Torsten Mayer-Gürr
Gravitationsfeldbestimmung aus der Analyse kurzer Bahnbögen

Heft 8 2008	Boris Kargoll On the Theory and Application of Model Misspecification Tests
Heft 7 2008	Hamza Alkhatib On Monte Carlo Methods
Heft 6 2008	Klaus Borchard Annäherungen an Städtebau und Raumentwicklung
Heft 5 2008	Jens Jähnke Zur Teilmarktbildung beim Landerwerb der öffentlichen Hand
Heft 4 2008	Atef Abd-Elhakee Makhloof The Use of Topographic Isostatic Mass Information
Heft 3 2008	Markus Vennebusch Singular Value Decomposition and Cluster Analysis
Heft 2 2007	Christian Beder Grouping Uncertain Oriented Projective Geometric Entities
Heft 1 2007	Klaus Börger Geodäsie und Quantenphysik

Vertrieb: Rheinische Friedrich-Wilhelms-Universität Bonn
Institut für Geodäsie und Geoinformation
- Bibliothek -
Nußallee 17
53115 Bonn

Tel.: +49 (0)228 73-3566
Fax: +49 (0)228 73-2988

Internet: http://www.igg.uni-bonn.de

ISSN 1864-1113