Strategies to Improve Urban Energy Efficiency for Urban Resilience

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Abstract. Greenhouse gas (GHG), which is a determining factor in climate change is a result of human activities, namely climate change is human-caused (anthropogenic). Cities, where 60% of the world's population of approximately 7.3 billion living today, are responsible for 60-80% consumption of energy, which is the lifeblood of intense human activities, thus at least 70% of GHG. Nevertheless, cities are the cause of climate change and other global environmental problems, as well as the innovation centres and laboratories to deal with their impact. With climate change becoming more explicit and active in the 21st century, researchers, governments and international institutions question cities’ strength/vulnerability against these problems, especially their energy production and consumption patterns that cause GHG, and they anticipate that urban resilience be the motivating force for urban policies. The widespread and effective use of renewable energy is regarded as an influential tool against climate change. However, this should be endorsed by spatial strategies. In the light of this approach, this study evaluates the urban form, building design and production technologies that are focused on energy efficiency and renewable energy use.

1. Introduction

Cities are engines of the economy, accounting for more than 80% of global gross domestic product (GDP). Cities are complex systems in which thousands of economic, social, cultural, institutional, and natural constructs and environmental threats, affecting individual and communal welfare, are intertwined. In accordance with the power and capacity of this system, cities may be resilient or vulnerable to disasters, hazards, shocks and stresses that are dangerous and destructive. They may be of natural, technological or social origin. Examples are earthquakes, floods and hurricanes, but also outbreaks of violence, migration crises, water contamination, nuclear incidents, economic recessions and health epidemics. While stresses are long-term tendencies, and are, as such, predictable, the others are unforeseeable events.

Among cities, there exist inequalities stemming from their development stages, economic bases, and population, and further disparities caused by them. With the increase in urban population (from 3.9 billion at present to approximately 6.3 billion in 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa) and the decline in rural population (form 3.4 billion at present to 3.1 billion in 2050) [1], it is evident that the scale and impact of dangerous and destructive incidents in
cities will also ascend. At present, even large cities may be unguarded to the significant economic, social, environmental, and institutional impacts of any given shock, therefore, to risks. As such, it is of utmost significance that “resilient cities be promoted” for sustainability and inclusive urban development by means of key global agreements of the 21st century, such as the New Urban Agenda-UN, 2016, the Agenda 2030 for Sustainable Development-UNDP, 2015, the Paris Agreement on Climate Change-UNFCCC, 2015, Kyoto Protocol-UNFCCC, 2020.

Despite the fact that resilience is increasingly a part of fields such as climate change, sustainability, and risk of natural disasters and of scientific and political discourses, it is a relatively new concept in city planning. As a motivating force in urban policies, this concept may be defined as a theoretically more integrated, multi-disciplinary and multi-functional planning system that regards stakeholders as central in the planning process and planners as innovative and creative [2, 3]. Urban Resilience (UR) is the coping force and/or defense mechanism of urban sectors (such as social protection, education, energy, health, information-communication, economy, finance, logistics, waste, transportation and accessibility, water and sanitation, and food system) and stakeholders against present and/or potential dangerous and destructive events and other elements repressing the city (such as migration, epidemic, terror, and war). The degree to which urban sectors are impacted by acute shocks and chronic stresses is a vital criterion for UR. Especially resilience to climate change is the most significant goal of sustainable development. On the other hand, with the current 60% rate of choosing to or having to live in cities, cities are responsible for the consumption of natural resources at the rate of 75% [4], for energy consumption at the rate of 60-80% [5], and consequently for greenhouse gas (GHG) emission at the rate of 70-76% [6, 7, 8]. In other words, it is known that as the city’s population and socio-economic development level increases, so does its energy need, based on high or low urbanization dynamics, and hence, its carbon dioxide (CO₂) emissions [9]. As such, cities incur sources for acute or chronic stresses relating to climate change [10, 11]. For this reason, in the advancement of UR, increasing the level of renewable energy to solve problems relating to energy dependency and supply is a vital strategic goal also of sustainable urbanization. This issue is emphasized in numerous research and international agreements on UR, its principles and criteria. Insights into production and consumption perspectives also signify that cities can significantly decrease their material and energy flows through urban form and built environment [2, 11, 12, 13, 14]. Thus the aim of this study is to derive inferences towards an urban typology that determines the current status and tendencies of energy use and takes into consideration reduction options in the future at the urban level. As such, urban macro form is being designated as one of the resilience-oriented urban planning principles.

In this framework, recent literature relating to energy sources, their use, and reduction potential is analyzed with focus on three points: 1) the context of UR and energy, 2) renewable energy sources, energy production in the world and in Turkey, and 3) the efficiency of urban form, urban construction stocks and urban consumption patterns in reducing urban energy use.

2. Energy for Urban Resilience
The concept of UR is loosely defined as a city’s ability to cope with destructive incidents, to renew itself, and to maintain its basic functions. In the light of this approach, academic literature on UR is surveyed for an understanding of 1) its theoretical origins and development, 2) its energy context, and 3) the significance and efficiency of city planning for UR.

The term “resilience” is used under many subjects, from law to politics, psychology to social studies, and mechanics to production. It was used for the first time in the 1960s for the capacity to protect the ecosystem in the face of problem-causing situations, and in the 1970s in the context of ecology through “resilience thinking” [15, 16, 17]. In the 1990s, it became widespread through the concepts of engineering, ecological, and evolutionary resilience [18, 19]. Yet, it is not quite clear what resilience means, beyond the simple assumption that it is good to be resilient. The reason for this may
be explained by the fact that resilience is a variable and dynamic process shaped according to problems. At present, this term is articulated along with global problems, and used in studies on economics and city planning [15, 20]. In addition to these efforts at definition, there are options being generated on issues focusing on how urban systems can be resilient against global threats and on UR principles, components, and policies. UR is defined by various approaches such as Resilience Connected, Sustainable Resilience, Socioeconomic, Climatic, Geographic, Systemic Behaviour, Urban Metabolism, and, accordingly, through various components such as redundancy, diversity, efficiency, autonomy, strength, collaboration, interdependency, adaptability [21], cooperation, modularity, mobility [13]. Work on the categorization of these components (Built Environment, Social Dynamics, Governance Networks, Metabolic, Supply Chains, and the like) [22] and the identification of some evaluation criteria (infrastructural, economic, social, demographic, ecological, and the like) [2] is ongoing. At present, three main approaches for UR are widespread: “socio-ecologic, sustainability, and reducing the risk of natural disasters” [23]. In fact, these approaches are intertwined, and they should be addressed through policies and strategies developed by interdisciplinary cooperation. “Current preparedness resistance and performance” are application strategies. The first, preparedness ability, observes current circumstances, and provides the city to be prepared for present and future risks through potential solutions. The performance stage is directed at perpetuating and preserving the city’s basic functions, and at managing, re-developing, protecting resources [24]. Efficiency, which is at the core of each of these various approaches or policies, relies on processes involving energy efficiency, reduction of energy consumption, effective and widespread use of renewable energy resources, energy production and flow, its supply and consumption stages, and its recuperation. Nevertheless preparedness and performance in the context of energy is limited to energy sources. Based on their use, these sources are defined as renewable and non-renewable energy sources, and based on their convertibility, as primary – if they have been transformed or converted, and as secondary – for the energy produced through conversion (Table 1).

**Table 1. The Categorization of Energy Resources**

| ENERGY RESOURCES | Usability | Convertibility |
|------------------|-----------|----------------|
| Non-renewable Energy | Renewable Energy | Primary |
| Fossil Sourced | Hydraulic | Coal |
| Coal | Sun | Electricity |
| Oil | Biomass | Oil |
| Natural Gas | Wind | Natural Gas |
| Core Sourced | Geothermal | Nuclear |
| Uranium | Ocean Thermal | Biomass |
| Thorium | Tide and Waves | Nuclear |
| | Hydrogen | Nuclear |

As more technological products were in use in parallel with the rapidly advancing technology towards the end of the 20th century, the need for energy, hence consumption, has increased. Energy is the bloodstream of cities that empower transportation, industrial production, commerce, public works, lighting, air conditioning, and numerous other activities relating to people. As cities use up approximately 75% of global primary energy, they play a vital role in advancing and shaping global energy transition. In this case, urban areas have high levels of air pollution combined with GHG emissions, and 98% of cities with populations over 100,000 in low- and middle-income countries do not meet the air quality [18]. Therefore, new approaches to energy use (green energy, clean energy, sustainable city, UR, and the like) are being developed. More specifically, with the impact of climate change and the experience of energy crises, energy production and consumption processes are being
questioned, and new projections are being shaped. In this process, renewable energy (RE) and/or renewable energy technologies (RETs) – though not yet economical – hold a central role in decreasing climate change by means of further energy efficiency and in providing cleaner air, therefore, in UR. To this end, this study evaluates the efficiency of the urban built environment for the planned use of energy sources in the city and for the widespread use of RE. That is because, while RETs are developed by the global energy sector and RE usually by national policies, many precautions (such as building and transportation sectors) are taken at the level of the city.

2.1. Renewable Energy Sources and Production
RE signifies self-renewable sources that will remain un-exhausted in a considerably distant future (Table 1). RE is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment. However, it is possible to utilize biomass at a greater rate than it can grow, or to draw heat from a geothermal field at a faster rate than heat flows can replenish it [25]. 80% of the world’s energy demand is provided by fossil fuels (oil, natural gas, and coal). The damage done on the atmosphere by the gases and particles emerging when these fuels are burnt, such as CO₂, Sulfur oxide compounds (SOx), Nitrous oxide compounds (NOx) and Methane (CH₄), are among the causes of global warming, therefore, of climate change. Thus, RE(s) are at the center of the transition to a less carbon-intensive and more sustainable energy system and/or UR.

2.2. Global Renewable Energy Demand and Production
Future energy demand is likely to increase due to climate change, but the magnitude depends on many interacting sources of uncertainty. Population expansion, economic growth, shifts in the sectoral composition of economies, behavior of individuals and organizations, and the pace of technological development are multiple sources of uncertainty and variable that will interact to determine the future demand of different energy sources across regions. As such, projections in different models and scenarios, carried out through these variables in different geographies, also demonstrate differences. Nonetheless the common view that as population and socio-economic development level increases, so does the demand for energy is accepted [11, 26, 27, 28, 29, 30]. On the other hand, it is expected that the use of RE will become widespread through the foresight that inefficient fossil fuel subsidies should be removed according to the “Net Zero by 2050 Analysis” of the International Energy Agency (IEA), which is at the center of policies on the struggle against climate change.

Commonly used sources of RE in the world are hydrolic energy, geothermal energy, biomass energy, solar power, and wind power. In IEA’s Renewables 2019 report, it is estimated that the world’s RE-based total energy capacity will increase by 50% (approximately 1,200 gigawatts-GW) between the years 2019 and 2024. Solar photovoltaic (PV) accounts for 60% of the increase. The share of renewables in global power generation is set to increase from 26% at present to 30% in 2024 [31]. This increase is significantly below the global sustainable energy goals. The report highlights the three main challenges that need to be overcome to speed up the deployment and the production of renewables: policy and regulatory uncertainty, high investment risks and system integration of wind and solar PV. The cost of producing electricity through distributed Solar PV systems is below the retail electricity prices in many countries. It is estimated that, by the year 2024, these costs will reduce by 15% to 35%, thereby encouraging this technology throughout the world. In IEA’s Renewables 2020 report, it is indicated that global energy investments will increase in 2021 but that, especially in rising markets and developing economies, RE will not be applied adequately. Notwithstanding, it is expected that renewable heat investments, oriented by China, the European Union, India, and the US, will increase by 20% between the years 2019 and 2024 [32].
2.3. Renewable Energy Production/Consumption in Turkey

As there is not enough RE investment in Turkey despite the increasing energy demand, even the ascending trend of the established power based on RE sources falls inadequate in reducing the impact of climate change and in sustaining the ecosystem. RE, which was 25.6 GW in 2013, increased by 10% to approximately 47 GW by September 2020 [33]. It is anticipated that the established power will reach 109.5 GW by the year 2023 [34]. Based on the 2019 capacity data, 28,503 GW hydropower, 19,949 GW wind energy, 7,803 GW solar energy, 2,650 GW biomass energy, 2,159 GW biogas and 7,431 GW geothermal energy is produced in Turkey [33]. In the 2012-2023 period, it is planned that 125 GW of additional production will be implemented in order to meet the 75.4% increase in demand, that the RE share in electricity production will be increased to 30%, and that, through various technologies, RE will be increased (at least 34 GW hydropower, 20 GW wind energy, 1 GW geothermal energy, 11 GW solar energy and 1 GW bioenergy) and communication network will be enhanced (transmission line of 60,717 kms and distribution unit of 158,460 MVAs). It is deemed significant that the bio-fuel sector (bio-diesel and bio-ethanol) be advanced by means of support from the agriculture sector. Hence, it is intended that the share of RE sources in the general energy consumption is increased at least by 20% by 2023 [34]. Investments are being made so that energy density is decreased by 20%, at minimum, by 2023, and that it meets at least 30% of the demand for electrical energy and 10% of the transportation sector. The share in the established power of plants producing electricity has increased to 50.4% in the first quarter of 2020 (which was 33% in 2005 and 44.8% in 2019). Hydro-Electric Plants (63.7%), Solar Energy Plants (13.4%) and Other Renewable Energy Plants (17%), and, implemented in 2020, have been influential in this increase [34]. Electricity production of RE sources has been the only energy source to record growth in 2020 through its 1.5% increase. While its share in electricity production was 32.5% in 2019, it is planned to be 38.8% in 2023 [35]. The decrease in electricity consumption, therefore, its production, during the Covid-19 pandemic has resulted in thermal power based electricity production. On the other hand, while the search for oil in the Mediterranean and for natural gas in the Black Sea is ongoing, investments in and research-development on atomic energy and polygenous hybrid technology are also continued.

3. Urban Built Environment and Energy Consumption Patterns in Urban Energy Efficiency

Urban areas are expected to absorb increases in world population, adding at least 3 billion urban dwellers by 2050 [1]. In this process, along with natural disasters based on climate change, unaccountable urbanization (insensible consumption of natural resources, unrenewable energy consumption, and the like), socio-economic and cultural stresses that hamper progress (poverty, inequality, injustice) and environmental problems (pollution, loss of biodiversity, decrease in ecosystem resources, and the like) also affect UR negatively. As cities are both sources of these problems and innovation areas for dealing with them, and as they are laboratories, in theory and in practice, for resilience, solution options relating to urbanization and the built environment become crucial. Hence, through UR-based sustainable city models (new urbanism, smart urbanism, compact city, citta slow, eco-city, and the like), alternative plan types based on local circumstances, such as climate and topography and socio-economic level, are being addressed in various cities of the world. In this manner, through efficient energy planning and design approaches, urban macro form options are being evaluated and their fundamental principles are being set. Based on these reasons, the impact of cities – and of urban planning and design – on the global climate is becoming increasingly important. Specifically, with urban energy use in 2005 being tripled by 2050, city planning has on its agenda how cities will spatially develop in the future and, especially, how the urban form will impact energy consumption patterns [36].

3.1. Urban Macro form Options for Energy Efficient

As GHG, which is a factor in climate change in the present century, is a result of human activities, climate change is referred to as “antropogenic” (human-caused) climate change [37]. While global population has increased by four times in the last century, the surface area of cities – in which
approximately 60% of the population live (estimated to go up to 70% by 2023) – at least doubled, in proportion with the population, and their material and energy use multiplied ten times. Unmethodically and inadequately administered cities are territorially expanding through unsustainable production and consumption patterns. By this expansion, cities are responsible for 67-76% of global energy use and for 71-76% of CO₂ emissions, and therefore, for climate change [7]. City planning may be influential in solving this problem through its power to shape the city that impacts all urban activities and the amount of energy required for them (and to some extent the type of energy). In other words, cities with strong zoning laws and land-use controls may be determinative over energy demands by means of structural factors such as more easily affecting the urban macro form and residence density and encouraging multi-use development (limiting the segregation of residential, commercial and industrial activities). As such, it is possible to form the cities’ capacities for RE and to integrate the solutions appropriate for their authentic circumstances and needs into the city planning processes.

According to policy makers, since urban growth is a natural reflection of free markets, cities’ macro form should be planned with less government intervention – along with significant historical, economic, and social issues – and in line with sustainability principles. Although national energy policies shape actions at the local level, municipalities’ determination in planning and implementing factors and drivers (Figure 1) directly related to urban space in relation to the issue of energy is crucial [8]. Despite the fact that these factors and drivers vary according to the cities’ unique circumstances, urban macro form offers beneficial options to reduce the effects of climate change, thereby increasing UR.

Figure 1. Factors and drivers motivating municipal energy policies and shaping cities’ roles in the energy transition [8]

Urban sprawl usually varies according to the urban dwellers’ income level and life style, to regional production (such as economic and industrial activities) types and large service areas (such as harbors, airports, and hospitals) [9]. To illustrate, urbanization and industrialization in relation with the 9.8% average economic growth in China in the last three decades has led to the rapid increase in energy consumption and CO₂ emission and to China being the 2nd in the world [37]. In the urban sprawl, the socio-economic level (the choice for spatial and social segregation, vehicle ownership, and the like) is also determinant. For instance, factors supporting automobile-dependent sprawl in the US include comparatively inexpensive gasoline, extensive highways, building-height limits, and parking
requirements [38]. In such cities where individual motor vehicle transportation and detached housing are common, more energy is demanded for heating and for cooling, as well as for transportation. Many studies relating the urban form to daily travel, too, indicate that, in the urban sprawl, globally 500 Exa-Joules (11942 MTOEs) of primary energy consumption per year and 60 billion tons increase raw material extraction by 30-40% [9], and CO$_2$ emissions by 14% [36].

In energy efficiency, the Compact City Model, instead of the urban sprawl, is based on the belief that while aiming to provide energy and resource efficiency in relation to multi-purpose land use and density increase, lively and active urban spaces may be created at the same time. At present, this urban model is evaluated according to the interest areas of different organizations. OECD has addressed the compact city approach environmentally and defined criteria on dense and close settlement-development pattern, public transportation systems and accessibility. All of these criteria have been related to energy, and decrease in energy consumption and local renewable energy production have been proposed [39]. By the Eco-City Model and/or as an environmentally healthy city, the European Union and UNDP regard the compact macro form more influential in providing energy efficiency at the utmost level through the “source efficient settlement approach” for sustainable settlements. As for built environment criteria, it is anticipated that the re-use of the current urban space and existing buildings be increased, the demand for new residential areas and buildings be decreased, multi-use be promoted, and the time/distance between time and space be shortened [40, 41]. In city planning practices, the compact city macro form is preferred despite its many disadvantages in relation to energy efficiency.

3.2. Energy Efficient Buildings

As of the 1990s, and with reference to sustainability, the energy efficient building approach has been the issue of priority in all disciplines related to building production. While being supported by laws, this approach introduces novelties to the field of material and technology, as well as to architectural design [42]. New design criteria that aim at using energy efficiently, preserving resources, decreasing the damage done to the environment by the construction sector, and producing of renewable energy by the building are being redefined. These criteria vary according to design parameters which are defined as variables of the built environment that affect the values internal climate elements would take in relation to external climate elements. These are, in short, the shaping of the building shell and form according to physical environment data, the possibilities of benefiting from solar power at the maximum, the forming of padding between the inside and outside of the building, the choosing of environment-friendly ecological construction material and components that use and protect energy efficient siding systems and renewable energy sources and that require minimal upkeeping. In this framework, design principles comprising flexible solutions, through the modular system, which provide function-appropriate sizes, are simple and of geometrical form, and which enable reuse are regarded significant. As such, not only newly-constructed buildings but also old buildings that go through interventions appropriate to the criteria can be made more economical and more comfortable.

On the other hand, after the energy crisis of the 1970s and along with global sanctions, high-rises, parallel to the compact city form, are taking their place in the city for the purpose of increasing energy performance and decreasing the carbon footprint [42]. As of the 1990s, many highly ecological and energy efficient strategies have been applied in high-rises, such as central atrium (Commerzbank-Franfurt, 1997), rooftop garden and skygarden (One Bryant Park-New York, 2008; Manitoba Hydro Place-Winnipeg, Canada, 2008), green roof (California Science Museum-1997), smart shell and/or application of double shell (GSW Headquarters Building-Frankfurt, 1999; Hearts Tower-New York, 2001), smart siding set up and apparatuses (British Pavilion, Expo Fair-Seville, 1992; Delft Technical University Library-Netherlands, 1998), and natural ventilation (Swiss Headquarters, Great Britain, 2004). While the need for energy in high-rises is aimed to be reduced through these passive design approaches, the required energy load in high-rises in the last decade has been provided by renewable
sources at the building site. Through this approach, as wind turbines of different scales (World Trade Centre-Bahrain, 2008; Pearl River Tower-Guangzhou, 2010), PV batteries/panels (Swiss Re Tower-London, 2004), sun collectors or dynamic solar façade (Eco Building, Istanbul Technical University-Istanbul, 2007; Varyap Meridian Shopping Center-Istanbul, 2011), integrated heat and power ( cogeneration) systems (One Bryant Park Tower-New York, 2009) and fuel cells (Conde Nast Bulding-New York, 2000) are integrated into the building, investors and engineers should work together in building construction. In high-rises, known in the past as collective consumers of energy and natural resources, significant developments are on the agenda at present towards becoming “net-zero energy building” through technological support. As a result, energy management in all of the buildings has become an increasing trend in the use of renewable energy resources, as they become smart and efficient [43, 44]. Therefore, it can say that - as exemplified above after 2010 - the potential of these buildings is concerned with their energy sustainability, safety and reliability.

4. Conclusions and Recommendations

Despite the fact that 60% of the world’s population live in cities and that less than 3% of the world’s surface area is encompassed by them, cities are responsible for 70-76% of CO$_2$ emissions relating to global energy. Hence, as cities continue to spatially expand and urban populations continue to increase, thereby being the source of climate change and other global environmental problems, they also take on the function of solution-oriented innovation centers and laboratories. Although cities are not equal in coping with difficulties and uncertainties, such as their settlement styles, populations, development stages or economic bases and climate change, UR is of vital importance for each and every city. While UR is being defined in different progress sectors, although the focus of the energy context is on renewable energy, cities’ CO$_2$ emissions can be reduced through efficient urban form and built environment. Since time and space congestion in the city, due to developments in the communication-transportation technologies of the 21st century, has led to the loss of clarity in urban space borders, the compact urban form, instead of urban sprawl, is regarded as a spatial strategy that increases urban resilience. Nevertheless, this strategy should be supported by energy efficient high-rises. Therefore, although global and national energy policies are determinative in the formation of the energy efficient city, municipalities’ determination and power in applying this strategy to many significant construction activities, building production technologies and renewable energy production/consumption is becoming more crucial.

Considering that, in Turkey, the construction sector constitutes a major percentage in energy spending and that renewable energy production is very limited, it is imperative that all related disciplines, investors, urban dwellers, lawmakers and municipalities be responsive to this issue.

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