Environment, Development and Sustainability (2020) 22:5129–5152
https://doi.org/10.1007/s10668-019-00417-1

Sustainable urban planning strategies for mitigating climate change in Saudi Arabia

Ismaila Rimi Abubakar[1] · **Umar Lawal Dano**[2]

Received: 27 October 2018 / Accepted: 5 July 2019 / Published online: 16 July 2019

Abstract
There is a growing attention on the role of rapidly growing developing countries in mitigating climate change, especially in curbing the emissions of greenhouse gases. Estimates show that in the year 2011, carbon dioxide (CO_2) emissions from developing countries constituted about 63% of the world's total, compared with only 37% for developed countries. Thus, developing countries must be an integral part of global actions toward combating climate change. In Saudi Arabia, the energy use per capita of 6937.23 kg of oil equivalent in 2014 was 3.6 times the global average and the per capita CO_2 emission of 19.53 metric tons was the seventh highest. With sensitive ecosystems, limited freshwater resources and substantial coastal developments, the country is vulnerable to climate change. As such, the country has recently initiated some sustainable urban planning strategies in its major urban centers as part of its climate change mitigation and adaptation efforts. However, few studies have assessed the extent of the implementation of the strategies. Based on secondary data analysis, this article found that the implementation of the strategies is at infancy with urban greening, public transportation, and green building projects gradually gaining prominence. The paper recommends more focus on rising building and population density, mandating mixed land uses, as well as public enlightenment and engagement about climate change impacts and energy choices.

Keywords Adaptation and mitigation · Building density · Carbon emissions · Climate change · Compact cities · Environment · Greenhouse gases · Sustainability · Transportation · Urban planning

✉ Ismaila Rimi Abubakar
irabubakar@iau.edu.sa

[1] College of Architecture and Planning, Imam Abdulrahman Bin Faisal University (formerly, University of Dammam), P.O. Box 1982, Dammam 31441, Saudi Arabia

[2] Department of Urban and Regional Planning, College of Architecture and Planning, Imam Abdulrahman Bin Faisal University (formerly, University of Dammam), P.O. Box 1982, Dammam 31441, Saudi Arabia

1 Introduction

Recent decades have witnessed increasing attention on the role of rapidly growing developing countries in mitigating climate change, especially in reducing their greenhouse gas (GHG) emissions, and heavy reliance on fossil fuels for energy generation and transportation. Estimates show that in the year 2011 carbon dioxide (CO_2) emissions from developing countries, most of which emanate from urban areas, constituted about 63% of the world's total, compared with only 37% for developed countries (Center for Global Development 2015). Due mainly to their large population size and density, and intense socioeconomic activities, urban areas throughout the world are intensely contributing to finite resource consumption and a substantial upsurge in GHG emissions (Carter et al. 2015; Gouldson et al. 2016; VijayaVenkataRaman et al. 2012). Urban areas, covering only about 3% of the earth surface, consume about 80% of global energy and account for around 70% of global CO_2 emissions (World Bank 2010, p. 15)—with pervasive impacts on humanity and the entire ecosystem and high degree of vulnerability (Bulkeley et al. 2009; Hoornweg et al. 2011). Thus, urban areas must be central in global actions toward combating climate change and fostering sustainability (Balaban and de Oliveira 2017; Chen et al. 2011; Kammen and Sunter 2016; Norton et al. 2015).

Urban areas are also global leaders in tackling climate change through GHG mitigation, climate adaptation, building resilience and fostering sustainability (Araos et al. 2016; Spiess 2008; Solecki et al. 2015). The importance of cities in combating climate change has been reflected in international charters and meetings, including the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto protocol—a non-binding commitment by signatories to lower emissions of GHGs, and the Paris Agreement ratified by 176 member nations to maintain global warming less than 2°C above pre-industrial temperatures (Bai et al. 2018). Similarly, the Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report has dedicated a chapter on the role of "human settlements, infrastructure, and spatial planning" in mitigating climate change (IPCC 2014). Similarly, several international conferences, books, and academic articles published on the topic, including dedicated special issues, are the testimony of the link between urban development and climate change. For instance, Habitat International recently had a special issue on the connection between climate change and human settlements, and Environment, Development and Sustainability journal has a special issue entitled, "Effects of Climate Change in Developing Countries." This indicates the increasing research interest in the role of urban planning and development on mitigating the threat of climate change, though economic growth is often prioritized over emissions reduction in several developing countries (Broto and Bulkeley 2013).

Although many developing countries are reluctant to embark on efforts toward reducing the risk of climate change, many have implemented some initiatives to curtail their GHG emissions (Alshehry and Belloumi 2015; Chen 2015; Fang et al. 2015; Gouldson et al. 2016). However, the literature on climate change mitigation in developing regions concentrates on studying the efforts of nations and cities toward cutting anthropogenic GHG emissions, renewable energy (RE) generation and use, energy-efficient technologies, research and development, rational use of energy and carbon sequestration. Few studies have researched the contribution of spatial planning in alleviating the adverse effect of climate change (Araos et al. 2016; Broto and Bulkeley 2013; Matthews et al. 2015).

Saudi Arabia, a country of 33 million inhabitants in 2018, is particularly at risk of climate change. It has sensitive ecosystems, limited freshwater resources, and faces frequent incidences of coastal flooding, which make it ranked 84th on the 2018 Global Climate Risk Index (Eckstein et al. 2018). Also, the country has one of the highest rates of energy consumption and CO_2 emission per capita in the world, in addition to significant demographic pressures (2.3% annual population growth rate). In 2014, its energy consumption of 6937.23 kg of oil equivalent (kgoe) was 3.6 times the global average and the per capita CO_2 emission of 19.53 metric tons (mt) was the seventh-highest (World Bank 2016). Primary energy consumption has grown from 164.5 million tons of oil equivalent (mtoe) in 2006 to 260.8 in 2015, representing a 58.5% increase in less than a decade (BP (British Petroleum) 2017, p. 8). Similarly, the 2016 domestic oil and gas consumption, mainly for power production, transportation, and industrial use, was 167.9 million tons (40.2% of the Middle East total) and 98.4 million tons of oil equivalent (21.3% of the Middle East total), respectively (BP 2017). Also, as the resource demand is threefold greater than the ecosystem capacity, the country's ecological footprint is enormous (Abubakar and Aina 2016).

Based on the recognition of its high energy consumption, carbon emission, and vulnerability, Saudi Arabia has ratified the UNFCCC in 1994, albeit GHG mitigation efforts were not mentioned, and the Kyoto Protocol in 2005. The government is also implementing some climate change mitigation and adaptation measures, including RE deployment (Malik et al. 2019; Tlili 2015), carbon capture and storage (Liu et al. 2012), electricity and water conservation measures (Gazzeh and Abubakar 2018), environmental research (Aina et al. 2019; Tolba and Saab 2009) and urban planning schemes to address climate change impacts and to make the transition to low-carbon communities (Darfaoui and Al Assiri 2010). Yet, few studies have explored the urban planning strategies being deployed to help alleviate the adverse effect of climate change in the country.

To fill this research gap and build upon the literature, the objective of this study is to assess the extent to which urban planning strategies for mitigating climate change are being implemented in Saudi Arabia and their likelihood impacts, as well as to recommend measures toward mainstreaming climate change adaptation and mitigation into urban development planning in Saudi Arabia and other developing countries faced with similar challenges. The paper is organized into the following sections. The next section reviews the literature on the relationship between urbanization process and climate change. Section 3 describes the study methodology. While Sect. 4 provides an overview of climate change challenges in Saudi Arabia, Sect. 5 explores the extent of implementing urban planning strategies for climate change mitigation in Saudi cities. The paper concludes in Sect. 5 with some recommendations for improvement.

2 Literature review

Climate change mainly results from anthropogenic emissions of greenhouse gases (GHGs), especially CO_2, methane and nitrous oxide into the atmosphere, which causes severe, widespread and irreversible effects on humans and the entire ecosystem (World Bank 2010). Warming of the climate system has been linked to extreme occurrences of drought, heat waves, melting of glaciers, sea-level rise, storms and floods, unstable rainfall patterns, as well as public and environmental health risks (Al-Maamary et al. 2017; UN Habitat 2011). As shown in Table 1, within one and half decades (1990–2014), the average per capita energy consumption in the world has risen by about 16%, and the CO_2 emission has grown by 19%, despite the increasing number of international agreements and calls for actions toward mitigating climate change. Regional variations in per capita energy consumption

Table 1 Global and regional energy use and CO_2 emissions, 1990–2014 (Compiled from: World Bank 2016)

	Energy consumption per capita (kilograms of oil equivalent)			Carbon dioxide emissions per capita (metric tons)		
	1990	2014	Growth (%)	1990	2014	Growth (%)
World	1661	1921	15.7	4.2	5.0	19.0
East Asia and Pacific	1014	2136	110.7	2.6	6.3	142.3
Europe and Central Asia	3758	3159	− 15.9	9.0	6.9	− 23.3
Latin America and Caribbean	1046	1342	28.3	2.3	3.1	34.8
Middle East and North Africa (MENA)	1187	2338	97.0	3.6	6.2	72.2
North America	7665	7053	− 8.0	19.0	16.4	− 13.7
South Asia	333	576	73.0	0.6	1.5	150.0
Sub-Saharan Africa	690	683	− 1.0	0.9	0.8	− 11.1

and CO_2 emission are quite striking. North America had the world's highest per capita energy use of 7053 kg of oil equivalent (kgoe), and the highest CO_2 emission at 16.4 metric tons (mt) in 2014. In contrast, South Asia had the world's least energy use (576 kgoe), and sub-Saharan Africa had the least CO_2 emission (0.8 mt) in the same year. On average, a North American uses energy 12 times more than South Asian and emits 20 times more CO_2 than a sub-Saharan African. The trend in energy use indicates that from 1990 to 2014, per capita energy use has risen more than twofold in East Asia and Pacific (111%), almost twice in MENA (97%), and by 73% in South Asia, and 28% in Latin America and the Caribbean. However, within the same period, the per capita energy use declined in Europe and Central Asia (16%), North America (8%) and slightly (1%) in sub-Saharan Africa.

As expected, the trend in CO_2 emissions is similar to that of energy use, because the first is driven mainly by the latter. Within the period under review, the per capita CO_2 emissions have more than doubled in East Asia and Pacific (2.6–6.3 mt), almost doubled in MENA (3.6–6.2 m), and grew by about a third (2.3–3.1 mt) in Latin America and the Caribbean. However, Europe and Central Asia recorded a decrease in per capita energy use (23%), trailed by North America (14%) and sub-Saharan Africa (11%). Anthropogenic CO_2 emissions are largely from fossil fuel combustion: oil, gas, and coal, which provide nearly three-quarters of the world's energy. To avert the drastic consequences of climate change, it is necessary to maintain global average GHG concentrations below 400–450 ppm by mainly curbing anthropogenic CO_2 emissions (UN Habitat 2011).

Emission of CO_2, the leading cause of climate change, is primarily spurred by the human population, size and intensity of economic activity, energy consumption, lifestyle, technology, land-use patterns and existing climate policies (World Bank 2010). Given that all these factors are related to the urbanization process, climate risks are more concentrated in urban areas (Carter et al. 2015; Solecki et al. 2015; UN Habitat 2011). Urban population has reached 53% in 2015, and by 2050 around 4 billion people or about two-thirds of humanity will be living in urban areas, and that 90% of the projected growth in global urban population, which is around 2.5 billion people, will happen in Asia and Africa alone (UN 2015 p. 81). Similarly, three-quarters of the global urban population is currently living in low- and middle-income nations, and developing regions are home to 70% of the 400 cities with more than one million people (UN 2015). In terms of economic activities, urban areas have become the global platforms for manufacturing, trade, innovation and service provision, thus becoming the key engine of international economic growth. Oxford Economics (2016) estimated that about 57% of the global GDP in 2015 is produced by only 750 cities, which is expected to reach 61% or USD80 trillion by 2030. Concerning energy use, urban areas consume not only twice the energy rural areas use, but they account for close to three-quarters of global CO_2 emissions (Hoornweg et al. 2011).

Urban areas can contribute in reducing the risks of climate change through adaptation, defined as “a place- and context-specific process of decreasing vulnerability and exposure to climate variability, which contributes to human well-being, the security of assets and maintenance of ecosystem functions, goods and services” (IPCC 2014). Integrating climate change mitigation and adaptation into land-use planning and urban governance can advance synergies with other development objectives, but it requires effective selection and implementation of strategies in collaboration with stakeholders such as governments, private sector, civic societies, and communities (UN Habitat 2011). These strategies are reinforced or undermined by interrelated factors such as efficient institutions, good governance, investing in environmentally friendly infrastructure and technologies, sustainable livelihoods and lifestyle preferences. Indigenous and traditional knowledge systems, societal values and practices and socio-economic development objectives are additional resources for effective climate change mitigation and adaptation. To effectively lessen and manage climate change risks and to foster sustainability, mitigation, and adaptation efforts should be complementary (IPCC 2014). Common obstacles to successful mitigation/adaptation planning and implementation include financial, technical and managerial limitations, inadequate coordination and competing interests among various stakeholders, lack of clarity about impacts and risks and absence of monitoring and researching of mitigation and adaptation effectiveness (IPCC 2014).

Curbing climate change can be achieved through various mitigation and adaptation efforts. In urban areas, the United Nation’s “Global Report on Human Settlements 2011: Cities and Climate Change” outlined several schemes to guide climate change mitigation. Table 2 shows the details of the schemes compiled according to the following urban sectors: the built environment, infrastructure, transportation, urban form and structure, and carbon sequestration. This guideline is useful in helping urban areas to design climate change mitigation schemes or to assess the extent to which a city is implementing urban planning strategies for mitigating climate change.

The implementation of climate change mitigation schemes in urban areas varies from one country to another. In Delhi (India), all new public buildings such as offices, schools, hospitals, and the hospitality sector are mandated to implement rainwater harvesting, solar water heating systems and green building technologies such as efficient lighting and water usage, as well as heating, ventilation and air-conditioning (HVAC). Also, the city has an efficient metropolitan rail transit system and BRT, a scheme for energy recovery from waste, and provides a 30% subsidy on buying battery-operated vehicles, and grants to households willing to install solar water heaters. Similarly, the city enforces emission standards on all new vehicles and directed all public transit buses, taxis and rickshaws to convert to using compressed natural gas (CNG) (Bulkeley et al. 2009). In Cape Town, South Africa, low-carbon urban planning strategies include retrofitting of 2300 low-cost houses with insulation materials, efficient lamps, and solar water heaters. In 2011, the city launched a reliable and low-cost BRT service covering 60 routes. Also, about 10% of the city’s energy demand is being supplied via wind energy. In Mazda City (United Arab Emirates), low-carbon urban development schemes include powering the city using solar energy, using wind towers to provide ventilation on the streets and connecting the entire city with LRT services (Abubakar and Bununu

Table 2 Climate change mitigation schemes in urban areas (Compiled from: UN Habitat 2011)

Urban sector	Type of scheme	Description
Built environment	Energy-efficient materials	Use energy-efficient materials in the construction of the built environment
	Energy-efficient design	Use energy- and water-efficient design principles, such as ‘passive’ heating and cooling
	Building-integrated alternative energy supply	Utilize renewable and low-carbon energy technologies to provide energy to individual buildings
	Building-integrated alternative water supply	Use off-grid water supply and processing techniques which reduce energy use in the production and heating of clean water
	New-build energy and water-efficient technologies	Employ energy- and water-efficient devices in constructing and developing new buildings
	Retrofitting energy- and water-efficient technologies	Use energy- and water-efficient devices in renovating existing buildings
	Energy- and water-efficient appliances	Utilize efficient appliances within the built environment
	Demand reduction measures	Reducing the demand for energy and water within the built environment
Infrastructure	Alternative energy supply	Develop renewable energy or low-carbon energy supply systems
	Landfill gas capture	Utilize gas produced by landfill sites for energy provision
	Alternative water supply	Use alternative forms of water supply, storage and processing to reduce energy use
	Collection of waste for recycling or reuse	Develop alternative collection systems and ways of using waste to reduce methane produced at landfill sites
	Energy and water efficiency/conservation	Enhance the efficiency of existing infrastructure systems or development of new efficient systems
	Demand reduction	Reduce demand for energy and water use, and for the collection of waste
Transportation	New low-carbon transport infrastructure	Develop new transport infrastructure to encourage low-carbon modes of transportation
	Low-carbon infrastructure renewal	Renewal/upgrading of transport infrastructure to reduce GHG emissions
	Fleet replacement	Replace vehicle fleet with energy-efficient or low-carbon vehicles
	Fuel switching	Switch from using fossil fuels for powering fleet to alternative low-carbon or renewable fuels
	Enhancing energy efficiency	Enhance the energy efficiency of existing vehicles and their use
	Demand reduction measures	Reduce the demand for individual motorized transport
	Demand enhancement measures	Enhancing the demand for alternative forms of travel (e.g., public transport, walking, and cycling)

Table 2 (continued)

Urban sector	Type of scheme	Description
Urban form and structure	Urban expansion, informal settlements and suburban development	Apply land-use planning and design policies to limit energy use in the expanding areas of existing cities
	New urban development	Apply land-use planning and design policies to limit energy use in new urban areas
	Reuse of brownfield land	Urban development on old industrial or other derelict areas of the city to encourage densification, mixed-use development, and reduce energy use
	Neighborhood and small-scale urban renewal	Renew existing housing stock and redevelop urban layout and design at a neighborhood or street scale in order to reduce energy use in the city
Carbon sequestration	Urban carbon capture and storage	Capture CO_2 emissions from energy generation within the city and place in long-term storage
	Urban tree-planting programs	Planting trees to develop the urban 'sink' capacity for CO_2
	Restoration of carbon sinks	Restore areas of natural carbon sinks in the city
	Preserving and conserving carbon sinks	Preserve and enhance areas of natural carbon sinks in the city
	Carbon offset schemes	Purchase carbon sequestration offsets by actors within the city from schemes located either in the city or elsewhere

2019). In Sao Paulo (Brazil), since 2007, buildings with at least three bathrooms are required to use solar water heating systems. Also, two waste-to-energy plants have also been constructed to generate clean electricity for the city. The city also operates convenient public transport and has constructed cycling lanes to lower carbon emissions. In Mexico City, green roofs have been installed on public buildings and all new constructions are mandated to have energy efficiency label. The metropolis has also constructed about 300 km of bicycle lanes, replaced all official vehicles with low-emission vehicles and mandated private schools to establish bus use scheme. Similarly, through a "day without car program," every car will be off the road on one weekday from 5 a.m. to 10 p.m. (Bulkeley et al. 2009). This review indicates that several cities of developing countries are increasingly implementing low-carbon urban development schemes that could serve as lessons to countries like Saudi Arabia where such schemes are nascent.

3 Materials and methods

3.1 Study setting

Saudi Arabia's total landmass of 2.15 million square kilometers makes it the 14th largest country in the world and the largest in the Middle East, covering 80% of the Arabian Peninsula (CIA (Central Intelligence Agency) USA 2019). The country's climate is characterized by very low and irregular rain (averaging 70.5 mm annually), dry winds and high evapotranspiration that contribute to freshwater scarcity and reduced vegetation (Gazzeh and Abubakar 2018). The average annual temperature in Saudi Arabia increases by around 0.75 °C, which is projected to reach 2.2–2.7 °C by 2040, thereby surpassing the global average of 1.5–2.0 °C (Darfaoui and Al Assiri 2010). Even though the country has 2.7 million hectares of light forest, 3500 hectares of mangroves and 148,000 hectares of coral reefs, more than half of the total land area consists of desert and mountain ranges (Al-Maamary et al. 2017). Indeed, just 2% of the nation's landmass is arable, with major crops being dates, vegetables, and fruits (Fig. 1). The country is strategically located where Europe, Asia, and Africa meet. It is bordered to the west by the Red Sea with a shoreline of 1760 km, to the northeast by the Arabian/Persian Gulf with a shoreline of 560 km and by seven countries: the United Arab Emirates and Qatar to the east, Yemen and Oman to the south and Iraq, Kuwait and Jordan to the north (Gazzeh and Abubakar 2018).

There were 33.1 million people living in Saudi Arabia in 2018 (83.8% residing in urban areas), which is projected to reach 37.6 million by 2025 based on the mean growth rate of 2.7% per annum (GAS (General Authority for Statistics, Saudi Arabia) 2010). The country, administratively divided into 13 regions, has an average population density of 12.8 persons/km^2 in 2010 (the 20th lowest in the world), which varies from 118.7 persons/km^2 in Jazan region to 2.9 persons/km^2 in the northern border region (GAS 2010; Gazzeh and Abubakar 2018). The country's GDP of USD1775 billion in 2017, which has been annually growing by at least 3% in the last decade, makes it the richest country in the Middle East and North Africa (MENA) region and among the 20 largest economies in the globe (CIA (Central Intelligence Agency) USA 2019). It has abundant mineral resources, including iron ore and limestone deposits, 15.6% of the world's oil reserves and the fifth largest gas reserves in 2016, as well as exporting the highest volume of crude oil in the globe (BP 2017).

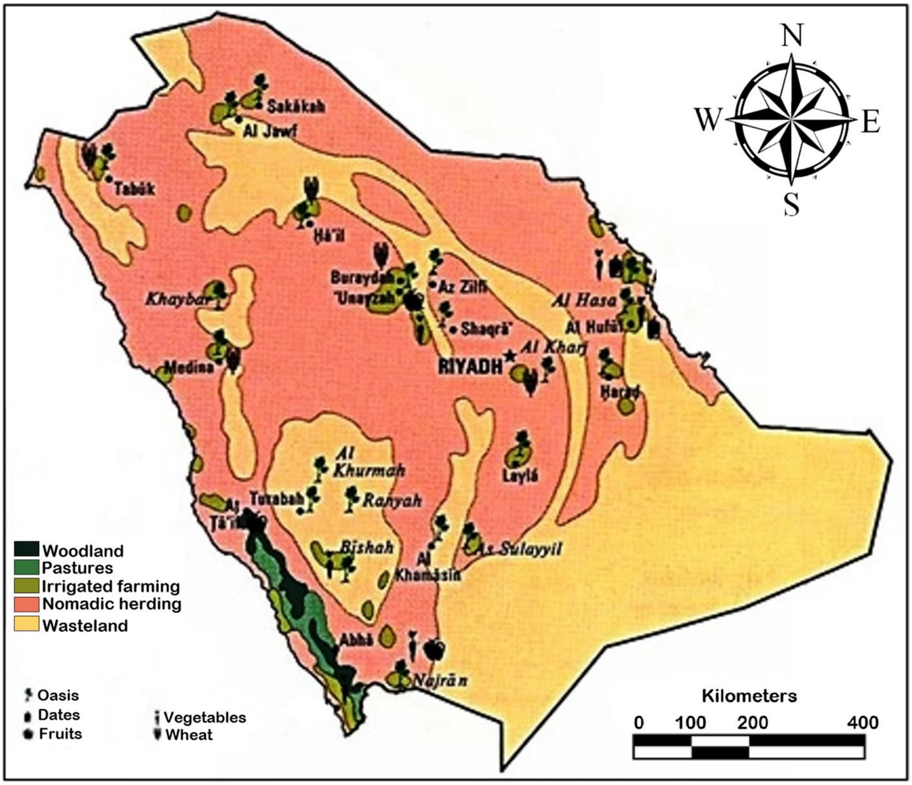

Fig. 1 Vegetation distribution in Saudi Arabia (http://www.mappery.com/Saudi-Arabia-Land-Use-Map. Accessed 02 October 2018)

3.2 Data collection and analysis

Data collection involved a desktop study of the key literature addressing the research objective and analysis of secondary data. Firstly, Google Scholar, Science Direct and Crossref being among the most comprehensive search engines were used to identify and collect the relevant literature using search terms such as climate change, mitigation, and adaptation, GHG emission, global warming, air pollution and urban heat island, water stress, sea-level rise, coastal flooding, human health, urban sustainability, and related topics. Online resources including journal articles, books, technical reports, conference proceedings, and web contents were collected. The review aimed to provide the context of the study, situate it within the global literature on climate change and identify a suitable analytical framework to assess the urban planning strategies being implemented in Saudi Arabia for mitigating climate change. In this study, the UN-Habitat's guideline for climate change mitigation in urban areas (UN Habitat 2011) was selected as the analytical framework because it is comprehensive, developed based on global studies performed by experts, and it has been widely adopted in the literature (Broto and Bulkeley 2013).

Secondly, secondary data were gathered to assess the extent to which sustainable urban planning strategies are being implemented in Saudi Arabia's seven cities: Riyadh, Jeddah, Makkah, Madinah, Dammam, Buraydah, and Hofuf-Mubarraz. The justification for selecting these cases is that they are: (a) the largest urban centers that house 50.3% of the nation's total inhabitants, and (b) they are regional capitals that serve as models to smaller cities and towns (Abubakar and Aina 2016). The sizes and population densities of these cities are shown in Table 3, with Riyadh (the national capital) being the largest city in terms of population, landmass, and density. Riyadh has the highest population density (4175 persons/km^2), followed by Hofuf-Mubarraz (3144 persons/km^2), while Buraydah has the lowest (480 persons/km^2).

The collection of the secondary data involved a systematic study of websites of municipal, regional and central governments, civil societies, private sector, newspaper articles, and reports for each of the seven chosen cities and the country in general. In addition, the following data were specifically obtained from the sources below:

- Electricity consumption and CO_2 emission from 2016 World Development Indicators (World Bank 2016);
- Geographical background of Saudi Arabia from the Central Intelligence Agency (CIA), USA 2019);
- Oil and gas production and consumption from British Petroleum's Statistical Review of World Energy 2017 (BP 2017);
- Land area and population of Saudi Arabia's major cities from City Mayor's website; and
- Mass transit projects in Saudi Arabia from the Global Mass Transit Report (2016).

Data analysis was conducted using content analysis of qualitative data and statistical analysis of quantitative data. In the content analysis technique, a three-step iterative process was used. First, the collected resources were organized according to search terms mentioned above or the cities under study, although some resources belong to multiple categories. Second, based on our analytical framework, five themes were developed according to the urban sectors; built environment; infrastructure; transportation; urban form and structure; and carbon sequestration. Then, each of the resources was systematically searched, by iterating throughout it to validate the emerging themes or discover new perspectives until there is no additional information. Finally, the themes were synthesized by identifying their relationships and points of convergence or divergence (Yin 2010). The analysis of quantitative data involved tabulating the findings against each city and using charts to graphically present trends in energy consumption and emissions over the years.

Table 3 Background of seven largest cities in Saudi Arabia, 2018 (Compiled from City Mayors, n.d.)

City	Designation	Land area (km^2)	Population (million)	Density (person/km^2)
Riyadh	National capital	1798	7.506	4175
Jeddah	Major city	1600	4.276	2672
Makkah	Provincial capital	1200	1.675	1396
Madinah	Provincial capital	589	1.183	2008
Dammam	Provincial capital	810	1.166	1440
Hofuf-Mubarraz	Major city	254	0.791	3114
Buraydah	Provincial capital	1291	0.620	480

4 An overview of climate change challenges in Saudi Arabia

Climate change poses substantial challenges to humanity, the environment, and global economic systems. The energy supply sector is the largest emitter of GHG emission in the world (IPCC 2014). In Saudi Arabia, the 2014 per capita consumption of electricity (9444.2 kWh), produced largely from fossil fuels, has surpassed that of high-income countries (9086.8 kWh) and more than tripled the global average of 3125.3 kWh (Fig. 2). In 1970, the per capita electricity consumption of only 323.7 kWh was about a third of the global average (1199.4 kWh) and a little higher than the MENA's average. However, within a decade, the per capita consumption (1961.2 kWh) has exceeded the global average (1585.0) in 1980 and by 1990, it has doubled its 1980 figure. Between 1980 and 2010, the country's electricity consumption rate rose more than threefold; reaching 7973.5 kWh/capita/day.

This unsustainable electricity consumption pattern is spurred by low electricity tariff and lifestyle that does not support conservation. Electricity tariff for residential buildings is Saudi Riyals 0.18 (USD0.048) per 1 kW hour (kWh) for the first 6000 kWh and SR0.30 (USD0.08) per kWh for extra units over the threshold (Gazzeh and Abubakar 2018). Another issue is the attitude of not switching off lights and electric appliances when not in use in public buildings and in some residences, as well as prolonged and unnecessary operating of street lights, especially in undeveloped layouts that substantially contribute to high energy consumption in the cities. As such, the following are the major climate change challenges that affect the people and their local ecosystem.

4.1 Air pollution and urban heat islands

Urban heat island is a situation of severe surface temperature when built-up neighborhoods generate and preserve heat because of vast building mass, impermeable built surfaces and

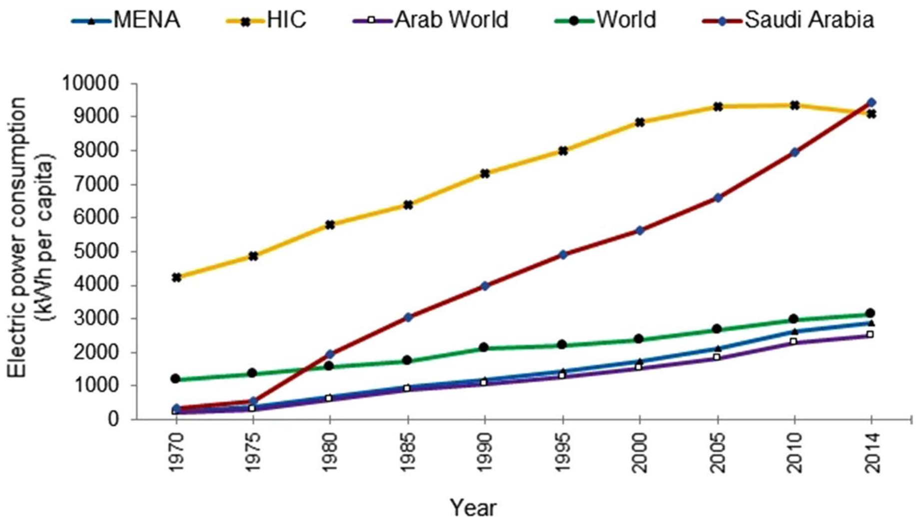

Fig. 2 Per capita electricity consumption in Saudi Arabia is higher than regional and global averages (Data source: UN Habitat 2016)

heat generation from human activities, as well as lack of vegetation and water bodies for heat absorption (Abubakar and Bununu 2019; Carter et al. 2015). In Saudi Arabia, climate change impact is obvious as the ambient temperature has increased by about 4 °C more than its average in the last five decades and temperatures near the coastal areas are projected to rise by 2–2.75°C (Al-Maamary et al. 2017). Some areas within cities record up to 52°C in the summer due largely to emissions from vehicles and human activities (Abubakar and Aina 2016). In 1990, the per capita CO_2 emissions were 11.4 mt, which rose to 14.3 in 2000 and then to 19.5 mt in 2014; almost twice the average for high-income countries (11 mt/capita) (Fig. 3), with 90% contributed by the energy sector, 8% by industries and 2% by agriculture (UNFCCC 2016). The climate trend indicates general warming throughout the country, ranging from 0.15 to 0.75°C, averaging around 0.40°C (Tolba and Saab 2009). The estimated 2040 average warming of 2.2–2.7°C in Saudi Arabia could be higher than the global average (Darfaoui and Al Assiri 2010).

As such, the country is among the countries with the most toxic air in the world, with 108 µg of atmospheric particulate matter per cubic meter ($PM_{2.5}$), which is beyond the WHO's acceptable level of 10 µg/m^3 of $PM_{2.5}$ (World Economic Forum 2017). Pollution from automobiles is spurred by high car ownership rate and cheap gasoline whose price is the cheapest in the MENA region, retailing at Saudi Riyals 1.37–2.06 (USD$0.37–0.55) per liter, compared with USD1.41 for the world's average (Gazzeh and Abubakar 2018).

4.2 Groundwater depletion

Saudi Arabia is also facing water stress due to a severe decrease in precipitation, high evaporation and over-drawing of underground aquifers (DeNicola et al. 2015). The country is cited in one of the most water-stressed regions on earth, with freshwater sources facing an overall reduction of 241–1435 million m^3 per annum, compared with recharge rate of about 3850 million m^3/annum (Odhiambo 2017), due largely to rising

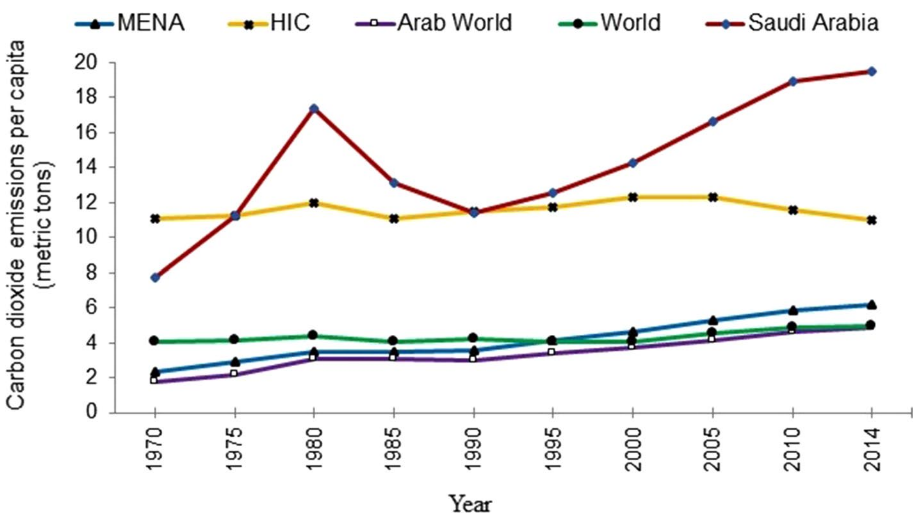

Fig. 3 Comparing Saudi Arabia's per capita CO_2 emissions with regional and global averages (Data source: UN Habitat 2016)

temperature and increased demand for irrigation which is expected to rise by 5–15% in 2050 (Chowdhury and Al-Zahrani 2013). A dam in the southern part of the country is reported to experience depletion through surface evaporation in the range of 4.7–6.0 m^2 yearly (Missimer et al. 2012). Not helping the situation is the domestic demand for piped water that has been annually increasing by about 6% for the past 40 years (Abubakar and Aina 2016). In 2010, while the average national water consumption was 235 L per capita per day, the mean water consumption in these seven largest cities was more than 300 L/person/day, which is similar to cities of developed countries that have abundant freshwater bodies (Gazzeh and Abubakar 2018). This is caused by an affluent lifestyle, wasteful attitude of residents and highly subsidized water prices where households pay not up to 50% of water production cost (Abubakar and Aina 2016). This substantial financial burden of water subsidies undermines water conservation and sustainability.

4.3 Sea-level rise and coastal flooding

Climate change induces sea-level rise and coastal flooding, which affects buildings and infrastructure in low-land coastal areas. With a coastline of 2640 km and 30.3% of the population living within 100 km of coastline in 2000 (Tolba and Saab 2009), the country is experiencing several incidences of flooding in coastal cities of Jeddah and Dammam. For example, in 2009 Jeddah city experienced its worst flood in the last three decades, which caused 122 deaths, 37 people missing and 3861 homes flooded and rendered uninhabitable (Al-Maamary et al. 2017). Dammam, Riyadh, and the two holy cities have also experienced several incidences of floods that severely affected religious and socio-economic activities. Based on the estimated sea-level rise according to IPPC scenarios and a 1% increase in coastal development per annum, by 2100 about 4674 and 1087 hectares of sandy beaches could be lost along the Red Sea and Arabian/Persian Gulf, respectively (Darfaoui and Al Assiri 2010). Lack of stormwater drainage to collect runoff in cities contributes to flood risks in the country (Aina 2017).

4.4 Low agricultural productivity

Climate change undermines food security and rises the likelihood of malnutrition and hunger for millions of people throughout the world (UN Habitat 2011). In Saudi Arabia, losses in wheat, dates, vegetables, and fishing yields increased with climate change, with attendant local increases in food prices, given that about 50% of the irrigation systems rely heavily on underground water in valley basins which sometimes dry up because of the low amount of rainfall (Alkolibi 2002). Several plant species are unable to tolerate the current and estimated high temperatures in most environments. Moreover, nearly 30% of vegetable productions take place in greenhouses, and the remaining percentages are affected by the variations in temperature and limited rainfall (Alkolibi 2002). According to Tolba and Saab (2009), about 80 animal species are threatened and rainfall is expected to reduce by 20–25% annually in the country. Similarly, aquatic organisms are increasingly facing a drop in oxygen levels as well as high amounts and frequencies of sea temperatures and acidification.

4.5 A threat to public health

Climate change negatively impacts the health and well-being of societies largely by exacerbating the existing health problems (IPCC 2014). In Saudi Arabia, there are climate change-related risks that include heat stress, the spread of epidemics and diseases associated with air pollution, sand storms and exposure to infrared and ultraviolet radiation. Periodic intensification of certain allergens in the air, which causes allergic reactions and respiratory diseases, has been reported (Dano and AlQahtany 2019; Al-Maamary et al. 2017). The country's estimated climate change impacts on the burden of diseases, quantified in disability-adjusted life years (DALYs), is 14 DALYs/100,000 (Tolba and Saab 2009). Brauer et al. (2015) estimated that on average Saudi's life is shortened by almost 1.5 years as a result of air pollution.

5 Sustainable urban planning strategies for climate change mitigation in Saudi cities

This section analyzes key urban planning strategies to mitigate climate change that are being implemented in Saudi Arabia's seven largest urban areas. These strategies are related to the built environment, infrastructure, transportation, urban form, and carbon sequestration projects (Table 3). This classification is based on UN-Habitat's guideline for climate change mitigation in urban areas (UN Habitat 2011).

5.1 Green buildings

The building sector consumes about 40% of the total energy produced and account for about one-third of GHG emissions in the majority of the nations in the world (UN-Habitat 2011). To reduce energy consumption and the environmental impacts of buildings such as CO_2 emissions, Saudi Arabian government promotes the construction of green buildings that use less energy for air-containing and are equipped with appliances that are energy- and water-efficient (Abubakar and Aina 2016). The expected growth of green buildings in the country in the housing sector was planned to reach around 30–40% in 2018, with a total area of residential projects of around 250,000 square meters, which is anticipated to grow by 25–40% over the next 5 years. In execution of these projects, developers are urged to adhere to sustainable development principles. Solar home systems are also being encouraged throughout the country, albeit modestly.

The country is investing USD1.154 billion worth of green building projects. In Riyadh, for example, the King Abdullah Financial District—a 160 ha green building development—has been completed. There is also a plan to retrofit 90,000 mosques to make them more energy-efficient, targeting to lower their electricity consumption by about 40% and water use by 30–40% (Arab News 2014). Saudi Arabia is transforming its built landscape with 1218 green building projects currently under way across the country covering a total of 296.55 ha, certified by Leadership in Energy and Environmental Design (LEED) green building rating system (Table 4). The five largest cities house about three-quarters (79.23%) of the total floor areas of the certified green buildings, with Riyadh being home to close to the half (48.84%). The government is also

Table 4 LEED-certified green building in Saudi Arabia (*Source*: Green Information Gateway 2018)

City	Number	Floor area in hectares
Riyadh	352 (28.90%)	144.84 (48.84%)
Jeddah	65 (5.34%)	8.89 (3.00%)
Makkah	71 (5.83%)	61.41 (20.71%)
Madinah	1 (0.08%)	15.20 (5.13%)
Dammam	3 (0.25%)	4.63 (1.56%)
Other cities	726 (59.61)	61.58 (20.77)
Saudi Arabia total	1218	296.55

directly involved in establishing public buildings based on smart design principles and is LEED certified (Aina 2017).

To house the rapidly growing urban population populations in Saudi Arabia and other developing nations, new buildings are being constructed everyday, which provides an opportunity for improving their efficiency and optimizing urban form. New constructions can be made 70% more efficient than existing buildings by using insulated windows, more efficient lighting and HVAC system, and implementing renewable energy technology such as roof-top photovoltaic (PV) and solar water heaters (Kammen and Sunter 2016). In Tokyo (Japan), sustainable renovation of buildings can achieve 26–33% reduction in energy use and 32–38% reduction in CO_2 emissions compared with other kinds of renovations, plus energy cost saving of USD1.0–1.5 million/annum/building (Balaban and de Oliveira 2017). Co-benefits of green buildings include improving air quality and health conditions of their occupants. Globally, the estimated annual investment of USD300 billion is required from 2015 to 2020 to construct new buildings and retrofit the existing ones to high energy efficiency standards (Kammen and Sunter 2016). The process of retrofitting existing buildings is environmentally sustainable because it averts waste generation from building demolition, and can be cheaper than new constructions. In spite of these benefits, the worldwide rate of retrofitting existing buildings for efficiency improvement is sluggish. For example, commercial buildings in the USA are being retrofitted at a rate of about 2.2% per annum, yielding average energy savings of around 11% per building (Kammen and Sunter 2016).

5.2 Sustainable transportation

Although transportation contributes 23–30% of global energy-related GHG emissions (UN Habitat 2011), in Saudi Arabia private automobile is the dominant means of urban mobility, with a vehicle ownership rate of 219 cars per 1000 population, thanks to highly subsidized gasoline price and the availability of roadside parking spaces (Dano and AlQahtany 2019). To encourage the use of public transportation, the government has established bus rapid transit (BRT) system in its major cities and has recently launched light rail transit (LRT) in Riyadh, Jeddah, Makkah, Madinah and Dammam (Table 5). The Riyadh metro, spanning a total of 178 km with 85 stations, is expected to eliminate 30% of city's traffic by conveying 1500 passengers per hour when fully operational in 2021 (Arab News 2015). In Makkah, an LRT consisting of four lines, spanning 182.3 km and covering 88 stations, and a BRT has been proposed, which together are expected to better public mobility around the holy sites and the entire city. In Jeddah, a plan to develop efficient public transportation

Table 5 Urban mass transit projects in Saudi Arabia (Global Mass Transit Report 2016)

City	Light rail length (km)	Bus rapid transit length (km)	No. of stations	Total budget (USD)	Expected completion year
Riyadh	177.8	1200	85 (rail), 6765 (bus)	23.0 billion	2019
Jeddah	149.8	288	85 (rail), 724 (bus)	11.9 billion	2020–2022
Makkah	182.3	–	88 (rail)	16.5 billion	Some segments are opened during hajj
Madinah	95.0	–	To be determined	–	2020
Dammam	50.0	110	To be determined	16.0 billion	2021

system consisting of metro rail, BRT and ferries, at the cost of SAR 48 billion to be completed by 2020, has been finalized and the construction work has started. The LRT system will comprise four lines, spanning 149.8 km and covering 85 stations. On the other hand, the Dammam projects will include 110 km of bus way and 50 km of LRT to be linked with the outskirts of the city by 350 km road lanes for feeder buses.

These public transit projects could help reduce fossil fuel consumption and air pollution, in addition to promoting social equity by serving communities without personal automobiles (Dano 2018; Abubakar and Dano 2018; Dano and AlQahtany 2019; Aina 2017). Urban public transit is environmentally friendly if it operates using vehicles powered by renewable energy or low-carbon fuel (Kammen and Sunter 2016). Estimates suggest that a 1% growth in public transportation could result in a 0.48% reduction in GHG emission (UN Habitat 2011). However, cheap gasoline coupled with the tradition of not traveling together with strangers in the same vehicle among citizens could undermine these initiatives. Some strategies implemented by cities for reducing transport-related carbon emissions include improving accessibility, capacity and quality of public transit, promoting non-motorized modes of transport (walking and cycling) and vehicles powered by alternative or low-carbon fuels such as biodiesel, methanol, CNG, hydrogen and enforcing vehicle emissions and efficiency standards (Bulkeley et al. 2009).

5.3 Infrastructure: electricity and water supply efficiency and conservation

Green infrastructure schemes involve developing low-carbon energy alternatives, water supply efficiency and conservation, sanitation systems, urban flood drainage, and shore protection and landfill gas capture to produce energy (Abubakar 2018; Dano et al. 2019; UN-Habitat 2011). In Saudi Arabia, there are a few initiatives for low-carbon energy supply systems in the cities under review. In Dhahran (part of Dammam Metropolitan Area) for instance, Saudi Aramco has mounted a 10-MW solar PV panels and wind energy infrastructure in its corporate headquarters. The solar PV on top of the parking facility is estimated to cut energy consumption corresponding to 30,000 barrels of oil, while the wind turbines would decrease energy use by around 19,000 barrels. In January 2017, the company also established the country's first private sector-owned wind turbines for power production in the northwestern part of the country. Based on estimates using IEA and OPEC data, other solar energy projects in urban areas such as home solar systems could save the country around 300,000 barrels of oil used in electricity generation (Anthony 2017).

Street lighting is a key arena in which city governments have been utilizing solar energy to improve the environment and save money.

In terms of water efficiency and conservation, the government has been promoting reuse of treated municipal wastewater for agricultural production, especially fodder (Chowdhury and Al-Zahrani 2013). Apart from conserving groundwater and saving energy in water pumping during irrigation, reuse could reduce human and environmental risks by minimizing the discharge of wastewater into the ecosystem, thereby contaminating depression areas (Wadis), aquifers and other water bodies. Green urban infrastructure is essential in reducing climate change impacts in cities. Absent or shortage of infrastructure or its poor maintenance is capable of aggravating climate change impacts as well as socioeconomic exclusion and vulnerability of urban residents (Matthews et al. 2015). The choice of using renewables or fossil fuel can influence GHG emissions intensity and impact of cities on the global ecosystem (Bulkeley et al. 2009).

5.4 Sustainable urban form and carbon sequestration

Cities provide vital opportunities for socioeconomic development because of agglomeration economies and employment in different economic sectors, thus acting as growth poles that attract people to them. A sustainable urban form contributes in climate change mitigation by creating compact, mixed land use, walkable and dense neighborhoods, in addition to the co-benefit of improving health and urban livability (Chen et al. 2011; Younger et al. 2008). In Saudi Arabia, as part of Vision 2030, there is a proposal for revising planning and architectural ordinances and standards to support the country's goal of green cities and green economy. The aim is to reduce urban sprawl, promote infill development and decrease energy and water consumption in cities, given that high water demand drives energy consumption as the demand is met mostly through desalination. In 2017, the government started levying 2.5% tax on undeveloped residential and commercial plots that exceed 10,000 square meters after 12 months of allocation. This is aimed at discouraging leapfrog development and land speculation in towns and cities. However, it is not clear whether the tax will be applied on the purchased or current market value of the property and what would be the basis for the valuation. Also, some landowners have resorted to partial development of their plots or reducing their sizes to fall below the threshold.

The government is also implementing some carbon sequestration and urban greening projects, especially parks, green areas, and tree-planting programs. For example, Saudi Aramco is actively involved in carbon captures, storage and uses to produce carbon-based value products such as fertilizer and petrochemical products (Malik et al. 2019). Carbon sequestration, which is among the country' intended nationally determined contributions for climate change mitigation under the UN's framework convention on climate change, could assist government's efforts in introducing new energy technologies and in its drive toward economic diversification (Liu et al. 2012). A notable example of the urban greening project is *Andalus Park* in Jeddah, which covers 2.5 hectares planted with various varieties of grasses, flowers and trees: 70 tree species including exotic palm trees (Saudi Gazzette 2018). Another urban greening project is the Wadi Hanifah in Riyadh which was a brownfield (industrial waste basin and old refuse dump) that has been transformed into a large park measuring 120 km from northwest to southwest and consisting of greenery and recreational amenities, which has been promoting ecotourism and attracting both local and international visitors (Abubakar and Aina 2016).

Roof-top gardening and green roofs are additional schemes for carbon sequestration and reducing air pollution and urban heat island phenomenon that cities should consider, more especially in a warm climate like Saudi Arabia. By lowering indoor temperature, green roofs and facades can synergistically decrease energy consumption in artificial cooling of buildings (Norton et al. 2015). Trees planting and using low water and native plants in landscaping and shading also help in protecting biodiversity habitat, providing flood protection to infrastructure such as roads and increasing carbon sequestration (Chen 2015; Urge-Vorsatz et al. 2018). Similarly, open stormwater systems are effective in sinking carbon through urban wetlands and cool urban environments from surface water (Laukkonen et al. 2009). Aside from carbon sequestration and reducing heat islands, other co-benefits of urban greening include improving quality of life and environmental health. However, the water demand for maintaining urban green areas should not be in variance with the sustainability goal of limiting water use except if the irrigation system utilizes recycled water and renewable energy for its operation.

6 Recommendations for curbing GHG emissions and promoting urban sustainability

With 84% urbanization rate, seven major cities accounting for at least half of Saudi Arabia's population and 76.4% of the industrial areas located in the five largest cities, Saudi Arabia's climate mitigation efforts must focus on cities. This section, therefore, recommends three key strategies that our study found are lacking in these cities, which can help reduce GHG emissions and promote urban sustainability. The recommendations are based on the fifth IPCC Assessment Reports (IPCC 2014) and UN Habitat's guideline for climate change mitigation in urban areas (UN Habitat 2011).

6.1 Increasing population and building density

The gross population and building densities of urban areas in Saudi cities are low. While the mean annual population growth in 2010 was 2.9%, cities are expanding at an average of 6.4% annually (Abubakar and Aina 2016). In Riyadh, for example, the residential density was 34 dwelling units per hectare in 2016 and the population density was 4175 person/km^2 in 2018 (Gazzeh and Abubakar 2018). Next to Riyadh in terms of population density is Hofuf-Mubarraz (3114 person/km^2) and Jeddah (2672 person/km^2). While Dammam's built areas grew from 2200 to 25,000 ha from 1972 to 2004, thus expanding 11.4 times in 33 years, the number of its inhabitants grew by only 4.6 times in the same period (Abubakar and Aina 2016). This situation is caused mainly by real estate businesses owned by elites with powerful political support that empowers them to "draw urban sprawl" to districts outside designated city limits, which impacts negatively on the ecological footprint or resource demand per capita, which is presently three times greater than the capacity of the local ecosystem. Although per capita energy use in single-family residences is higher than in multi-family housing, more than two-thirds of housing units in Riyadh and Dammam are villas (Abubakar and Aina 2016). As such, the Ministry of Municipal and Rural Affairs (MOMRA) should mandate increasing residential density in all urban areas through infill development, more vertical rather than horizontal developments, and modify the existing building codes to allow for denser development. For a city to be sustainable, a minimum density of 150 persons/hectare is recommended (UN Habitat 2011).

Densification through vertical development contributes in reducing climate change impact because multistory buildings help lower air temperature during the day by creating sizable shadow areas with temperature lower than the city's average (Fang et al. 2015). Similarly, densification make the public transit system more feasible, as the required minimum urban density for the system to be economical is around 5000 persons/km^2 (Kammen and Sunter 2016). As such, the ongoing BRT and LRT projects in these cities could only be efficient with densification. Similarly, studies have shown that per capita petrol use declines with urban density and infrastructure and basic public services provision is relatively cheaper in compact cities. Dense development is more environmentally sustainable and encourages social interaction and reduces travel distance to various parts of the city, thus reducing carbon emissions (Hassan and Lee 2015). Although high density in urban areas help in minimizing commuting distances and providing opportunities for incorporating many schemes for reducing emissions and energy use, care should be taken so that densely built environment does not intensify urban heat or endanger urban greening and landscaping that plays important roles in mitigating climate impacts (Laukkonen et al. 2009).

6.2 Mixed land uses and compact urban form

The morphology and spatial organization of cities vary greatly, with several implications for a city's GHG emissions level (Carter et al. 2015; UN Habitat 2011). In Saudi Arabia, based on land-use policies that support large-scale residential development projects and interest-free loans and land grants, thousands of residential plots were given free of charge to citizens, which caused massive expansion of urban areas, more especially Riyadh, Jeddah and Dammam. In Riyadh, for example, out of the 3115 km^2 total built areas, roads constituted 31.7% of the land uses in 2014, in comparison with 18.8% for residential and 39.1% for offices, public facilities, and services (Abubakar and Aina 2016).

To address this unsustainable land-use pattern, the government should mandate mixed-use urban form, which can encourage walkability and bicycling thus promoting health, reducing private automobiles dependency and bringing people into public spaces to have lively interaction and vibrant street life. Mixed and urban compact form also lowers heating and cooling costs, which results from smaller houses, shared walls in multi-unit homes and closeness to residences and businesses can encourage the use of public transit (Fang et al. 2015). Single zoning should be discouraged because it often led to grave urban problems such as escalation of sprawl, more reliance on private automobiles, traffic congestion and decline in the quality and vitality of city centers. Mixing residential, commercial and office land uses has co-benefits that include promoting the local economy, providing proximity to public services and community support and decreasing landscape fragmentation (Abubakar 2017). Similarly, energy-efficient buildings with solar heating tanks are recommended as they can increase adaptation, especially in warmer urban areas of Saudi Arabia, and can mitigate emissions through energy generation and savings.

An urban form that refers to the spatial organization and arrangement of human activities influences urban growth and expansion, and the configuration of resources, land uses, infrastructure and basic urban services (Chen et al. 2011). Unlike urban sprawl, compact urban form contributes in decreasing energy use by about 35% in Helsinki City, and in 125 large US cities it is responsible for reducing 35% of household energy consumption and 48% of CO_2 emissions from transportation (Fang et al. 2015). In China, a fragmented urban form contributes to rising CO_2 emissions in 35 provincial capital cities (Chen 2015).

In addition, compact form facilitates the use of non-motorized modes of transport (walking and bicycling), supports the development of public transit that reduces private automobile use per capita and average daily trip distance, and it can increase accessibility to employment, shopping and recreation destinations (Kammen and Sunter 2016).

6.3 Public enlightenment and engagement

Public enlightenment informs the citizens of the characteristics of climate change challenges and how and why behavior change can help address this problem (Bulkeley et al. 2009). This is important because culture, livelihoods, behavior, and lifestyles strongly influence the rate of GHG emissions, susceptibility to climate change and the capacity for adaptation and mitigation (IPCC 2014). As such, there is the need for the government to establish websites, social media platform and educational programs at schools and through print and electronic media to educate the citizen about the link between GHG emissions and environmental pollution, severe weather events and health risks such as lung cancer and other respiratory diseases (Abubakar 2013). Because behavioral interventions foster transition to low-carbon city, the public should be enlightened to change their consumption and life patterns, to conserve energy and reduce private automobile use and embrace public transportation and alternative forms of travel such as walking, cycling and ride-sharing (Kammen and Sunter 2016). Indeed, a survey found that, though only 6% of respondents understand what climate change is, 92% believed it is mainly caused by human activities and 81% agreed that it is a serious problem for the country (Tolba and Saab 2009). Similarly, involving communities more directly in initiatives such as home gardening and installing PV on rooftops are effective in addressing climate change. Thus, communities and civil society should be actively involved in scaling up adaptation and risk management.

According to Kammen and Sunter (2016), "behavior shapes how we live our lives and the energy choices we make." In China, for example, local authorities have created hotlines, websites, educational programs and enlightenment campaigns to inform the public about the relationship between air pollution and respiratory diseases such as lung cancer, promoting the reduction in motor vehicle use for curbing urban GHG emissions. In Sweden and Japan, local governments educate and inform their citizens about climate change impacts (Bulkeley et al. 2009). Schools are particularly considered as important avenues for increasing ecological knowledge and concerns and its widespread dissemination among students, parents, and staff (Abubakar 2013).

7 Conclusion

Most of the global assets and economic activities are concentrated in cities, which their enormous density and spatial scale significantly affect local microclimate. As such, climate change mitigation and adaptation are largely contingent upon what is done in urban areas, with city administrators central to its success. Climate adaptation in cities also hinges on local context and its integration into local policies, governance, and investments (Gouldson et al. 2016). This study has indicated that urban planning strategies for mitigating climate change in Saudi Arabian cities are at infancy and they focus mainly on green buildings, public transportation, and urban greening. As such, there is the need to double the efforts in promoting the construction of more green buildings, mixed land use and compact urban form, public transportation and public enlightenment toward behavior change. In addition to spatial planning initiatives, there is the urgent need to curtail local oil and natural gas consumption that has been increasing at 7% per annum in the last decade, which in 2016 gulped around 28% and 100% of the country's total crude oil and gas productions, respectively (BP 2017). Removing energy subsidy can help in reducing energy consumption, as low-priced energy is a key driving force for high rates of private automobile ownership and sub-urbanization. The existing energy subsidy is economically unsustainable, detrimental to public transportation, discourages conservation and disincentivizes the development of RE alternatives like solar and wind. Co-benefits of climate mitigation include energy security, environmental sustainability and fostering economic development.

Lastly, urban planning strategies for climate change mitigation should be planned in harmony with sustainable development goals, while appreciating the co-benefits, and taking into account any possible undesirable effects and risks that could emanate from their implementation (Urge-Vorsatz et al. 2018). Municipal agencies should also collaborate with MOMRA, civil societies, residents as well as international organizations in developing and implementing climate change mitigation plans. Urban areas comprised of multi-faceted and interrelated systems that can be leveraged in fostering effective urban planning and governance for climate change mitigation and adaptation. Less emission of GHGs is associated with urban areas that are denser, promote green buildings and sustainable transportation and depend mostly on renewables. According to Abubakar and Bununu (2019, p. 10), "the comprehensive and sustained application of low-carbon city principles can lead to urbanized areas becoming more environmentally friendly, economically efficient and competitive for investments that can contribute toward climate change mitigation and achieving a more sustainable future." Future studies of each city are essential for detail assessment of adaptation actions, including vulnerability assessments of future risks. Given that climate change has widespread impacts on people and ecosystems, urban planning adaptation and mitigation efforts not only reduce its threat but can as well promote environmental sustainability.

References

Abubakar, I. R. (2013). Role of higher institutions of learning in promoting smart growth in developing countries: University of Dammam as a case study. In Schiuma, G., Spender, J. C. & Pulic, A. (eds), *IFKAD 2013: 8th international forum on knowledge assets dynamics: Smart growth: Organizations, cities and communities* (pp. 591–608). Zagreb, Croatia.

Abubakar, I. R. (2017). Household response to inadequate sewerage and garbage collection services in Abuja, Nigeria. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2017/5314840.

Abubakar, I. R. (2018). Strategies for coping with inadequate domestic water supply in Abuja, Nigeria. *Water International*, *43*(5), 570–590.

Abubakar, I. R., & Aina, Y. A. (2016). Achieving sustainable cities in Saudi Arabia: Juggling the competing urbanization challenges. In Benna, U. G. (ed), *Population growth and rapid urbanization in the developing world* (pp. 42–63). Hershey, US: IGI Global. https://doi.org/10.4018/978-1-5225-0187-9.ch003.

Abubakar, I. R., & Bununu, Y. A. (2019). Low carbon city: Strategies and case studies. In Leal Filho W., Azul A., Brandli L., Özuyar P., Wall T. (eds), *Encyclopedia of the sustainable development goals: Transforming the world we want*. Berlin: Springer.

Abubakar, I. R., & Dano, U. L. (2018). Socioeconomic challenges and opportunities of urbanization in Nigeria. In Benna, U. & Benna, I. (eds), *Urbanization and its impact on socio-economic growth in developing regions* (pp. 219–240). Hershey, USA: IGI Global.

Aina, Y. A. (2017). Achieving smart sustainable cities with GeoICT support: The Saudi evolving smart cities. *Cities, 71,* 49–58.

Aina, Y. A., Wafer, A., Ahmed, F., & Alshuwaikhat, H. M. (2019). Top-down sustainable urban development? Urban governance transformation in Saudi Arabia. *Cities, 90,* 272–281.

Alkolibi, F. M. (2002). Possible effects of global warming on agriculture and water resources in Saudi Arabia: Impacts and responses. *Climatic Change, 54*(1–2), 225–245.

Al-Maamary, H. M., Kazem, H. A., & Chaichan, M. T. (2017). Climate change: The game changer in the Gulf Cooperation Council region. *Renewable and Sustainable Energy Reviews, 76,* 555–576.

Alshehry, A. S., & Belloumi, M. (2015). Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renewable and Sustainable Energy Review, 41,* 237–247.

Anthony D. B. (2017). Saudi Arabia turning to wind and solar power. https://www.renewableenergyworld.com/articles/2017/02/saudi-arabia-turning-to-wind-and-solar-power.html. Accessed 29 March 2018.

Arab News. (2014). Green building technology: KSA offers fantastic opportunities. http://www.arabnews.com/economy/news/659191. Accessed 05 April 2018.

Arab News. (2015). Jeddah metro to eliminate 30% of traffic movement. *Arab News*. http://www.arabnews.com/saudi-arabia/news/792526. Accessed 13 March 2018.

Araos, M., Berrang-Ford, L., Ford, J. D., Austin, S. E., Biesbroek, R., & Lesnikowski, A. (2016). Climate change adaptation planning in large cities: A systematic global assessment. *Environmental Science & Policy, 66,* 375–382.

Bai, X., Dawson, R. J., Ürge-Vorsatz, D., Delgado, G. C., Barau, A. S., Dhakal, S., et al. (2018). Six research priorities for cities and climate change. *Nature, 555*(7694), 23–25.

Balaban, O., & de Oliveira, J. A. P. (2017). Sustainable buildings for healthier cities: Assessing the co-benefits of green buildings in Japan. *Journal of Cleaner Production, 163,* S68–S78.

BP (British Petroleum). (2017). BP Statistical Review of World Energy 2017. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf. Accessed 13 March 2018.

Brauer, M., Freedman, G., Frostad, J., Van Donkelaar, A., Martin, R. V., Dentener, F., et al. (2015). Ambient air pollution exposure estimation for the global burden of disease 2013. *Environmental Science and Technology, 50*(1), 79–88.

Broto, V. C., & Bulkeley, H. (2013). A survey of urban climate change experiments in 100 cities. *Global Environmental Change, 23*(1), 92–102.

Bulkeley, H., Schroeder, H., Janda, K., Zhao, J., Armstrong, A., Chu, S. Y., & Ghosh, S. (2009). Cities and climate change: The role of institutions, governance and urban planning. In *World Bank symposium on climate change*.

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning, 95,* 1–66.

Center for Global Development (2015). Developing Countries Are Responsible for 63 Percent of Current Carbon Emissions. https://www.cgdev.org/media/developing-countries-are-responsible-63-percent-current-carbon-emissions. Accessed 06 April 2019.

Chen, W. Y. (2015). The role of urban green infrastructure in offsetting carbon emissions in 35 major Chinese cities: A nationwide estimate. *Cities, 44,* 112–120.

Chen, Y., Li, X., Zheng, Y., Guan, Y., & Liu, X. (2011). Estimating the relationship between urban forms and energy consumption: A case study in the Pearl River Delta, 2005–2008. *Landscape and Urban Planning, 102*(1), 33–42.

Chowdhury, S., & Al-Zahrani, M. (2013). Implications of climate change on water resources in Saudi Arabia. *Arabian Journal for Science and Engineering, 38*(8), 1959–1971.

CIA (Central Intelligence Agency) USA. (2019). *The World Factbook*. Middle East: Saudi Arabia. https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html. Accessed 13 March 2019.

City Mayors. (n.d.). http://www.citymayors.com/. Accessed 08 Aug 2018.

Dano, U. L. (2018). Improving traffic safety towards sustainable built environment in Dammam City, Saudi Arabia. In Scholz, M. & Hermanowicz, S. (eds), *IOP conference series: earth and environmental science*.

Dano, U. L., & AlQahtany, A. M. (2019). Issues undermining public transport utilization in Dammam city, Saudi Arabia: An expert-based analysis. *Journal of Sustainability Science and Management*, *14*(2), 155–169.

Dano, U. L., Balogun, A., Matori, A., Wan Yusouf, K., Abubakar, I. R., et al. (2019). Flood susceptibility mapping using GIS-based ANP: A case study of Perlis, Malaysia. *Water, 11*(3), 615.

Darfaoui, E. M. & Al Assiri, A. (2010). *Response to climate change in the Kingdom of Saudi Arabia*. A report prepared for the Food and Agriculture Organization, United Nations. http://www.fao.org/forestry/29157-0d03d7abbb7f341972e8c6ebd2b25a181.pdf. Accessed 08 Aug 2018.

DeNicola, E., Aburizaiza, O. S., Siddique, A., Khwaja, H., & Carpenter, D. O. (2015). Climate change and water scarcity: The case of Saudi Arabia. *Annals of Global Health, 81*(3), 342–353.

Eckstein, D., Kunzel, V., & Schafer, L. (2018). The Global Climate Risk Index 2018. https://germanwatch.org/en/download/20432.pdf. Accessed 18 Sept 2018.

Fang, C., Wang, S., & Li, G. (2015). Changing urban forms and carbon dioxide emissions in China: A case study of 30 provincial capital cities. *Applied Energy, 158,* 519–531.

GAS (General Authority for Statistics, Saudi Arabia). (2010). The general population and housing census 1431 H. https://www.stats.gov.sa/en/13. Accessed 08 Aug 2018.

Gazzeh, K., & Abubakar, I. R. (2018). Regional disparity in access to basic public services in Saudi Arabia: A sustainability challenge. *Utilities Policy, 52,* 70–80.

Global Mass Transit Report. (2016). Public transport in Saudi Arabia: Priority sector for government investment. https://www.globalmasstransit.net/archive.php?id=24083. Accessed 28 Aug 2018.

Green Information Gateway. (2018). Popular Programs in Saudi Arabia. http://www.gbig.org/places/851. Accessed 08 Oct 2018.

Gouldson, A., Colenbrander, S., Sudmant, A., Papargyropoulou, E., Kerr, N., McAnulla, F., et al. (2016). Cities and climate change mitigation: Economic opportunities and governance challenges in Asia. *Cities, 54,* 11–19.

Hassan, A. M., & Lee, H. (2015). The paradox of the sustainable city: Definitions and examples. *Environment, Development and Sustainability, 17*(6), 1267–1285.

Hoornweg, D., Sugar, L., & Trejos Gómez, C. L. (2011). Cities and greenhouse gas emissions: Moving forward. *Environment and Urbanization, 23*(1), 207–227.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 151). Geneva: IPCC.

Kammen, D. M., & Sunter, D. A. (2016). City-integrated renewable energy for urban sustainability. *Science, 352*(6288), 922–928.

Laukkonen, J., Blanco, P. K., Lenhart, J., Keiner, M., Cavric, B., & Kinuthia-Njenga, C. (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat International, 33*(3), 287–292.

Liu, H., Tellez, B. G., Atallah, T., & Barghouty, M. (2012). The role of CO_2 capture and storage in Saudi Arabia's energy future. *International Journal of Greenhouse Gas Control, 11,* 163–171.

Malik, K., Rahman, S. M. Khondaker, A. N., Abubakar, I. R., Aina, Y. A. & Hasan, M. A. (2019). Renewable energy utilization to promote sustainability in GCC countries: Policies, drivers and barriers. *Environmental Science and Pollution Research*, *26*(20), 20798–20814.

Matthews, T., Lo, A. Y., & Byrne, J. A. (2015). Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. *Landscape and Urban Planning, 138,* 155–163.

Missimer, T. M., Drewes, J. E., Amy, G., Maliva, R. G., & Keller, S. (2012). Restoration of wadi aquifers by artificial recharge with treated waste water. *Groundwater, 50*(4), 514–527.

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning, 134,* 127–138.

Odhiambo, G. O. (2017). Water scarcity in the Arabian Peninsula and socio-economic implications. *Applied Water Science, 7*(5), 2479–2492.

Oxford Economics. (2016). Future trends and market opportunities in the world's largest 750 cities: How the global urban landscape will look in 2030. https://www.oxfordeconomics.com/Media/Default/landing-pages/cities/OE-cities-summary.pdf. Accessed 21 Jan 2018.

Saudi Gazzette. (2018). New parks set to increase Jeddah's green cover and leisure activities. http://saudigazette.com.sa/article/533253/SAUDI-ARABIA/New-parks-set-to-increase-Jeddahs-green-cover-and-leisure-activities. Accessed 28 Aug 2018.

Solecki, W., Seto, K. C., Balk, D., et al. (2015). A conceptual framework for an urban areas typology to integrate climate change mitigation and adaptation. *Urban Climate, 14,* 116–137.

Spiess, A. (2008). Developing adaptive capacity for responding to environmental change in the Arab Gulf States: Uncertainties to linking ecosystem conservation, sustainable development and society in authoritarian rentier economies. *Global and Planetary Change, 64*(3–4), 244–252.

Tlili, I. (2015). Renewable energy in Saudi Arabia: Current status and future potentials. *Environment, Development and Sustainability, 17*(4), 859–886.

Tolba, M. K., & Saab, N. W. (2009). Arab environment: Climate change. In Tolba, M. K., & Saab, N. W. (eds), 2009 Report of The Arab Forum for Environment and Development. http://www.afedonline.org/afedreport09/Full%20English%20Report.pdf. Accessed 07 April 2019.

UN. (2015). *World population prospects: The 2015 revision Key findings and advance tables*. New York: Department of Economic and Social Affairs, Population Division, United Nations.

UN Habitat. (2011). *Global report on human settlements 2011 cities and climate change*. London: Earthscan.

UNFCCC. (2016). United Nations framework convention on climate change. http://cdm.unfccc.int/. Accessed 03 Sept 2018.

Urge-Vorsatz, D., Rosenzweig, C., Dawson, R. J., Rodriguez, R. S., Bai, X., Barau, A. S., et al. (2018). Locking in positive climate responses in cities. *Nature Climate Change, 8*(3), 174.

VijayaVenkataRaman, S., Iniyan, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation. *Renewable and Sustainable Energy Reviews, 16*(1), 878–897.

World Bank. (2010). *Cities and climate change: An urgent agenda. Urban development series*. Washington, DC.

World Bank. (2016). World development indicators 2016: Featuring the sustainable development goals. *Databank*. http://databank.worldbank.org/data/download/WDI_excel.zip. Accessed 21 July 2018.

World Economic Forum. (2017). The best- and worst-countries for air pollution and electricity use. https://www.weforum.org/agenda/2017/02/the-best-and-worst-countries-for-air-pollution-and-electricity-use. Accessed 27 Aug 2018.

Yin, R. K. (2010). *Qualitative research from start to finish*. New York: Guilford Press.

Younger, M., Morrow-Almeida, H. R., Vindigni, S. M., & Dannenberg, A. L. (2008). The built environment, climate change, and health: Opportunities for co-benefits. *American Journal of Preventive Medicine, 35,* 517–526.