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Climate Change Drivers, Effects, and Mitigation-Adaptation Measures for Cities

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ABSTRACT

Climate change has severe impacts on cities in many countries. This review covered climate change sources, consequences, and options for mitigation and adaptation in cities. The global rate of urbanization rose from 13% in 1900 to 52% in 2011. However, the links between urbanization and greenhouse gas emissions remain complicated, influenced by factors such as demographic structure, economic growth, individual income and lifestyles, the nature of urban systems, urban form, and geographical location. These drivers cause climate-induced vulnerabilities in cities, such as drinking water shortages, health impacts, and severe extreme events. Population, urban form, and infrastructure might increase these vulnerabilities. In cities, efficient energy consumption, multi-modal transportation, hydroelectrically powered transportation, land use planning, building direction, height-spacing densification of structures, multiple centers, mass transportation, and non-motorized transportation are found as the main mitigation measures. Likewise, adaptation measures include space greening, green infrastructure, ventilation and air-conditioning, blue spaces, flood protection embankments, polders, dams, etc. Spatial planning is crucial for executing local, regional, and international mitigation and adaptation policies and agreements. To make cities and communities less vulnerable to climate change, these policies and agreements might include: how land is used and developed; how non-fossil fuel energy is promoted; and how buildings and transportation systems use less energy.

Keywords*:* Climate change, Extreme weather, Green transportation, Health, Lifestyle, and Urban heat island.

INTRODUCTION:

Human activities in the natural environment play a significant role in global warming and contribute to the increasing emission of greenhouse gases in the atmosphere. Fossil fuels' induced greenhouse gas emissions occurred on a large scale during the Industrialization period, which led to urbanization. Further, urbanization contributes to land transformation with-in and near the urban area. It is reported that many cities in Asia are found as the epicenters of economic growth and a major source of greenhouse gas emissions (Gu & Han, 2010; IPCC, 2007; Umezawa *et al.*, 2020). Globally, about 55% of the world's population lives in cities in 2018, while it was only 30% in 1950. This urban population is projected to increase by 68% by 2050. In 2018, Africa (13%) and Asia (53.7%) were home to almost two-thirds of the global urban population. It is estimated that together, they will be home to three-fourths of the urban population by 2050 (United Nations, 2019).

The key determinants of global greenhouse gas emissions and climate change are population growth, patterns of economic activity, energy demand, building design and infrastructure, lifestyle, land-use pattern, geographical location, and current climate policies, all of which are linked to the urbanization process (Abubakar & Dano, 2019; Dodman, 2011; Minx *et al.*, 2011; Siddik *et al.*, 2021; Siddik & Zaman, 2021; World Bank, 2010). Human behaviors have a significant impact on the climate in urban areas as their emission effects vary significantly from those in neighboring rural areas (Salleh *et al.*, 2013).

The Intergovernmental Panel on Climate Change (IPCC) distinguishes energy supply (26%), transportation (13%), residential and commercial buildings (8%), industry (19%), agriculture (14%), land use change and forestry (17%), and waste and wastewater (3%) as the key contributors to worldwide greenhouse gas (carbon dioxide, nitrous oxide, methane, and ozone) emissions (Barker *et al.*, 2007). However, greenhouse gases are generated by a variety of activities in cities, including power generation, infrastructure, services and manufacturing industries, and transportation (Dodman, 2011). The energy consumption rate of urban areas is found to be twice as much as rural areas, but they are responsible for almost three-quarters of global CO_2 emissions (Shahjalal, 2021; Hoornweg *et al.*, 2011).

Climate change poses a major threat to the urban environment and its economy worldwide. Its consequences are likely to worsen shortly. Many urban areas are prone to being impacted by extreme weather events such as higher annual rainfall, tropical storms, lightning, and flooding, as well as heat island effects (Grafakos *et al.*, 2018, 2020; Shalaby & Aboelnaga, 2018). In cities, the human population, water resources, biodiversity, buildings, and infrastructures are extremely susceptible to the consequences of climate change, including sea-level rise, urban heat island, tidal surges, floods, and droughts. Moreover, climate change has an effect on how stakeholders in the city behave. These behavioral changes are expressed in a variety of ways in the urban system, including morphological changes in the city, institutional, operational, economic, cultural, social, and environmental changes (Attaur-Rahman *et al.*, 2016; Balaban & Puppim de Oliveira, 2014; Grafakos *et al.*, 2018, 2020; Shalaby & Aboelnaga, 2018).

Grafakos *et al.* (2018) describe the development and implementation of policies and actions to reduce current and future anthropogenic greenhouse gas emissions, known as mitigation strategies, as well as responses to climate change-induced impacts and uncertainties for adjusting the built environment to mitigate the adverse effects of extreme events, known as adaptation measures. Cities are taking the lead in climate change mitigation and adaptation by reducing greenhouse gas emissions, building resilience, and promoting sustainability (Pietrapertosa *et al.*, 2018; Solecki *et al.*, 2015). This role has been reflected by signing up to different agreements in international charters and meetings, including the United Nations Framework Convention on Climate Change (UNFCCC) signed in 1992-93 but effective from 1994, the Kyoto Protocol signed in 1997 but effective from 2005, and the Paris Agreement signed and effective from 2016 (Kuyper *et al.*, 2018). This review looked at how climate change affects cities and what they can do to mitigate or adapt to it.

METHODOLOGY:

Researchers used academic databases and search engines such as ScienceDirect, Web of Science, Scopus, Google Scholar, PubMed, and Science Open to conduct literature searches on the subject matter. Various keyword combinations such as cities and climate change, urban and climate change, climate change effects on cities, urban drivers of climate change, climate change mitigation, climate change adaptation, urban forms, green spaces and climate change, blue spaces and climate change, urban green transportation, and policies for climate change mitigation adaptation were used until the middle of 2022. Duplicate literature was removed after screening the results of the literature search. Relevant literature was identified at this stage. The findings of this review are presented in Section as urban drivers of climate change, effects of climate change on cities, and climate change mitigation-adaptation). Finally, some concluding remarks are made in the conclusion section.

RESULTS:

Urban Drivers of Climate Change

Urban areas, in the context of climate change, significantly differs from rural areas in many countries. The global rate of urbanization has risen from 13% in 1900 to 36% in 1970 and 52% in 2011, but the links between urbanization & GHG-emissions levels remain complicated and require various drivers such as population and demographic structure; economic growth; individual income and lifestyles; the nature of urban systems; urban form and design; and geographical location (Blanco *et al.*, 2015; Dodman, 2011; Minx *et al.*, 2011; Shalaby & Aboelnaga, 2018). With the rapid growth of urbanization and industrialization in Asia, anthropogenic emissions have accelerated more than in many other Western countries in recent decades (Patella *et al.*, 2018).

Population and demographic structure

The global population grew by almost 87% between 1970 and 2010, to about 6.9 billion in 2010, from 3.7 billion in 1970 (Blanco *et al.*, 2015; United Nations, 1999). About 55% of the global population lived in cities in 2018, and that is expected to rise to 68% by 2050. According to this project, about 2.5 billion more people will be added to cities because of rapid urbanization (United Nations, 2018). Each additional person raises GHG emissions, while the contribution rate varies greatly depending on their socioeconomic and geographic circumstances (Dietz & Rosa, 1997; O'Neill *et al.*, 2012). The global urban population has increased dramatically from 0.75 billion (1950) to 4.2 billion (2018). Despite its lower degree of urbanization, about 54% of the global city population exists in Asia (United Nations, 2018). For example, the 35 largest and most important cities in China account for 18% of the country's population, and these cities are accountable for about 40% of the energy-related CO_2 emissions (Dhakal, 2010).

Economic growth

Across countries, per capita energy consumption is closely associated with per capita income (Krausmann *et al.*, 2008). It's possible that economic growth in developing countries would be more emissions-oriented than in developed economies (Jakob *et al.*, 2012). Rapid economic growth in middle-income countries continues to devastate the effects of carbon emissions, resulting in strongly increasing emissions. However, since economic growth in developed countries is slower, the impact of technological change is more noticeable, and emissions rise quite slowly or decrease (Brock & Taylor, 2010). Hence, it is evident that energy consumption and its environmental impacts go up or down quite slowly in the early stages of economic cycles and afterwards decrease more rapidly throughout the later stages (Grossman & Krueger, 1994; Jotzo *et al.*, 2012). From 1970 to 2010, Asia had the world's fastest economic growth, averaging 5.0% per year. In all regions except Asia, per capita emissions have decreased over time. Despite this convergence, there are still significant differences in per capita emissions between countries (Matisoff, 2008; Pellegrini & Gerlagh, 2006; Stern, 2012). Consumption-based greenhouse gas emissions are highly associated with the economic growth of a country. It may be a developing or developed country. Researchers found that rising consumption is the main cause of rising emissions in the Netherlands between 1987 and 1998 (De Haan, 2001) and in the UK between 1992 and 2004 (Baiocchi & Minx, 2010). Within cities, the types of economic activities that have an effect on green-house gas emissions. Capitalist manufacturing and industries that use a lot of energy are strongly linked to more pollution, especially when the energy they use comes from fossil fuels (Dodman, 2011).

Individual income and lifestyles

We follow a consumption lifestyle as we consume more and use more resources in our real experiences, resulting in increased emissions from our lifestyles. Between 1992 and 2007, urban development and lifestyle changes in China contributed to an increase in energy-related carbon dioxide emissions (Minx *et al.*, 2011). The lifestyle we lead largely depends on the household income. The amount of household income is noteworthy as it influences house size as well as the housing neighborhood's thermal comfort threshold temperatures (Blanco *et al.*, 2015; Kennedy *et al.*, 2009). However, a high quality of life can be found in cities without releasing significant quantities of greenhouse gases. There are so many cities across the worlds that have low energy consumption while still ensuring a comfortable lifestyle (Spivak, 2011).

Nature of urban system

Urban systems lead to climate change because of their several functions, including spatial, transport, and supply functions, which require huge amounts of fossil fuels. Spatial urban functions include buildings to house people and industry, and spaces for social-cultural and economic interactions (Shalaby & Aboelnaga, 2018). Buildings accounted for 28% of worldwide energy-associated CO_2 emissions, with direct CO_2 emissions from the burning of fossil fuels responsible for nearly a third of the total emissions. In addition to that, another 11% of CO_2 emissions from the energy sector originated from the construction process, including the process of building raw materials including cement, steel, brick, etc., transportation of raw materials, and the construction process (UN Environment and International Energy Agency, 2017). Urban transportation functions include the movement of people, raw materials, and products towards and from urban areas as well as their periphery (Shalaby & Aboelnaga, 2018). In 2010, final energy demand for transportation accountted for 28% of total end-use energy, with about 40% of that used in urban transportation (Sims *et al.*, 2014).

Urban form and design

Urban form and design can have an inclusive range of consequences for an urban area's greenhouse gas emissions. Denser buildings require less energy to heat. In addition to that, single-family housing uses more energy to heat and cool than the other types of dwellings. Furthermore, a multi-functional neighborhood is more practical than a mono-functional neighborhood for decreasing energy demand and consumption ratio and for encouraging walking, cycling, and other non-motorized vehicle travel (Dodman, 2011; Farjam & Hossieni Motlaq, 2019; Keeley & Frost, 2014). Hence, it's likely that urban design will exacerbate climate change effects and make urban spaces more vulnerable. Bitumen, pavement, and other hard surfaces absorb solar heat, resulting in a heat island in urban areas that contributes to rising urban temperatures (Shalaby & Aboelnaga, 2018).

Geographical location

A city's GHG emissions are highly influenced by its geographic position. The amount of energy needed to heat urban buildings is now heavily influenced by the climate of the area, especially on warm days (Kennedy *et al.*, 2009). It is evident that household energy use (such as heating, cooling, and lighting) or household GHG emissions in an urban area obviously depend on its geographical location (Dodman, 2011; Kennedy *et al.*, 2009). In the United States, cities with colder winters have higher home heating emissions in January, whereas cities with hotter summers have higher energy use linked with home cooling in July (Glaeser & Kahn, 2010). On the other hand, hydropower access for generating electricity in cities like Geneva in Switzerland, Toronto in Canada, Rio de Janeiro in Brazil, etc. considerably diminishes the concentration of greenhouse gas emissions (Kennedy *et al.*, 2009; Schmidt Dubeux & Rovere, 2007).

Effects of Climate Change on Cities

Climate-induced vulnerabilities in the cities may include unavailable drinking water, health impacts, severe and intensive extreme events, e.g., floods, cyclones, storm surges, heat waves, etc. These vulnerabilities can be extended or triggered based on the agglomeration of people, urban activities, and infrastructure in the cities (Condon *et al.*, 2009; Shalaby & Aboelnaga, 2018).

Effects of extreme weather events

Cities are incredibly susceptible to natural disasters, which are predicted to occur more frequently as a result of climate change. Cities are becoming denser and, in some cases, larger or both because of upward urban population growth. This upward trend makes cities more vulnerable to all kinds of extreme events (Masson *et al.*, 2020). A total of 530 cities, comprising 517 million people around the world, were reported as vulnerable to climatic hazards in 2018 (CDP, n.d.). By 2050, people will be twice as likely to be affected by extreme weather events like floods, cyclones, and tidal surges as they are now (World Economic Forum, 2014). In Asia, nearly all cities are susceptible to multiple natural hazards, including flooding, cyclones, storm surges, heat waves, sealevel rise, excessive rainfall, droughts, etc. (Shaw *et al.*, 2009; Shaw & Sharma, 2011). Super Typhoon Haiyan and its associated storm surge cost USD 13 billion in China's coastal cities (Caulderwood, 2014). In 2005, the Mumbai flood cost USD 100 million. In Hanoi, about 20 thousand households were affected and 45 thousand ha of secondary crops were damaged in the 2008 flood. The total estimated loss was USD 1.6 million (Mulyasari *et al.*, 2011). Church and White estimated global mean sea-level (GMSL) rise using satellite altimeter records and in-situ reconstruction and found 3.2 ±4 mm year-1 rise in GMSL from 1993 to 2009 (Church & White, 2011). Climate change effects on sea-level rise can be felt both directly and indirectly. Changes to the coastline, coastal flooding, coastal erosion, disruption and damage to natural ecosystems and coastal infrastructure, displacement, saltwater intrusion (into estuaries, surface water, and ground water), high storm surges during cyclones, rising ground water tables near to the coast, etc., are all examples of direct effects. In addition, possible indirect effects include changes in soil properties, ecosystem functions, coastal dweller economic activities, psychological effects, recreational effects, land use change, and so on (Dwarakish *et al.*, 2009; Hunt & Watkiss, 2011; Lankao & Gnatz, 2008; Siddik *et al.*, 2018). Many large cities are situated in low-lying areas or along the coast with huge human populations (65% of coastal cities have more than 5 million people) and are the hub of national economic activities, including trade and commerce, and are highly vulnerable to sea-level rise and its associated inundation, high storm surge, erosion, etc. (McGranahan *et al.*, 2007; Nicholls, 2004). Floods have struck three to nine times more frequently than they did five decades ago in eight coastal states in the United States and cost US $14.1 billion between 2005 and 2017. Coastal flooding days have increased significantly in 27 states from a yearly average of 2.1 days during 1956-1960 to 11.8 days during 2006 - 2010 (Amadeo, 2020). In Asia, the majority of large cities are clustered along the coastal areas of the Indian and Western Pacific Oceans. These cities are significantly affected by sea-level rise and associated impacts (Shaw & Sharma, 2011). In the last century, the Indian Coast has experienced a mean sea-level rise of mostly less than 1 mm (Unnikrishnan *et al.*, 2006). About 1% of Indian coastal cities will be inundated or more than 1% of the urban population will be affected by a 3m sea-level rise (Revi, 2008).

Effect on temperatures

Climate change is expected to reduce heating demand during the winter while increasing cooling demand in the summer. However, the magnitude of such effects is significantly influenced by their geographical location (IPCC, 2001). The likelihood of a link between climate change and an increase in the severity of heat waves is very high. Rising temperatures can result in discomfort, monetary disruption, displacement, and higher death rates. Heatwaves reportedly cause an increase in fatalities and casualties in Europe and North America. However, they are also associated with age, location, and socio-economic conditions (IPCC, 2014). Another example: the industrial development and economic prosperity of Brazil are significantly dependent on hydropower, which is extremely susceptible to changing patterns of precipitation (Geller *et al.*, 2004). Heat waves hit much of Europe in the summer of 2003. Seasonal temperatures in Portugal, France, Italy, England, and Wales are found to be the hottest years on record, which causes an enormous mortality rate (Conti *et al.*, 2005; Johnson *et al.*, 2005). In all Italian capitals, mortality increased by 3134 in 2003 during the three summer months compared to the previous year (Conti *et al.*, 2005). Furthermore, a total of 2139 additional deaths occurred in England and Wales in August 2003 (Johnson *et al.,* 2005). Moreover, heat stroke claimed a total of 3,442 people's lives in the United States during 1999 – 2003 (CDC, 2006). The IPCC forecasts that heat waves will become more intense and occur at a higher frequency in the years to come. This will make people temporarily uncomfortable and give them respiratory illnesses. It will also make cities need more energy to cool down (Ampatzidis & Kershaw, 2020).

Effect on water resources

Urban water resources comprise underground water, surface water (inland), seawater, and rainwater. Climate change, urban heat islands, flooding, cyclones, storm surges, droughts, and sea-level rise all have potential consequences for urban wetlands (Diaz & Yeh, 2014; Jamei & Tapper, 2018). The effects are a reduction in the availability of water, both surface and ground water; increased water demand; hampered water supply systems, including infrastructure and treatment; deteriorating water quality, etc. (Hunt & Watkiss, 2011; UN-Habitat, 2011). Climate change has hastened urbanization along with population growth and intensified water usage, putting more pressure on urban water sources (WHO, 2017). In addition, increases in mean air temperature would accelerate evaporation and increase water demand for cooling in buildings, potentially driving up total per capita water consumption (Ali, 2009; Diaz & Yeh, 2014; Hunt & Watkiss, 2011). An increasing population and mean air temperature would necessitate a significant increase in urban water demand (Lv *et al.*, 2020). Drought and prolonged periods without precipitation would inevitably result in a reduction in the supply of potable surface water and groundwater recharge (Diaz & Yeh, 2014). Such negative effects significantly decrease the availability of freshwater in semi-arid and arid regions. Kundzewicz *et al.* (2007) stated that water supplies are likely to drop in the Western United States, the Mediterranean Basin, northeastern Brazil, and southern Africa. Sea-level rise may cause salt water to seep into surface and ground water in coastal cities (Diaz & Yeh, 2014; Lv *et al.*, 2020). Reduced river flow is considered a key cause of the development of severe saline conditions at the estuary, as saline seawater eventually flows upstream. Seawater can also make coastal groundwater salty by seeping in from the side or from below (Diaz & Yeh, 2014).

Effects on human health

Extreme heat is one of the most hazardous environmental conditions, impacting people (heat-related death and illness) in many countries (Kalkstein *et al.*, 2009). Human tolls and causalities are the direct effects of several natural calamities frequently caused by climate change (Hunt & Watkiss, 2011). A total of 2039 human tolls due to heat stroke were recorded in the United States between 1999 and 2010. While this situation worsens over time among all climate change-related fatalities (Leighton, 2019), an average of 1500 deaths are recorded during the summer (Kalkstein *et al.*, 2009). An extreme heatwave killed over 70,000 people in Europe in 2003 (Leighton, 2019). More than 1,000 people died in Mumbai in 2005 because of a tropical cyclone and the 94 cm of rain that fell in 24 hours (de Sherbinin *et al.*, 2007). Besides, psychological effects includeing post-traumatic depressive illness, anxiety, complicated grieving, and sadness are also observed following disaster events (Silove *et al.*, 2006). Furthermore, changing seasonal climate conditions, such as temperature, precipitation, and humidity, can alter the distribution pattern of disease vectors, potentially increasing health illnesses such as diarrhea, fever, and so on (Costello *et al.*, 2009). The expanded distribution zone of disease vectors will result in an additional 260 – 320 million individuals being infected by malaria worldwide by 2080 (Lindsay & Martens, 1998). Furthermore, acute famine is often an outcome of extreme weather conditions, which can have a substantial bearing on the health of people. Severe famine incidents have been recorded in the past as a result of climatic variations. The great mediaeval famine of Europe (1315 - 1317) is a case of climate-induced severe crop shortages, food price increases, starvation, and death (Mcmichael, 2003). Climate change and the rapid acceleration of its appearance in the past few decades, together with hunger, disparity, and contagious and non-communicable diseases, pose a significant threat to public health. Climate change's health effects will impact most communities, both rural and urban, in the upcoming decades, putting billions of people's lives and well-being at risk. In addition, even though they produce the least amount of greenhouse gases, the people living in the world's poorest countries will be the ones to suffer the most from the repercussions of climate change (Costello *et al.*, 2009). African poor people are projected to lose healthy life years more than 500 times more than European nations as a result of global environmental change (Campbell-Lendrum *et al.*, 2007).

Effects on urban forestry

One way to think about the urban forest, which in many respects is distinct from forests found in the countryside, is as the trees that are found in cities. In the context of forests, urban trees can be found in parks, along streets in rows, or even as individual trees. However, they are required to be in close proximity to people who live in cities and structures that are built in cities. They differ in relation to composition, age, health status, and ownership patterns. Urban trees have environmental, economic, and social values (Dwyer & Nowak, 2000; Ordóñez *et al.*, 2010). The hydrological cycle is changing as a result of climate change, and this has an effect on urban forests. Winter precipitation increases the risk of physical damage to urban forests due to higher ice loading and snowfall. On the other hand, water scarcity is worsened during the summer months as a direct result of increased evapotranspiration. Moreover, extreme events like cyclones, storm surges, and floods may damage urban forests (Safford *et al.*, 2013). The capacity of forests to provide ecological services may be decreased, and the existence of urban forests and their composition can be affected as a result of the mentioned effects (Nowak, 2010; Ordóñez *et al.*, 2010). For example, Hurricane Sandy, which hit New York City in October 2012 accompanied by high-speed winds and a storm surge, had a negative impact on urban green spaces and populations. Sandy uprooted and washed away 10,926 trees in New York City (Sutton, 2016).

Effects on urban tourism

One of the areas of the global economy that is growing at the quickest rate is tourism, which is extremely susceptible to variations in regional weather and other aspects of the natural environment (Fang *et al.*, 2018). However, this sector is in the enormously difficult position of being both a significant source of greenhouse gases and a substantial victim of climate change. The impacts of climate change depend upon a destination's location, capacity, willingness, and readiness (Berrittella *et al.*, 2006). Extreme events and environmental circumstances, including temperature variation, excessive or inadequate rainfall, loss of ecological habitat, and infectious diseases, have an effect on resource-oriented attractions for tourists (Hall *et al.*, 2004). The total number of visitors, duration of stay, trend of recreational activities, destination preferences, customer satisfaction, operational cost, and even standards of safety and security in tourist areas are all likely to be influenced by the impacts of climate change on both a domestic and international scale (de Sherbinin *et al.*, 2007; Gössling *et al.*, 2006; Scott *et al.*, 2008; Smith, 1990). For example, coastal cities like Rio de Janeiro that rely upon beach tourism may be affected by rising sea-levels combined with an increased frequency and severity of destructive tidal waves. In Rio de Janeiro, coastal erosion brought on by sea-level rise increases operational costs (de Sherbinin *et al.*, 2007). The number of tourists may decline as many cities are transforming their tourist sites because of the severe effects of flooding, heat waves, sea-level rise, storm surges, etc. (Buckley, 2012). Another study explored that the majority of tourists in tropical regions, those who are spending their holidays in their own country or nearby, will change their destinations to mountainous areas to address climatic effects (Amelung *et al.*, 2007).

Climate Change Mitigation-Adaptation

According to the Intergovernmental Panel on Climate Change, mitigation is defined as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)" while adaptation is defined as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014). In the context of urban planning, mitigation measures include in the energy sector: efficient energy consumption including energy savings lifestyle, renewable energy use, and smart technologies; the transporttation sector: multi-modal, public, and hydroelectriccally powered transportation; land use planning; building and infrastructure: building direction, height and spacing density of structure, multiple centers, mass transportation, non-motorized transportation including cycling and walking; and adaptation measures include in building and infrastructure: space greening, green infrastructure, ventilation and air-conditioning; water management: blue spaces, flood protection embankments, polder, dams, etc (Grafakos *et al.*, 2018; McEvoy *et al.*, 2006). Spatial planning is significantly important for implementing several measures for mitigation and adaptation and agreements formulated and signed at local, regional, and international levels. These strategies and agreements may be linked with land use pattern and land development, encouraging usage of non-fossil fuel energy, energy savings technology in building and transport systems, etc. for reducing the vulnerability of cities and neighborhoods (Davidse *et al.*, 2015; Wang *et al.*, 2018).

Urban form and structure

It is necessary to be prepared for the threats posed by climate change and to make plans for adaptation in light of the fact that the world population is becoming increasingly urbanized and concentrated. Because of their highly urbanized and compact populations as well as their urban structure, cities is accountable for 75% of the world's emissions of greenhouse gases that are caused by the consumption of energy (Leibowicz, 2020; Wang *et al.*, 2018). In order to devise solutions that are effective and trustworthy for lowering emissions of greenhouse gases, it is necessary to have a solid understanding of the various urban shapes and structures. An effective urban form must instigate the development of green transportation, including mass transportation systems, hydroelectrically powered vehicles, walking, cycling, etc. (Dulal *et al.*, 2011; Wang *et al.*, 2018). However, the building sector is responsible for 25% of global greenhouse gas emissions, particularly related to fossil fuel-based energy, mostly used for cooling and heating (Fosas *et al.*, 2018; Schünemann *et al.*, 2020). In this context, every new building's bioclimatic architecture and layout, including the design of its site and direction, should be promoted to optimize the advantages of local environments, such as ventilation and lighting. The creation of a green corridor would aid in the flow of air masses that enable cooling and ventilation processes within a compact urban form and structure (Yiannakou & Salata, 2017). Further, about 30% of energy consumption can be reduced by adding 5 cm of expanded polystyrene and energy-efficient windows (Andric *et al.*, 2020). Moreover, changes in urban form and structure, including urban design, building materials, building structure, etc., significantly affect urban heat islands and urban climate (Emmanuel & Fernando, 2007; Hart & Sailor, 2009). At this size, the structure and spacing of dwellings in relation to one another, which mainly affect shading and wind speed, are physically expressed (Ramyar *et al.*, 2019). Mixed-use development is the outcome of the spatial planning process and is referred to as the "complex developments" that take place in the public domain. Mixed-use planning aims to provide urban land-use with a mix of shopping, institutional, residential, recreational, and other functions clustered in one location, the same building, or adjacent to one another (Keeley & Frost, 2014; Raman & Roy, 2019; World Bank, 2014). One of the key benefits of mixed-use planning is that it promotes cycling and walking as modes of transportation. The effect of mixed-use on walking trips is greater than the vehicle miles traveled (VMT). Frank *et al.* (2011) found that mixed uses are strongly linked to both the number of miles driven and the amount of carbon dioxide released.

Urban greening and green infrastructure practices

Urban greening has been conceptualized and promoted as a means of making communities more resilient in recent decades. In many cities across the world, the idea of urban greening has already been put into practice as a potential solution to the problem of the urban heat islands' (UHI) influence and as a method for lowering the greenhouse gases that are emitted. Urban greening may include street trees, urban parks, green walls, green roofs, etc. (Aram *et al.*, 2019; Bowd *et al.*, 2015; Grafakos *et al.*, 2018; Kong *et al.*, 2016; Norton *et al.*, 2015). Another ecosystem or environmental management approach, green infrastructure, is also one of the best strategic tools for both the adaptation and mitigation measures of climate change (Pauleit *et al.*, 2013; Yiannakou & Salata, 2017). Green infrastructure, such as street trees, city parks, green corridors, and rooftops, improves the quality of built environments in cities and provides resilience to climate extremes such as heat waves, droughts, and floods (Jamei & Tapper, 2018; Oke, 1989). The key advantages of urban greening and practices of green infrastructure are capturing and storing water; using it as carbon sinks; sustainable ecosystems; neighborhood cooling; etc. (Aram *et al.*, 2019; Jamei & Tapper, 2018; Yiannakou & Salata, 2017). Urban reforestation measures are being strongly advocated as a city planning strategy to offset climate change, support human health, social well-being, and reduce environmental contamination exacerbated by urbanization (Salmond *et al.*, 2016). Trees can influence wind behavior, including wind movement and velocity. This is, however, reliant on the types of trees. Trees can enhance pedestrian or neighborhood thermal comfort (Bonan, 1997; Park *et al.*, 2012; Shashua-Bar *et al.*, 2011). About 30% to 40% of wind velocity can be reduced under the canopy of a deciduous tree (Oke, 1989). Moreover, the presence of trees in the surrounding area can lower wind velocity by up to 51% (Park *et al.*, 2012). Besides lowering wind speed, street trees help to increase air quality by absorbing air pollutants, airborne contaminants, and noise, reducing stormwater runoff, providing shade, and reducing the severity of the UHI effect (Ferrini *et al.*, 2020; Salmond *et al.*, 2016). Parks have the greatest cooling influence in city areas. However, the cooling efficiency depends on park size, plant species, drainage capacity, etc. A study (Vaz Monteiro *et al.*, 2016) found that large areas of green space (up to 12.1 ha) within 180 - 300 m of eight city center parks in London cool down by 1°C.

Forests serve as important carbon sinks, capturing and storing water, maintaining ecosystems, cooling neighborhoods, and protecting them from the waves of several natural disasters like cyclones, storm surges, riverbank erosion, etc. (Bowd *et al.*, 2015; Kole & Ellison, 2018; Valle Junior *et al.*, 2015). Kole and Ellison, (2018) said that replanting trees in places where they have been cut down could help minimize the consequences of climate change. Green walls and rooftops help to combat climate change by acting as carbon sinks, controlling indoor temperatures, lowering albedo, preserving local habitats and landscapes, and mitigating the severe effects of urban heat islands (Grafakos *et al.*, 2018; Vijayara-ghavan, 2016). Morau *et al.* (2012) did a study on bituminous and green roofs on the island of Reunion in the Indian Ocean. They found that the maximum mean temperature on the bituminous roof was 73.5 ±1.4 °C, while on the green roof it was 34.8 ±0.6 °C. Green walls reduce cooling demand significantly in warm climates.

However, such walls may also serve as external insulation in cold weather. During the winter, green facades reduce heat loss across the building envelope, lowering energy consumption. Hence, in all the above-mentioned cases, green walls contribute to reducing greenhouse gas emissions (Jamei & Tapper, 2018). An average reduction of 4.4°C in surface temperature in the case of green facades compared to bare walls was investigated by a study carried out in

Singapore (Wong *et al.*, 2010). In the case of winter, green walls can save 20% of energy demand (Djedjig *et al.*, 2017).

Blue spaces

Urban "blue spaces" or waterbodies are the available surface water sources in an urban area, which comprise ponds, lakes, rivers, canals, and streams. The provision of a thermally comfortable environment for city inhabitants is significantly aided by the presence of blue spaces (Ampatzidis & Kershaw, 2020; Tominaga *et al.*, 2015). The effects of climate change are starting to become apparent in the nation's metropolitan water systems. Urban heat islands, extreme flooding or drought, storm incidence and severity, and sea-level rise are all having direct impacts on natural water supplies (Diaz & Yeh, 2014; Jamei & Tapper, 2018). Food processing, waste disposal, electricity generation, and a variety of other essential urban functions would all come to a halt if there were no surface waterbodies or blue spaces. Since cities now house the bulk of the world's people, it's critical that water providers take steps to address current and upcoming climate change challenges. Since 55% of the worldwide population lives in urban areas, it is of the utmost significance that urban planners take the steps needed to increase the amount of water available in surface areas to deal with climate change and associated consequences (Diaz & Yeh, 2014; Lv *et al.*, 2020; United Nations, 2019). Blue spaces have the potential to diminish the thermal condition of their vicinity. However, this potential varies based on their size, distribution pattern, and distance from the neighborhood. For example, a large single wetland has a greater cooling effect than many smaller and commonly shaped wetlands with the same total volume of water (Steeneveld *et al.*, 2014). Further, blue spaces have a cooling capacity that is highly correlated with the local urban form and surface temperatures within a 500-meter radius (Cai *et al.*, 2018). At a distance of ~30 m, blue spaces can produce a cooling effect of 1-3 °C (Kleerekoper *et al.*, 2012).

Moreover, blue spaces, particularly rivers, canals, and streams, may contribute to distributing spatial heat release (Hathway & Sharples, 2012).

Green Transportation

The transportation industry is a significant contributor to the release of greenhouse gases. In 2010, the final demand for energy associated with transportation contributed to 28% of the total end-use energy, with around 40% of that amount being consumed in urban transportation (Sims *et al.*, 2014). Promoting non-fossil-fuel green transportation is viewed as a critical strategy for mitigating climate change (Kole & Ellison, 2018). Green transportation, which is also called "sustainable transformation," is a way to get around that is good for the environment and has a low carbon footprint. The implementation of environmentally friendly modes of transportation is beneficial for many reasons, including the effective use of existing road infrastructure, the sharp decline of traffic, the decrease in energy consumption, the improvement of air quality, and the enhancement of the general welfare of citizens (Li, 2016). For example, since 2013, more than 5,000 vehicles in Oslo, Norway, have been powered by hydroelectricity. Because of this, there have been fewer emissions of carbon dioxide, as well as improvements in air quality and reductions in noise (Charan & Venkataraman, 2017). Even though urban development has a limited effect on reducing greenhouse gas emissions in the short term because it takes time to build the necessary infrastructure, it has the potential to be very effective in the long term by shifting from a reliance on private vehicles to a reliance on public and other environmentally friendly forms of transportation, such as hydroelectrically powered vehicles, cycling, and walking (Dulal *et al.*, 2011).

Strategies and frameworks

Cities are at the transition point between local policy and national-international agreements such as the UNFCCC, the Kyoto Protocol, and the Paris Agreement to adapt and mitigate climate change (Heidrich *et al.*, 2016; Kuyper *et al.*, 2018). Local, national, and international governments are working with cities to come up with and carry out actions and policies regarding climate change. Climate policies and actions assist planners in developing integrated urban planning strategies that take into account multi-level urban governance approaches (Bulkeley, 2010; Grafakos *et al.*, 2018; Pietrapertosa *et al.*, 2018; Solecki *et al.*, 2015). City councils may be the best at protecting their communities from the current and future effects of climate change (Kole & Ellison, 2018). So, in 2018, almost 8,000 cities and other national and regional governments from every continent (except Antarctica) set goals to reduce greenhouse gas emissions in their own communities (Grafakos *et al.*, 2020). Spatial planning is becoming more important for meeting climate change goals because it helps reduce carbon dioxide emissions by making sure that land is used in a fair way. This is done by putting in place zoning laws to increase energy production, protect green spaces and infrastructure, and distribute land uses in a fair way (Wang *et al.*, 2018). Spatial planning strategies and frameworks can adjust and reform urban form and structure in order to combat climate change (Wang *et al.*, 2018). Hence, addressing the bottom-up approach, hundreds of cities and state councils have created and adopted municipal climate action plans over the last few decades to tackle climate change (Sethi *et al.*, 2020). In most European municipalities, urban planning is done in two stages: comprehensive spatial planning, which focuses on making a policy framework for the whole city, and site-specific detailed planning within the municipality, as well as the implementation of regulatory instruments (Albrechts, 2004; Davidse *et al.*, 2015).

CONCLUSION:

Urbanization resulted from the increased use of fossil fuels and the release of greenhouse gases. By 2050, 68% of people will live in cities. This review identified the drivers and consequences of climate change in cities and the associated mitigation and adaptation measures. The urban population rose from 0.75 billion (1950) to 4.2 billion (2018), causing climate change. Besides, rapid economic expansion in middle-income countries worsens carbon emissions. Urban form and design can also affect greenhouse gas emissions. Bitumen, pavement, and other hard surfaces create urban heat islands. As the urban population continues to rise, cities are becoming denser and, in some cases, larger. It has been identified that nearly all Asian cities are vulnerable to flooding, cyclones, storm surges, heat waves, sea-level rise, excessive rainfall, drought, etc., and it is expected that extreme weather will double by 2050. Climate change has accelerated urbanization, population expansion, and water demand, putting pressure on urban water sources. Similarly, it has a notable impact on urban forest hydrology. Furthermore, cyclones, storm surges, and floods can destroy urban forests and urban tourism. For mitigating and adapting to climate change, spatial planning is crucial. To create effective plans, people must comprehend urban forms and design. The effective urban form must promote green transportation, such as hydropower vehicles, walking, and cycling. In addition, mixed-use development combines retail, institutional, residential, recreational, and other uses in one location or building. Urban greening may reduce the effects of urban heat islands. Blue spaces can reduce surrounding temperatures. Green transportation is low-carbon and eco-friendly. Finally, cities take the lead in creating and executing climate actions and policies to adapt and mitigate climate change. Therefore, in 2018, about 8,000 local, national as well as regional governments from every continent (except Antarctica) set goals to reduce carbon emissions.

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CONFLICTS OF INTEREST:

The authors declare no conflict of interest.

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