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REVIEW

The role of energy management in transition towards green cities: a review

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Abstract

The concept of green cities has been getting sustained focus for some time, intending to transform dispersed cities into environmentally, ecologically, and socially healthier spaces to live. The concept interlinks different domains of urban development, such as spatial planning, transport, water and sanitation services, urban greenery, renewable energy, sustainable building construction, and socioeconomic growth through green solutions. Energy planning and management play a vital role in transforming urban areas into environmentally sustainable cities. Integrating energy management as a key aspect of green city strategies from the pre-planning to post-implementation stages can expedite the process. This paper attempts to comprehend the intertwined role of energy management in green city planning through a comprehensive literature review. Relevant articles that discuss energy and management in interdisciplinary domains under the green city concept were identified and reviewed for the period—2000–2021. Diverse energy-efficient management measures and techniques are reviewed under seven domains of green city planning: green spatial planning, transportation, public infrastructure, urban agriculture, buildings, energy, and growth. The summarized literature emphasizes the relevance and significance of efficient energy management in the transition toward a green city. The study also discusses the need for a gradual transition and the challenges in successfully implementing and managing sustainable strategies. The successful implementation of climatic and environmental solutions through policy-level strategic interventions demands continuous effort and monitoring to achieve the long-term goal of sustainability. Energy-efficient urban development practices, with the foundation of a policy framework, can act as sustainable solutions to maintain the synergy between energy independence and urban development. Expediting the transformation of green cities with the adoption of energy-efficient strategies and renewables to decarbonize the energy supply is an accomplishable vision for every city.

Keywords Green city · Energy management · Energy efficiency · Renewable energy · Literature review

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1 Introduction

The international quest to contain the growth of cities in a sustainable way has emerged with many concepts, such as garden cities, sustainable cities, compact solar cities, eco-cities, and green cities. The green city concept is one among the recent ideas that evolved in the last thirty-five years (Lehmann, 2011). This idea has emerged with the thought of transforming dispersed cities into environmentally, ecologically, and socially healthier spaces. Examining this idea of green urbanism has eventually resulted in numerous attempts to provide a conceptual framework for green city planning from a workable implementation viewpoint. According to the Asian Development Bank's definition of green cities in 2012, they conceptualized urban densification with compact development for increasing energy and land-use efficiency. Green city planning targets clean transport, environmentally-friendly industries, green consumerism, eco-friendly design, and production, water resource conservation and management, urban agriculture, efficient Information and communications technology (ICT), greening infrastructure for public services, and waste management for a sustainable living (Asian Development Bank, 2012). The concept and definitions are then reformed many times with evolving ideas in the research field. According to IHS (Institute for Housing and Urban Development Studies of Erasmus University Rotterdam)-Green City Conceptual Framework (IHS-GCCF) formulated in 2018, "While the compact city concept was proposed in an attempt to solve the issues of urban expansion and resource efficiency, the Green City Concept (GCC), is a more recent response to the problem of creating denser, greener and more livable cities" (The green city: Defining & measuring performance, 2023). According to this green city framework, energy efficiency in all sectors, compact spatial planning, extensive urban greenery, and overall green growth with equity principles act as the four pillars or entry points of the concept (Brilhante & Klaas, 2018). Strengthening energy planning and management of various domains of urban planning collectively plays a crucial role in attaining these four pillars. According to Cervero and Sullivan, overall advancement in energy efficiency across all activities can enhance a city's resource efficiency and thus the environmental performance, sustainability, and livability (Brilhante & Klaas, 2018). Understanding the vital role of energy planning and management in green city transition to improve attentiveness from the pre-planning to the post-implementation stage of strategies. It is also pivotal to impart awareness of the need to accelerate this transition to every person involved in that loop, including politicians, policymakers, stakeholders, planning agencies, implementation agencies, and citizens.

Given the current state of the climate crisis, various strategic attempts are being taken across the globe in cities with their ambitious goal for a sustainable future. The critical need for a green city transition points towards continuous efforts for a substantial reduction in carbon emissions in various sectors, initiatives for a gradual shift towards the renewable energy-supported electricity supply, attempts to ensure energy-efficient practices and policy-level decision-making for a green economy. In this background, the current paper tries to understand the interwoven alliance of energy management with green cities. Several studies are available that try to explain eco-cities and green cities. The identified studies predominantly fall into two categories; one tries to define the green city concept and green urbanism principles, while the latter details the studies on interdisciplinary attributes, highlighting their working, technological, social, economic, or environmental aspects associated with sustainable urban development (Cervero & Sullivan, 2011; Lehmann, 2011; Yu et al., 2020). However, a detailed search did not identify any literature that links the role of energy in different domains under the concept of a green city. Hence, this paper attempts to explore how energy management becomes an integral and key component of the green city concept alongside the greening aspect through a comprehensive literature review.

The paper is structured as follows: Sect. 1 briefs about the relevance of understanding the synergy between energy independence and urban development. Section 2 summarizes the literature to examine the significance of efficient energy management in the transition toward green cities. Section 3 discusses the challenges and examples of energy management initiatives in different cities, and Sect. 4 winds up the conclusions.

2 Materials and methods

The methodology used for the systematic literature review began by establishing the conditions for the search. The boundary conditions limited the literature establishing the relevance of energy-management techniques in different domains within the green city concept, such as spatial planning, transportation, public infrastructure, urban greenery, agriculture, and economic growth. Search terms were formulated based on the distinctive aspects of the green city concept and energy management. Detailed literature identification was conducted in Scopus and Web of Science (WoS) (1990–2021) since the databases have a greater extent of articles related to the field (Lazar & Chithra, 2021). The major literature is found to be published from the year 2000 onwards and the dataset is revised to the period 2000–2021. Below-specified search terms were applied in the databases considering the scope of the study:

- Energy
- Efficiency/Planning/Management
- Green/Sustainable
- Spatial Planning/Transportation/Public Infrastructure/Urban Agriculture/Buildings/Renewable/Growth

The search code was finalized based on the search terms identified, as given:

(TITLE-ABS-KEY (energy) AND TITLE-ABS-KEY (efficiency OR planning OR management) AND TITLE-ABS-KEY (green OR sustainable) AND TITLE-ABS-KEY (spatial AND planning OR transportation OR public AND infrastructure OR urban AND agriculture OR buildings OR renewable OR growth))

The initial search identified 1777 articles published in the English language during the years 2000–2021 for further screening. To narrow down to the most relevant articles, only the papers within the limiting boundary conditions were reviewed. The number of papers has come down to 1122 by limiting to only journal publications. These publications are then segregated under the respective domains under the green city framework and descend to 503, as depicted in Fig. 1. To understand each domain in a comprehend manner, the literature highlighting fundamental and pertinent theories and advancements relating to the topic of study was chosen. The most relevant articles were segregated, exploring various interdisciplinary elements within the significant domains in detail. The refined database of 94 articles was finalized by including other relevant literature with further exploration in the field. The critical review of these selected articles collectively comprehended the application of energy efficiency management measures, techniques, and strategies in urban development.

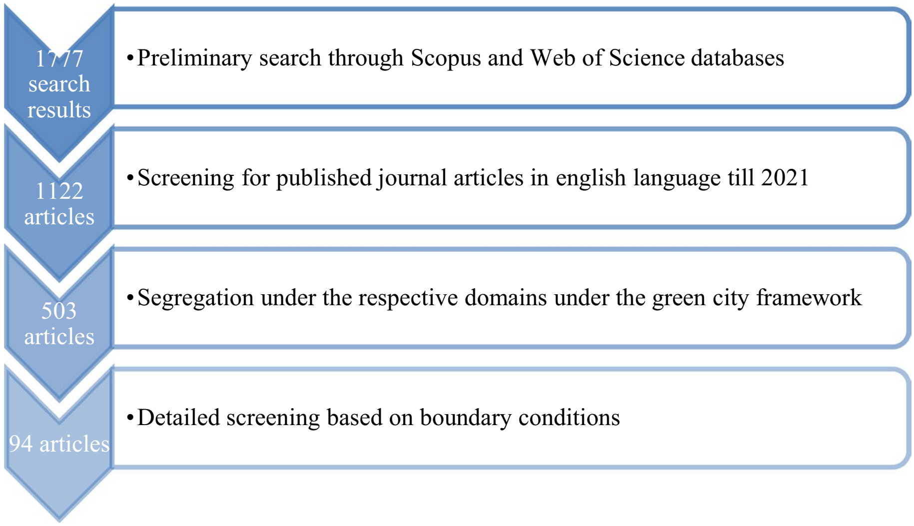

Fig. 1 Methodology for article identification

3 Literature review

Exploring the concept of green urbanism has eventually led to many attempts to develop a conceptual framework of green city planning with a viable implementation perspective. According to Brilhante and Klaas, a green city is "a city that promotes energy efficiency and renewable energy in all its activities, extensively promotes green solutions, applies land compactness with mixed land use and social mix practices in its planning systems, and anchors its local development in the principles of green growth and equity" (Brilhante & Klaas, 2018). In contrast to other definitions of green cities, the one provided above highlights energy efficiency as a crucial component that holds different key features together. The Green City Conceptual Framework held together on the four major principles i.e., energy efficiency and renewable energy in all sectors, extensive greenery, spatial planning with land compactness, mix-use, and social mix, along with green growth and equity (The green city: Defining & measuring performance, 2023). The key domains under the Green City Conceptual Framework are listed down to systemize the literature review in connection, as shown in Fig. 2.

The refined database of articles is then reviewed and collated upon the identified domains from the Green City Conceptual Framework, for a systematic appraisal of the different aspects of the green city concept. The established need for overall advancement in the energy efficiency of all activities for improving any city's resource efficiency and thus

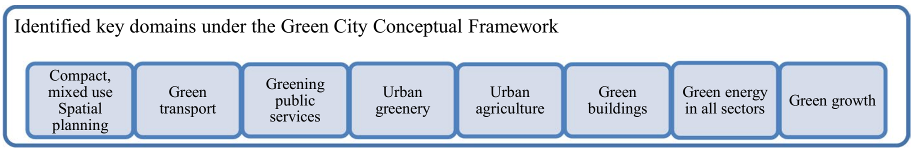

Fig. 2 Identified key domains under the green city conceptual framework

the environmental performance, and sustainability, highlights the relevance of this paper in exploring the possibilities in energy management strategies in all sectors.

3.1 Compact, mixed-use spatial planning

The green city concept aims to transform our cities into livable, healthier urban centers. According to the Asian Development Bank, conceptualizing urban densification with compact development is one of the prime objectives of green city planning that would increase energy and land-use efficiency (Asian Development Bank, 2012). Compact urban development has many advantages, including reduced energy consumption relative to transportation and energy waste during transmission from production infrastructure to consumers (Abdullahi et al., 2015). Mixed land use and infill development are critical criteria in compact cities that promote non-motorized transport modes and urban sustainability (Bibri et al., 2020; Vorontsova et al., 2016). It is also stressed that the design principles of the compact city concept, i.e., compactness, high density, mixed land use, sustainable transportation, green structure, and intensification, act as strategies for a green and sustainable development where energy efficiency is a recurrent outcome.

Xu et al. revealed that population density negatively correlates with energy-related greenhouse gas emissions, whereas physical compactness has correlated positively (Xu et al., 2019). According to Hui, urban density has both positive and negative effects on a city's energy demand and requires a more careful design process (Hui, 2001). Transforming existing cities or urban districts into green urban areas is imperative for overall sustainability, although it is difficult. Determining the energy-efficient retrofitting measures is dependent on the climatic conditions (Huang et al., 2013). Magnani et al. opined that even though energy retrofit is indispensable, sociological studies establish the need for the slow diffusion of retrofit interventions among people through persuasive and redistributive policy tools (Magnani et al., 2020). Lloyd-Jones emphasized phases of retrofitting in culturally valued existing urban heritage-built forms and conserved areas (Lloyd-Jones, 2010). The authors also revealed how an integrated public realm and open space strategy would address more significant sustainability issues. Reducing overall energy consumption through effectual spatial planning strategies is a foundation for socially responsible development practices.

3.2 Green transport

It is essential to connect the whole city to the city center with safe and structured transport networks that reduce time and energy consumption. Green transportation aims at a convenient, safe, efficient, low-pollution, space-saving, humanized, and diversified urban transportation system by prioritizing the transport modes from walking, bicycle, and regular public transport and then to privately owned vehicles (Li, 2016). The idea encourages low-pollution vehicles, such as dual-energy vehicles, natural gas vehicles, electric vehicles, hydrogen fuel vehicles, solar energy vehicles, and electrified vehicles for transportation like trolleybuses, tramcars, light rail, and subways. Silva et al. discussed the importance of an urban development plan that fosters interconnected green infrastructure through a multi-modal transportation system and mixed-use developments for sustainable development (de Silva et al., 2016). Whitelegg and Williams summarized the traditional means of transport focusing on non-motorized transport and how they play an essential role in urban sustainability to provide an energy-conservative, pollution-free, low-cost, and low-maintenance alternative (Whitelegg & Williams, 2000). According to Lehmann, the ultimate goal does not constrain within just its carbon footprint and technical solutions for energy conservation, whereas it aims at holistic societal sustainability and healthy communities (Lehmann, 2011).

Taiebat et al. provided an overview of the energy, environmental, and sustainability implications of Connected and Automated vehicles (CAVs) and how they attribute higher energy efficiency and lesser emissions than conventional vehicles (Taiebat et al., 2018). Also, they overcome the efficiency challenges of Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) to an extent. The paper also talks about technological advancements in the field of electric CAVs and their potential impact on transport decarbonization and the economy of electrification. The carbon-intensive procedure of Information and Communication Technology (ICT) manufacturing and the requirement of large, energy-intensive data centers are found to be the major barriers in the process, attracting more research in that area. Integrated public transport and shared mobility automated systems reduce the usage of private vehicles and maximize efficient utilization. Dogra et al. reviewed the need to adopt an interdisciplinary human-centered approach that ensures integrated mobility that interconnects the city (Dogra et al., 2021). The role of active transportation reflects direct health benefits and also leads toward the low carbon transportation system. Prause and Hunke explored the role of multi-modality and supporting ICT systems in the management and monitoring of the performance of freight traffic in green corridors by integrating the functions and coordinating and thus optimizing energy consumption (Prause & Hunke, 2014). Batarliene and Jarašuniene comprehended the applicability of Advanced Technologies (AT), which ease the ICT systems and thus increase energy efficiency (Batarliene & Jarašuniene, 2016). Also, it is the societal and environmental responsibility of the leaders to administrate the concept of green logistics in facilitating and coordinating the system (Beškovnik & Twrdy, 2012).

The technological advancement in the field of Solar Electric Vehicles has proved their potential to contribute towards the targeted energy-saving and zero-emission future (Su et al., 2010). Shinde et al. assessed alternative options for biogas utilization with the biogas-based electricity generation for electric vehicles and how this bioenergy could be utilized in the operation of public transport systems to achieve green urban mobility with its environmental performance (Shinde et al., 2021). Biogas is a renewable source that is abundant and readily available. The availability of the raw materials and generation capacity of biogas generators facilitates the accessibility to the fuel substitute, which involves raw material collection, transport, storage, processing, conversion, and utilization stages (Shinde et al., 2021). Several studies have been conducted to improve the knowledge base of the energy performance of various biogas vehicle fuels produced from different energy crop-based systems. Börjesson et al. evaluated different crop-based biogas fuels in terms of energy efficiency and emission capacity. Crop-based biogas is expressed as 35–44% energy efficient and has greenhouse gas (GHG) reduction up to 70–120% (Börjesson et al., 2015). Ley crop-based vehicle fuel systems are identified as the best option, followed by maize and wheat, leading to highly GHG-efficient vehicle fuels. Dahlgren compared various biogas-based fuels such as Compressed Biogas (CBG), Liquefied Biogas (LBG), hydrogen, methanol, Dimethyl Ether (DME), and Fischer–Tropsch fuel (FT) in the transport sector in terms of their volumetric energy density (Dahlgren, 2020). The author summarized the role of each fuel as a renewable energy fuel alternative and the potential of hydrogen in pollution-free fuel cell vehicles in the future. A well-planned transport network with integrated emerging energy-efficient techniques significantly contributes to the city's systematic flow.

3.3 Greening public services

Another step in the process is to green the public services, drinking water, sanitation, and stormwater infrastructure. Many authors have explored the role of the water-energy nexus at the urban level in achieving sustainable cities. There are multiple domains where energy has been intertwined with water, such as direct water supply, rainwater management, aquifer recharge, stormwater management, irrigation, groundwater extraction, drinking water, and wastewater treatment. According to Novotny, conserving water is the most important solution to attain water security, proportionally reducing energy consumption (Novotny, 2011). The author also addressed the three phases of the nexus, i.e., the water conservation phase, which results in a linear reduction in water use and energy demand; the inflexion phase, in which the collection, treatment, and supply lead to higher energy usage and the rising energy demand phase due to the requirement of higher efficiency treatment methods for brackish water or groundwater. Makisha and Kazimirova indicated the need to identify the energy-saving potential in each component of a city-level water supply and sewage system (Makisha & Kazimirova, 2018). Various aspects, from regulation of resource consumption to auditing engineering systems in pump operation, water treatment plants, pipeline network and maintenance, metering and controlling systems, boilers operation, sewage network, and wastewater treatment plants, have an individual share of contribution in the overall energy savings of the system. The automated control systems directly affect energy savings with their systematic operational management capacity (Makisha & Kazimirova, 2018).

Individual open-loop groundwater extraction and the general water supply system add to operational energy use. So, the efficiency of the extraction system is crucial. Conservation of rainwater from individual building level to the neighborhood level and repurposing that water for drinking and other household needs, flushing, landscape irrigation, and aquifer recharge is the natural way to curtail the pressure on water resources. Adopting a rainwater harvesting system with necessary chemical treatments is one of the viable solutions that could save energy directly by reducing potable water demand (Chiu et al., 2015; Rahman et al., 2014). Life cycle assessment of the rainwater harvesting system over the conventional water supply and distribution system indicated the former as a safe and reliable alternative with significant water savings of up to 44–54%, less operational energy use, and reduced greenhouse gas emissions considering its dependency on the annual rainfall and location (Racoviceanu & Karney, 2010). The study also stated the lesser embedded energy of water-efficient appliances compared to domestic water-heating energy use, with the example of 4% for Toronto. Adopting Green Infrastructure (GI) and Low Impact Development (LID) practices instead of grey infrastructure or conventional stormwater management shows its ability to save energy and attenuate flood impacts. Incorporating green infrastructure in new developments and retrofitting the existing areas, even from the building level to the urban scale, has long-term economic benefits (Thiagarajan et al., 2018). Racoviceanu and Karney established the necessity of a whole-system approach in water demand management, considering the positive synergy between various infrastructure systems and their interconnection with the environment (Racoviceanu & Karney, 2010). According to Novotny, it is essential to achieve energy balance for a city in transition to sustainable water management by the adoption of advanced resource management options like distributed Resource Management Cluster (RMC) or eco-block, Integrated Resource Recovery Facility (IRRF), and Hydrogen Based Integrated Resource Recovery Facility (H2-IRRF) (Novotny, 2011).

3.4 Urban greenery and agriculture

Extensively adding greenery to cities has always been the key component of the concept. The idea of greening the city under the concept brings many benefits in terms of urban biodiversity, local food efficiency, urban cooling, and, eventually, healthy urban development. The idea of a green city ensures bringing back landscapes, community gardens, public parks, vertical farming, terrace gardens, green roofs, urban agriculture, and urban forests within the city (Lehmann, 2011; Tian et al., 2012). Much research has been conducted to understand the long-term effects of implementing various greenery systems in buildings and at the urban level on energy consumption. Hsu and Liao reviewed the benefits of urban agriculture with respect to agricultural outcomes and energy savings by applying the Economic Value Added (EVA) technique along with the indirect social, economic, and psychological benefits (Hsu & Liao, 2018). Urban agriculture also helps to reduce energy consumption through a short food supply chain and packaging (Tapia et al., 2021). According to Senosiain, urban green infrastructure consists of urban public space components, i.e., green canopies, green permeable systems, green pavements, bio-retention areas, etc., and individual building components, i.e., green roofs and green walls (Senosiain, 2020). Mutani and Todeschi stated that the use of green roofs and urban greenery can result in energy savings with a reduction of 12% for space cooling energy consumption (Mutani & Todeschi, 2021). Considering the seasonal changes and temperature variation in a year, the study could prove the significant positive impact of roof-integrated green technologies in reducing energy consumption by reducing solar radiation absorption and mitigating the Urban Heat Island effect. Thus, at the urban level, the green aspects regulate the local climate and consequently reduce the heating and cooling energy consumption; also, at the building level, the green components help efficient energy performance. Retrofitting the green roofs in existing buildings is feasible in construction and has long-term benefits (Castleton et al., 2010). Azis et al. established the potential of an integrated green wall along with green roofs with respect to the annual electricity savings (Azis et al., 2019).

Building greenhouses on unused rooftops can be another potential space for urban farming. Integrated rooftop greenhouses take up the role of the sink for waste heat by integrating the building HVAC systems with the greenhouses (Muñoz-Liesa et al., 2020). Despoina Avgoustaki and Xydis affirmed that Indoor and outdoor vertical farming is more profitable with higher energy savings than greenhouses (Avgoustaki & Xydis, 2020). Combining indoor urban vertical farming (IUVF) with renewable energy supporting systems or batteries can reduce energy costs and provide a sustainable food production system. The energy requirement for artificial lighting maintaining the set temperature and humidity can be fulfilled by optimizing maximum solar irradiance collection by the orientation of the planting trays at the required angles (Ng & Foo, 2020). Substituting energy-efficient LED lighting can help in reducing energy consumption to half (Balasus et al., 2021). The urban horticulture on the usable rooftops can mitigate the temperature inside the building in the summertime, which lowers the HVAC cost (Bonito et al., 2018).

Considering the seasonal and unpredicted weather variation, energy-efficient and resource-efficient irrigation management is essential at the building level for urban farming. Each agro-technical requirement, including the supply, pumping, metering, and moisture-retaining in the soil, is crucial in an energy-resource-saving irrigation system (Andreev et al., 2018). Integrating a renewable energy-based intelligent irrigation system can reduce resource wastage and electricity consumption compared to the traditional irrigation system (Sudharshan et al., 2019). The application of wireless sensor technology for farm monitoring is also an energy-efficient idea for precision farming (Jawad et al., 2017). Raji et al. reviewed the effects of greening systems on reducing the cooling load in summer and suggested that the probable increase in the heating load during winter can be mitigated with passive heat gain techniques through the building envelope (Raji et al., 2015). Self-sufficient neighborhoods and urban areas in terms of food and energy security with added ecosystem benefits are a vision towards sustainable living.

3.5 Green buildings

Buildings define the shape and spread of urban areas to an extent. Green buildings create an opportunity to achieve reduced energy-demanding systems with long-term economic and social benefits. Many researchers have identified energy efficiency as the critical criterion for green buildings. The shape and orientation of the building, external wall insulation, comprehensive indoor environment, integration of green energy-supported systems, utilization of daylight illumination, and solar thermal and photoelectric applications are effective energy-saving measures (Tong, 2017). The role of climatic responsive design is not just limited to the layout or orientation. Incorporating Passive heating and cooling methods in the design to attain desirable thermal comforts has been followed from vernacular times. Solar energy in passive and active forms evidently reduces the energy consumption of heating, cooling, and air conditioning systems (Qaemi & Heravi, 2012). Integration of various techniques in the design like direct solar gain, indirect solar gain, double-glazed window, solarium, and glazed Trombe wall for passive heating is an effective way to reduce the heating load of HVAC systems in winter.

Similarly, passive cooling is achieved through the prevention of heat gains in buildings using various levels of shading. On the other hand, Passive cooling through solar cooling systems using Induced ventilation techniques reduces the prevalent use of air conditioning and other energy-dependent systems (Adebisi et al., 2018). Other passive cooling techniques of evaporative cooling, wind towers, unglazed Trombe walls, solar shading, and earth air heat exchangers reduce summer cooling load (Gupta & Tiwari, 2016). Aziz et al. explained the scope of active, passive, and hybrid cooling technologies with buildings' thermal energy storage (TES) systems (Aziz et al., 2018). The authors further stressed that active cooling techniques are more versatile since the passive techniques are over-dependent on climatic factors, storage materials properties, and the architecture of the building. Lower energy utilizing choices of construction technologies and use of materials with lesser embodied energy would reduce the whole building's embodied energy by a remarkable amount (Ajayi et al., 2018; Venkatarama Reddy & Jagadish, 2003). Evaluation of green buildings is generally conducted during the design and building performance stages. Even though the concept of green construction aims at an environmentally responsible and resource-efficient process throughout the lifecycle, i.e., design, construction, operation, maintenance, renovation, and demolition (Ding et al., 2018). Building assessment systems and certification systems would encourage people to adopt energy-efficient and environmentally friendly techniques in building design and construction (Lazar & Chithra, 2021).

3.6 Green energy

Transforming the city from an energy consumer to an energy producer with local solutions for renewables and de-carbonizing the energy supply is the ultimate goal of the green energy principle (Lehmann, 2011). According to Brilhante and Klaas (2018) share of renewable energy in total electricity consumption in percentage is an indicator of overall city green performance. The green energy potential of any region has an invariable dependency on the region-specific weather conditions. Identification of the adoptable renewable sources for each location with appropriate scientific calculation technologies does act as the primary step for the clean energy transition of any region or country. Adopting rooftop solar photovoltaic panels in individual buildings with a supporting battery storage unit is feasible for green energy planning. Salamanca et al. affirmed that the deployment of cool roofs and rooftop solar photovoltaic panels reduces near-surface air temperature and cooling energy demand at the metropolitan area scale (Salamanca et al., 2016). Complete dependence on photovoltaic electricity for smart appliances might not be possible in areas with seasonal low solar in-feed (Gercek & Reinders, 2019). In terms of energy-saving, cost-saving, and greenhouse gas emissions, grid-connected rooftop solar panels with super-efficient appliances are a better option than the off-grid solar PV system (Ghenai & Bettayeb, 2020). Building-integrated photovoltaic thermal (BiPVT) systems utilize the maximum absorbed solar energy; thus, the systems are highly efficient as they generate electricity and provide thermal energy (Gupta & Tiwari, 2016).

Home Energy Management Systems (HEMS) are considered the future of smart grids for monitoring the optimal energy use in a building and scheduling the optimal energy consumption to maintain consumer comfort. Lee and Choi further stressed that Q-learning home energy management algorithm can provide better efficiency in managing the distributed energy resources, energy storage systems, advanced metering infrastructure, and smart home appliances (Lee & Choi, 2019). The advantages of substituting solar energy-based appliances for space heating, air conditioning, water heating, lighting, washing, and cooking are deeply explored by diverse researchers considering specific geographic and climatic conditions. Jaisankar et al. their studies indicated that solar water heaters are widely adopted due to their ease of use and need for less maintenance (Jaisankar et al., 2011). The advanced research happening in the field for thermal efficiency augmentation and performance improvement can entice more. Incorporation of renewable sources at the building level depends on the renewable energy potential of the region and energy conversion efficiency of renewable sources like wind energy harvesting using wind resource assessment at various scales, Built-environment wind turbines (BEWTs) to wind farms, and their connection to the grids (Islam et al., 2013; Zheng et al., 2019). Replacing street lighting and garden lighting with solar photovoltaic powered street lighting systems or hybrid systems are also effective methods to reduce electricity consumption (Liu, 2014). According to Qaemi and Heravi (2012), detailed planning, incentives and financial support are essential to improve awareness among people about renewable energy systems. Energy from waste is an area explored extensively over time. Waste management and energy production are collaborative processes that benefit society either way (Caneghem et al., 2019). The transition towards green energy practices in the public sector definitely has the potential for positive influence in the private sector.

3.7 Green growth

Incorporating each environmentally sustainable decision under the green city concept ultimately aims at achieving economic growth with equity considerations. Shi et al. explained the need to understand green growth while formulating economic development policies and the importance of evaluating the socio-economic and environmental decisions and outcomes after implementation (Shi et al., 2016). Many organizations have proposed the city green economy evaluation model for assessing a city's green growth, considering all the advantageous and disadvantageous factors involved in urban green economy development (Bagheri et al., 2018; Šneiderienė et al., 2020) further explored green growth indices that can function as a schematic guideline to planners and policymakers with the vision of short- and long-term programs. The need for removing compartmentalization and integrating global energy and climate governance is essential to improve the pace of greenhouse gas emission reduction (Heubaum & Biermann, 2015). The role of international agencies in advocating that change with individual and collaborated contributions is vital. Connecting the interrelated areas of the global energy scenario and rectifying the interconnected issues are essential in bridging the existing gap and improving energy security (Florini & Sovacool, 2011). Doukas et al. opinioned that the current energy policy covers the energy planning of various sectors and the security in energy supply, the competitiveness of the energy market, and environmental protection (Doukas et al., 2008). The government's role is critical in lowering the energy production cost through context-based renewable energy policies (Cullen, 2017). Effective Implementation of renewable energy policies by mitigating the barriers to adopting green energy technologies can achieve each country's targeted renewable energy share. According to Horschig and Thrän, applying quantitative, qualitative, and hybrid modeling approaches in renewable energy policy planning and evaluation in suitable contexts can support decision-makers effectively (Cullen, 2017). UN Environment focuses on policy development and implementation, supporting technological and economic tools, institutional strengthening, and capacity building (Lehmann, 2011). The policy framework of every country with the aim of achieving green economies acts as the foundation for their sustainable growth and development. Even though the types of policies vary across the globe, the key idea remains to mainstream the green economy through policies and strategic interventions at national and regional levels.

4 Discussion

Every discipline in the world has its interlinkage with each other in the global system, as each part of the globe is a part of the global landscape. Reducing overall energy consumption has appeared to be either a direct or indirect goal of green city strategies. The green city concept fundamentally intermingles distinctive aspects of spatial planning, urban greenery, energy efficiency, and green growth by way of accomplishing zero emissive transport, energy-efficient infrastructure, productive urban agriculture, better environmental quality, water security, green buildings, and smart technology, with policy regulations, stakeholder collaboration, and organized governance as facilitator tools. The literature review critically analyzed the most relevant articles selected from each category to inspect various strategies focusing on energy management. The literature highlighting the significant and relevant developments and theories related to the field of study was chosen to comprehend each domain collectively. The boundary restrictions refined the literature database to energy-efficiency management studies that can be used in several fields related to the green city concept, including spatial planning, urban agriculture, transportation, building construction, public infrastructure, and green growth. Various foundational spatial planning aspects of compact urban development, mixed land use, urban density, multimodal transportation system, and transport-oriented development are explored by a large number of researchers with a focus on specific locations (Leduc & Kann, 2013; Saunders et al., 2008). Implementation of every innovative concept or theory targets encouraging self-sufficient neighborhoods with reduced automobile dependencies, which in the long run impart self-sustained and less energy-consuming urban areas. Reducing fossil fuel dependency is one of the most explored domains for carbon–neutral inventions. Retrofitting of low carbon- higher efficiency technologies in the existing vehicles, application of renewable energy electro fuels, socio-economic benefits from electric and hybrid vehicles, and the feasibility of vehicle-to-grid integrated energy systems and automated systems have got considerable attention from researchers (Amado et al., 2016; Saunders et al., 2008). The evident need for integrated public transport along with shared mobility automated systems has been established through studies considering the potential contribution in lowering fossil fuel consumption and carbon emissions. The practicality of a sudden shift to alternative sources is an issue as the development, economic and climatic conditions vary from country to country. Diversification of energy sources can be beneficial in the transition stage of phasing out fossil fuel sources if alternative sources that complement the country-specific climate and geographic conditions have been adopted. Improving energy independence and energy security with climate-sensitive and low-carbon measures is the way to a sustainable future. Countries like Germany, Norway, and Sweden exhibit the feasibility of a gradual transition to renewable energy alternatives from nuclear and fossil fuel methods and the requirement of comprehensive measures as the solution for energy system transformation (Hansen et al., 2019; Ydersbond, 2014). Shifting to the energy-sensitive water management system in both public and private sector facilities and reducing energy-consuming processes for drinking water treatment and supply, rainwater management, stormwater management, irrigation, groundwater extraction, and wastewater treatment are necessary steps toward a sustainable future.

At the building level, climate responsive architecture techniques from the design stage to the post occupational stage of a building are another area of interest explored quite widely. Attaining the desired thermal comfort levels inside a building with active and passive design techniques, renewable energy-supported or hybrid systems, and appliances is a long-term investment. Adoption of renewable energy for solar photovoltaic systems with/without battery storage, solar appliances for HVAC or lighting or cooking, and bioenergy systems in every household, commercial, industrial, and public building in a city can be a giant leap towards the goal. Understanding the existing practices in a city, improving them to sustainable practices, and encouraging people to adopt renewable technologies as an alternative energy source to outpace conventional methods is quite a task. A transition towards a diverse energy portfolio with renewable energy sources in all urban development sectors is crucial for effective carbon stabilization and a low-carbon future. Understanding people's perspectives towards green energy initiatives and the level of awareness about the need for a planned transition to a sustainable energy economy is essential to mitigate the barriers to adoption. A large number of researches have been conducted on enablers and barriers to adopting something non-conventional in different contexts (Elavarasan et al., 2020; Moorthy et al., 2019; Walters et al., 2018). Feasibility of retrofitting green components from the building level, i.e., green roofs, vertical gardens, and rooftop farming of lesser energy consumption for lighting and irrigation to urban agriculture level, inspiring optimism towards a transforming future. Technical advancement of SMART technologies acts as a technological enabler in energy reduction strategies with its wide application of smart systems in all sectors, i.e., transport systems, building energy management, farming, and irrigation management. Exploring new concepts and theories that inspire energy-conscious interventions in the physical environment must be encouraged (Stremke & Koh, 2010).

The potential direct and indirect contributions of green city planning strategies toward the overall energy management of a city have been established through the published research in the 'literature review' section. Every component of green strategies contributes to maintaining energy security and fostering sustainability. It is important to acknowledge the sustainable initiatives effectively implemented in these countries which made it possible to attain the top positions in the ranking process. Table 1 exhibits the planning initiatives taken by different cities for their journey towards green and sustainable cities.

Cities like Oslo, Stockholm, Tokyo, Copenhagen, etc. advance in their overall performance in the sustainability transition. According to the Arcadis Sustainable Cities Index 2022, Oslo ranked in first position in their overall performance in the sustainability transition, followed by Stockholm, Tokyo, and Copenhagen (Arcadis, 2022). Under the green city concept, every environmentally sustainable strategy targets green jobs, investments, and economic growth with reduced cost and environmental impact. Appraising the ground-level applications of these energy management techniques and possibilities explored in the literature review section helps to understand the practicality of implementing these regional-scale initiatives. Retrofitting energy efficiency under every domain of a city's infrastructure is not an easy task for any city. Cities like Vienna, Munich, Berlin, Vancouver, and many others also are closer to their vision with the successful implementation of urban planning, socio-economic, environmental, and governance plans of action (Mocca et al., 2020; Sarker et al., 2020; Thierfelder & Kabisch, 2016; Vuckovic et al., 2018). Opportunities and challenges for embracing the concept and becoming a green city are different in each country, which ultimately depends on the geographical, climatic, social, economic, cultural, and environmental characteristics of the country (Alyami, 2019; Culligan, 2019; Sandu, 2017). Every city with its ambitious goal for sustainable future practices, continuous efforts for a substantial reduction in carbon emissions, initiatives for a gradual shift towards the renewable energy-supported electricity supply, attempts to ensure energy-efficient appliances and practices in all sectors, and creating the basic awareness on the need for effective energy management from the citizen's level. The successful implementation of climatic and environmental solutions through policy-level strategic interventions demands continuous effort and monitoring to achieve the long-term goal of sustainability. An integrated way of dealing with climate, energy, and governance is vital for effective implementation. It is crucial to consider how energy security policy investments and implementation affect the environment. Considering today's climate sensitivity, a balance should be found by ensuring energy for all. The globalization of impacts of energy choices is peremptory to be studied by countries to adapt to the climate change scenario.

Table 1 Initiatives taken by different cities for their journey towards green and sustainable cities

	Oslo	Stockholm	Tokyo	Copenhagen
Urban densification with compact development for increasing energy and land-use efficiency	• Emerging urban densification policies and practices with mixed use and brown-field development programmes (Cavicchia, 2022). The 34% increase in the population of urbanized region during 2000–2020 accommodated in only 9% increase in area (Næss, 2022) • Urban ecology programs and well-preserved protected forests act as natural carbon sinks for the city (Oslo-EGC 2019, 2018) • The city of Oslo shows a 16% reduction in carbon emissions during the period of 2009–2019 (The green city: Defining & measuring performance, 2023)	• Effective green area management through urban planning, having nearly 1/3rd of the total area for green spaces (Adem Esmail et al., 2022) • Smart planning ideas for population growth management with compact development and public transport connectivity (Stockholm City Plan, 2018)	• Maintaining the green areas within the city in consideration of the increasing population as part of the Climate Change Adaptation Policy (Tokyo Metropolitan Government, 2021) • Balancing the city's planned development with compacting the upcoming spatial growth (Seya, 2014; Toh, 2022)	• Efforts to maintain the compactness of the city with developments (The London School of Economics & Political Science, 2014) • Finding the balance between population expansion, controlled growth, and integrated urban public spaces and green areas (European Green Capital Secretariat, 2014)

Table 1 (continued)

	Oslo	Stockholm	Tokyo	Copenhagen
Well-planned green transport network with integrated emerging energy-efficient techniques	• Convenient integrated public transport with ICT management systems (Ole, 2020) • Availability of rented bicycles within the city • Bio-gas based transportation fuel and supporting biogas plants • Encouraging electric vehicles with more charging points, toll free travel and public vehicle lane preference • More than 60% of public vehicles with renewable energy as part of climate policy • Encouraging car sharing to reduce private car usage (Oslo-EGC 2019, 2018)	• Multi-modal public transport system that reduced substantial transport emissions. Policy (LSE Cities, 2013) • Walking and cycling-friendly roads with proper accessibility in the urban form (LSE Cities, 2013)	• More electric vehicles and charging stations to address the greenhouse gas emission issue from the city (Goswami et al., 2017; Tokyo Metropolitan Government, 2021) • Promoting zero-emission vehicles as part of the decarbonization plan as part of environmental policy (Tokyo Metropolitan Government, 2021) • Well-connected train and subway services and future focus on expanding the accessibility of the public transport system (Brilhante & Klaas, 2018; Seya, 2014) • Maintain bicycle friendliness considering the geographical constraints of the city (The Economist Intelligence Unit, 2021)	• Encouraging walking and non-motorized transport modes with shared bicycles within the city • In the process of shifting towards electric and hydrogen-based vehicles to lower CO_2 emissions as part of environmental policy (European Green Capital Secretariat, 2014) • Well-planned public transport system and car-sharing practices (Christensen et al., 2022)
Greening public services with smart and efficient water-energy nexus	• Attracting more investment towards blue-green infrastructure within the city (Wilbers et al., 2022)	• Smart measures are taken for efficient water consumption and management with energy-efficient practices (Stockholm Stad, 2020)	• Utilization of geothermal energy, sewage heat, and hydel power for water management and supply (Tokyo Metropolitan Government, 2021) • Implementing energy-efficient urban infrastructure development measures (Tokyo Metropolitan Government, 2021)	• Ensuring energy efficiency as a core principle for infrastructure planning • Energy efficient metering and management equipment for water resource, sewage, and wastewater management (European Green Capital Secretariat, 2014)

Table 1 (continued)

	Oslo	Stockholm	Tokyo	Copenhagen
Urban agriculture and greenery for energy and food security with added ecosystem benefits	• More focus on resource-efficient urban farming and landscape planning (Norwegian Ministries, 2021) • Implementing sustainable agriculture practices for urban farming and community gardening (Eiterstraum, 2014)	• Energy and water efficient aquaponics, maintenance practises for vertical farming and urban farming (Martin & Molin, 2019; LSE Cities, 2013)	• More initiatives on urban farming and vertical cultivation with resource efficient technology and practices (U. D. Series, 2012)	• Encouraging pocket parks and green roofs for mitigating Urban Heat Island effect within the city • Encouraging energy saving urban farming and vertical gardening practices (European Green Capital Secretariat, 2014)
Green buildings with energy-efficient construction and practices	• Focus on energy-efficient construction practices and green buildings as part of environmental and climate plans (Brilhante & Klaas, 2018) • Encouraging terrace gardens and green roofs into building design and certification (Brilhante & Klaas, 2018)	• Environmentally friendly, energy efficient practices within buildings with maximizing the utilization of sunlight and solar heat (Stockholm Stad, 2020)	• Implementing green building strategy for new constructions as part of sustainable building policy • Promoting energy-efficient appliances and hydrogen-based society for the domestic sector as part of environmental policy (Tokyo Metropolitan Government, 2021)	• Focusing on more green buildings and certification to encourage the public for sustainable construction and renovation practices (Gluszak et al., 2021)
Renewables and de-carbonizing the energy supply	• Intelligent street lighting for reduced energy consumption • Up to 80% of district heating systems with biomass energy from residual waste • Waste to energy process, in turn, leads to low emissive waste management (Oslo-EGC 2019, 2018) • 98% of the electricity supply is from hydroelectric power (The green city: Defining & measuring performance, 2023)	• Generating biofuel from sewage as an alternative transport fuel (Stockholm Stad, 2020) • Reduced energy wastage with an excellent city-wide heating system (Stockholm Stad, 2020) • Working towards clean energy production, utilization, and management for various purposes for a fossil-free and climate responsive city (Stockholm Stad, 2020)	• Encouraging and subsidizing local production of self-consumption and storage renewable energy facilities at buildings (Tokyo Metropolitan Government, 2021)	• Initiatives for a transition towards alternative energy sources with wind power, biomass and geothermal energy from a coal dependency • Renewable energy-based district heating and cooling systems for buildings (European Green Capital Secretariat, 2014)

Table 1 (continued)

	Oslo	Stockholm	Tokyo	Copenhagen
Green growth reflecting energy security	• More investments in low-carbon initiatives for sustainable transport and energy generation • Oslo Business Region (OBR) encourages climate-friendly companies and green business initiatives through policy regulations aiming at a green economy for the city • Regular green awareness programs among neighborhoods and schools • Project grants and support for green initiatives (Oslo-EGC 2019, 2018)	• Promoting green innovations and ideas by attracting more investments in the green economy through policy support (LSE Cities, 2013) • Involving citizens in initiatives and communicating the need for a resource-smart city (Stockholms Stad, 2020) • Collaborations and follow-ups for the implementation of these efforts (Stockholms Stad, 2020)	• Supporting solar energy harnessing initiatives with financial and fiscal support (Tokyo Metropolitan Government, 2021)	• Creating awareness in schools and citizens for an overall green development • Encouraging more investments in green innovations along with skill development • Ensuring the effectiveness of energy consumption and resources (The London School of Economics & Political Science, 2014)

5 Conclusion

This paper presented a collective review of relevant published articles that emphasize energy management's significant role in achieving green cities. Even though a large number of articles are available on energy efficiency, planning and management, no study is found that connects different sectors of green city planning and energy management comprehensively. Hence, this study was employed to comprehend energy management with multi-disciplines under various domains of the green city concept through identified literature. The review explored the indispensable part of energy planning and management for a faster transition into a sustainable future. Diversified energy efficient solutions and management techniques under spatial planning, green transportation, greening public services, urban agriculture, green buildings, green energy, and green growth are apprised of the varied possibilities for effective energy management. The study highlighted the need to integrate an energy management plan as a fundamental part of green city strategies' formulation, implementation, and lifecycle management. The application of these green city strategies from different cities ranked top for their transition shows the practicability of achieving a sustainable tomorrow with comprehensive planning and effective implementation. Adopting energy strategies with the support of new and emerging technologies through policy regulations and programs and implementing them with the help of a responsible society seems achievable in the future. Mitigation of potential barriers in diverse energy planning and implementation stages has scope for future research.

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