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REVIEW

Renewable Energy and Urban Sustainability Using the Siemens Green City Index: Comprehensive Review

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ABSTRACT: The highly important requirement for achieving urban sustainability for any city is the availability of renewable energy, as reducing carbon emissions is considered one of the most important factors in improving the quality of life and health of people in green cities. The main objective of this research is to provide an in-depth study and analysis of the role of renewable energies, especially solar energies, in promoting sustainable development in cities around the world, in general, and in Iraq in particular. Strategies for using clean energy sources in a hybrid manner, such as solar energy, wind energy, and bioenergy, in urban infrastructure were analyzed. The focus was also on highlighting the most important challenges associated with the transformation of traditional cities into semi-green or green cities that depend primarily or largely on renewable energy, with a focus on the environmental, economic, and social benefits or importance of this transformation. A comprehensive picture was provided on how to apply the Siemens Green Cities Index as a promising assessment tool or benchmark for city performance, in addition to highlighting the criteria of staff efficiency, carbon emissions, environmental resource management, and analyzing the extent to which global urban policy and planning are compatible with the index criteria. Finally, the necessary proposals and recommendations were presented to enhance the use of available renewable energies in cities, as this will contribute significantly to achieving a large percentage of sustainable development goals. This study is considered the cornerstone for providing a roadmap for decision-makers and companies to develop or transform traditional cities into cities that rely on renewable energy, and it also contributes to the transformation or improvement of the environmental and economic levels in the world.

KEYWORDS: Renewable energy; green cities; urban sustainability; siemens green city index; sustainable development; carbon emissions reduction

1 Introduction

Green cities can be characterized as the paradigm shift to cities, including the utilization of renewable energy, environmentally friendly infrastructures, and transport systems for resilient and livable urban areas in relation to sustainable development [1–4]. The Green Cities concept requires a combined strategy in urban planning to reduce environmental effects, besides enhancing the standard of living among the people. In addition to this, salient features that are being evaluated may include those related to effective energy consumption, wide use of renewable energy sources, and the use of smart city technologies in terms of ecological well-being and economic sustainability [5].

1.1 The Concept of Green Cities

Green city definition usually involves such traits as sustainable infrastructure, emissions, low energy and water consumption, and green spaces. Such cities put a premium on environmental custodianship, economic sustainability, and social inclusiveness [6]. An example is sustainable urban mobility, which is an important part of green city planning, with integrated networks of renewable energy systems used to facilitate the network of public transport and electric vehicles to cut the reliance on fossil energy and air pollution [5].

Al-Thani et al. (2022) [5] emphasized the need for cohesive planning in renewable energy deployment to support sustainable urban mobility. The review highlighted the integrated systems that combine solar, wind, and energy storage as foundational technologies. In developing countries, where rapid urbanization presents unique challenges, the green city model is increasingly seen as a path toward sustainable growth. In their article, Debrah et al. (2023) [7] found the reasons behind the green city development in such locations as Ghana, where financial limitations, insufficient infrastructure, and other factors require creative solutions. On this occasion, too, the solutions to the problem of sustainable cities can be renewable energy technologies and decentralized solar systems, as well as sustainable waste management. The reason is that green cities address not only the social needs, but also the environmental goals. The Green cities can be scaled to varying contexts—including those based on low resources—by actualizing the Localized solutions to harnessing the Natural advantage of every area [7]. Other features of a green city that are featured in Fig. 1 are sustainable transportation, incorporation of renewable energy, green spaces, and buildings that are energy efficient. All of these will come together in order to make the city environmentally friendly and, at the same time its economically viable. Shen and Fitriaty (2018) [8]. Additionally stressed that green city planning in Asian cities tends to focus on culture. The review also addressed problems that are unique to urban areas that experience high population density and lack land as well as the development of flexible systems of sustainable urban development.

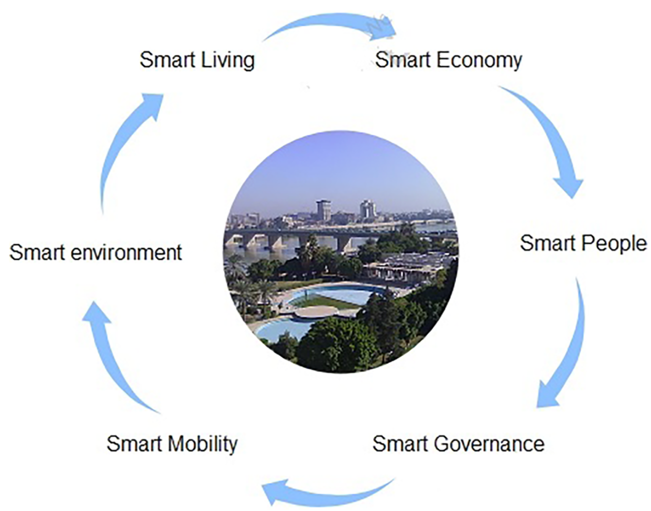

Figure 1: Characteristics of a smart city.

1.2 The Importance of Renewable Energy in Urban Sustainability

Renewable energy is a cornerstone of green city development, addressing critical issues such as carbon emissions, energy security, and environmental degradation. Cities adopting high renewable energy penetration are able to decrease their reliance on non-renewable energy sources, thus significantly lowering greenhouse gas emissions [9]. Teske et al. (2018) [9] discussed scenarios in which cities with high renewable energy usage benefit from improved air quality, reduced carbon footprints, and enhanced resilience against energy price fluctuations. All these, in turn, are augmented by the incorporation of renewable energy into urban transport, residential, and commercial spheres; this further situates the Green Cities at the leading edge of the transition towards a low-carbon economy. Urban environments that integrate renewable energy in building designs and public infrastructure can support significant reductions in resource consumption.

Debrah et al. (2023) [6] investigated the content of sustainability in the green city projects and highlighted renewable energy as a major element. The research cited that it also assists in reducing energy spending by city residents and therefore leads to economic sustainability. The infrastructure of the cities themselves, even the solar panels on the roofs, the energy-saving design of buildings, etc., in cities where there are large renewable systems, is becoming an active resource to help them operate with sufficient energy functionality. Fig. 2—Renewable energy sources in the transportation and building infrastructure of cities of different types: This drawing suggests the rates of implementation of solar photovoltaic systems, wind turbines, and storage of energy as a way of providing more energy independence to cities with constant streams of electricity to the services that are the most important. This diversified energy portfolio is guaranteed to ensure reliability, besides achieving the vision of the green city of minimum environmental impacts and maximum utility and economic efficiency.

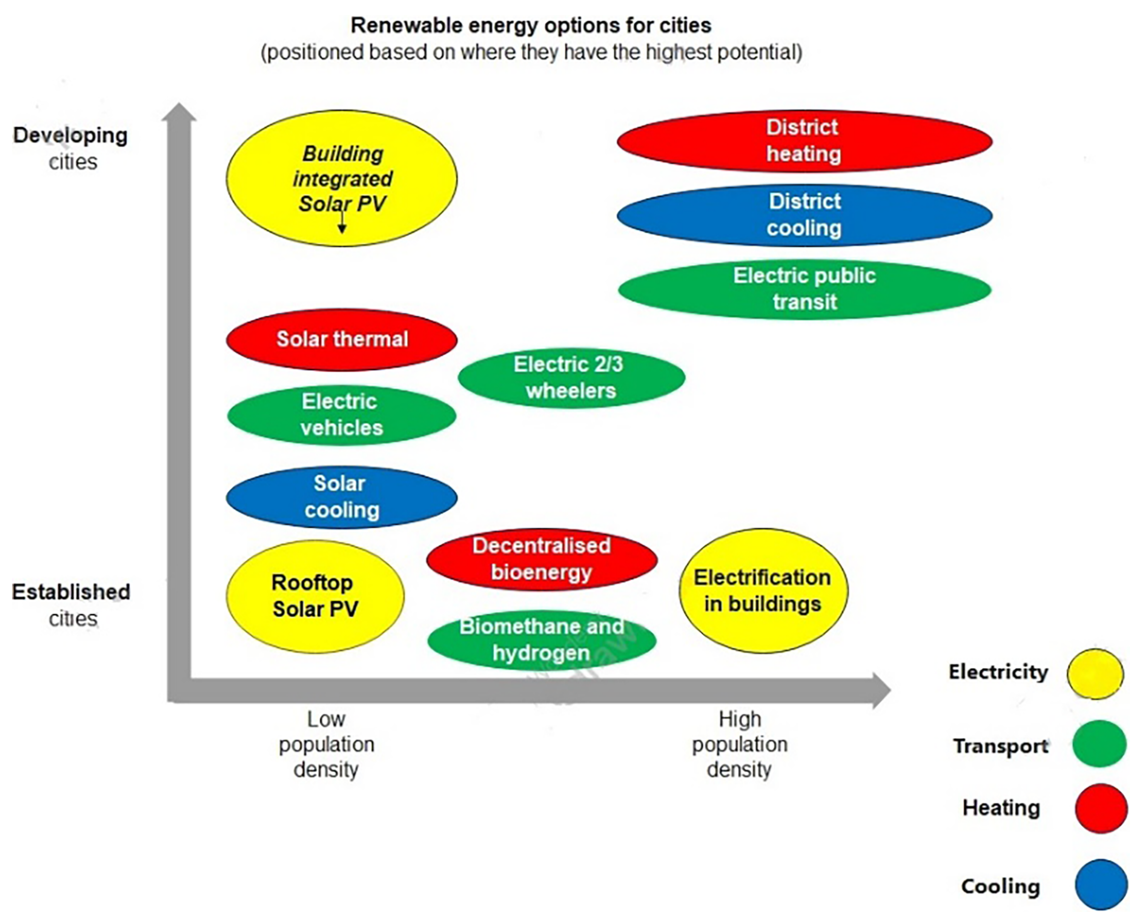

Figure 2: Renewable energy options for transport and buildings in different city types.

Overall, green cities harness renewable energy to promote an environmentally sustainable future urban system that entrenches social and economic co-benefits. The green city offers a sustainable development model that adjusts to varying degrees of urbanization and availability of resources by incorporating renewable energy technologies into urban infrastructure, such as public buildings, transport systems, and housing. As has been observed, in efforts, the general intensifying world trend towards city sustainability is against renewable power. The review contributions can be summarized as follows:

- This review provides a novel integrated perspective by directly linking renewable energy technologies and hybrid systems to the performance dimensions of the Siemens Green City Index (SGCI). Rather than discussing green cities, renewable energy, or sustainability indices independently, the study establishes a structured connection between technological deployment and measurable urban sustainability indicators.
- The manuscript advances existing reviews by critically analyzing how global renewable energy strategies and SGCI criteria can be realistically adapted to developing-country contexts, with Iraq used as a representative case. It highlights structural, financial, regulatory, and data-related constraints that are often overlooked in generalized global assessments.
- Beyond summarizing prior work, this review synthesizes agreements, limitations, and implementation barriers across studies and identifies technological, economic, and policy gaps. It proposes a clearer pathway for aligning renewable energy planning with index-based urban sustainability benchmarking, thereby offering practical value for decision-makers and researchers.

2 Recent State-of-the-Art Advancements

This review was conducted using a structured literature search and screening procedure to ensure transparency and reproducibility. Relevant publications were retrieved primarily from Scopus, Web of Science, and Google Scholar, covering the period 2010–2025 to reflect both foundational and recent developments in renewable energy integration, urban sustainability, and applications of the Siemens Green City Index (SGCI). The search combined keywords and Boolean operators such as "green city" OR "urban sustainability" OR "smart city" AND "renewable energy" OR "solar PV" OR "wind energy" AND "Siemens Green City Index" OR "green city index" OR "urban sustainability index", with additional terms related to policy frameworks (e.g., "Paris Agreement", "European Green Deal") and regional focus (e.g., "Iraq", "Middle East"). Inclusion criteria were: (i) peer-reviewed journal articles and high-quality conference papers written in English, (ii) studies explicitly linking renewable energy to urban sustainability indicators or city-level performance assessment, and/or (iii) works discussing SGCI (or closely related city sustainability indices) in evaluation, benchmarking, or policy contexts. Exclusion criteria included non-scholarly sources, studies lacking clear methodological detail, and papers not directly relevant to renewable energy–urban sustainability coupling. After removing duplicates, titles/abstracts were screened, followed by full-text assessment; the final set of studies was synthesized thematically to extract consistent evidence on technology pathways, policy instruments, SGCI-related metrics, and implications for Iraqi cities.

The renewable energy technologies have been rapidly becoming part and parcel of the quest for areas of urban sustainability due to their broad application in the generation, heating, and cooling, as well as the storage. The world has many cities that are already into solar, wind, and hybrid systems, and they have incorporated these systems in the city infrastructure to curb the use of fossil fuel and environmental effects. Moreover, the renewable energy systems are also making the energy supply in the urban centres more robust; they will play a major role in supporting the rising energy needs of the urban populations in line with the global sustainability goals.

Iqbal and Khan (2017) [10] explored the use of renewable energy sources to provide uninterruptible power for robotic systems, specifically in Pakistan, where the country's abundant renewable resources—such as solar and wind—hold significant potential for powering energy-intensive applications. Their study highlights the feasibility of these green energy sources in supporting advanced technological needs, like robotics, while reducing dependency on traditional power sources. Syahputra and Soesanti (2021) [11] conducted a case study on micro-hydro and solar photovoltaic systems in rural Yogyakarta, Indonesia. Using optimization techniques, they assessed the best configuration for integrating these renewable sources to ensure reliable and cost-effective power for rural communities, demonstrating the adaptability of renewable technologies across diverse geographies. Adelaja et al. (2010) [12] projected how much renewable energy could be generated in brownfield sites (e.g., manufactured gas plants) in the State of Michigan, taking into account the underutilized lands' reuse for renewable projects redevelopment. These authors concluded that redevelopment of such sites for wind and solar energies had the potential to meet up to 43% of residential needs for electricity in the state and thus make a considerable contribution toward local energy self-sufficiency. Al Afif et al. (2023) [13] have evaluated hybrid renewable energy systems at the Al-Karak site, in Jordan, with a prime view of off-grid and grid-connected solutions for minimum energy cost and emissions. They have optimized several configurations combining wind, solar, and biogas to arrive at economically viable options that integrate renewables in regions with high solar and wind potential.

In Australia, Abu-Salih et al. (2022) [14] investigated the potential for peer-to-peer energy trading facilitated by renewable energy systems, analyzing data from distributed solar photovoltaic (PV) systems in residential settings. They used advanced forecasting models to optimize the generation and consumption of renewable energy, empowering residents to participate actively in local energy markets. In their study, Rosiek and Batlles (2013) [15] investigated the use of solar-assisted cooling and heating in institutional buildings (southern part of Spain) due to the hot climate in the country, which presents a serious energy problem. Their analysis did show that solar absorption cooling systems would consume 61 percent of primary energy than traditional cooling systems, and this represented the environmental and economic advantages of solar technologies in cities. In a study by Robalino-Lopez et al. (2014) [16], the authors examined how renewable energy can be implemented in the reduction of CO_2 emissions in Ecuador. On the basis of a system dynamics applied model of this work, they indicated that, with the growing consumption of renewable energy, as well as the improvement in the efficiency of fossil fuel combustion, there is certainly potential even in the context of economic growth to reduce emissions. The supporting mechanism of green finance when investing in renewable energy in China was reviewed by Wang and Fan (2023) [17]. They discovered that economic factors and financial policies stimulate increased investment by the enterprise in the infrastructure of sustainable energy, thereby facilitating the wider application of renewable sources in an urban environment. According to Zarnikau (2011) [18], the incorporation of renewable energy, especially wind power, into the competitive electricity market in Texas was successful. Nevertheless, the state has achieved a lot in renewable energy implementation despite the challenges that are associated with intermittency and market coordination, and this has in the process, caused the U.S to be a leader in non-hydro renewable energy capacity.

Mellouk et al. (2019) [19] investigated a hybrid renewable energy system for the Laayoune region in Morocco, which utilized an optimized algorithm for managing microgrids. Their study highlighted the importance of efficient energy management in maximizing renewable integration, showing that advanced control methods could reduce costs and emissions in energy-intensive regions. Salameh et al. (2021) [20] performed a feasibility study of hybrid renewable energy systems in Neom City, Saudi Arabia, taking into consideration hydrogen production and its storage regarding urban energy management. From the results, environmental and economic benefits were clearly depicted for integrating solar/diesel/batteries in storage to meet the urban energy demand. The topic of alternative sources of energy in Ghana was raised in the article by Arthur et al. (2011) [21]. They also initiated the usage of biogas as a sustainable solution to ensure Ghana comes out of the intense reliance on wood fuel. Their arguments were founded on the fact that the country has plenty of organic waste that can be utilized as feedstock to produce biogas fuel to minimize the inconveniences of deforestation and emissions. Finally, Tin et al. (2010) [22] studied renewable energy solutions under the conditions of extremities, in this case, in Antarctica. Their research established that solar and wind technologies have the potential of being effective to supply power in difficult environmental situations, and this proved that the renewable systems can be effective even in isolated and difficult areas. This discussion was further developed by Aydin et al. (2013) [23], who used the Geographic Information System (GIS) to determine the most suitable location to use a hybrid renewable energy system in Turkey and revealed that spatial analysis can facilitate strategic planning of the implementation of renewable energy in urban settings. Table 1 shows the summary of the Key Studies on Renewable Energy Technologies and Applications in Varying Urban and Regional Environments.

Table 1: Overview of key studies on renewable energy technologies and applications in various urban and regional settings.

Ref.	Location	Renewable Energy Technology	Key Findings
[10]	Pakistan	Solar, Wind, Biological	Highlighted the potential of renewable energy for powering robotics, emphasizing Pakistan's abundant resources and opportunities for green energy application in high-tech areas.
[11]	Yogyakarta, Indonesia	Micro-hydro, Solar Photovoltaic	Optimized hybrid system for rural areas, showing that integrating micro-hydro and solar can provide reliable, cost-effective electricity for off-grid communities.
[12]	Michigan, USA	Wind, Solar on Brownfield Sites	Redevelopment of brownfields for renewable projects could meet 43% of Michigan's residential energy needs, supporting energy independence through land reuse.
[13]	Al-Karak, Jordan	Hybrid (Wind, Solar, Biogas)	Evaluated the economic and environmental benefits of hybrid systems, achieving a 71.8% renewable energy share while reducing costs and emissions.
[14]	Western Australia	Peer-to-peer Solar Photovoltaic	Examined peer-to-peer trading of solar energy in residential areas, enhancing community energy autonomy and local renewable energy consumption.
[15]	Southern Spain	Solar-assisted Cooling, Heating	Solar cooling systems reduced primary energy use by 61%, proving viable in hot climates and decreasing dependency on conventional energy for air conditioning.

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Table 1 (continued)

Ref.	Location	Renewable Energy Technology	Key Findings
[16]	Ecuador	Solar, Wind	System dynamics modeling showed that renewable energy adoption can significantly reduce CO_2 emissions, even amid economic growth.
[17]	China	Green Finance Mechanisms for Renewables	Green finance policies promoted investment in renewable energy enterprises, supporting urban energy infrastructure and sustainable economic development.
[18]	Texas, USA	Wind Power	Texas leads U.S. renewable energy capacity; strategic market mechanisms addressed intermittency and reliability challenges in a competitive energy market.
[19]	Laayoune, Morocco	Hybrid Micro-grid (Solar, Wind, Battery Storage)	Optimized energy management in a hybrid micro-grid setup, showing that renewable-dominated systems are cost-effective and reduce emissions in high-energy-demand regions.
[20]	Neom City, Saudi Arabia	Hybrid (Solar PV, Diesel, Battery Storage)	Showed that hybrid systems can support urban energy demands and industrial applications, such as hydrogen production, through optimized energy and resource use.
[21]	Ghana	Biogas	Biogas from organic waste presents a sustainable alternative to wood fuel, reducing deforestation and emissions, with the potential to meet a large portion of Ghana's energy needs.
[22]	Antarctica	Solar, Wind	Demonstrated renewable energy feasibility in extreme environments, indicating that solar and wind systems are adaptable to even the most challenging conditions.
[23]	Turkey	Hybrid (Wind, Solar) with GIS Optimization	GIS-based methodology optimized site selection for hybrid systems, integrating environmental and economic factors to enhance feasibility and sustainability.

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Table 1 (continued)

Ref.	Location	Renewable Energy Technology	Key Findings
[24]	India	Solar, Wind	COVID-19 impacts on the renewable sector highlighted; findings showed economic resilience in renewables despite the pandemic's economic challenges.
[25]	Southeast Germany	Wind, Solar (Community Co-ownership Model)	Demonstrated that community co-ownership increased local acceptance of renewable projects, contributing positively to local renewable energy adoption

3 Renewable Energy

The integration of renewable energy into urban planning and policy frameworks is essential for advancing sustainable cities [26,27]. As urbanization increases, so does the need for energy, and strategic policies can help kick-start the use of renewable energy sources [28,29]. International agreements on actions revisit the frameworks that set guiding structures on how cities can take up green energy systems, optimize energy use, and reduce greenhouse gas emissions [30–35]. Such frameworks will, in turn, enable the urban areas to transition towards renewable sources of energy, supported fully at both the national and international levels, in line with the local goals of environmental, economic, and social sustainability.

3.1 Urban Planning and Renewable Energy

The aspect of including renewable energy in urban design is comprehensive since it must ensure that energy generation matches the urban growth. The transition to resilient cities is placing all existing urban planning projects on the way to green infrastructure e.g., renewable energy grids, solar rooftops and electric transportation systems [36–47]. It is also useful in energy security in incorporating renewable energy sources in the urban planning through lessening reliance on fossil fuels, which are normally vulnerable to changes in prices and availability constraints. Furthermore, with the integration of renewables, energy self-sufficient cities with the highest demands will assist in achieving goals as set by various international agreements. Among those, perhaps the most influential guiding framework for urban renewable energy integration is the Paris Agreement through its series of targets for the reduction of greenhouse gas emissions over three key periods: 2020, 2030, and 2050 [48–50]. The Paris Agreement encourages nations to adopt renewable energy sources as primary drivers within their urban energy mixes, a factor that includes those comprising the European Union. Such targets are given in the European Union's commitments of a 20% cut in emissions by the year 2020, a 40% cut by 2030, and 80%–95% by 2050 based on 1990 levels, as shown in Fig. 3. These set targets challenge the urban planners as they have to consider the integration of renewable energy systems such as solar, wind, and biomass into the city structure, especially when urban areas contribute a great deal to global carbon emissions.

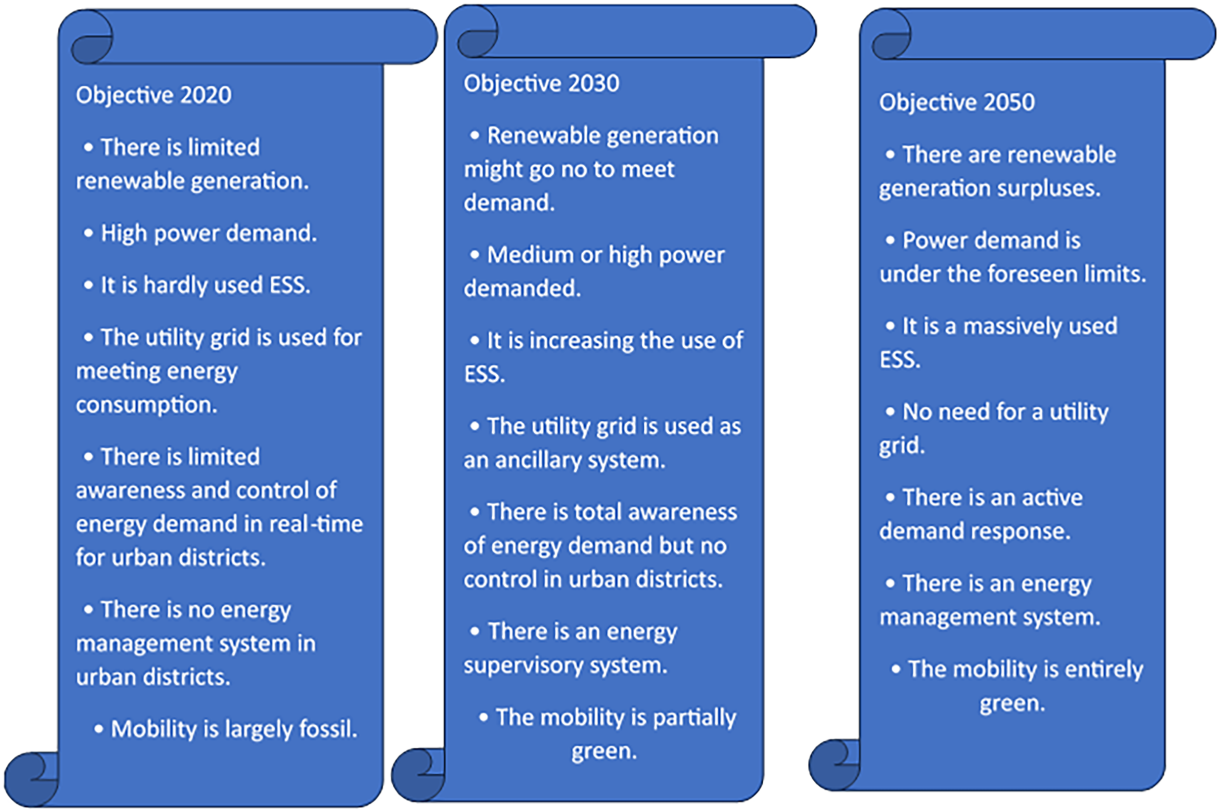

Figure 3: European commitments under the Paris Agreement for 2020, 2030, and 2050.

3.2 Policy Frameworks and Incentives

Policy frameworks such as the European Green Deal set specific guidelines and incentives for cities to achieve climate neutrality and environmental sustainability [51,52]. The European Green Deal aims to transform Europe into the first climate-neutral continent by 2050 [53]. This involves policymaking that would drive green energy forward, providing fiscal or technical assistance to cities with a preference for investment in renewable energy. These policies encourage innovations in energy that smart grids and decentralized systems would provide resilience in cities, but also provide the cities with better means of dealing with energy. Fig. 4 shows the European Green Deal encompasses everything from clean energy to sustainable industry and energy-efficient buildings in creating a circular economy across Europe.

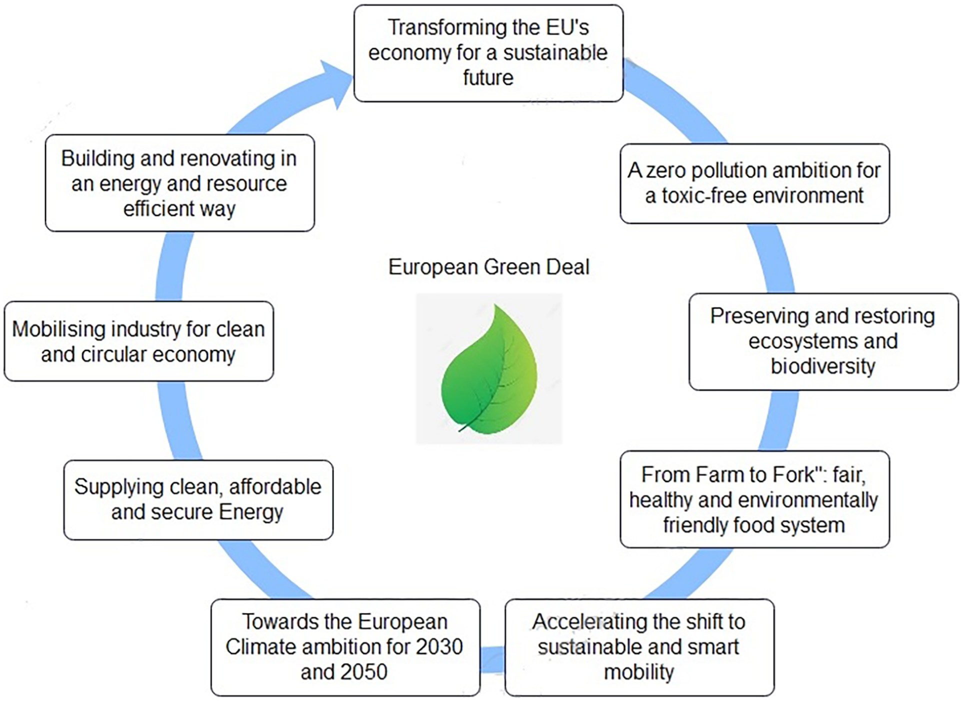

Figure 4: European Green Deal main objectives.

More and more cities across Europe take advantage of incentives provided under frameworks such as the European Green Deal. For instance, funding mechanisms like the Just Transition Mechanism have large-scale financing for regions heavily dependent on fossil fuels to adopt renewable energy technologies. The grants, tax incentives, and subsidies will, in turn, incentivize the cities to invest in solar photovoltaic systems, wind turbines, and energy-efficient building designs that help attain conformity with renewable energy targets. These policy-driven investments support cities to achieve reduced emissions and lower energy costs and enhance local economic resilience through the creation of jobs in the green energy sector. The adoption of the international treaties the Paris Agreement and the newer European Green Deal-presupposes that the city realizes its renewable energy plans in compliance with the peculiarities of local natural resources and should economize in accordance with local economical conditions and demands. In this context, localization would imply the extensive adjustment of policy in accordance with the city-specificities and may involve the modification of building codes, the creation of renewable energy zones, or the encouragement of partnerships between the government and the business. This makes the cities implement world policies to fulfill their unique energy needs in a sustainable manner. To illustrate, cities that have high solar potentials invest more on incorporation of photovoltaic systems whereas those that have abundance of wind resources may prefer to invest on installations of wind turbines to produce wind energy first. In that manner, the localized strategies, which are triggered by the global policy frameworks, will give the urban areas the opportunity to enhance the use of renewable energy integrations to their fullest potential.

Acceptance of renewable energy within city set-ups has wide economic and ecological implications that define fiscal dynamics and ecological sustainability. The transition into renewable energy sources is highly governed by high energy use, hence providing a way forward in mitigating what have been perceived as environmental challenges: carbon emissions, air pollution, and depletion of natural resources. In other words, excluding those, renewable energy sources had been found to actually create impressive economic benefits due to jobs created, reduction in energy costs, and financial freedom from fuel price volatility to the contribution of economic resiliency and development of urban economies. Renewable energy investments in urban regions, in terms of economics, have the effect of stimulating the local economy in the employment of individuals and energy savings. Creation of solar and wind facilities as well as other renewable facilities require skilled labor in installing, maintaining and managing them thus creating a number of jobs in different industries. Also, there is a tendency that the cities investing in renewable energy systems tend to reduce the total expenses of energy costs, since renewable energy technologies such as solar and wind are inexpensive to operate once installed. This economic efficiency saves on the use of imported fossil fuels that would mean that cities would have more funds to invest in development projects and social programs that in turn promotes economic growth and resilience. Switching to renewable energy also cushions the cities against the unpredictability of the price of fossil fuels which would otherwise disrupt the local economies. Such stability, in its turn, will stimulate the additional investment in renewable energy technologies to form a reinforcing cycle of economic and environmental rewards.

It is important environmentally in reducing the urban footprint, as it reduces to a great amount of degree the potential impacts of climate change. Since the towns are significant sources of carbon emissions, thereby renewable energy systems have provided an opportunity to substitute for fossil fuels, which are among key contributors to greenhouse gas emissions. Solar, wind, geothermal, and hydropower are some of the main renewable sources applied with the intent of reducing carbon fuel intensity. Since renewable energies displace fossil fuels, the adoption of renewable energy can significantly lower urban air pollution, improving public health due to a reduction in respiratory and cardiovascular problems linked to poor air quality. Reduction in greenhouse gas emissions drives cities to meet international emission targets, as Fig. 5 shows the dynamic effect multiple sectors have on carbon emission. Another related cause with the environmental benefits of renewable energy is resource conservation. In contrast to fossil fuels, which are finite resources whose extraction and use contribute to environmental degradation, the base resource for renewable energy, like sunlight, wind, and water, naturally renews itself. Just this one fact alone would make renewables increasingly important tools for reaching environmental preservation and climate resilience. The cities could lower their ecological footprint and increase biodiversity by exploiting resources that have small ecological footprint. The bulk of renewable forms of energy sources such as solar, wind and hydropower require less intensive land use and generate less of waste products, thereby being more attuned to urban sustainability of efficient land and resource utilization (Fig. 5). These are some of the most common sources of renewable energies that have varied environmental dividends in contributing to the overall climate change mitigation drive.

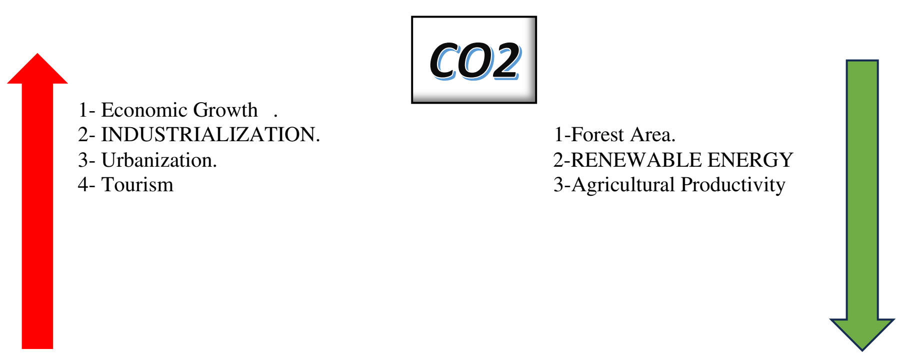

Figure 5: Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, tourism, agriculture, and forests on carbon emissions.

The transition to renewable energy would also be in line with international climate objectives, such as those of the Paris Agreement. Renewable energy is a critical component of the climate action of the cities moving towards carbon neutrality because the renewable energy can help achieve significant benefit in terms of greenhouse gas emission and is also related to economic and social welfare. Also, policies to use the renewable energy in the city level are receiving support of local policies and incentives more and more promoting the business and the population to take part in the process of transforming to the green power. Tax breaks, subsidies, and grants for the installation of renewable forms speed up adoption rates and put renewable forms of energy within the purview of more urban stakeholders

4 Recent State-of-the-Art Advancements in Iraq

The renewable energy technologies have been rapidly becoming part and parcel of the quest for areas of urban sustainability due to their broad application in the generation, heating, and cooling, as well as the storage. The world has many cities that are already into solar, wind, and hybrid systems, and they have incorporated these systems in the city infrastructure to curb the use of fossil fuels and environmental effects. Moreover, the renewable energy systems are also making the energy supply in the urban centres more robust; it will play a major role in supporting the rising energy needs of the urban populations in line with the global sustainability goals.

In this respect, from a renewable viewpoint, Iraq is one of those countries that have strategic positions to overcome most of their energy problems, become less dependent on fossil fuels, and help reduce environmental degradation. Iraq's solar energy resource, in this regard, provides a real opportunity to ensure a clean and dependable power supply to meet the increasing demand of its growing population and industry. In their study, Aziz et al. (2021) [54] presented the effects of meteorological conditions albedo, and temperature on photovoltaic efficiencies concerning Iraqi conditions. In their conclusion, they insisted on the optimization of configuration parameters, such as tilt angles, which have to be performed by garnering maximum economic benefits. Al-Shammari et al. 2021 [55] developed a proper hybrid micro-grid driven by solar, wind, and battery storage for rural electrification at Zerbattiya, southeast Iraq. This model showed how the hybrid systems might be trusted in order to generate inexpensive power in the isolated regions and how renewable technologies could suit the rural landscape of Iraq. The grid-connected solar systems are becoming popular in urban areas as a potential source of domestic energy. Aziz et al. (2022) [56] investigated the design and optimization of a grid-connected PV/battery hybrid system customized to the households in Iraq using a new dispatch strategy that optimally balances between the solar generation and the household demand. Their paper suggested that the incorporation of renewables would result in significant decrease in greenhouse gas emissions as well as the expense of electricity and offer a viable alternative to traditional utility fueling.

A good potential to diversify the energy mix of the country has been shown by the wind energy of Iraq, which is not well developed as compared to the solar power of the country. The study by Darwish et al. (2019) [57] suggested a methodology for selecting the best form of wind turbine system can be selected to be applied to low wind speed regions. It was a good model to successful implementation of wind energy in problematic weather. A different study conducted by Al-Shammari Zaidoon et al. (2021) [58] assessed the optimal sites to integrate solar, wind, and biomass in 88 regions of Iraq with the aim of minimizing the cost and emission of energy by a spatial-specific hybrid system, which it proved highly efficient in enhancing the efficiency of energy saving and achieving long-term sustainability goals of Iraq. Equally, Al-Shammari et al. (2021) [59] carried out an analysis of the HOMER software population used to simulate the feasibility of the solar microgrid in Baghdad in both grid-connected and islanded operation modes. According to their findings, it was emphasized that due to the rate of power outages and environmental advantages, solar PV can be considered in terms of enhancing the rate of renewable in the city energy infrastructure of Iraq. Isolated and rural areas of Iraq have their own set of problems connected with the availability of energy, and hybrid energy proposals are developed.

In addition, Ghanim and Farhan (2023) [60] predicted how the estimated climate change patterns would influence Iraq's PV energy potential, hence needing strategic planning due to the rising temperature and shifting weather conditions to sustain energy productivity within urban and rural areas of Iraq. Table 2: Summarized discussion of literature to understand the presented research gap for further analysis. The potential of renewable energy systems for various climatic regions of Iraq shows the way to energy independence and ecological sustainability. Aziz et al. (2019) [61] assessed a PV-wind-diesel hybrid system for the off-grid electricity requirements of. They reported that hybrid configurations can reduce costs while ensuring a reliable power supply in those areas that are far from the grid. Therefore, their study targeted the economic feasibility of wind and diesel systems concerning grid-dependent power solution systems.

Table 2: Overview of renewable energy applications and key findings in Iraq.

Ref.	Location	Renewable Energy Technology	Key Findings
[54]	Choman, Iraq	Solar PV	Optimized PV performance based on temperature, tilt, azimuth, and albedo conditions, demonstrating that precise configurations can enhance efficiency and cost-effectiveness.
[55]	Zerbattiya, Iraq	Solar, Wind, Battery Storage	Proposed a hybrid micro-grid system for rural areas, highlighting economic and reliable electricity for off-grid communities through renewable integration.
[56]	Iraq (urban areas)	Grid-connected PV/Battery Hybrid	Grid-connected hybrid systems reduced emissions and energy costs, showcasing a sustainable alternative for residential electricity needs.
[61]	Baghdad, Iraq	Solar PV Microgrid	Feasibility analysis showed PV microgrids are viable even during power outages, with economic advantages and environmental benefits for Baghdad's urban energy infrastructure.
[58]	Al-Faw, Iraq	Solar, Wind, Grid	Flexible hybrid system optimized for remote regions, reducing dependency on outdated networks and providing reliable electricity to isolated areas.
[59]	Iraq (nation-wide)	Solar PV	Projected climate change impacts PV performance, showing stable PV potential with minor declines in output, emphasizing the need for strategic adaptation.

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Table 2 (continued)

Ref.	Location	Renewable Energy Technology	Key Findings
[62]	Iraq (southern regions)	Solar PV (Farm Site Selection)	GIS and multi-criteria analysis identified southern Iraq as ideal for solar farms, emphasizing location-based optimization to maximize solar energy production.
[63]	Zerbattiya, Iraq	PV, Wind, Diesel, Battery	Assessed cost-effectiveness and reliability of PV-wind-diesel systems, finding the hybrid design optimal for cost and consistent power supply in remote areas

5 Siemens Green City Index (SGCI) and Its Potential Application in Iraq

Urban sustainability is widely inspecte when it comes to modern development of countries, especially Iraq [64–73]. The Siemens Green City Index presents a very valuable framework for urban sustainability [74,75], especially in comparing cities along parameters of renewable energy use [76,77], environmental quality [78,79], and overall livability. The SGCI supplies key performance indicators through which cities can measure progress in categories such as energy, water, air quality, and comfort factors. The SGCI provided a structured approach for Iraq, where irregular urban planning and reliance on conventional energy sources significantly impact the environment and public health, to find opportunities for urban development sustainably. Al-Swaiedi et al. (2022) [80] implemented the SGCI to review sustainability in terms of local conditions related to renewable energy, water resources, air quality, and comfort factors in four Iraqi cities: Um Qasr, Baghdad, Anah, and Sulaymaniyah. For renewable energy-renewable resources, mainly solar and wind, the best score was obtained for the city of Um Qasr, with a result of 60.88% in that category. Anah had the highest score in water resource availability with 85%, crucial for sustainable urban planning. Sulaymaniyah had the lowest air pollutant score with only 24.86% of its pollutants, while it was at the same time high on comfort factors by scoring 94% due to good temperature and wind chill factors. Overall, Sulaymaniyah proved to be the best candidate for a sustainable city in Iraq location bolstered by its rich endowment of natural resources, good air quality, and high comfort factor with an overall score of 72%. Using the SGCI framework to guide the development of green cities in Iraq allows for informed decision-making that considers local environmental conditions, resource availability, and potential renewable energy sources. As Iraq faces environmental challenges and increasing urbanization, the application of the SGCI can help direct sustainable growth to ensure that cities are both livable and resilient to climate impacts.

Table 3 below shows a synthesis and analysis that shows the advancements in such index treated in Iraq.

Table 3: Critical synthesis of hybrid renewable energy systems and SGCI-oriented urban sustainability assessment.

Focus Area	Key Evidence from Reviewed Studies (Examples)	Agreements/ Converging Findings	Common Limitations in the Literature	Practical Barriers for Developing Contexts (e.g., Iraq)	Research/ Technology/Policy Gaps
PV–Wind–Battery hybrid microgrids (rural/remote)	Iraq and comparable hybrid microgrid studies ([50,53,55,59])	Hybrids improve reliability and reduce fuel dependence compared to diesel-only systems	Heavy reliance on simulation tools; limited long-term operational validation	High capital cost, limited O&M expertise, weak technical infrastructure	Need multi-year field data, realistic O&M modeling, and local capacity-building strategies
PV–Battery grid-connected systems (urban)	Household PV-battery optimization in Iraq ([56])	Storage enhances resilience and self-consumption	Battery degradation and lifecycle costs often simplified	Tariff uncertainty, limited net-metering clarity, import constraints	Standardized economic modeling frameworks and regulatory reform studies
PV microgrids for outage mitigation	Baghdad microgrid feasibility studies ([47,63])	PV microgrids reduce outage impacts and emissions	Limited analysis of grid-code compliance and protection coordination	Grid instability, weak distribution infrastructure	Grid-integration studies aligned with national utility regulations
PV–Wind–Diesel hybrids (transitional systems)	Off-grid electrification case studies ([50,53,64])	Diesel backup improves reliability in weak-grid contexts	Carbon externalities and fuel volatility often underrepresented	Fuel logistics, maintenance burdens, environmental concerns	Transition pathways toward reducing diesel share and incorporating carbon pricing
Solar–Wind–Biomass GIS optimization	Spatial multi-criteria planning in Iraq ([45,49,52])	GIS tools effectively identify optimal renewable zones	Sensitivity to weighting assumptions and data quality	Data scarcity, land-use conflicts, grid expansion limitations	Transparent weighting justification and stakeholder-integrated planning models
Peer-to-peer energy trading	Distributed PV and forecasting studies ([16])	Local trading increases renewable utilization and community engagement	Often tested in mature regulatory markets	Regulatory readiness and metering infrastructure gaps	Pilot regulatory frameworks and digital infrastructure development
SGCI benchmarking application	Iraqi SGCI evaluation ([80])	Index-based assessment clarifies sustainability priorities	Limited localization of SGCI indicators to regional conditions	Inconsistent municipal data and monitoring limitations	Adapted SGCI framework with Iraq-specific baselines and indicator normalization
Linking renewables to SGCI performance	Combined renewable and index discussions ([55])	Renewables positively influence emissions and sustainability indicators	Lack of quantitative linkage between technology deployment and index scores	Difficulty justifying investment without measurable SGCI impact	Development of KPI translation models connecting renewable penetration to SGCI metrics
Climate impacts on renewable performance	PV performance under Iraqi climatic ([54])	Meteorological factors strongly influence PV efficiency	Climate uncertainty rarely integrated into long-term economic models	Planning under temperature rise and dust conditions	Integration of climate projections into techno-economic planning

6 Conclusions

The current review has been concerned with the issue of renewable energy in the development of green cities and the sustainable urban infrastructure policy frameworks, as well as the impacts of renewable energy economically and to the environment. Urban planning is progressively focusing on renewable energy sources, especially solar and wind, as one of the key elements of providing sustainable development and counteracting the effects of the environment. Research indicates that the adoption of renewable energy systems in cities not only improves the quality of the environment by minimizing emissions but also boosts the economy in such cities by creating employment opportunities and saving on expenditure.

The paper further discussed the possible use of the SGCI as a tool to assess urban sustainability in Iraq. Since the metrics of the SGCI are built for renewable energy, water, air quality, and comfort factors, their output will carry significant value for Iraqi cities aiming at the path toward sustainability. Application of the metrics of the SGCI, along with the various region-specific challenges and opportunities that have been mentioned, may thus serve to orient policymakers towards focused sustainable urban development policies in specific areas. There are, however, gaps that remain in research, especially in applying the metrics of SGCI in localized ways both to Iraqi cities and to the broader Middle Eastern context. Further studies using such global metrics under regional conditions will help set up benchmarks tailored to Iraq's urban sustainability goals.

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References

1. Thellufsen JZ, Lund H, Sorknæs P, Østergaard PA, Chang M, Drysdale D, et al. Smart energy cities in a 100% renewable energy context. Renew Sustain Energy Rev. 2020;129:109922. doi:10.1016/j.rser.2020.109922.
2. Hoang AT, Pham VV, Nguyen XP. Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process. J Clean Prod. 2021;305(4):127161. doi:10.1016/j.jclepro.2021.127161.
3. Kammen DM, Sunter DA. City-integrated renewable energy for urban sustainability. Science. 2016;352(6288):922–8. doi:10.1126/science.aad9302.
4. Mousa MH, Miljkovic N, Nawaz K. Review of heat transfer enhancement techniques for single phase flows. Renew Sustain Energy Rev. 2021;137:110566. doi:10.1016/j.rser.2020.110566.
5. Al-Thani H, Koç M, Isaifan RJ, Bicer Y. A review of the integrated renewable energy systems for sustainable urban mobility. Sustainability. 2022;14(17):10517. doi:10.3390/su141710517.
6. Debrah C, Owusu-Manu DG, Amonoo-Parker L, Baiden BK, Oduro-Ofori E, Edwards DJ. A factor analysis of the key sustainability content underpinning green cities development in Ghana. Int J Constr Manag. 2023;23(14):2469–78. doi:10.1080/15623599.2022.2068786.
7. Debrah C, Owusu-Manu DG, Darko A, Oduro-Ofori E, Acquah PC, Asamoah E. Drivers for green cities development in developing countries: ghanaian perspective. Int J Constr Manag. 2023;23(6):1086–96. doi:10.1080/15623599.2021.1955321.
8. Shen Z, Fitriaty P. Overview: green city planning and practices in Asian cities. In: Green city planning and practices in Asian cities. Berlin/Heidelberg, Germany: Springer; 2018. p. 1–16. doi:10.1007/978-3-319-70025-0_1.
9. Teske S, Pregger T, Simon S, Naegler T. High renewable energy penetration scenarios and their implications for urban energy and transport systems. Curr Opin Environ Sustain. 2018;30:89–102. doi:10.1016/j.cosust.2018.04.007.

10. Iqbal J, Khan ZH. The potential role of renewable energy sources in robot's power system: a case study of Pakistan. Renew Sustain Energy Rev. 2017;75:106–22. doi:10.1016/j.rser.2016.10.055.
11. Syahputra R, Soesanti I. Renewable energy systems based on micro-hydro and solar photovoltaic for rural areas: a case study in Yogyakarta, Indonesia. Energy Rep. 2021;7(3):472–90. doi:10.1016/j.egyr.2021.01.015.
12. Adelaja S, Shaw J, Beyea W, Charles McKeown JD. Renewable energy potential on brownfield sites: a case study of Michigan. Energy Policy. 2010;38(11):7021–30. doi:10.1016/j.enpol.2010.07.021.
13. Al Afif R, Ayed Y, Maaitah ON. Feasibility and optimal sizing analysis of hybrid renewable energy systems: a case study of Al-Karak. Jordan Renew Energy. 2023;204(C):229–49. doi:10.1016/j.renene.2022.12.109.
14. Abu-Salih B, Wongthongtham P, Morrison G, Coutinho K, Al-Okaily M, Huneiti A. Short-term renewable energy consumption and generation forecasting: a case study of Western Australia. Heliyon. 2022;8(3):e09152. doi:10.1016/j.heliyon.2022.e09152.
15. Rosiek S, Batlles FJ. Renewable energy solutions for building cooling, heating and power system installed in an institutional building: case study in southern Spain. Renew Sustain Energy Rev. 2013;26(2):147–68. doi:10.1016/j.rser.2013.05.068.
16. Robalino-López A, Mena-Nieto A, García-Ramos JE. System dynamics modeling for renewable energy and CO_2 emissions: a case study of Ecuador. Energy Sustain Dev. 2014;20:11–20. doi:10.1016/j.esd.2014.02.001.
17. Wang Q, Fan Z. Green finance and investment behavior of renewable energy enterprises: a case study of China. Int Rev Financ Anal. 2023;87:102564. doi:10.1016/j.irfa.2023.102564.
18. Zarnikau J. Successful renewable energy development in a competitive electricity market: a Texas case study. Energy Policy. 2011;39(7):3906–13. doi:10.1016/j.enpol.2010.11.043.
19. Mellouk L, Ghazi M, Aaroud A, Boulmalf M, Benhaddou D, Zine-Dine K. Design and energy management optimization for hybrid renewable energy system—case study: laayoune region. Renew Energy. 2019;139(2):621–34. doi:10.1016/j.renene.2019.02.066.
20. Salameh T, Sayed ET, Ali Abdelkareem MA, Olabi AG, Rezk H. Optimal selection and management of hybrid renewable energy System: neom city as a case study. Energy Convers Manag. 2021;244(5):114434. doi:10.1016/j.enconman.2021.114434.
21. Arthur R, Baidoo MF, Antwi E. Biogas as a potential renewable energy source: a Ghanaian case study. Renew Energy. 2011;36(5):1510–6. doi:10.1016/j.renene.2010.11.012.
22. Tin T, Sovacool BK, Blake D, Magill P, El Naggar S, Lidstrom S, et al. Energy efficiency and renewable energy under extreme conditions: case studies from *Antarcti*ca. Renew Energy. 2010;35(8):1715–23. doi:10.1016/j.renene.2009.10.020.
23. Aydin NY, Kentel E, Sebnem Duzgun H. GIS-based site selection methodology for hybrid renewable energy systems: a case study from western Turkey. Energy Convers Manag. 2013;70(3):90–106. doi:10.1016/j.enconman.2013.02.004.
24. Pradhan S, Ghose D, Shabbiruddin. Present and future impact of COVID-19 in the renewable energy sector: a case study on India. Energy Sources Part A Recovery Util Environ Eff. 2024;46(1):13226–36. doi:10.1080/15567036.2020.1801902.
25. Musall FD, Kuik O. Local acceptance of renewable energy—a case study from southeast Germany. Energy Policy. 2011;39(6):3252–60. doi:10.1016/j.enpol.2011.03.017.
26. Franco MAJQ, Pawar P, Wu X. Green building policies in cities: a comparative assessment and analysis. Energy Build. 2021;231:110561. doi:10.1016/j.enbuild.2020.110561.
27. Chen L, Huang L, Hua J, Chen Z, Wei L, Osman AI, et al. Green construction for low-carbon cities: a review. Environ Chem Lett. 2023;21(3):1627–57. doi:10.1007/s10311-022-01544-4.
28. Runfola DM, Hughes S. What makes green cities unique? examining the economic and political characteristics of the grey-to-green continuum. Land. 2014;3(1):131–47. doi:10.3390/land3010131.
29. Andersson I. 'Green cities' going greener? Local environmental policy-making and place branding in the 'Greenest City in Europe'. Eur Plan Stud. 2016;24(6):1197–215. doi:10.1080/09654313.2016.1152233.
30. Ragab KM, Orhan MF. Evaluating conventional and renewable energy systems for green buildings: a case study on energy efficiency and cost optimization. Case Stud Therm Eng. 2024;63(3):105233. doi:10.1016/j.csite.2024.105233.

31. Koley S. Electrochemistry of phase-change materials in thermal energy storage systems: a critical review of green transitions in built environments. Trends Sci. 2024;21(10):8538. doi:10.48048/tis.2024.8538.
32. Valente C, Hillring BG, Solberg B. Greenhouse gas emissions, energy use, and costs—case studies of wood fuel supply chains in Scandinavia. Int J For Eng. 2012;23(2):71–81. doi:10.1080/14942119.2012.10739963.
33. Das M, Pektezel O, Sımsek M. Solar energy for greenhouse drying: performance evaluation of parabolic trough solar collector with two-axis tracking system. Sol Energy. 2025;299:113716. doi:10.1016/j.solener.2025.113716.
34. Guan Y, Zhou L, Hu W, Wei Z, Li G, Liu Y, et al. Comparative analysis of the thermal performances of two parabolic trough solar air collectors used for greenhouse heating: an experimental study. Therm Sci Eng Prog. 2025;62:103666. doi:10.1016/j.tsep.2025.103666.
35. Essa FA, Abd Elaziz M, Elsheikh AH. Prediction of power consumption and water productivity of seawater greenhouse system using random vector functional link network integrated with artificial ecosystem-based optimization. Process Saf Environ Prot. 2020;144:322–9. doi:10.1016/j.psep.2020.07.044.
36. Nazir MS, Bilal M, Sohail HM, Liu B, Chen W, Iqbal HMN. Impacts of renewable energy atlas: reaping the benefits of renewables and biodiversity threats. Int J Hydrogen Energy. 2020;45(41):22113–24. doi:10.1016/j.ijhydene.2020.05.195.
37. Saidi K, Omri A. The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. Environ Res. 2020;186(3):109567. doi:10.1016/j.envres.2020.109567.
38. Khan SAR, Zhang Y, Kumar A, Zavadskas E, Streimikiene D. Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. Sustain Dev. 2020;28(4):833–43. doi:10.1002/sd.2034.
39. Levenda AM, Behrsin I, Disano F. Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies. Energy Res Soc Sci. 2021;71:101837. doi:10.1016/j.erss.2020.101837.
40. Kazem HA, Chaichan MT. Status and future prospects of renewable energy in Iraq. Renew Sustain Energy Rev. 2012;16(8):6007–12. doi:10.1016/j.rser.2012.03.058.
41. Pristupa AO, Mol APJ. Renewable energy in Russia: the take off in solid bioenergy? Renew Sustain Energy Rev. 2015;50(4):315–24. doi:10.1016/j.rser.2015.04.183.
42. Hlongwane NW, Khobai H. Renewable energy transition on employment dynamics in BRICS nations. Economies. 2025;13(2):45. doi:10.3390/economies13020045.
43. Ogaili AAF, Jaber AA, Hamzah MN. Statistically optimal vibration feature selection for fault diagnosis in wind turbine blade. Int J Renew Energy Res. 2023;13(3):1082–92. doi:10.20508/ijrer.v13i3.14096.g8782.
44. Ogaili AAF, Hamzah MN, Jaber AA. Integration of Machine Learning (ML) and Finite Element Analysis (FEA) for predicting the failure modes of a small horizontal composite blade. Int J Renew Energy Res. 2022;12(4):2168–79. doi:10.20508/ijrer.v12i4.13354.g8589.
45. Im H, Kim B. Numerical study on the effect of blade surface deterioration by erosion on the performance of a large wind turbine. J Renew Sustain Energy. 2019;11(6):063308. doi:10.1063/1.5115080.
46. Hu X, Feng F, Liu K, Zhang L, Xie J, Liu B. State estimation for advanced battery management: key challenges and future trends. Renew Sustain Energy Rev. 2019;114:109334. doi:10.1016/j.rser.2019.109334.
47. Wang W, Olguin G, Hotza D, Ali Seelro M, Fu W, Gao Y, et al. Inorganic membranes for *in-situ* separation of hydrogen and enhancement of hydrogen production from thermochemical reactions. Renew Sustain Energy Rev. 2022;160:112124. doi:10.1016/j.rser.2022.112124.
48. Ackah I, Graham E. Meeting the targets of the Paris Agreement: an analysis of renewable energy (RE) governance systems in West Africa (WA). Clean Technol Environ Policy. 2021;23(2):501–7. doi:10.1007/s10098-020-01960-6.
49. Baruch-Mordo S, Kiesecker JM, Kennedy CM, Oakleaf JR, Opperman JJ. From Paris to practice: sustainable implementation of renewable energy goals. Environ Res Lett. 2019;14(2):024013. doi:10.1088/1748-9326/aaf6e0.
50. Lima MA, Mendes LFR, Mothé GA, Linhares FG, de Castro MPP, da Silva MG, et al. Renewable energy in reducing greenhouse gas emissions: reaching the goals of the Paris agreement in Brazil. Environ Dev. 2020;33(3):100504. doi:10.1016/j.envdev.2020.100504.

51. Panarello D, Gatto A. Decarbonising Europe–EU citizens' perception of renewable energy transition amidst the European Green Deal. Energy Policy. 2023;172(6):113272. doi:10.1016/j.enpol.2022.113272.
52. Miłek D, Nowak P, Latosińska J. The development of renewable energy sources in the European union in the light of the European green deal. Energies. 2022;15(15):5576. doi:10.3390/en15155576.
53. Maya-Drysdale D, Krog Jensen L, Vad Mathiesen B. Energy vision strategies for the EU green new deal: a case study of European Cities. Energies. 2020;13(9):2194. doi:10.3390/en13092194.
54. Aziz AS, Tajuddin MFN, Adzman MR, Ramli MAM. Impacts of albedo and atmospheric conditions on the efficiency of solar energy: a case study in temperate climate of Choman, Iraq. Environ Dev Sustain. 2021;23(1):989–1018. doi:10.1007/s10668-019-00568-1.
55. Al-Shammari ZWJ, Kother S, Taha IA, Hayder HE, Hussam M, Hadi A, et al. Green micro-grid based on PV/WT hybrid system for remote and rural population in Iraq: a case study. In: Intelligent manufacturing and mechatronics. Singapore: Springer Singapore; 2021. p. 1081–93. doi:10.1007/978-981-16-0866-7_96.
56. Aziz AS, Tajuddin MFN, Zidane TEK, Su C, Mas'ud AA, Alwazzan MJ, et al. Design and optimization of a grid-connected solar energy system: study in Iraq. Sustainability. 2022;14(13):1–29. doi:10.3390/su14138121.
57. Darwish AS, Shaaban S, Marsillac E, Mahmood NM. A methodology for improving wind energy production in low wind speed regions, with a case study application in Iraq. Comput Ind Eng. 2019;127:89–102. doi:10.1016/j.cie.2018.11.049.
58. Al-Shammari Zaidoon WJ, Azizan MM, Rahman ASF, Hasikin K. Flexible hybrid renewable energy system design for a typical remote city in Iraq: a case study. AIP Conf Proc. 2021;2339(1):020011. doi:10.1063/5.0044277.
59. Al-Shammari ZWJ, Azizan MM, Rahman ASF, Hasikin K. Analysis on renewable energy sources for electricity generation in remote area of Iraq by using HOMER: a case study. AIP Conf Proc. 2021;2339(1):020007. doi:10.1063/5.0044278.
60. Ghanim MS, Farhan AA. Projected patterns of climate change impact on photovoltaic energy potential: a case study of Iraq. Renew Energy. 2023;204:338–46. doi:10.1016/j.renene.2023.01.027.
61. Aziz AS, Tajuddin MFN, Adzman MR, Mohammed MF, Ramli MAM. Feasibility analysis of grid-connected and islanded operation of a solar PV microgrid system: a case study of Iraq. Energy. 2020;191(1):116591. doi:10.1016/j.energy.2019.116591.
62. Al-Shammari ZWJ, Azizan MM, Rahman ASF. Feasibility of PV-wind-diesel hybrid renewable energy power system for off-grid rural electrification in Iraq: a case study. J Eng Sci Technol. 2021;16(3):2594–609. doi:10.20508/ijrer.v6i3.4301.g6898.
63. Khazael SM, Al-Bakri M. The optimum site selection for solar energy farms using AHP in GIS environment, a case study of Iraq. Iraqi J Sci. 2021:4571–87. doi:10.24996/ijs.2021.62.11(si).36.
64. Haseeb QS, Yunus SM, Aziz AI. Sustainability-based hybridization interventions, the urban fabric of Erbil Citadel-Iraq—as a case study. Alex Eng J. 2023;75:615–25. doi:10.1016/j.aej.2023.04.064.
65. Mohsin MM, Beach T, Kwan A. Consensus-based urban sustainability framework for Iraqi cities: a case study in Baghdad. Heliyon. 2020;6(12):e05348. doi:10.1016/j.heliyon.2020.e05348.
66. Ameen RFM. Evaluation of the sustainability of the urban development sector in Iraq. IOP Conf Ser Mater Sci Eng. 2021;1067(1):012064. doi:10.1088/1757-899X/1067/1/012064.
67. Allawi AH, Al-Jazaeri HMJ. A new approach towards the sustainability of urban-rural integration: the development strategy for central villages in the Abbasiya District of Iraq using GIS techniques. Reg Sustain. 2023;4(1):28–43. doi:10.1016/j.regsus.2023.02.004.
68. Ameen RFM, Mourshed M. Urban sustainability assessment framework development: the ranking and weighting of sustainability indicators using analytic hierarchy process. Sustain Cities Soc. 2019;44(5):356–66. doi:10.1016/j.scs.2018.10.020.
69. Al Jarah SH, Zhou B, Abdullah RJ, Lu Y, Yu W. Urbanization and urban sprawl issues in city structure: a case of the sulaymaniah Iraqi Kurdistan Region. Sustainability. 2019;11(2):485. doi:10.3390/su11020485.
70. Yawer AS, Bakr AF, Fathi AA. Sustainable urban development of historical cities: historical Mosul City, Iraq. Alex Eng J. 2023;67(4):257–70. doi:10.1016/j.aej.2022.12.042.

71. Al-Shebillawy EJ, Korniyenko S, Al-Mossawy BA. Assessment of the green urban structure and its role in promoting sustainable environmental development in the city of karbala, Republic of Iraq. In: Proceedings of the 8th International Conference on Construction, Architecture and Technosphere Safety; 2024 Sep 8–14; Sochi, Russia. doi:10.1007/978-3-031-80482-3_41.
72. Hassan MKR. Urban environmental problems in cities of the Kurdistan region in Iraq. Local Environ. 2010;15(1): 59–72. doi:10.1080/13549830903406073.
73. Abdulameer HN, Al-Jaberi AA, Al-Khafaji AS, Alrobaee TR, Al-Ansari HA. Evaluating of urban space vitality: the role of safety, security, and urban planning in the religion center of Kufa city, Iraq. Int J Des Nat Ecodyn. 2024;19(1):155–67. doi:10.18280/ijdne.190118.
74. Gülalan SN, Ernst FB, Karabulut Aİ. Future modeling of urban growth using geographical information systems and SLEUTH method: the case of sanliurfa. Sustainability. 2025;17(15):6833. doi:10.3390/su17156833.
75. Handayani KN, Murtyas S, Wijayanta AT, Hagishima A. Thermal comfort challenges in home-based enterprises: a field study from Surakarta's urban low-cost housing in a tropical climate. Sustainability. 2024;16(16):6838. doi:10.3390/su16166838.
76. Kumar CMS, Singh S, Gupta MK, Nimdeo YM, Raushan R, Deorankar AV, et al. Solar energy: a promising renewable source for meeting energy demand in Indian agriculture applications. Sustain Energy Technol Assess. 2023;55:102905. doi:10.1016/j.seta.2022.102905.
77. Ahmad Sarow S, Flayyih HA, Bazerkan M, Al-Haddad LA, Al-Sharify ZT, Ali Farhan Ogaili A. Advancing sustainable renewable energy: xGBoost algorithm for the prediction of water yield in hemispherical solar stills. Discov Sustain. 2024;5(1):510. doi:10.1007/s43621-024-00782-6.
78. Ali W, Gohar R, Chang BH, Wong WK. Revisiting the impacts of globalization, renewable energy consumption, and economic growth on environmental quality in South Asia. Adv Decis Sci. 2022;26(3):75–98.
79. Anser MK, Hanif I, Vo XV, Alharthi M. The long-run and short-run influence of environmental pollution, energy consumption, and economic activities on health quality in emerging countries. Environ Sci Pollut Res Int. 2020;27(26):32518–32. doi:10.1007/s11356-020-09348-1.
80. Al-Swaiedi S, Altmimi A, Alkhalidi A. Application of siemens index of green cities for selected areas in Iraq. J Earth Space Phys. 2022;47(4):177–85.