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Case Studies on the Successful Integration of Green Energy in Cities

Kentlerde Yeşil Enerjinin Başarılı Entegrasyonuna İlişkin Örnek Olay İncelemeleri

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ABSTRACT

Energy functions as the fundamental lifeblood of modern societies, a vital resource that permeates all facets of life, driving economic growth and facilitating social well-being. The reliance on fossil fuels for energy poses a significant global threat. Fossil fuels, along with nuclear energy, are non-renewable resources that exert considerable pressure on the planet. While contributing to climate change through greenhouse gas emissions, they also entail increasingly severe economic costs in the long term. In this context, green energy emerges as a vital solution for ensuring both environmental and economic sustainability. By offering alternatives that can replace fossil fuels and enable energy production with lower environmental impacts, green energy contributes to the achievement of sustainable development goals. The literature section of this study focuses on the relationship between sustainable development and green energy; as green energy plays a crucial role in addressing environmental issues, it also emerges as a key tool in achieving sustainable development. This study addresses the research question of which key dynamics enable the successful integration of green energy in cities. The aim of the research is to comparatively analyze the implementation processes of green energy policies through the cases of Copenhagen, Reykjavik, and Istanbul in order to identify effective strategies for sustainable urban development. The findings reveal that successful energy transitions are closely linked to strong local governance, long-term climate targets, renewable energy investments, and stakeholder participation. Furthermore, geographical conditions and institutional capacity significantly shape policy outcomes. Based on these findings, the study recommends that cities develop context-specific integrated energy policies, enhance public participation, and adopt planning approaches centered on energy efficiency and sustainability.

Keywords: energy efficiency, long-term sustainability, energy transition, urban transition pathways, green energy integration

ÖZ

Enerji; modern toplumların temel yaşam kaynağı olup yaşamın tüm alanlarına nüfuz eden, ekonomik büyümeyi yönlendiren ve toplumsal refahın sağlanmasına katkı sunan vazgeçilmez bir unsurdur. Enerji üretiminde fosil yakıtlara olan bağımlılık ise küresel ölçekte ciddi bir tehdit oluşturmaktadır. Fosil yakıtlar, nükleer enerji ile birlikte yenilenemez kaynaklar arasında yer almakta ve gezegen üzerinde önemli bir baskı yaratmaktadır. Bu enerji kaynakları, sera gazı emisyonları yoluyla iklim değişikliğine katkıda bulunmalarının yanı sıra, uzun vadede giderek artan ekonomik maliyetler de doğurmaktadır. Bu bağlamda yeşil enerji hem çevresel hem de ekonomik sürdürülebilirliğin sağlanması açısından kritik bir çözüm olarak öne çıkmaktadır. Fosil yakıtların yerini alabilecek ve daha düşük çevresel etkilere sahip enerji üretimini mümkün kılan alternatifler sunan yeşil enerji, sürdürülebilir kalkınma hedeflerine ulaşılmasına önemli katkılar sağlamaktadır. Bu çalışmanın literatür bölümü, sürdürülebilir kalkınma ile yeşil enerji arasındaki ilişkiye odaklanmaktadır. Yeşil enerji, çevresel sorunların çözümünde merkezî bir rol üstlenirken, aynı zamanda sürdürülebilir kalkınmanın gerçekleştirilmesinde temel bir araç olarak değerlendirilmektedir. Bu çalışma, kentlerde yeşil enerjinin başarılı entegrasyonunu mümkün kılan temel dinamiklerin neler olduğu sorusuna odaklanmaktadır. Araştırmanın amacı, Kopenhag, Reykjavik ve İstanbul örnekleri üzerinden yeşil enerji politikalarının uygulanma süreçlerini karşılaştırmalı olarak analiz ederek sürdürülebilir kentleşme açısından etkili stratejileri ortaya koymaktır. Bulgular, başarılı enerji dönüşümünün güçlü yerel yönetişim, uzun vadeli iklim hedefleri, yenilenebilir enerji yatırımları ve paydaş katılımı ile doğrudan ilişkili olduğunu göstermektedir. Ayrıca coğrafi koşullar ve kurumsal kapasitenin politika sonuçlarını belirlediği anlaşılmıştır. Bu doğrultuda, şehirlerin yerel koşullara uyarlanmış bütüncül enerji politikaları geliştirmesi, toplumsal katılımı artırması ve enerji verimliliğini merkeze alan planlama yaklaşımlarını benimsemesi önerilmektedir.

Anahtar Kelimeler: enerji verimliliği, uzun dönem sürdürülebilirlik, enerji dönüşümü, kentsel geçiş stratejileri, yeşil enerji entegrasyonu

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INTRODUCTION

The ultimate aim of governments is to construct a societal structure where citizens experience freedom, prosperity, and security, and are able to realise their individual potential. Achieving this requires long-term sustainability, which has emerged as one of the most critical challenges of our time, necessitating the attention and action of governments, industry, and academia.

Sustainability as a concept gained prominence in the latter part of the 20th century, driven by escalating environmental concerns. Over the past 25 years, the global population has risen from 6 billion to 8 billion, driving a dramatic increase in energy demand, with a substantial proportion still derived from fossil fuels due to their ease of access and relatively low cost. Fossil fuel consumption rose from 3,514.2 mtoe/y in 1965 to 11,306.4 mtoe/y in 2015, contributing to a rise of more than 100 ppm in atmospheric CO2 concentration and approximately 1°C increase in global mean surface temperature over the past century (Zhang & Guo, 2017, p. 65). States are confronting significant challenges in reconciling rapid economic growth with the need to mitigate greenhouse gas emissions, while striving to ensure the long-term availability of energy resources for future generations at minimum cost and emission levels (Sen & Ganguly, 2017: p. 1172; Xie et al., 2022, p. 1).

An increasing number of states, particularly developed ones, are progressively implementing eco-friendly measures such as renewable energy, environmental finance, and establishing a green economy in response to the demands of sustainable development. These initiatives possess significant potential to facilitate long-term environmental and economic sustainability (Zeng et. al, 2024, p. 2). According to Yushchenko and Patel (2016), green energy fulfills the objectives of sustainability by providing a cost-effective and efficient means of enhancing the long-term viability of a nation's productive sector, improving the standard of living for its people, and minimizing environmental impact. Similarly, by highlighting the advantages of green energy compared to fossil fuel-based energy, Midilli et al., (2004) (as cited in Aktar et al., 2020, p. 4-5) argue that long-term and proactive policies should be implemented on a larger scale to promote the widespread adoption of green energy globally, as it is regarded as a crucial element in the interaction between nature and society.

This study addresses this research gap by comparatively examining the green energy transition strategies of Copenhagen, Reykjavik, and Istanbul, representing different geographical, institutional, and developmental contexts. Rather than focusing solely on technological aspects, the study evaluates green energy integration from the perspectives of local governance, policy implementation, stakeholder participation, and institutional capacity. In doing so, it identifies common success factors and context-specific differences, thereby contributing to the literature on sustainable urban energy transition and providing practical policy implications for cities pursuing green energy transformation.

Green energy policies are regarded as a crucial pillar of the transition to a green economy and have become a central focus of energy policy agendas in Europe and other regions. This study examines the green energy integration processes of three cities worldwide through a case study approach, analyzing the strategies and projects they have successfully implemented. The theoretical framework of green energy and sustainability concepts is also addressed, highlighting the complementary relationship between the two. Based on the experiences of the relevant cities, the study concludes with policy recommendations at both local and national levels, emphasizing that success in green energy requires a holistic approach that integrates energy policies with other policy domains.

1. LITERATURE REVIEW

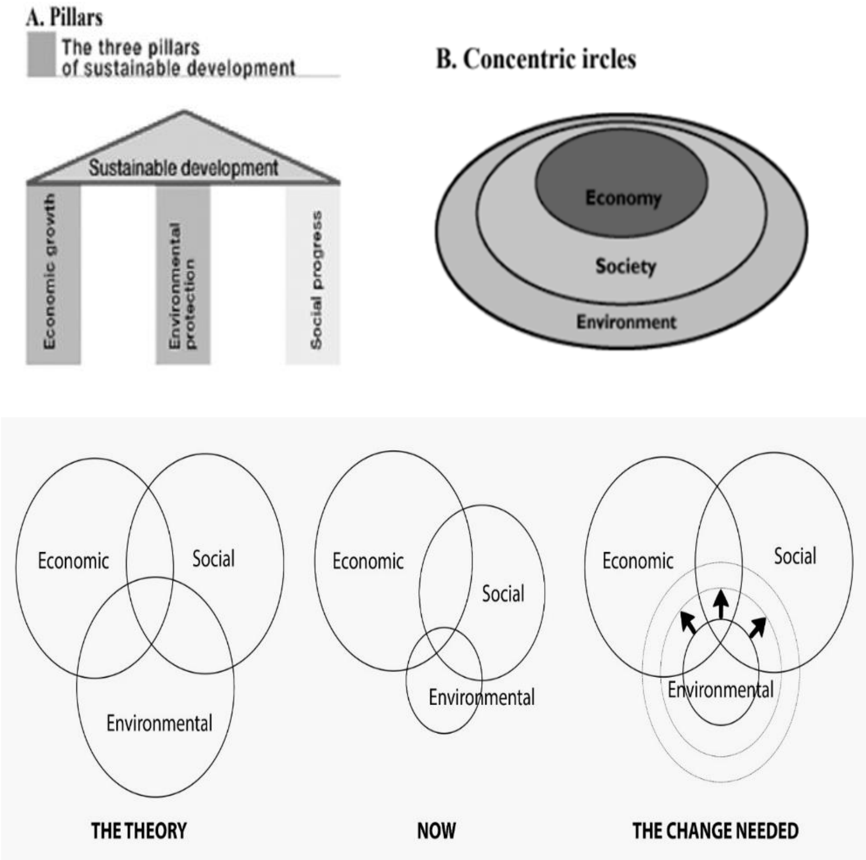
The impacts of human activities on the environment remained relatively limited for a long period due to the natural regenerative capacity of ecosystems. However, industrialization, urbanization, and increasing consumption have caused pollutants to exceed ecosystems' carrying capacities, accelerating environmental degradation. Initially manifesting as air, water, and soil pollution has today evolved into multidimensional problems associated with climate change, including rising sea levels, increasing temperatures, glacier retreat, and biodiversity loss.

These phenomena are primarily driven by rising greenhouse gas concentrations in the atmosphere. CO_2, the most dominant greenhouse gas, is largely released through the combustion of fossil fuels. The IPCC's Third Assessment Report (2001) concluded that most of the warming observed over the last 50 years is attributable to human activities, while the Fourth Assessment Report (2007) projected a temperature rise of 1.1–6.4°C and a sea level rise of 16.5–53.8 cm by the end of the 21st century. Rising sea levels pose severe consequences for coastal populations, including mass displacement, loss of agricultural land, and threats to food and water security (IPCC, 2001; 2007; Lau et al., 2010). The Paris Agreement (2015) established the goal of limiting global warming to below 2°C, yet a significant gap remains between this target and current trajectories (Roberts, 2017). In this context, developing effective green energy strategies is essential for achieving a sustainable future (Aktar et al., 2020, p. 4).

In fact, citizens, governments, and international organizations became aware of sustainability and resource management following the 1972 Club of Rome report, The Limits to Growth, which predicted the depletion of essential natural resources within one or two generations (Meadows et al., 1972). The Brundtland Report (WCED, 1987) prepared after the report that was interpreted as a harbinger of disaster, was met with approval as it provided a way out of the impending catastrophe. This report adopted the concept of sustainability and has established the widespread recognition it holds today (Kuhlman and Farrington, 2010, p. 3437). According to this report, sustainable development is defined as “meeting the needs of the present generation without compromising the ability of future generations to meet their own needs”. In this context, it can be stated that sustainable development aims to ensure both intergenerational and intergenerational justice (WCED, 1987). According to Sebesta (2005, p. 58), “sustainability is a process that reduces the long-term impact on natural resources and the environment in a cost-effective and socially acceptable manner”. Furthermore, sustainable development extends beyond environmental protection, constituting a dynamic process in which resources, investments, technology, and institutional transformations are aligned with both current and future societal needs.

The United Nations and other international organizations have conceptualized international development within the context of sustainability, thereby providing authoritative definitions of this fundamental concept. These definitions encompass both social, environmental and economic dimensions. These dimensions are encapsulated in the following definition: Sustainable development is achieved when economic prosperity is pursued within the parameters of social equity, human rights, peaceful interrelations among societies, and ecological balance (Simpson et al., 2005, p. 26). In Figure 1, these dimensions are depicted as pillars, concentric circles, and overlapping circles.

Figure 1. Three Conceptual Models of Sustainable Development: Pillars, Concentric Circles, and Overlapping Circles



Source. Adams, 2006.

The culmination of the global recognition of the importance of the concept of sustainable development was the United Nations Conference on Environment and Development (UNCED, 1992) held in Rio on 3-14 June 1992. This conference addressed a range of emerging and contemporary issues, while highlighting the critical role of energy as a key factor in the advancement of sustainable development.

Cities are responsible for a significant share of global energy consumption and greenhouse gas emissions, making them both a primary source of the problem and the most critical arena for green energy transition. As the home of the majority of the world's population, cities are where energy demand is most concentrated and where the impacts of climate change are most acutely felt. In this context, urban energy transition should be viewed not merely as a technical matter, but as a multidimensional process encompassing local governance capacity, urban planning, stakeholder participation, and long-term policy commitments (OECD, 2020). Studies show that successful urban energy transitions are closely associated with strong institutional structures, integrated policy approaches, and community engagement mechanisms (Yatzkan et al., 2025). Stakeholder engagement, in particular, plays a pivotal role in shaping the trajectory of renewable energy initiatives and determining the success of their implementation (Gan & Miao, 2024, p. 3). Therefore, the integration of green energy into cities is regarded as both a means and an indicator of sustainable urban development.

Currently, approximately 90% of the global energy demand is supplied by fossil fuels, with the remaining 10% derived from renewable sources. While fossil fuels satisfy a large portion of global energy demand, their environmental impact leads to an increase in greenhouse gas emissions, thereby accelerating climate change (Gül, 2024, p. 175). As previously stated, the development of green energy strategies is essential for ensuring a sustainable future. As a matter of fact, the reason for the emergence of the green energy concept is to create a road map that can overcome such challenges.

Although the terms renewable energy and green energy are often used interchangeably, they are not fully synonymous. Green energy refers to energy generated from natural sources with minimal environmental impact, whereas renewable energy denotes energy derived from naturally replenishing sources, regardless of its environmental footprint. Accordingly, a source may be renewable without qualifying as green. Biomass combustion, for example, is renewable but emits CO_2 during combustion, while the ecological impacts of large-scale hydropower also challenge its classification as green (Tripathi, 2024, pp. 4864–4867). Since this study focuses on urban energy transitions driven by low-impact renewable energy sources, the distinction is not critical for the present analysis. Therefore, the two terms are used interchangeably throughout the manuscript, except where the technical classification of energy sources is specifically discussed.

Despite these definitional nuances, renewable energy sources -including solar, wind, biomass, and geothermal energy -can generate energy with zero or nearly zero emissions when properly managed and are often referred to as alternative energy sources (Meena & Meena, 2020, p. 1232). Their development will facilitate the resolution of critical contemporary challenges, including enhancing the reliability of energy supply and optimizing the efficiency of organic fuel utilization. Additionally, it will contribute to addressing issues related to local energy and water supply, improving the standard of living and employment levels within local communities, and promoting the sustainable development of remote regions, particularly in desert and mountainous areas. Furthermore, the implementation of renewable energy initiatives will support countries in fulfilling their commitments under international environmental protection agreements (Zakhidov, 2008 as cited in Panwar et al., 2011, p. 1514).

The effective utilization of green energy holds significant potential for both stimulating economic growth and reducing pollution. Therefore, many countries, especially developed ones, have implemented various policies that support green energy (Sarbu & Sebarchievici, 2013, p. 287). The utilization of wind energy has seen a significant increase in recent years; for instance, the Netherlands and Germany have deployed wind turbines in the northern and western regions to generate electricity. Furthermore, several Asian countries, including India and Malaysia, have built wind turbine power plants to produce electricity. In Manjil City, located in northern Iran, numerous wind turbines are installed, while in northwestern Iran, mineral resources are utilized for the production of geothermal energy. In Iceland, nearly 70% of industrial facilities rely on geothermal energy for their operations (Ullah et al., 2013, p. 500). As evidenced by these examples, global green energy production has been progressively increasing, and the following section provides a comparative analysis of successful green energy implementations in three cities.

2. METHODOLOGY

This study is designed as a narrative review with a comparative perspective, adopting a conceptual and analytical framework based on existing literature. Copenhagen, Reykjavik, and Istanbul were selected through a purposeful sampling strategy aimed at capturing diverse yet complementary models of green energy integration. In this study, rather than selecting cities with similar socioeconomic characteristics, cities with different geographical conditions, population scales, and energy resource profiles were purposefully chosen. In this context, Copenhagen was included in the study due to its internationally recognized achievements in carbon neutrality and its pioneering practices in wind energy, district heating, energy efficiency, and sustainable urban mobility. Reykjavik represents a distinctive energy transition model that integrates a geothermal- and hydropower-based energy system with strong local governance and long-term climate policies. Istanbul, as a large metropolitan city with high energy demand, provides an important example of the adaptation of renewable energy, energy efficiency, and climate governance practices within the context of rapidly growing urban areas. Nevertheless, Reykjavik and Istanbul differ considerably in terms of population size, urban scale, geographical characteristics, and institutional capacity. In this context, Reykjavik's small-scale urban structure and its abundant geothermal energy resources, together with Istanbul's status as a densely populated metropolitan city with high energy demand, significantly influence the scope, feasibility, and effectiveness of green energy implementation. Therefore, the findings should not be interpreted as a direct comparison of urban performance, but rather as an evaluation of the policies and practices developed by each city within its own geographical, institutional, and socio-economic context. This comparative approach enables the identification of common success factors while also highlighting the importance of considering local conditions when adapting successful practices to different urban contexts.

The primary contribution of this study to the literature lies in its holistic examination of green energy integration, considering not only technological applications but also the dimensions of local governance, institutional capacity, strategic planning, and stakeholder participation. In this respect, unlike previous studies, the research aims to contribute to the comparative assessment of the common policy dynamics influencing successful energy transitions across cities with different scales and characteristics.

To ensure a systematic comparison, the three cities were analyzed using a common analytical framework. The comparison focused on five dimensions identified from the literature as critical for successful urban green energy integration: (i) renewable energy production strategies, (ii) energy efficiency practices, (iii) sustainable urban mobility policies, (iv) local governance and institutional capacity, and (v) stakeholder participation and long-term climate planning. These dimensions were examined through official policy documents, climate action plans, municipal strategic reports, and relevant academic studies. This common framework enabled the identification of both shared success factors and context-specific differences among the selected cities.

This study has several limitations that should be acknowledged. First, the analysis is based on a qualitative comparative review of three selected case studies and therefore does not aim to provide statistically generalizable findings. Second, the study relies primarily on official policy documents, municipal reports, and existing academic literature rather than primary empirical data collected through field research. Third, the selected cities represent different geographical, institutional, and socio-economic contexts; therefore, the successful practices identified in one city may not be directly transferable to another without considering local conditions.

3. CASE STUDIES OF SUCCESSFUL GREEN ENERGY INTEGRATION IN CITIES

This section examines case studies of three cities that have achieved notable progress in integrating green energy into urban systems. Copenhagen and Reykjavik are analyzed as internationally recognized pioneers in renewable energy, while Istanbul is included as a large metropolitan city undergoing an ongoing transition within the EU Cities Mission framework. Together, these cases offer a comparative perspective on diverse urban pathways toward sustainable energy integration.

3.1. Copehagen

Cities today are becoming progressively more vital in addressing global climate change. Danish capital, Copenhagen, stands out as one of the most ambitious cities, aiming to become carbon neutral by 2025 (https://international.kk.dk/about-copenhagen/liveable-green-city). The European Union's goal of achieving carbon neutrality by 2050 provides a significant framework supporting Copenhagen's energy transition (European Green Deal, 2019). Additionally, Copenhagen aims to become one of the world's most sustainable cities as part of the C40 Climate Action Plan (https://www.c40.org/). Copenhagen's energy policies are in line with Denmark's target to reduce carbon emissions by 70 per cent by 2030 compared to 1990 levels and to achieve climate neutrality by 2050 at the latest (https://www.en.kefm.dk/energy/renewable-energy). Since the implementation of its first Climate Plan in 2009, the City of Copenhagen has achieved a significant reduction in carbon emissions, leading to its designation as the 'European Green Capital' in 2014 (Fayed et al., 2020, p. 4). The Copenhagen

Climate Plan 2025, developed to achieve these goals, is a comprehensive strategy covering four main areas: energy consumption, energy production, green mobility, and municipal governance initiatives. The planning process included the participation of the government, academics, businesses, and citizens (Copenhagen Climate Plan, 2021-2025, pp. 1-68). Within this framework, Copenhagen is implementing large-scale green projects such as district heating, wind energy investments, low-emission transport solutions, smart city technologies, and energy efficiency measures.

In the theme of energy production within the Copenhagen Climate Plan 2021-2025, the transformation of the district heating system and the installation of wind turbines to meet Copenhagen's electricity consumption are some of the key areas of work. In this regard, various energy production practices are being adopted, including the installation of large-scale solar panels, the establishment of onshore and offshore wind turbines, the utilization of bioenergy sources (biomass, biogas) to replace fossil fuels and make energy production more sustainable, the integration of smart systems into electricity and heating networks to improve energy supply efficiency, and the implementation of waste separation projects to better manage urban waste (Copenhagen Climate Plan, 2025, p. 27).

In Copenhagen, which boasts the largest district heating network in the world, this system serves approximately 98% of the city's buildings. Copenhagen's district heating system is primarily supplied by cogeneration plants, also known as Combined Heat and Power (CHP) plants. Cogeneration plants in Copenhagen focus on biomass and waste-to-energy production, aiming to reduce dependence on fossil fuels. CopenHill is one of the world's largest and cleanest waste-to-energy plants, converting approximately 400,000 tons of municipal waste into energy annually. The biomass-fuelled BIO4 plant replaced the last coal-fired plant, eliminating coal use and contributing to 80% carbon neutrality in district heating (Copenhagen Climate Action Plan, 2021-2025, p. 28). The BIO4 produces both heat and electricity when needed; meeting 25% of heat demand, its efficiency is 30% higher than the former coal plant and exceeds 110% (https://uabio.org/en/news/13013/). The Greater Copenhagen Utility (HOFOR), a municipal company of Copenhagen, supports the transition of the district heating system to carbon neutrality by shifting from coal, oil, and natural gas to sustainable biomass (https://www.c40.org/case-studies/cities100-copenhagen-carbon-neutral-district-heating/). More than half of electricity consumption comes from wind, biomass, solar energy, and other renewable sources (https://www.greencitytimes.com/copenhagen/). Wind energy constitutes a low-cost and environmentally sustainable source of electricity generation. In 2020, 46% of Denmark's total electricity supply was generated from wind power, and Copenhagen has been integrated into this green transition. Through the deployment of both onshore and offshore turbines, wind energy has become the most widespread and competitive renewable energy source across the country (Danish Ministry of Climate, Energy and Utilities, 2025). Some of the challenges related to wind energy in Copenhagen are the limited space available in the existing urban area for large-scale implementation of wind energy, the high costs of building wind turbines, and the emergence of public resistance due to the noise they produce (Fayed et al., 2020, p.7).

The energy consumption theme of the Copenhagen Climate Plan 2021–2025 (2025, pp. 19–23) aims to reduce heating and electricity use while improving energy efficiency in public and private buildings. Key strategies include renovation of building systems, energy-saving technologies, low-energy standards for new buildings, expansion of solar and photovoltaic systems, and increased renewable electricity generation. Renovations alone are expected to reduce electricity consumption by 10% and heating consumption by 20% by 2025 compared to 2010 levels (Fayed et al., 2020, p. 6). Since around 70% of energy use in Copenhagen comes from buildings and the municipality owns only 5% of the building stock, achieving targets requires collaboration. The Energispring partnership programme, carried out under the leadership of the Municipality of Copenhagen and with the participation of major property owners, managers, and housing associations, has promoted the improvement of energy performance and the integration of buildings into the district heating system; it achieved a 10% reduction in heating consumption between 2021 and 2023 (https://energispring.kk.dk/om-energispring/hvad-vi-vil).

The Municipality of Copenhagen is collaborating with Copenhagen Properties (KEJD) and Copenhagen Solutions Lab to implement AI-driven energy optimization applications. This project aims to reduce energy consumption and enhance indoor climate conditions within municipal buildings. The application will increase the efficiency of the system by automating energy management based on local weather forecasts and building usage data. Thus, by improving forecasts of when and how much heat and electricity buildings can provide, CO_2 emissions will be reduced and municipal energy costs will be lowered (Copenhagen Solution Lab, 2022).

Under the reduced-emission mobility theme of the 2021–2025 Climate Plan, transport is identified as the largest source of CO_2 emissions in Copenhagen. The Municipality promotes cycling, integrates public transport with electric vehicles, and restricts fossil-fuel vehicles to achieve carbon neutrality. It aims for 75% of all trips to be made by walking, cycling, or public transport (https://urbandevelopmentcph.kk.dk/mobility-cycling/mobility-how-we-get-around-in-the-city). According to the Mobility Report (2023; p. 29), this share has reached 74%; bicycle use stands at 26%, commuting by bicycle at 45%, and zero-emission buses at 100%. Public transport achieved a 56% CO_2 neutrality rate in 2019 compared to 2008 (no data available for 2024).

Under the theme of municipal governance initiatives in the Copenhagen Climate Action Plan (2021-2025; p. 47-51), the Municipality of Copenhagen continues its efforts towards achieving the goal of becoming a carbon-neutral city by implementing a range of activities. These include enhancing energy efficiency, promoting the use of renewable energy, encouraging green procurement policies, developing smart city applications, and supporting initiatives to raise social awareness. To achieve its goals in the transformation process, the municipality plays a facilitative role by collaborating with residents, businesses, and public authorities in this process of change (Copenhagen Urban Development, 2025).

The use of renewable energy varies depending on climate and geographical conditions. In this context, wind energy, biomass and solar energy are predominant in Copenhagen. When the projects carried out by Municipality of Copenhagen in line with the targets set within the framework of four main themes, namely energy consumption, energy production, green mobility and municipal management initiatives, are analysed, it is seen that the city has made significant progress towards becoming a carbon neutral city by getting rid of fossil fuels in energy production and turning towards renewable energy sources such as wind, biomass and waste heat. However, it is understood that it aims to reduce CO_2 emissions and create a sustainable urban model by reducing energy consumption through smart energy systems and renewable energy investments. On the other hand, within the framework of a sustainable green transformation perspective, it is essential to encourage residents to prefer environmentally friendly transport methods and ensure that they can move efficiently and comfortably within the city. In this framework, Municipality of Copenhagen has developed green transport strategies and implemented exemplary practices in this field. According to Maliszewska-Nienartowicz et al., (2024: p. 6), despite all these steps and ambitious plans, by 2022 it has become clear that the goal of becoming a carbon-neutral city by 2025 is unlikely to be realized. However, Copenhagen continues to lead as the city with the highest potential to become the world's first carbon-neutral city in the next few years.

3.2. Reykjavik

Reykjavik, the capital of Iceland, is among the leading cities aiming to reduce fossil fuel dependence and environmental impacts through the efficient use of renewable energy, with the long-term goal of achieving carbon neutrality. The city has been a member of the Covenant of Mayors for Climate and Energy since 2011 and became a signatory of the Covenant of Mayors for Climate Change Adaptation in 2014, strengthening its commitment to climate mitigation and adaptation (https://reykjavik.is/en/reykjavik-and-climate). The Municipality implements its environmental policies under the Climate Action Plan and the Green Deal. In 2016, Reykjavik set the target of becoming carbon neutral by 2040 and developed a comprehensive action plan accordingly. The 2021–2025 Climate Action Plan (2020, p. 9) emphasizes broad stakeholder collaboration and diverse projects to support the transition to a carbon-neutral society. Within the 2020 Green Deal framework, five main objectives were defined for 2030: reducing greenhouse gas emissions, increasing carbon sequestration and green spaces, adapting to climate change, improving access to healthy lifestyles and food, and promoting sustainable transport (https://reykjavik.is/en/green-deal/green-city). The 2021–2025 plan also identifies six core goals, including walkable cities, energy transition, healthy mobility, circular economy, green buildings, and carbon capture technologies (City of Reykjavik Climate Action Plan, 2020, p. 18). These actions aim to contribute to the Paris Climate Agreement and limit global warming to 1.5°C. In this context, Reykjavik's wind energy practices will be evaluated in two main themes, namely "energy production and efficiency" and "green mobility".

An examination of the targeted and implemented projects in Reykjavik indicates that the city's electricity and heating needs are predominantly met through geothermal and hydroelectric energy. In Iceland, 73% of electricity generation is provided by hydroelectricity and 27% by geothermal energy sources. Approximately 90% of building heating in the country is provided by geothermal district heating systems, thereby minimizing dependence on fossil fuels (https://www.greencitytimes.com/green-city-solutions-reykjavik-iceland/). In this context, the Hellisheidi and Nesjavellir geothermal power plants play a significant role in Reykjavik's energy production and district heating systems. The Hellisheidi Geothermal Power Plant, the largest geothermal power plant in Iceland, not only generates electricity at a high capacity but also significantly contributes to district heating networks. This plant is a flash steam Combined Heat and Power (CHP) facility, generating 303 MW of electricity and 400 MW of thermal energy. Similarly, the Nesjavellir Power Plant not only produces electricity but also supplies hot water to Reykjavik through an extensive pipeline network. These power plants contribute to Reykjavik's sustainable energy strategy by increasing the use of renewable energy, reducing dependence on fossil fuels, and promoting environmental sustainability (https://www.power-technology.com/projects/hellisheidi-geothermal-power-plant/).

Iceland aims to integrate solar energy harvested from space into its renewable energy sources by 2030. Space-based solar energy systems have the potential to offer higher energy efficiency compared to terrestrial solar panels. In this context, the UK-based company Space Solar, in collaboration with Iceland's Transition Labs and Reykjavik Energy, seeks to establish the world's first space-based solar power plant. However, key considerations include its high cost, environmental impact, and the risk of space debris (Lazaro, 2024).

On the other hand, Reykjavik Energy (Orkuveita Reykjavikur), a public energy company owned by the Municipality of Reykjavik, aims to enhance social sustainability and environmental resilience by providing innovative solutions in public services, energy supply, and carbon sequestration. In this context, Reykjavik Energy (OR) aims to achieve carbon neutrality at the Hellisheidi Geothermal Power Plant by 2025, and at the Nesjavellir Geothermal Power Plant by 2030. This goal will be achieved through the implementation of the Carbfix method, which captures and sequesters 95% of the carbon dioxide emitted from the plants in rocks (Reykjavík Energy Annual Report, 2023). In addition, Reykjavik Energy (Orkuveita Reykjavikur) signed a "Memorandum of Understanding" with Transition Labs and Clean Air Task Force (CATF) to develop and test technologies for the utilisation of deep geothermal energy in Iceland. This partnership aims to revolutionise future energy production by developing the use of geothermal energy that can be obtained from deep sources (Geothermal News, 2024).

Another significant energy source in Reykjavik is hydroelectric energy. Iceland's geography, with its abundant rainfall and extensive rivers, provides a favorable environment for hydroelectric power generation. The Búrfell Hydroelectric Power Plant meets a significant portion of the city's electricity needs. The hydroelectric power plants supplying energy to Reykjavik play a crucial role in meeting the city's energy demands. These power plants provide diversity in energy production, freeing the city from dependence on a single source and promoting sustainable energy production (Landsvirjun Búrfell Power Station, 2025).

Fifteen cities, including Reykjavik, are organising global competitions to promote carbon neutral and resilient urban regeneration. In this context, C40's 'Reinventing Cities' initiative has identified areas for redevelopment. These include vacant lots, abandoned buildings, a former airport, historic mansions, underused car parks and abandoned incinerators and landfill. One of the winning projects is 'The Fabric Info'. The 5,700 square meter unbuilt plot in Reykjavik is located in one of the city's main corridors and is unique in the availability of geothermal heat pumped from the ground. The project aims to reduce the overall carbon footprint through the selection of low-carbon construction materials (C40 Reinventing Cities, 2019).

The Reykjavik Municipal Plan 2010-2030 (2014: p.29) emphasises measures to develop environmentally friendly transport. In the City of Reykjavik Climate Action Plan (2021-2025, p.12), also states that almost all of the emissions in Reykjavik are caused by the use of fossil fueled vehicles. According to the announced emission data of Reykjavik City, 74% of total emissions are from public transport. Buildings cause 2%, industry 7%, waste 8% emissions, while other sectors account for 9% of total emissions (Global Covenant of Mayors for Climate and Energy, 2025). Considering the factors that the City of Reykjavik can directly influence, emissions from transport account for the largest share of total GHG emissions. These findings indicate that the transport sector is one of the key factors in achieving Reykjavik's emission reduction targets (City of Reykjavik Climate Action Plan, 2020, p.12). The solution is to reduce transport demand, increase the use of low- or zero-emission transport modes, and promote the adoption of clean energy vehicles in road transport. In this context, it is aimed to increase the rate of public transport use from 4% to 12% of all journeys; it is also aimed to increase the rate of pedestrian and bicycle users from 21% to over 30%.

The City of Reykjavik Climate Action Plan includes social equity assessments within the scope of climate actions and highlights that measures to combat climate change may have unequal impacts on different segments of society, such as the elderly and children. Therefore, social equity dimensions should be considered in climate action plans that shape green energy transition strategies, and the outcomes should be evaluated from this perspective (City of Reykjavik Climate Action Plan, 2020, p. 27). The inclusion of all segments of society in planning processes and their active participation in green energy initiatives are critical factors in the success of cities striving to achieve sustainability goals. On the other hand, Reykjavik's widespread adoption of renewable energy indicates a significant success in the city's energy production. However, Reykjavik's population of 142,316 (Population of Reykjavík, 2025) presents a significant distinction when compared to larger cities. Geographical and geological factors, especially the use of local geothermal resources, play a decisive role in the success of these strategies. Considering the need to develop city-specific energy policies, it can be said that Reykjavik's achievements are largely based on local conditions and the direct applicability of these strategies in other cities may be limited. However, Reykjavik's green energy initiatives not only fulfil the city's energy needs, but also make a significant contribution to meeting global climate goals.

3.3. Istanbul

Istanbul, where energy demand is constantly increasing due to rapid urbanization and population growth, is undergoing a transformation process that necessitates the use of sustainable and renewable energy resources. The environmental impacts of conventional fossil fuels, including air pollution and carbon emissions, are among the key factors compelling the city to shift towards renewable energy sources. Within the scope of Istanbul Metropolitan Municipality's (IMM) membership to the C40 Cities Climate Leadership Group, the 'Deadline 2020' commitment was signed in 2019 and Istanbul's goal of becoming a carbon neutral and resilient city by 2050 was accepted. In line with this objective, the Istanbul Climate Change Action Plan was revised and published in 2021 as part of the Technical Assistance Programme provided specifically for Istanbul by C40 (2021; p. 11). "Meanwhile, within the framework of its membership in the Global Covenant of Mayors for Climate and Energy (GCoM), the Istanbul Metropolitan Municipality (IMM) applied for and secured support from the 'EU4 Energy Transition Covenant of Mayors in the Western Balkans and Türkiye' project in 2021. This initiative is jointly financed by the European Union and the German Federal Ministry for Economic Cooperation and Development. Within the scope of the project, the "Sustainable Energy and Climate Action Plan (Istanbul SECAP)" was published in 2023 for Istanbul. In this context, IMM has committed to reducing greenhouse gas emissions by 40% by 2030 compared to 2019 levels. Istanbul SECAP outlines activities aimed at emission reductions across key sectors, including buildings, equipment/facilities, urban transport, and waste management” (Istanbul SECAP, 2021, p. 21).

In its Strategic Plan 2025-2029 (2024; p. 10), the Istanbul Metropolitan Municipality has established a strategic roadmap in line with the vision of ‘Fair, green and creative city, happy Istanbulites’. Under this vision, within the framework of the “Environmentally Conscious Istanbul” theme, six key objectives have been set to ‘Strengthen Sustainable Environmental and Energy Management’ (Strategic Plan, 2024, p.12). These objectives are “to increase the recovery rate by improving waste management practices”, “to activate and expand activities for renewable energy, energy efficiency and lighting facilities”, “to create, protect and develop sustainable and accessible urban green areas”, “to protect the environment through urban cleaning, inspection and awareness activities”, “to protect and develop the urban ecosystem and biodiversity”, “to be a resilient city on the path to carbon neutrality by combating climate change”. In Istanbul’s GHG emissions inventory, the stationary energy sector accounts for the largest share (62.9%), with the majority of emissions originating from the residential sector. These emissions primarily result from the consumption of natural gas for cooking, water heating, and space heating. The transport sector contributes 28.3% of total emissions, while the waste sector accounts for an 8.8% share. Furthermore, 89.4% of emissions within the waste sector stem from solid waste disposal processes (Istanbul SECAP, 2021, p.76). Within the scope of the ongoing and pilot studies in Istanbul, good practices that stand out in line with the stated objectives are listed below.

Among the renewable energy sources utilised in the city, solar energy and energy from waste are the most widely preferred. In line with the objective of meeting 50% of the municipality’s electricity demand by 2030, plans have been set in motion for the establishment of solar power plants and the utilisation of alternative energy sources (Istanbul SECAP, 2021; p. 20). To this end, the Istanbul Metropolitan Municipality (IMM) has installed solar energy systems on the rooftops of 35 designated facilities and enterprises. Construction of solar energy facilities with a total installed capacity of 4,577.50 kWp at IMM service buildings has been completed (IMM Annual Report, 2023, p. 217-218). Furthermore, at the IMM Waste Incineration and Energy Generation Facility, which has a daily capacity of 3,000 tones, municipal solid waste is incinerated for disposal, and the resulting thermal energy is converted into 85 MWh of electricity. The generated electricity is sufficient to meet the needs of approximately 1.4 million Istanbul residents and contributes to the prevention of 1.38 million tons of CO_2 emissions annually. The facility manages the disposal of 15% of Istanbul’s daily municipal waste (IMM Department of Environmental Protection and Control, 202.). Additionally, over the course of a year, 6,620 tons of organic waste have been converted into compost fertiliser, and 45,368 tons of recyclable waste have been reintegrated into the economy. Through energy recovery from waste, 1.32 TWh of electricity has been generated, and 37,221 m^3 of dewatered petroleum-derived waste has been reclaimed (IMM Annual Report, 2023, p. 212).

Landfill gas generated from mixed municipal waste delivered to disposal sites is collected through controlled gas collection systems and converted into electrical energy. The landfill gas is systematically captured, subjected to appropriate conditioning processes, and rendered suitable for use as fuel. By combusting the gas in engines, electricity is generated at three distinct landfill sites: Silivri-Seymen, Odayeri, and Şile-Kömürcüoda Landfill Gas-to-Energy Facilities (IMM Department of Environmental Protection and Control, 2025).

In Istanbul’s greenhouse gas emissions inventory, the stationary energy sector has been identified as the largest contributor, accounting for 62.9% of total emissions. In response, the Istanbul Metropolitan Municipality (IMM) is implementing the Green and Carbon Neutral Building Transition Guide – Istanbul Model (Build4GreenIST) project as part of the EU Cities Mission Pilot Cities Programme, affiliated with the European Union. To support actions related to building energy in the city, a guideline will be developed to ensure that buildings undergoing urban transformation are renovated with green and carbon-neutral features. Additionally, in a selected pilot area, energy consumption in residential buildings will be monitored using sensors, and guidance will be provided to encourage behavioural changes aimed at improving energy efficiency (IMM Annual Report, 2023, p. 234).

Advancing with steadfast steps on this path, the Istanbul Metropolitan Municipality (IMM) organises various training programmes to raise awareness and educate the public on energy efficiency as part of its efforts to reduce greenhouse gas emissions. These training sessions provide information on key aspects such as heating, lighting, washing, and cooking, as well as guidance on the proper use and purchase of electrical appliances (IMM Department of Parks, Gardens, and Green Spaces, 2022). For a major metropolis such as Istanbul, with a population of 15.701.602 million (TUİK, 2024), adopting an effective governance approach and integrating green energy practices is of strategic importance in contributing to global climate sustainability goals.

In line with the strategic plans of the Istanbul Metropolitan Municipality (IMM) and its international collaborations, a comprehensive set of projects is being implemented to reduce greenhouse gas emissions, enhance energy efficiency, and promote the widespread adoption of renewable energy sources. Promoting green and carbon neutral buildings in urban transformation processes contributes to both energy efficiency and minimising environmental impacts. In this context, the guidelines and monitoring systems created by the Istanbul Metropolitan Municipality serve as an important strategic tool to promote sustainable energy use and raise public awareness in this area.

Table 1. Comparative Summary of Green Energy Integration in the Selected Cities

Comparison Dimension	Copenhagen	Reykjavik	Istanbul
Main Renewable Energy Sources	Wind, biomass, solar, waste-to-energy	Geothermal, hydropower	Solar, waste-to-energy, landfill gas
Energy Efficiency Practices	District heating, smart energy systems, building renovation	Geothermal district heating, carbon capture, energy-efficient buildings	Solar PV installations, energy recovery from waste, efficiency projects
Sustainable Mobility	Cycling infrastructure, electric public transport, low-emission mobility	Public transport, walking, cycling, clean vehicles	Metro expansion, electric transport initiatives, sustainable mobility projects
Governance and Planning	Climate Plan 2021–2025; strong municipal leadership	Climate Action Plan; Green Deal; municipal energy company	SECAP; Climate Action Plan; Strategic Plan 2025–2029
Stakeholder Participation	Government, businesses, academia, and citizens	Broad stakeholder collaboration	Local government, EU-supported initiatives, and institutional cooperation
Main Challenges	Limited urban space, investment costs, public acceptance	Dependence on local geographical advantages	High energy demand, rapid urbanization, fossil fuel dependence

Source: Compiled by the authors.

The comparative assessment demonstrates that the three cities have adopted distinct transition pathways toward achieving carbon neutrality, reflecting their differing geographical, institutional, and socioeconomic contexts. Copenhagen exhibits the most advanced level of implementation in its pursuit of carbon neutrality by adopting an integrated approach that combines renewable energy deployment, energy efficiency measures, sustainable mobility solutions, and effective governance practices. Reykjavik, on the other hand, has achieved significant success in renewable energy utilization through its reliance on geothermal and hydropower resources; however, this model is largely dependent on the city's unique geographical conditions. In contrast, although Istanbul has established a strong strategic policy framework, the city appears to be at a stage where the implementation, diffusion, and scaling-up of carbon neutrality initiatives are still in progress.

4. CONCLUSION

How have we left our mark on the only planet that sustains life? After pausing for a few seconds to reflect and taking a few deep breaths, anyone who answers this question honestly will likely say that these marks are negative. Particularly after the Industrial Revolution, humanity, believing itself to be the master of natural resources—or rather, having been led to believe so—ignored the planet's carrying capacity, destroyed ecosystems, consumed resources recklessly, and in doing so, disrupted the balance of nature. Forests have dwindled, oceans are filled with plastic, air pollution hinders human respiration, and fish can no longer thrive in the waters.

By declaring nature an adversary and focusing solely on its own future, humanity needs to realise that it has lost the very battle it thought it had won. While researchers continue to search for evidence of life on other planets, there is currently no other place that could serve as an alternative to Earth. Therefore, anyone wishing to secure the right to a healthy and balanced life here must be more mindful and sustainable in using the planet's resources. In this context, it is crucial to consider the future of the planet. Notably, the sustainability and green transformation movement, which originated in developed countries and has progressively expanded to developing nations, aims to reduce humanity's impact on the environment and protect nature. This movement seeks to adopt renewable energy sources to replace fossil fuels, enhance energy efficiency, and, in doing so, achieve a balance between environmental protection and economic development.

This study aims to offer insights into best practices in the field of green energy through an analysis of successful green energy implementations. The experiences of cities such as Copenhagen and Reykjavik, which have made significant strides in sustainability and green transformation processes, can serve as guiding models for cities like Istanbul that focus on green transformation. The cases of Copenhagen, Reykjavik, and Istanbul examined within the scope of this study demonstrate that green energy integration cannot be reduced solely to the utilisation of renewable energy sources; rather, urban planning approaches, governance capacity, the quality of energy infrastructure, and policy instruments adapted to local conditions should be addressed within an integrated framework. While the case of Copenhagen highlights the decisive role of long-term climate targets, energy efficiency practices, and comprehensive urban policies in the energy transition process, the Reykjavik case illustrates how the integration of its geothermal and hydropower potential into urban energy systems can support sustainable energy transformation. The case of Istanbul, on the other hand, reveals that the success of green transformation in large-scale and complex urban structures depends not only on technological investments but also on the development of institutional coordination, infrastructure capacity, and effective governance mechanisms.

When these three cases are evaluated together, it is concluded that there is no universal and one-size-fits-all model for green energy integration; rather, diverse transformation strategies should be developed in accordance with the scale, natural resource potential, existing energy infrastructure, and governance capacities of cities. Cities wishing to pursue a similar path should involve all segments of society in both the preparation and implementation phases when developing short- and long-term strategic plans. This process will evolve from being merely a financial, technical, and administrative issue into a societal transformation. The participation of various stakeholders in the community will ensure the adoption of an integrated approach to the widespread implementation of green energy solutions, fostering strong social ownership in achieving sustainability goals. In this way, the green transition will become a goal embraced not only by municipalities and governments but also by all city residents. It must be remembered that the future of this planet is a matter too important and urgent to be left solely to politicians, scientists, or specific groups such as environmentalists.

Compliance with the Ethical Standard

Conflict of Interest: The authors declare that there are no conflicts of interest related to this manuscript, either among themselves or with any third parties or institutions. If any potential conflicts were to arise, they would be fully disclosed along with an explanation of how such conflicts would be addressed. Author contribution declaration forms, bearing original signatures, have been submitted as part of the article submission process.

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