GREEN AND CARBON NEUTRAL BUILDING TRANSITION GUIDE

ISTANBUL MODEL

Build4GreenIST

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Build4 GreenIST

ISTANBUL METROPOLITAN MUNICIPALITY

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TURKISH GREEN BUILDING COUNCIL

DemirEnerji

florawise

Letter of Mayor's Office

Dear İstanbulites,

As İstanbul Metropolitan Municipality (IMM), we have been working with the goal of a fair, green and creative İstanbul since 2019. We are happy to provide equal service to 16 million İstanbulites and to produce solutions to İstanbul's problems with important services and projects.

It is important to develop long-term, strategic plans in the management of a world city like İstanbul. When we came to power, we established the İstanbul Planning Agency (IPA), which plans İstanbul's future in every aspect and creates road maps. Under the coordination of IPA, we prepared the İstanbul Vision 2050 Strategy Document as a result of a participatory approach and data-based analysis. This document is our road map for İstanbul's goal of becoming a carbon-neutral and climate-resilient city in 2050.

Local governments have great responsibilities at the critical threshold the world is crossing due to climate change. It is a fact that rational and holistic policies are needed. As İstanbul Metropolitan Municipality, we aim to make İstanbul one of the world's leading actors in the fight against climate change. We follow a sustainable and holistic method by integrating this struggle into different policies. At the C40 Mayors Summit held in Copenhagen in 2019, we accepted the "Deadline 2020" commitment and signed İstanbul's goal of becoming a "carbon neutral" and "resilient city" by 2050. In line with this goal, we prepared our İstanbul Climate Change Action Plan. We carry out all our efforts to combat climate change under the coordination of our Climate Change Branch Directorate, which we established under our Environmental Protection and Control Department.

Valleys of Life, Urban Forests, Protection of Water Basins and Afforestation Efforts, Green Transformation in IBB Buildings, Kemerburgaz Waste Incineration and Energy Generation Plant and Silivri Seymen Landfill Gas to Energy Plant are among the most important steps we have taken to combat climate change.

In 2022, we were one of the 100+12 pioneering mission cities selected from 377 applicants for the "Climate Neutral and Smart Cities Mission", launched by the European Commission. In this context, we committed to achieve our 2050 targets set in our Climate Change Action Plan by 2030. With the Climate City Contract document we prepared within the scope of the mission, we submitted our strategies and requirements to the European Commission to accelerate our actions. As a result of the Commission's evaluations, İstanbul became one of the pioneering cities to receive the EU Mission Label.

We participated in the call for Pilot Cities opened under this mission with the project "Green and Carbon Neutral Building Transition Guide-İstanbul Model (Build4GreenIST)" and we were entitled to receive technical and financial support for 2 years. İstanbul, the locomotive of our country, became the first pilot city selected from Türkiye.

We wish that the Guide for Transition to Green and Carbon Neutral Building-İstanbul Model, which is the output of the Pilot City (Build4GreenIST) Project, will be beneficial for our İstanbul, and we thank our colleagues and stakeholders who contributed to the project on behalf of all İstanbulites.

Together, we will build a fairer, happier İstanbul where we look to the future with confidence.

Hope is here!

Sincerely,

İstanbul Metropolitan Municipality

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İstanbul Metropolitan Municipality

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We would like to thank all the units/individuals who contributed to this project, especially the representatives of the NetZeroCities Pilot City Program and the staff of IMM Directorate of Climate Change, our project partners and finance expert Mustafa Kerem TOPUZ. The knowledge, skills and selfless efforts of each of them contributed greatly to the successful realization of the project. We would like to thank them for their efforts and cooperation during the project.

- İzmir Metropolitan Municipality
- Muğla Metropolitan Municipality
- City of Sarajevo
- City of Zagreb
- Municipality of Mytilene
- KİPTAŞ
- Boğaziçi Yönetim Inc.
- Institute İstanbul ISMEK
- IMM Department of Information Technologies
- IMM Directorate of Urban Transformation Planning
- IMM Bayrampaşa Urban Transformation Project Information Office staff
- KİPTAŞ Bayrampaşa Günışığı Houses Site Management and Residents
- All stakeholders and participants involved in our Conferences, Workshops and Trainings

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List of abbreviations

Abbreviation	Description
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
Appx.	Approximate
B40	B40 Balkan Cities Network
BAS	Building Automation Systems
BEEE	Behavioural Energy Efficiency
BIM	Building Information Modelling
BİMTAŞ	Bogaziçi Landscape Construction Consultancy Technical Services Industry and Trade Inc.
BREEAM	Building Research Establishment Environmental Assessment Method
C40	C40 Cities Climate Leadership Group
CAP	Climate Action Plan
CCC	Climate City Contract
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COM	Covenant of Mayors
COP	Conference of the Parties
CPR	Construction Products Regulation
DFIs	Development Finance Institutions
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
DHW	Domestic Hot Water
EBRD	European Bank for Reconstruction and Development
EED	Energy Efficiency Directive
EER	Energy Efficiency Ratio
Eff.	Efficiency
EIA	Energy Information Administration
EKB	Energy Identity Certificate
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
ESG	Environmental, Social, and Governance

EU	European Union
GCAP	Green City Action Plan
GCF	Green Climate Fund
GCOM	Green City Action Plan
GDP	Gross Domestic Product
GHG	Greenhouse Gases
Heat Ex.	Heat Exchanger
HP	Heat Pump
HVAC	Heating, Ventilating and Air Conditioning
IAQ	Indoor Air Quality
ICAP	İstanbul Climate Action Plan
IEA	International Energy Agency
IEDAS	İstanbul Electricity Distribution Company
IESVE	Integrated Environmental Solutions Virtual Environment
IMM	İstanbul Metropolitan Municipality
IPCC	Intergovernmental Panel on Climate Change
IPMV	International Performance Measurement and Verification Protocol
IWEC	International Weather for Energy Calculations
İETT	İstanbul Electric Tram and Tunnel Company
İPA	İstanbul Planning Agency Strategic Consultancy Inc.
İSMEK	İstanbul Metropolitan Municipality Art and Vocational Training Courses
İSTAÇ	İstanbul Environmental Management Industry and Trade Inc.
KİPTAŞ	İstanbul Housing Zoning Plan Industry and Trade Inc.
KOSGEB	Small and Medium Enterprises Development and Support Administration of Türkiye
LCA	Life Cycle Assessments
LEED	Leadership in Energy and Environmental Design
LoRa	Long Range
Mech. Vent	Mechanical Ventilation
NbS	Nature-based Solutions

NGOs	Non-Governmental Organizations
NMBE	Normalized Mean Bias Error
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
NZEB	Nearly Zero-Energy Buildings
On-Cont.	On Continuous
Opt.	Optimum
PM	Particulate Matter
Pmax	Maximum power point
PV	Photovoltaic
PVT	Photovoltaic Thermal
RED	Renewable Energy Directive
RES	Renewable Energy Systems
Sc	Scenario
SDGs	Sustainable Development Goals
SCoP	Seasonal Coefficient of Performance
SECAP	Sustainable Energy and Climate Action Plan
SEER	Seasonal Energy Efficiency Ratio
SSEER	System Seasonal Efficiency Ratio
SPVs	Special Purpose Vehicles
SUMP	Sustainable Urban Mobility Plan
UNFCCC	United Nations Framework Convention on Climate Change
USGBC	U.S. Green Building Council
UTM	Urban Transitions Mission
VAT	Value-Added Tax
YEKA	Renewable Energy Resource Area
WORLDGBC	World Green Building Council

Executive Summary

The Build4GreenIST project aims to accelerate the transition towards green and carbon-neutral buildings in İstanbul by providing an integrated framework combining sustainable construction, renewable energy, green finance, legal alignment, participative governance, and advanced urban planning practices. This guide offers a strategic roadmap to empower stakeholders—including public institutions, private sector partners, and citizens—in driving the sustainable, climate-resilient, and resource-efficient evolution of İstanbul's urban environment.

İstanbul has been selected as the pilot city, where the urgency of addressing climate goals intersects with intense urban transformation. This project is motivated by the need to integrate local development strategies with the European Green Deal, Sustainable Development Goals (SDGs), and national climate targets. Given the city's aging building infrastructure, this effort addresses both a pressing challenge and a key opportunity for sustainable urban progress.

The guide incorporates multiple modules:

Figure 1. Image of transition to green and carbon-neutral building guide modules

- "Green Building" Module introduces key concepts such as green buildings, nearly zero-energy buildings (NZEB), zero-energy buildings, and carbon neutrality. It highlights environmental, social, and economic benefits, while outlining certification requirements tailored to Türkiye's context.

- "Renewable Technology" Module, presents current renewable energy perspectives in Türkiye and Europe, examines system types and challenges, and details smart monitoring systems and behavioural interventions to influence user behaviour. It also includes a city-wide assessment of renewable integration potential, especially in urban transformation areas like Çubuklu in Beykoz.
- "Green Finance" Module focuses on how to mobilize financial resources, engage stakeholders, and deliver effective green financing mechanisms. It explores innovative financial models to facilitate the transition to sustainable buildings.
- "Legal Environment" Module evaluates EU and Turkish legislation and identifies areas where Turkish laws can be enhanced. Recommendations are provided to bridge legal gaps and align with international green building standards.
- "Sustainable Urban and Land Use Planning" Module discusses the importance of green districts, nature-based solutions, and urban planning tools for long-term sustainability. Examples and recommendations for residential-scale implementation in İstanbul are included.
- "Participative Transition" Module emphasizes inclusive governance by promoting public participation in the green transformation process. It outlines steps to foster social engagement, address participation barriers, and ensure broad community involvement.

Finally, the modelling framework presents a detailed case study of Beykoz, specifically the Çubuklu neighborhood. It defines building transformation scenarios, performs energy and financial analyses, and provides evidence-based insights to guide urban redevelopment.

The Build4GreenIST project establishes a scalable and replicable framework for cities aiming to incorporate sustainable building practices into urban transformation initiatives. By providing a structured approach to energy-efficient retrofits and low-carbon development, the project serves as a key instrument for advancing climate change resilience and sustainable urbanization in Türkiye.

Figure 2. An image of Bosphorus

1. Section

Introduction

1. Introduction

1.1. Pilot City İstanbul

İstanbul is a megacity and the most populous city in Europe, with an official population of more than

15.8 million. The official population is expected to reach 18 million in 2030[1]. The city's environmental problems and climate change issues are addressed through a holistic planning and design approach, supported by systematic thinking and action.

İstanbul Metropolitan Municipality (IMM) is the first and only municipality from Türkiye to be a member of the C40 Cities Climate Leadership Group. İstanbul committed to being a "carbon neutral" and "resilient city" by 2050 with the signing of the Deadline 2020 Commitment.

In line with this goal, a new Climate Change Action Plan (İstanbul CAP) has been prepared for İstanbul, various projections and scenarios have been put forward, and priority actions to be taken to achieve the goal have been determined. With an ecosystem including the stakeholders of the city, actions that the city can take against climate change have been evaluated. The İstanbul CAP includes 15 reduction actions and 6 adaptation actions. The reduction actions were selected for 4 different sectors: building-stationary energy, transportation, waste, and water-wastewater.

The annual greenhouse gas emission inventory prepared on a city basis every year is calculated on a sectoral basis. An analysis of the emission inventory data across multiple years reveals that the buildings and stationary energy sector constitutes the most significant contributor to overall greenhouse gas emissions. This situation reveals that especially the energy sector has an important impact on the efforts to combat climate change and requirements to be studied in more detail.

As a signatory to the Global Covenant of Mayors for Climate & Energy, the IMM has benefited from technical assistance to align its energy and climate-related objectives with the Sustainable Development Goals (SDGs), with a focus on enhancing renewable energy adoption and mitigating greenhouse gas emissions.

This support was recognised in the report 'EU for the Energy Transition: Covenant of Mayors in the Western Balkans and Türkiye project and the İstanbul Sustainable Energy and Climate Action Plan (İstanbul SECAP) was prepared. The project lasted for 48 months between March 1, 2021 and February 28, 2025 and consisted of two phases: 'SECAP Preparation' and 'SECAP Monitoring.' This project, funded by the European Union and the German Federal Ministry for Economic Cooperation and Development, was implemented under the coordination of the Climate Change Directorate in collaboration with the Energy Management and Lighting Directorate, with contributions from the relevant units. İstanbul SECAP includes a total of 67 actions, 45 reduction and 22 adaptation, excluding İstanbul CAP.

In May 2021, IMM signed a protocol with EBRD under the Green Cities Framework Programme and started the process of preparing a Green City Action Plan (GCAP). In May 2023, the preparation of this plan started, and the plan includes 52 investment and policy actions to strengthen the city environmentally. The GCAP targets improvements in areas such as water, energy, waste infrastructure, transport, buildings, and green spaces. İstanbul's GCAP is noteworthy for its spatial mapping and the first time topics such as cultural heritage, urban agriculture, food, and disaster logistics. The plan is based on a new methodology and includes elements such as social benefits, smart practices, and job creation. The GCAP, approved by the IMM Council, was finished in 2025.

Figure 3. Action plans of İstanbul Metropolitan Municipality Related with climate and sustainable (CAP, SECAP and GCAP)

In addition to the action plans, İstanbul has become a member of various missions and networks at the international level to become climate neutral and resilient. These missions serve to bolster the city's commitments to environmental sustainability, climate change mitigation, fostering international collaboration, and securing essential resources.

In 2022, İstanbul was selected as one of the leading 100+12 cities committed to becoming a climate neutral and smart city by 2030 within the scope of the European Union NetZeroCities "Climate Neutral and Smart Cities Mission". The aim of the mission is to select pioneering cities that will accelerate their efforts to become climate-neutral cities by 2030 and support their efforts.

Within the framework of the mission, efforts have been focused on accelerating the current 2050 goal for İstanbul to become a climate-neutral city by 2030 and accelerating the related actions. As a requirement for inclusion in the mission, initiatives were undertaken to develop a Climate City Contract (CCC), which serves as a strategic framework to guide the city toward achieving climate neutrality by the 2030 goal.

The Climate City Contract is a comprehensive document including Commitments, Action Plan and Investment Plan. The commitment document is a document that presents the good faith support of the city stakeholders towards this goal as a signed text with an inclusive approach. The Action Plan includes the presentation of the actions that our city should take with the 2030 goal within the framework of the plan, and the Investment Plan includes the planning of the investments and resources required by these actions. The İstanbul Climate City Contract (CCC) has been prepared in accordance with the format of the EU Mission and specific to İstanbul. As a result of the evaluation of the documents by the European Commission, İstanbul received the 'EU Mission Label' award.

Figure 4. EU mission label of İstanbul

Build4GreenIST is a project carried out with the successful outcome of our application to the Call for Pilot Cities opened under the European Union NetZeroCities "Climate Neutral and Smart Cities Mission". By engaging in the European Union's Climate Change Adaptation Mission, İstanbul seeks to strengthen its resilience to the impacts of climate change. This mission aims to help cities adapt to current and projected climate impacts. İstanbul participated in the inaugural meeting in Brussels in January 2023 and took part in the "Forum Mission on Adaptation to Climate Change" in Sweden in June 2023. As part of the Mission, İstanbul has benefited from technical assistance under the thematic priority "Support to Climate Adaptation Pathways", receiving expert recommendations to strengthen its climate change action plans. Adaptation mission studies are ongoing.

İstanbul is also involved in the Urban Transitions Mission. Launched at COP26 in November 2021, the Urban Transitions Mission (UTM) is a global initiative that aims to support cities to achieve net zero emission targets. The mission aims to increase the capacity and knowledge of cities, enabling them to mobilise their potential and develop customised solutions. The Urban Transitions Mission aims to make cities resilient to climate change impacts, net zero emission, and people-centred through multi- sectoral and multi-level partnerships. UTM aims to increase cities' access to clean energy at affordable prices and facilitate this transition through innovative technologies and financial instruments. As part of this mission, İstanbul participates in trainings on topics such as renewable energy, carbon capture, buildings, and transport.

1.2. Build4GreenIST - Project Motivation

Build4GreenIST (Green and Carbon Neutral Building Transition Guide - İstanbul Model) Project was entitled to receive financial and technical support scope of the Pilot Cities programme within the framework of the EU NetZeroCities Climate Neutral and Smart Cities Mission.

It was prepared under the coordination of İstanbul Metropolitan Municipality Environmental Protection and Development Department Climate Change Directorate in order to accelerate İstanbul's efforts to become a carbon-neutral city. The project was carried out together with project partners ÇEDBİK (Turkish Green Buildings Council), Demir Enerji, and Florawise (Smarte), and the project lasted for 2 years.

The project aligns with Sustainable Development Goals (SDGs) by integrating sustainability into construction and urban planning, driving systemic change towards greener, more sustainable practices.

Contributions of Guide to the SDG's	Sustainable Development Goals
Build4GreenIST promotes energy-efficient construction and renewable energy solutions, helping reduce energy consumption and carbon emissions in the built environment.	7 AFFORDABLE AND CLEAN ENERGY
The project encourages innovation in green building technologies, promoting sustainable infrastructure and the adoption of eco-friendly materials, which contribute to a more sustainable industry.	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
By focusing on sustainable urban development, Build4GreenIST aims to create cities and communities that are resilient, inclusive, and energy-efficient, improving the quality of life for urban populations.	11 SUSTAINABLE CITIES AND COMMUNITIES
The project supports responsible resource use by promoting circular economy principles, reducing waste, and enhancing the reuse and recycling of materials in construction processes.	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Build4GreenIST directly contributes to climate action by reducing the environmental impact of construction activities, enhancing energy efficiency, and promoting sustainable practices to mitigate climate change.	13 CLIMATE ACTION

Table 1. Sustainable development goals associated with the guide

iMM Climate Change Directorate calculates and publishes a yearly city-wide greenhouse gas emission inventory. The main motivation that is the focus of our Pilot City project is the fact that the highest contribution to greenhouse gas emissions in the city is stationary energy with 64% and the necessity to reduce energy use in buildings.

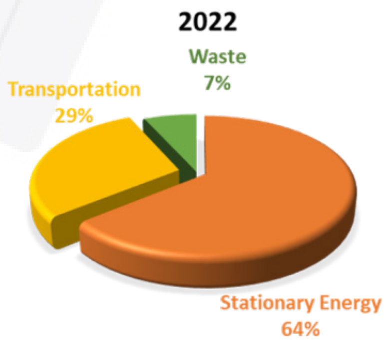


Figure 5. Sectoral distribution of İstanbul GHG emission inventory (2022)

The two most fundamental problems that require resilience in our city were taken into consideration in this project: earthquake and climate change. The high earthquake risk and old building stock necessitate the rapid renovation of buildings.

İstanbul Metropolitan Municipality carries out research and development activities on communication, promotion, organisation activities, urban transformation implementation models, financing models, legal roadmaps, etc. in order to develop Urban Transformation Plans.

IMM Urban Transformation Directorate, in co-operation with its subsidiary companies KİPTAŞ, İPA Inc (then- as BİMTAŞ) and İmar Inc., has accelerated its collective work on the renewal of buildings constructed before the 1999 Marmara Earthquake. The ‘İstanbul Renewal Platform’, which was established for this purpose, receives applications from citizens with old and risky buildings and ensures their renewal through reconciliation in a safe and financially planned manner.

The İstanbul Urban Analysis Report prepared in 2020 reveals that there are 1.13 million houses in İstanbul and 67.8% of the buildings in İstanbul were built before 2000[2]. According to the İstanbul Earthquake Workshop Report (published at the end of 2019), it is estimated that 194,000 buildings could be moderately and very severely damaged and 48,000 buildings could be severely and very severely damaged in a 7.5 magnitude earthquake[3]. This means that approximately 20 percent of the existing buildings in the city need urgent renovation due to earthquake risk. This is an opportunity for a city in the process of reconstruction to turn to green and carbon-neutral options and new technologies.

While the efforts to make the city earthquake-resilient are being carried out, at the same time, it is set out with the aim of creating a resource for the reconstruction of the city with buildings that are resistant to climate change and support efficient energy use. In addition to all these, renovation of old buildings in the city is being carried out in order to improve the quality of life. There is a significant potential for the implementation of the Guide for Transition to Green and Carbon Neutral Buildings in the future urban transformation of the city.

Build4GreenIST is a significant initiative dedicated to promoting the development of environmentally sustainable, energy-efficient buildings in İstanbul, with the overarching goal of advancing the city toward a climate-neutral future. Reducing the growing carbon footprint of cities and creating sustainable living spaces is one of the biggest environmental and economic challenges of today.

The Guide to be drawn up with the project covers a wide range of activities, starting from the works that can be carried out for the green construction of the city to the trainings aimed at raising awareness of all stakeholders in the sector. The primary objective of the project is to enhance incentives and research for the green and carbon-neutral transformation of buildings through targeted initiatives and guidelines. Additionally, it aims to strengthen collaborative efforts in this field and lay the groundwork for an environmentally responsible urban infrastructure.

The motivations of the Build4GreenIST project include environmental sustainability, energy efficiency, economic gains and social awareness. In line with İstanbul's goal of becoming climate neutral, the main objective of the project is to reduce carbon emissions and build a nature-friendly city. Energy efficiency is achieved by reducing the amount of energy consumed in buildings and increasing the use of renewable energy sources. In addition, the energy savings and low operating costs provided by green buildings in the long term also contribute to the economy.

The project encourages social awareness on the impact of renewable energy technologies on climate change efforts, as well as the growth of the green building market and increased investments in this field. The project, in which training and communication activities are carried out with an inclusive approach, is aimed to form the basis for future implementation studies. Build4GreenIST will be an important guide that will support İstanbul to become a greener, more livable and sustainable city and to reach its goal of becoming climate neutral.

1.3. Build4GreenIST Studies Supporting the Guide

The project was coordinated by İstanbul Metropolitan Municipality together with all project partners (ÇEDBİK,) Demir Energy and Florawise (Smarte). IMM and all partners professionally executed the relevant project actions according to their areas of expertise and competence.

Within the scope of the project, a stakeholder analysis was conducted to prioritise the key stakeholders of the city. As indicated in Figure 6, the journey of building a green and carbon neutral city requires a multi-layered approach.

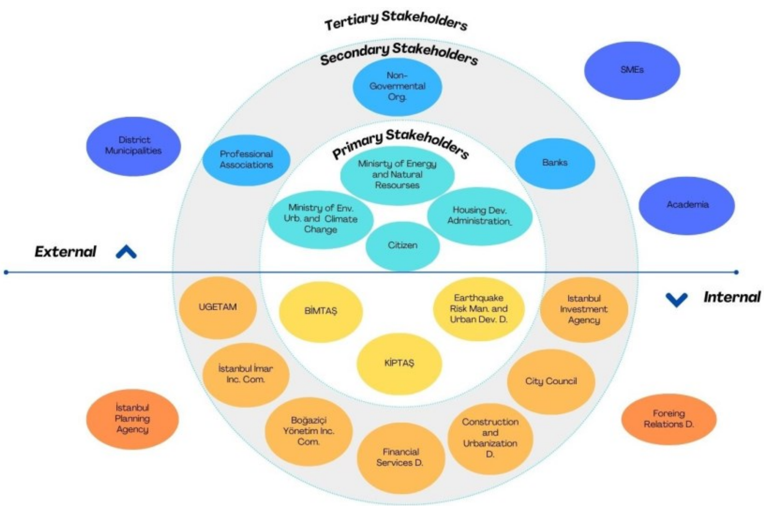


Figure 6: Stakeholder mapping of the project

With the organised Launch Event, our project was successfully introduced to the key and important stakeholders of the city. During the event, the aims, objectives and contributions of the project were explained in detail and stakeholders were informed about the project and involved in the process. Thus, it was aimed to reach a wide audience and promote the project effectively.

Figure 7. Build4GreenIST launch event

In cooperation with IMM and ÇEDBİK, Bahçelievler, Üsküdar Aziz Mahmut Hüdayi, Ümraniye Atatürk, Sultangazi İsmetpaşa, Sultangazi Sultançiftliği, Kağıthane Hamidiye and Kağıthane Seyrantepe Institute İstanbul İSMEK Trainees were provided with trainings on 'Green Buildings, Cities and Energy Efficiency' and a total of 255 citizens were reached. This training series aimed to raise awareness of citizens on green buildings, energy efficiency and sustainable cities. Participants were informed about saving energy in their daily lives, adopting environmentally friendly habits and using resources more efficiently. The awareness raised by the training will make it easier for individuals to support green transformation in their own living spaces and for this transformation to become a social movement.

Figure 8. ‘Green Buildings, Cities and Energy Efficiency’ training in institute İstanbul İSMEK

A total of 165 participants were trained on the themes of ‘Green Building and Renewable Energy’, ‘Green Cities and Participatory Transition’ and ‘Green Finance’ with the participation of practitioners from NGOs, district municipalities and relevant departments of İstanbul Metropolitan Municipality. The trainings demonstrated how cities can achieve sustainable, energy-efficient, and environmentally friendly transformation by leveraging academic literature and proven best practices, thereby supporting their transition toward green and carbon-neutral development. Beyond the training programs, capacity-building workshops were conducted, bringing together key stakeholders and reaching out a total of 68 participants.

Figure 9. Practitioner trainings

At the Mid-Term Conference, many stakeholders influential in the city's climate change and urban transformation efforts came together, panels were organised with the participation of experts and local government representatives, and 126 participants were reached.

Figure 10. Project team on mid-term conference

İstanbul Metropolitan Municipality is the founder of the Balkan Cities Network (B40) and undertakes its permanent secretariat. IMM attaches importance to being in close relations with B40 cities in different working groups, including the topic of Cooperation on Climate Action. Technical visits were organised to Zagreb in Croatia, Sarajevo in Bosnia and Herzegovina, İzmir and Muğla Metropolitan Municipalities in Türkiye, which are members of Balkan Cities Network (B40). Information was exchanged on the approaches and activities of the municipalities on climate and environment issues, and information was provided on the application stage of the pilot city project, processes, possible impacts on the city, risks and barriers planned to be encountered. Evaluations were made on the applicability of similar projects in cities and possible green and carbon neutral transformation.

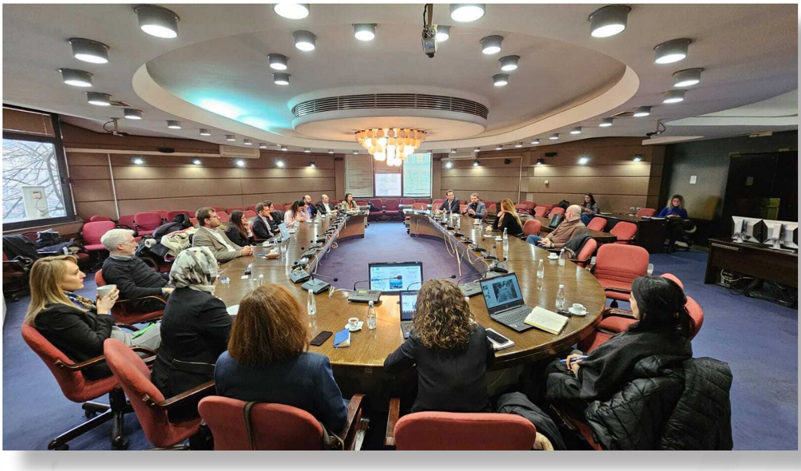


Figure 11. Visit to sarajevo as one of B40 cities

In order to pioneer European cities and share our project with more cities, we joined the Twinning Learning Programme and matched with the city of Mytilene in Greece. Within the scope of the programme, mutual technical visits and experience/information sharing were made with the municipal representative of the Municipality of Mytilene. Thus, evaluations were made on similar and different problems/solutions of the cities.

Figure 12. Visit of mytiline municipality represent to istanbul within the pilot cities twinning programme

All requisite tasks for the development of the guidebook have been diligently completed, ensuring thorough planning and precise coordination at every stage of the project. In order for the project to achieve its objectives, a total of approximately 100 meetings were organised with project partners and other relevant stakeholders, both online and offline, during which in-depth discussions were held on each detail. Consequently, the guide's content was meticulously crafted to align with the project's overarching objectives.

Figure 13. Routine internal meetings with project partners

Interviews and exchanges of experiences throughout all these studies played an important role in shaping the content of the guide. Throughout the project, feedback from stakeholders and different perspectives enriched the scope of the guide, enabling us to produce a more effective and comprehensive result. In addition, our work has been finalised by adopting an all-inclusive approach that takes into account the views of all stakeholders.


GREEN BUILDING CONCEPT

2. Section

Green Building Module

2.1. Concepts

2.1.1. The Concept of Green Buildings

The concept of ecological architecture emerged in the 1960s and gained significant momentum in the 1970s due to the energy crisis. During this period, interest in renewable energy sources such as solar, wind, and geothermal increased, and the development of more efficient building designs was encouraged. In the 1980s, the concept of "sustainable development" became more widely accepted, and developed countries began to implement building systems that promoted energy conservation on a large scale. In 1990, the United Kingdom introduced the world's first green building standard, and in 1993, the U.S. Green Building Council (USGBC) was established.

To provide a framework and verification for green building practices, the USGBC developed the Leadership in Energy and Environmental Design (LEED) green building rating system in the late 1990s. Although initially developed in the United States, its robust structure and comprehensive scope quickly made it an international benchmark.

Since the 1990s, numerous countries and organizations have established their own green building programs and standards. While the systems used may vary, the concept of green buildings has remained globally significant, becoming a fundamental principle in the construction sector. Additionally, it has been a central focus of both academic and industrial research, playing a critical role in the development of solutions to global energy challenges.

Definitions of Green Buildings by Different Organizations:

- **U.S. Green Building Council (USGBC):** While there are various definitions of green buildings, they are generally understood as structures designed, constructed, and operated with considerations for energy efficiency, water usage, indoor environmental quality, materials selection, and the impact on the surrounding site [4].

- **U.S. Environmental Protection Agency (EPA):** A green building is a sustainably designed and operated structure that prioritizes environmental responsibility and resource efficiency across its entire lifecycle—encompassing site selection, design, construction, operation, maintenance, renovation, and eventual demolition. This practice extends and complements traditional building design concerns such as economy, utility, durability, and comfort. Green buildings are also referred to as sustainable or high- performance buildings[5].

- **National Green Certificate System (YeS-TR):** A green building is defined as one that is in harmony with nature; evaluated within the framework of its entire life cycle, from site selection to demolition; suited to climate data and local conditions; consuming only as much energy and water as needed; utilizing renewable energy sources; and designed with a holistic approach[6].

- **Green Building Council of Australia:** A green building incorporates the principles of sustainable development to meet present requirements without compromising the ability of future generations to meet their own[7].

2.1.2. The Concept of Nearly Zero-Energy Buildings (NZEB)

Definition of Nearly Zero-Energy Buildings (NZEB)

According to Article 2 of the Energy Performance of Buildings Directive (EPBD), published in the Official Journal of the European Union on August 2, 2016, a Nearly Zero-Energy Building (NZEB) is defined as a building with a very high energy performance that meets the criteria outlined in Annex I. Within this framework, the energy required by the building is expected to be nearly zero or at very low levels. Moreover, a substantial proportion of this energy requirement shall be supplied from renewable energy sources, with priority given to production occurring on-site or within the immediate geographical proximity of the building.

The first part of the definition emphasizes that energy performance is the fundamental determinant of the NZEB concept. This performance level must comply with the criteria set in Annex I of the EPBD. The latter component of the definition emphasizes the methodological framework for attaining such high energy performance, stipulating that the building's energy supply must be predominantly derived from renewable sources to the greatest feasible extent.

The NZEB concept highlights the necessity of integrating renewable energy use with energy efficiency measures. When renewable energy systems are directly incorporated into the building, the net energy demand of the structure is significantly reduced. However, in most cases, on-site renewable energy generation alone is insufficient to approach zero energy demand without additional energy efficiency measures or significant reductions in primary energy factors for off-site renewable energy sources.

Consequently, enhanced performance criteria are being implemented for high-efficiency Nearly Zero-Energy Buildings (NZEBs), with the explicit objective of optimizing on-site renewable energy utilization. Simultaneously, it is emphasized that the primary energy factors for energy carriers should be adapted to enable the use of renewable energy sources beyond the building itself[8].

2.1.3. The Concept of Zero-Energy Buildings

The European Commission envisions that all newly constructed buildings must be zero-emission by 2030. To accelerate the transformation of the public sector, new public buildings will be required to comply with this standard starting in 2027.

In alignment with these requirements, zero-emission buildings must:

- Have minimal energy consumption,
- Meet their energy requirements predominantly from renewable sources,
- Emit no direct carbon emissions from fossil fuels,
- Include global warming potential over their entire lifecycle in Energy Performance Certificates.

Definitions of Zero-Energy Buildings by Different Organizations:

- **European Commission:** A zero-emission building is defined as a structure with very high energy performance, where the still-required minimal amount of energy is entirely supplied by renewable sources, and no on-site carbon emissions from fossil fuels occur[9].

- **Massachusetts Department of Energy Resources:** A Zero Net Energy Building (ZNEB) represents a structure designed to achieve optimal energy efficiency, wherein the total annual energy output from on-site renewable sources equals or exceeds the building's total energy consumption[10].

- **World Green Building Council (WorldGBC):** A building can be classified as net zero energy if 100% of its energy demand is met by on-site renewable energy sources[11].

2.1.4. The Concept of Carbon Neutrality

Carbon neutrality is a concept aimed at halting the increase in atmospheric carbon dioxide (CO_2) and mitigating the effects of global warming. Achieving this goal requires minimizing carbon emissions and offsetting the remaining emissions to achieve net-zero CO_2 output.

As of February 2021, 124 countries have pledged to achieve carbon neutrality by 2050 or 2060. This development is regarded as a tangible outcome of the ongoing international efforts to combat climate change within the framework of United Nations Climate Conferences, including the Kyoto Protocol (1997), the Bonn Agreements (2001), the Bali Road Map (2007), and the Paris Agreement (2015). Notably, the increasing commitment of countries to set legally binding and specific emission reduction targets is seen as a significant advancement in international climate policies[12]. In this context, as of September 2021, Türkiye has also committed to achieving carbon neutrality by 2053 in line with the Paris Agreement, reflecting the country's growing responsibility in the global effort to combat climate change.

The European Union (EU) aims to become the first continent to achieve carbon neutrality by 2050. This goal is part of the EU Green Deal and was legally established through the Climate Law adopted by the European Parliament and Council in 2021.

In the short term, the EU has set a goal to increase its emissions reduction goal from 40% to at least 55% by 2030. To achieve this, the EU is revising its existing climate regulations and introducing new measures under the "Fit for 55" legislative package. The Fit for 55 package includes regulations on emissions trading, national emission reduction targets, carbon removals in the land-use sector, and transportation-related emission policies, aiming to accelerate Europe's transition to carbon neutrality[13].

Definitions of Carbon Neutrality in Buildings by Different Organizations:

- **New York State Energy Research and Development Authority:** A carbon-neutral building is one whose design, construction, and operation do not contribute to climate change through greenhouse gas emissions. Reducing harmful greenhouse gas emissions from the building sector significantly supports the state's climate goals.
- **World Green Building Council:** There are various terms used to describe buildings on the path to net-zero emissions. As the WorldGBC advocates for complete decarbonization of the built environment, it calls on the sector to adopt a whole-life carbon approach, addressing emissions from both operational energy use and embodied carbon from building materials, construction, and renovation processes[14].

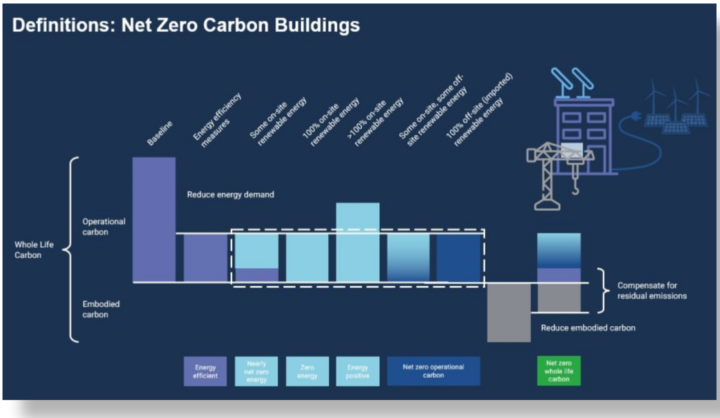


Figure 14. Diagram defining net zero carbon buildings[15].

The diagram above illustrates how a building's carbon emissions throughout its life cycle can be reduced to achieve net zero carbon. The process begins with reducing operational carbon through energy efficiency measures. Subsequently, the building's energy demand is met by on-site renewable energy sources, followed by off-site renewable energy options. Once operational carbon is minimized, efforts shift to reducing embodied carbon—emissions associated with construction and materials. In the final stage, any remaining emissions are offset through compensation mechanisms, ultimately achieving net zero carbon. This holistic approach encompasses both net zero operational carbon and net zero whole life carbon targets[16].

2.2. Benefits of Green Buildings from Environmental, Social, and Economic Perspectives

According to the latest report published by the Intergovernmental Panel on Climate Change (IPCC), achieving global carbon reduction targets requires a rapid and comprehensive transformation in land use, energy, buildings, transportation, and urban planning. Buildings, in particular, account for approximately 40% of global energy-related carbon emissions, making sustainable transformation in this sector crucial for combating climate change.

Green buildings offer a significant solution on a global scale for cities, neighborhoods, and communities. However, the environmental and economic benefits they provide are not always directly perceived by individuals. Through sustainable design, construction, and operational processes, green buildings reduce carbon emissions, optimize energy and water consumption, minimize waste, and lower exposure to toxins that threaten human health. These impacts have contributed to the rapid global growth of the green building sector. The 2018 World Green Building Trends SmartMarket Report indicates that a significant proportion of construction industry professionals expect the majority of their upcoming projects to adhere to green building standards. This transformation supports sustainable development, reduces environmental impacts, and simultaneously creates new opportunities that promote human health and economic growth.

Green buildings are also considered a promising long-term investment. While initial costs may be higher, new green building projects and sustainability upgrades to existing buildings have been demonstrated to generate savings in operating costs over time. Research indicates that green buildings have approximately 20% lower maintenance costs than conventional buildings and can reduce operating expenses by around 10% within just one year[17]. Additionally, initial investments in green buildings increase property values, providing long-term financial benefits. For example, a study conducted in the Austin-Round Rock Metropolitan Statistical Area found that between 2008 and 2016, the value of homes with LEED certification increased by 8%, while the value of homes meeting broader green standards increased by 6%[18].

Beyond its environmental and economic benefits, the green building sector holds substantial promise for driving large-scale job creation. Green construction has provided millions of jobs to date and has contributed hundreds of billions of dollars to economies. Between 2011 and 2014, the U.S. national green construction sector generated $167.4 billion in gross domestic product (GDP). During the same period, more than 720,000 jobs in Texas alone were linked to the green construction sector, and as of 2014, employment related to LEED certification contributed $1.09 billion in individual income tax revenue to state governments[19].

Green buildings also have significant positive effects on human health and well-being. A public opinion survey conducted by the USGBC found that one-third of participants reported experiencing health issues related to poor living and working conditions. Since people spend approximately 90% of their time indoors, green buildings that improve indoor air quality, reduce exposure to toxins, and enhance overall living comfort positively impact individual health. Improved indoor air quality has been shown to reduce health issues such as asthma, respiratory allergies, depression, and stress, thereby increasing workforce productivity. Research suggests that individuals who live or work in green buildings feel healthier, happier, and more productive, highlighting the importance of this transition.

From an environmental sustainability standpoint, green buildings play a pivotal role in enhancing energy efficiency, promoting water conservation, and reducing waste generation. The Intergovernmental Panel on Climate Change (IPCC) emphasizes the importance of reducing energy demand in the building sector, increasing electrification, and promoting the use of high-efficiency equipment[20]. Data from the U.S. Energy Information Administration (EIA) indicates that heating and cooling systems are responsible for roughly 52% of residential energy use, playing a significant role in greenhouse gas emissions[21]. Green buildings help mitigate these emissions by enhancing energy efficiency and promoting the use of renewable energy sources. Additionally, while the average person in the United States uses approximately 80–100 gallons (300–380 liters) of water per day[22], buildings are responsible for about 12% of the country's total water consumption[23]. Green buildings contribute to reducing this demand through strategies such as rainwater harvesting, greywater reuse, and water-efficient plumbing systems, supporting both environmental sustainability and urban water resilience[24].

Green Buildings Directly Contribute to the Following Sustainable Development Goals:

- **Good Health and Well-Being (Goal 3):** Supports public health by creating healthy and comfortable living environments.
- **Clean Water and Sanitation (Goal 6):** Enhances water efficiency, promotes the conservation of water resources, and improves access to safe water.
- **Affordable and Clean Energy (Goal 7):** Expands the use of renewable energy, increases energy efficiency, and reduces carbon emissions.
- **Decent Work and Economic Growth (Goal 8):** Generates employment through the green construction sector and promotes sustainable economic growth.
- **Industry, Innovation, and Infrastructure (Goal 9):** Develops sustainable and resilient infrastructure that supports the transition to a low-carbon economy.
- **Reduced Inequalities (Goal 10):** Contributes to a fair and equal standard of living for all by reducing energy poverty.
- **Sustainable Cities and Communities (Goal 11):** Supports the development of more resilient, inclusive, and environmentally friendly cities.
- **Responsible Consumption and Production (Goal 12):** Adopts circular economy principles to improve resource efficiency and reduce waste.
- **Climate Action (Goal 13):** Helps combating thgen global climate change by reducing greenhouse gas emissions.
- **Life on Land (Goal 15):** Promotes the conservation of natural ecosystems, enhances biodiversity, and ensures the sustainable management of water resources.

- **Partnerships for the Goals (Goal 17):** Supports the development of strong global partnerships for sustainable construction and urbanization.

For many, buildings may be seen as mere physical structures. However, sustainable built environments offer opportunities not only for energy and water conservation but also for supporting human health, revitalizing the economy, enhancing educational opportunities, and improving social life. The green building sector is acting as a real catalyst in addressing some of the world's most pressing issues. In the coming years, the large-scale integration of sustainable built environments will not only mitigate adverse environmental effects but also stimulate economic development and enhance societal well-being by fostering a transformative paradigm shift.

2.3. Green Building Certification Systems

Green building certification systems are assessment tools that aim to reduce the environmental impact of buildings, increase efficiency in the use of energy and resources, and protect occupant health. These systems rate buildings according to their environmentally friendly performance levels by scoring them according to specific sustainability criteria. Certificates encourage and document environmental decisions made throughout the entire life cycle, from design to construction, from operation to demolition.

Adapted to diverse geographical, climatic, and social contexts, these systems provide a comprehensive evaluation across multiple domains, including energy consumption, water management, waste reduction, indoor environmental quality, material selection, and transportation efficiency. In addition to international examples such as LEED (USA), BREEAM (UK), DGNB (Germany), countries also develop national certification systems according to their local requirements.

In Türkiye, the main systems developed in this field include YeS-TR (Green Certificate Türkiye) developed by the Ministry of Environment, Urbanization and Climate Change and BEST (Ecological and Sustainable Design in Buildings) developed by the Turkish Green Building Council (ÇEDBİK).

YeS-TR (Green Certificate Türkiye) is the first nationally applicable green building certification system developed by the Republic of Türkiye's Ministry of Environment, Urbanization and Climate Change. Designed to evaluate the environmental, economic, and social sustainability performance of buildings and settlements, the system adopts a holistic, life-cycle-based approach tailored to local conditions. Covering all stages from site selection to design, construction, operation, and demolition, YeS-TR aims to promote the efficient use of natural resources, reduce environmental impact, and prioritize user health and well-being.

The system provides performance-based criteria across core areas such as energy efficiency, water management, material selection, and indoor environmental quality, while encouraging innovative solutions. Evaluations are carried out through six main modules, covering integrated design, interior comfort, energy performance, water and waste management, sustainable materials, and innovation. Based on the total score obtained, projects are certified under one of four levels: Pass, Good, Very Good, and National Excellence.

Beyond improving environmental performance, YeS-TR promotes a building culture that respects local identity, supports social welfare, and prioritizes economically sustainable solutions. Applicable to a wide range of building types — from residential to public buildings, and from educational facilities to healthcare centers — the system also aligns with international certification frameworks, contributing to Türkiye's global sustainability goals. YeS-TR represents a significant step toward making sustainable construction a national standard.

Green building certification systems establish minimum requirements and prerequisites to ensure that buildings are designed, constructed, and maintained in line with sustainability principles. These requirements serve as a guideline for identifying projects eligible for certification and provide standards that promote sustainable building design.

In this context, LEED BD+C, LEED ND, LEED Cities and Communities, BREEAM New Constructions, BREEAM Communities, DGNB New Constructions, DGNB Districts, YeS-TR Buildings, YeS-TR Settlements, and B.E.S.T New Residential Certification Systems have been examined. The analysis of these certification programs has led to the following key findings regarding their fundamental requirements.

2.3.1. Minimum Requirements

Meeting specific fundamental criteria is essential for buildings seeking green building certification. For example, under LEED BD+C, projects must be permanently located on an existing site to be eligible for assessment. While temporary buildings are not eligible for LEED certification, prefabricated or modular buildings can qualify if they are permanently placed.

Additionally, LEED project boundaries must be defined according to certification process regulations. The project boundary cannot exclude certain areas to gain credit advantages. All spaces included in the certification process must be directly related to the project and support its operations.

Projects seeking LEED certification must also meet minimum area requirements:

- LEED BD+C and EB:O&M: Minimum area of 93 m^2 (1,000 ft^2)
- LEED ID+C: Minimum area of 23 m^2 (250 ft^2)

Apart from LEED BD+C, B.E.S.T Residential Green Building Guide mandates that projects must obtain an occupancy permit before certification. Furthermore, all building and district-scale certification systems require projects to comply with national laws, standards, and regulations as a fundamental prerequisite.

As of 2025, the number of buildings certified with a green building label in Türkiye has exceeded 700. This growth underscores the expanding recognition of eco-conscious and sustainable construction practices across the country, highlighting a critical transformation within the sector. The growing imperative to mitigate carbon emissions, enhance energy efficiency, and foster healthier living and working spaces has amplified engagement with sustainable development objectives among both public and private stakeholders. This has driven the deliberate incorporation of green building principles into urban regeneration initiatives.

However, despite these positive developments, Türkiye still lags behind many countries in Europe and North America in terms of green buildings per capita. Countries such as Germany, the Netherlands, and Canada have successfully expanded green building practices across various building types and scales, thanks to more mature regulatory frameworks and comprehensive incentive mechanisms.

To accelerate its progress in this field, Türkiye must implement broader and more accessible national incentive mechanisms that cover not only new constructions but also existing buildings.

2.3.2. Prerequisites and Credits

An analysis of green building certification systems—including LEED BD+C, BREEAM New Constructions, BREEAM Communities, DGNB New Constructions, YeS-TR Buildings, and B.E.S.T. New Residential Certification Systems—reveals that these programs establish prerequisites in the following categories:

- **Integrated Design Approach:** Sustainable buildings must be considered within a holistic process rather than as isolated structures. From the beginning of the project, all stakeholders should be involved, high-performance design should be prioritized, and the project must follow an integrated management approach.
- **Water Efficiency:** The Water Consumption Monitoring and Reduction prerequisite ensures efficient water use. Given the global decline in freshwater resources and deteriorating water quality, buildings are expected to monitor their water usage and implement sustainable water management strategies.
- **Energy Efficiency:** The Energy Measurement and Building Performance Improvement prerequisite requires buildings to minimize energy demand and consider renewable energy solutions. This applies to both new buildings and retrofit projects, emphasizing energy efficiency improvements.
- **Materials and Resource Use:** The Responsible Sourcing of Construction Products prerequisite mandates that building materials be selected with consideration for environmental, economic, and social impacts. Notably, BREEAM and DGNB require that wood and wood-based materials used in certified buildings come from sustainable sources.
- **Waste Management:** The Construction and Demolition Waste Management Planning prerequisite aims to increase material recovery during construction, reducing landfill waste and minimizing environmental impacts.

As a key driver of sustainable practices, green building certification systems define measurable criteria that improve ecological balance, cost-effectiveness, and societal well-being, significantly influencing sustainable urban transformation.

SLL Smart Location and Linkage		NPD Neighbourhood Pattern and Design		GIB Green Infrastructure and Buildings	
Prerequisite/ Credit	Concept	Prerequisite/ Credit	Concept	Prerequisite/ Credit	Concept
SLL P1	Smart Location	NPD P1	Walkable Streets	GIB P1	Certified Green Building
SLL P2	Imperilled Species and Ecological Community Conservation	NPD P2	Compact Development	GIB P2	Minimum Building Energy Performance
SLL P3	Wetland and Water Body Conservation	NPD P3	Connected and Open Community	GIB P3	Indoor Water Use Reduction
SLL P4	Agricultural Land Conservation	NPD C1	Walkable Streets	GIB P4	Construction Activity Pollution Prevention
SLL P5	Floodplain Avoidance	NPD C2	Compact Development	GIB C1	Certified Green Buildings
SLL C1	Preferred Locations	NPD C3	Mixed-Use Neighbourhoods	GIB C2	Optimize Building Energy Performance
SLL C2	Brownfield Remediation	NPD C4	Housing Types and Affordability	GIB C3	Indoor Water Use Reduction
SLL C3	Access to Quality Transit	NPD C5	Reduced Parking Footprint	GIB C4	Outdoor Water Use Reduction
SLL C4	Bicycle Facilities	NPD C6	Connected and Open Community	GIB C5	Building Reuse
SLL C5	Housing and Jobs Proximity	NPD C7	Transit Facilities	GIB C6	Historic Resource Preservation and Adaptive Reuse
SLL C6	Steep Slope Protection	NPD C8	Transportation Demand Management	GIB C7	Minimized Site Disturbance
SLL C7	Site Design for Habitat or Wetland and Water Body Conservation	NPD C9	Access to Civic and Public Space	GIB C8	Rainwater Management
SLL C8	Restoration of Habitat or Wetlands and Water Bodies	NPD C10	Access to Recreation Facilities	GIB C9	Heat Island Reduction
SLL C9	Long-Term Conservation Management of Habitat or Wetlands and Water Bodies	NPD C11	Visitability and Universal Design	GIB C10	Solar Orientation
		NPD C12	Community Outreach and Involvement	GIB C11	Renewable Energy Production
		NPD C13	Local Food Production	GIB C12	District Heating and Cooling
		NPD C14	Tree-Lined and Shaded Streetscapes	GIB C13	Infrastructure Energy Efficiency
		NPD C15	Neighbourhood Schools	GIB C14	Wastewater Management

Table 2. Sample checklist presents a summarized classification of prerequisites and credits. Additionally, the table facilitates the analysis of current planning or implementation processes in terms of their sustainability performance[25].

2.3.3. Green Certified Buildings in Türkiye

The approach to sustainable construction prioritizes design and implementation practices that reduce environmental impact, increase energy and water efficiency, and improve user comfort. In this context, green building certification systems (such as LEED and EDGE) enable independent evaluation of the environmental performance of buildings. In recent years, the number of certified projects has increased in Türkiye, particularly in large-scale and public buildings, where sustainable design principles are becoming more widely adopted. The following section examines two significant examples of certified green buildings in Türkiye: Ziraat Bank Tower 1 and Kartal Dr. Lütfi Kırdar City Hospital.

Figure 15: Ziraat Bank Tower 1[26].

Ziraat Bank Tower 1

Located in Ümraniye, İstanbul, Ziraat Bank Tower 1 stands out as a significant green building that has achieved LEED Platinum certification. The project was assessed under the LEED 2009 BD+C New Construction category, receiving 81 points and covering a total area of 65,032 m². The certification was granted on October 20, 2023.

The building demonstrates substantial improvements in both energy and material efficiency in line with sustainability principles. Overall building performance has improved by 32%, with 35% of the energy supplied from green sources. Moreover, 20% of construction materials consist of recycled content, and another 20% are regionally extracted, harvested, recovered, or manufactured. Additionally, 50% of the wood products used are FSC-certified.

The project also features effective waste management and water efficiency strategies. During construction, 75% of construction and demolition waste was diverted from landfills. Indoor water consumption was reduced by 40%, and wastewater generation was reduced by 50%. Potable water use in landscaping was completely eliminated.

Furthermore, 75% of regularly occupied areas benefit from daylight, and 90% of those areas offer access to quality views, enhancing user comfort and well-being.

With its alignment with LEED standards, energy efficiency, sustainable material use, and user-centered design, Ziraat Bank Tower 1 serves as a leading example of green building practice in Türkiye[27].

Figure 16. Kartal Dr. Lütfi Kırdar City Hospital[28].

Kartal Dr. Lütfi Kırdar City Hospital

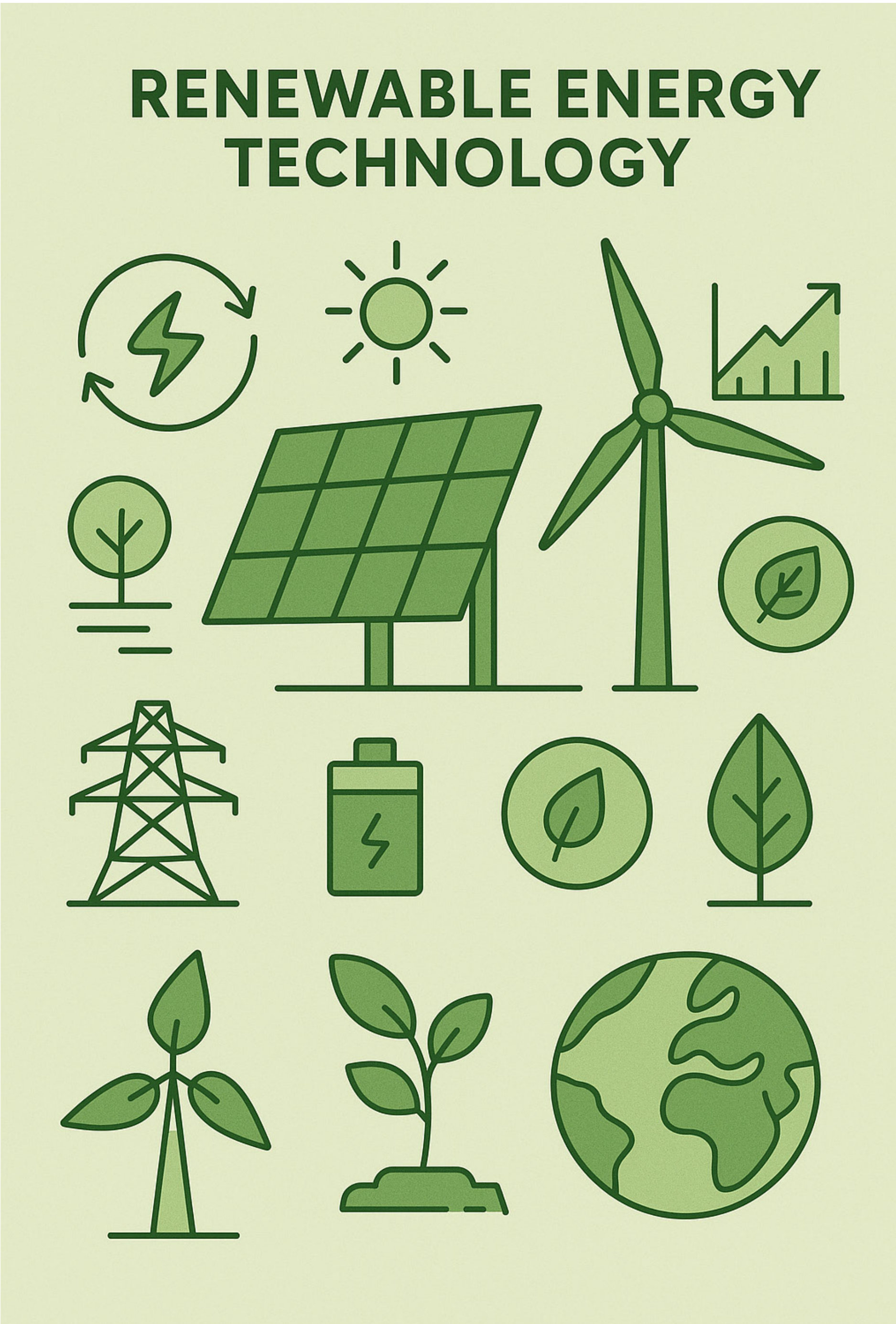
Located in Kartal, İstanbul, Kartal Dr. Lütfi Kırdar City Hospital is one of Türkiye's largest healthcare facilities and has been awarded both LEED Gold and EDGE certifications. This makes it Türkiye's first and the world's largest hospital building to achieve EDGE green building certification.

Designed with sustainability principles from the conceptual stage, the hospital was built on an existing healthcare site, in close proximity to public transportation and social amenities. During the construction process, erosion and sedimentation control plans were implemented, and precautions were taken to minimize dust, water, and construction pollution.

The project achieved 42% energy savings compared to international benchmarks, through the use of high-efficiency mechanical and electrical systems, optimized façade layering, and appropriate glazing selection. A portion of the domestic hot water demand is met through solar collectors, and energy performance of all systems is tracked via dedicated automation infrastructure.

Water efficiency was optimized through the installation of low-flow plumbing fixtures, and indoor environmental quality was elevated by augmenting fresh air ventilation and incorporating low-VOC materials, including paints, adhesives, and sealants. The façade design is optimized to maximize natural daylight penetration, enhancing occupant well-being and fostering a more comfortable indoor environment.

As a flagship project in sustainable healthcare design, Kartal Dr. Lütfi Kırdar City Hospital exemplifies the seamless incorporation of environmental performance targets into Türkiye's public infrastructure[29].


RENEWABLE ENERGY TECHNOLOGY

3. Section

Renewable Technology Module

3.1. Renewable Energy Perspectives in Türkiye and Europe

Europe has long been a global leader in the renewable energy transition, driven by ambitious policies at both the European Union (EU) and national levels. This leadership is further reinforced by the Paris Agreement, which sets global climate targets and encourages countries, including the EU, to take bold actions in reducing greenhouse gas emissions[30]. The Paris Agreement, adopted in 2015 during the UN Climate Change Conference (COP21), represents a landmark global commitment to combat climate change. The primary objective is to restrict global temperature rise to well below 2°C, ideally to 1.5°C, compared to pre-industrial levels, with participating nations committing to substantial reductions in greenhouse gas emissions and intensifying measures to mitigate the impact of climate change. This agreement marked a historic step in international cooperation, as nearly every country in the world came together to set climate goals and create a framework for collective action.

In line with the Paris Agreement, the European Green Deal, introduced by the European Union in 2019, serves as the EU's comprehensive strategy to meet its climate goals[31]. European Green Deal is a comprehensive plan introduced by the European Union aimed at making Europe the first climate- neutral continent by 2050. As part of this ambitious plan, the EU set a goal to reduce greenhouse gas emissions by 55% by 2030, compared to 1990 levels. This updated goal replaced the previous goal of a 40% reduction, which was established earlier. Recognizing the urgency of accelerating climate mitigation measures, the European Union raised its emission reduction goal to 55% to harmonize with the global objective of limiting temperature rise to 1.5°C. Enshrined in the European Climate Law, this goal serves as a central component of the EU's climate framework, legally mandating member states to attain carbon neutrality by 2050. To achieve this goal, the EU is focusing on various measures, including transitioning to renewable energy, improving energy efficiency, reducing reliance on fossil fuels, and promoting a circular economy. This transition not only aims to mitigate climate change but also seeks to create new jobs and foster green technologies, ensuring a sustainable future for Europe.

In European countries, Germany's energy transition strategy has contributed to accelerating the expansion of wind and solar energy, while Denmark leads the world in wind turbine technology and wind energy output. Spain, with its wide sunny landscapes, has emerged as one of Europe's leading solar power producers. Moreover, Northern European countries, like Sweden and Norway, rely largely on hydropower and geothermal energy. These countries have substantial natural resources and have created strong infrastructure to facilitate the transition to a renewable-powered energy system. Furthermore, Europe's concentration on smart grids, energy storage technologies, and cross-border power markets attempts to overcome the intermittent nature of renewable energy sources and assure a steady and predictable energy supply.

On the other hand, Türkiye has made significant progress toward incorporating renewable energy into its energy mix. The country's physical position provides major benefits in terms of renewable resources, including plentiful solar radiation, strong winds, and geothermal potential. In recent years, Türkiye has emerged as one of Europe's leaders in wind and solar energy capacity expansion. Due to Türkiye's excellent climate, solar energy has grown significantly, notably in the south and western regions (such as Antalya, İzmir and İstanbul cities). Türkiye also has significant wind energy potential, especially in the Aegean and Marmara areas, where average wind speeds are greater. Furthermore, Türkiye possesses significant geothermal resources, making it a pioneer in geothermal energy development. Hydropower, traditionally a major source of renewable energy in Türkiye, continues to play a significant role in meeting energy demand. In addition to hydropower, biogas plants have been developed across various regions to diversify the energy mix.

Türkiye's involvement with the Paris Agreement has been a significant part of its climate policy trajectory. Türkiye formally ratified the Paris Agreement, signaling its commitment to global climate efforts. This ratification came after much domestic debate and political negotiation, with the government acknowledging the growing importance of climate action for both environmental sustainability and economic resilience.

Since ratifying the Paris Agreement, Türkiye has taken various steps to align with its climate goals. In line with the agreement's objective to limit global warming to well below 2°C, Türkiye has committed to achieving a net-zero emissions goal by 2053, a step that reflects its growing commitment to reducing greenhouse gas emissions.

12th Development Plan of Türkiye (2024–2028) presents a comprehensive strategy focused on sustainable development, climate-resilient urban transformation, and a transition to clean energy. The initiative underscores the creation of urban environments that integrate climate resilience, environmental sustainability, and smart technologies, while concentrating on localized urban redevelopment, the proliferation of green areas, and optimized energy efficiency. New buildings are expected to achieve at least a "B" level energy performance, and the transition to "Nearly Zero Energy Buildings" is encouraged. Türkiye aims to increase solar energy capacity from 11,350 MW in 2023 to 30,000 MW by 2028, while promoting wider adoption of renewable energy and energy- efficient buildings. These initiatives are aligned with the national goal of achieving net-zero emissions by 2053. However, some critics argue that the plan may not sufficiently safeguard ecological balance and may favor capital-driven sectors[32].

On the other hand, the Energy Efficiency Strategy for 2030 and the Second National Energy Efficiency Action Plan of Türkiye aims to enhance energy efficiency, promote sustainable structures within urban transformation, and expand the use of renewable energy as part of the national effort to reach net- zero emissions. This initiative endorses sustainable construction practices through green building certification for new public developments and encourages energy performance upgrades in current buildings, prioritizing the widespread adoption of Nearly Zero Energy Building (nZEB) standards. To reduce emissions from urban transportation, the strategy includes the development of electric vehicle infrastructure, bicycle paths, and pedestrian-focused areas. It also outlines an investment of 20 billion US dollars in energy efficiency projects by 2030, with an expected energy savings of 46 billion US dollars by 2040. This comprehensive framework supports the national objectives for climate-resilient urbanization, a transition to renewable energy, and long-term environmental sustainability[33].

Furthermore, Türkiye has introduced national strategies such as Climate Change Mitigation and Adaptation Strategy Action Plans in Türkiye[34] and has taken steps towards expanding its use of renewable energy, improving energy efficiency, and fostering a green economy. The Action Plans of Türkiye are aligned with the structure of SECAP (Sustainable Energy and Climate Action Plan). SECAP is a framework introduced by the Covenant of Mayors for Climate and Energy[35] to help cities and local authorities in the EU and beyond develop comprehensive plans to reduce greenhouse gas emissions and adapt to climate change. For Türkiye, SECAP is part of its broader national strategy to meet the Paris Agreement targets and reduce emissions. The development of a Sustainable Energy and Climate Action Plan (SECAP) assists Turkish cities and municipalities in executing localized climate mitigation strategies, with a targeted emphasis on enhancing energy efficiency, expanding renewable energy adoption, and strengthening climate resilience at the municipal level. However, Türkiye still faces challenges related to its heavy reliance on coal and the need for significant investments in clean energy technologies and infrastructure. Despite these challenges, Türkiye's ratification of the Paris Agreement marks a crucial step in the country's transition towards a more sustainable and climate-resilient future.

In recent years, Türkiye has implemented various incentives and government policies to encourage renewable energy investments, including the Renewable Energy Resource Area (YEKA) model, which promotes large-scale renewable energy projects. These efforts have successfully attracted both local and international investments, positioning Türkiye as a significant player in the renewable energy sector. Expanding beyond the YEKA program, Türkiye has enhanced its renewable energy capacity via targeted investments in coastal wind farms across the Aegean and Mediterranean regions, complemented by utility-scale solar projects in southern and western municipalities. These developments have emerged as essential contributors to the country's transition toward low-carbon power production.

Additionally, biomass and hydropower plants have been developed across various regions.

İstanbul holds a unique role in the renewable energy transition in Türkiye. Given İstanbul's large population and urban landscape, the city can benefit from more localized renewable energy initiatives. Specific examples for İstanbul include:

- **Increased Solar Panel Integration:** Expanding the use of rooftop solar panels in residential and commercial buildings, particularly in districts with high solar potential, could significantly contribute to İstanbul's energy requirements. Several specific examples of solar panel integration were implemented in İstanbul. For instance, İstanbul Metropolitan Municipality has installed solar panels on the roofs of several public buildings with an annual 4416 MWp energy production capacity, including sports complexes, cultural centers and various municipal offices, as part of efforts to reduce energy consumption and promote renewable energy. In the Kadıköy district, solar panels have been integrated into the Kadıköy Marriage Office, with a total capacity of 12 kW, providing approximately 40% of the building's annual energy requirements. Additionally, İstanbul Airport has set up large-scale solar panel arrays to supply energy to the airport's operations, significantly lowering its carbon footprint. These initiatives showcase İstanbul's commitment to expanding solar energy use in both public and private sectors.

- **Energy Storage Solutions:** As renewable energy sources like solar and wind are intermittent, investing in energy storage systems in İstanbul would help stabilize the grid and ensure a steady supply of electricity even during low production periods. A notable example of this is İstanbul Elektrik Dağıtım A.Ş. (İEDAS), which has developed energy storage projects to integrate with renewable energy sources. One example is the solar and battery storage system at the İstanbul Büyükçekmece Solar Energy Storage Facility, which combines solar power with energy storage to provide a more reliable and consistent energy supply to the local grid. In a complementary initiative, İSKİ (İstanbul Water and Sewerage Administration) has integrated energy storage systems into water treatment plants, enabling the retention of excess solar energy produced during high-generation periods and its subsequent utilization during phases of diminished solar availability. These endeavors in energy storage reflect İstanbul's determination to enhance the reliability and efficiency of its renewable energy infrastructure.

- **Smart Grid Infrastructure:** Upgrading İstanbul's energy infrastructure with smart grid technologies would enhance energy efficiency, optimize the distribution of renewable energy, and reduce energy losses, making the city more resilient to energy demands. İstanbul Elektrik Dağıtım A.Ş. (İEDAS) has been working on implementing smart grid solutions across the city, including the deployment of Advanced Metering Infrastructure (AMI) to improve real-time monitoring and control of energy consumption in residential and commercial buildings. Additionally, smart grid technologies have been integrated into the Üsküdar and Kadıköy districts, where the grid can now more efficiently balance the supply of renewable energy from solar and wind sources, and quickly detect and respond to outages. These upgrades improve the overall efficiency of energy distribution, reduce energy losses, and ensure a more reliable energy supply across the city.

- **Public Transportation Electrification:** İstanbul can also invest in the electrification of public transportation networks, such as buses and ferries, powered by renewable energy sources, to reduce emissions and improve air quality. İstanbul has been making significant progress in electrifying its public transportation system to reduce emissions and improve air quality. Within the scope of the public transportation service offered in Adalar district, 60 electric E- JEST model vehicles and 10 CLEANVAC EMICRO, and 10 PILOTCAR PREMIUM PC-4 SL electric vehicles to be used as Ada Taxis were purchased[36].

Pursuant to its strategic mobility frameworks—including the İstanbul Sustainable Urban Mobility Plan (SUMP) and its subsequent implementation phase—the city has prioritized the modernization of public transit systems, metro line extensions, and the integration of electric mobility solutions. This commitment is reflected in the substantial growth of its rail infrastructure, which expanded from 233 km (2019) to 381 km (2024).

With the new generation express metro line, called SpeedRail Project, the targeted length of the İstanbul Rail System Network is planned to be approximately 740 km after 2030. Demonstrating its steadfast commitment to sustainable urban mobility, the İstanbul Metropolitan Municipality (IMM) is currently undertaking the concurrent construction of 10 new metro lines, establishing an unprecedented benchmark in global metro infrastructure development.

Additionally, İETT has successfully converted a 2006 model diesel bus into a fully electric vehicle, achieving 63 percent fuel savings and plans to convert 50 more buses within the year. The city is also introducing 40-meter-long electric metrobuses with a capacity of 420 passengers and features such as autonomous driving support and panoramic camera systems. These initiatives highlight İstanbul's commitment to sustainable mobility and the modernization of its transport infrastructure through clean energy technologies[37].

By focusing on these specific measures, İstanbul could further solidify its role as a leader in Türkiye's renewable energy transformation, contributing to national climate goals while addressing the city's unique energy challenges.

3.2. Overview of Renewable Energy Systems

Renewable Energy Systems (RES) are energy production systems that use natural resources such as geothermal heat, wind, water, biomass and solar to produce fuel, heat, and power. RES are considered as sustainable and eco-friendly energy sources since they reduce greenhouse gas emissions and the depletion of finite resources, in contrast to traditional fossil fuel-based energy sources. As concerns about climate change and energy security grow, the adoption of RES is increasingly seen as essential for a sustainable energy future.

Some of the main Energy systems:

- Solar energy systems use photovoltaic (PV) cells to convert sunlight directly into electricity. Solar power is one of the most widely used renewable energy sources worldwide due to its accessibility and sustainability. Solar panels can be installed on rooftops, in large solar farms, or integrated into building materials. They are highly effective in regions with high levels of sunlight, making them ideal for countries like Türkiye.

In İstanbul, solar energy usage has been growing steadily. Several initiatives have been launched to integrate solar panels into residential buildings, commercial structures, and public buildings, with the aim of reducing electricity costs and carbon footprints. The city's climate, with abundant sunshine, makes it well-suited for solar power adoption. There are also programs encouraging homeowners to install solar systems, supported by government incentives and subsidies (KOSGEB)[38].

- Wind energy systems convert the kinetic energy of wind into electrical power using wind turbines. Wind energy is one of the most promising renewable energy sources globally, especially in regions with consistent wind patterns. It is particularly effective in coastal and open areas where wind speeds are higher. Wind turbines can be installed on land or offshore, with offshore wind farms gaining popularity due to their higher energy efficiency. Türkiye, especially in coastal areas such as the Aegean and Marmara regions, has significant wind energy potential.

In İstanbul, wind power does not play a predominant role in the energy mix, primarily due to urban density and relatively low wind speeds. However, ongoing projects in nearby coastal regions, particularly in the Sea of Marmara, aim to expand its contribution. These projects contribute to Türkiye's overall wind energy capacity, which has been expanding rapidly. As İstanbul continues to grow, wind power installations in surrounding areas could further enhance the city's renewable energy mix.

- Geothermal energy systems utilize heat from beneath the Earth's surface to generate electricity or provide direct heating. This form of energy is particularly valuable in regions with significant geothermal activity, such as volcanic areas. Türkiye is one of the top countries in the world for geothermal energy potential, especially in the western regions.

Although İstanbul itself lacks large-scale geothermal power generation facilities, the city derives indirect advantages from Türkiye's extensive national geothermal energy infrastructure. The geothermal energy sector in Türkiye is expanding. These systems offer a clean and efficient way to heat buildings, reducing dependence on fossil fuels for heating.

- Biomass energy is derived from organic materials, such as plant and animal waste, which can be burned or processed into biofuels. Biomass can be a versatile and renewable energy source, especially for heating and power generation. It is most effective when used in agricultural or forestry-rich areas, where organic waste is abundant.

In İstanbul, biomass energy is being increasingly explored, especially in waste-to-energy projects. The municipality's substantial population density and corresponding organic waste generation present viable potential for biomass energy facilities to transform waste streams into renewable energy sources. The municipal authorities in İstanbul have enacted strategic waste management regulations that encourage biomass conversion for combined heat and power (CHP) generation, supporting the achievement of urban sustainability targets (İSTAÇ and IMM Department of Environmental Protection and Development) [39], [40]. IMM's Energy Generation Facilities generate electricity equivalent to the electricity requirements of 2.5 million people annually and prevent the emission of 4.5 million tons of CO2e into the atmosphere with new renewable energy investments to support carbon-neutral waste management targets and reduce external energy dependency.

- Hydropower involves the generation of electricity through the movement of water, typically by constructing dams on rivers or other bodies of water. This is one of the oldest and most widely used forms of renewable energy. Hydropower installations of significant scale demonstrate considerable electricity generation potential, particularly in geographic locations endowed with substantial water availability and marked elevation differentials. Türkiye has a considerable hydropower potential.

Several major dams across the country supply a large proportion of the national electricity demand.

While İstanbul's energy infrastructure is not predominantly reliant on hydropower, the periphery of the metropolitan area features small to medium-scale hydroelectric facilities that provide supplementary power to the regional grid. Hydropower continues to be an essential part of Türkiye's renewable energy strategy, providing a reliable and consistent source of power.

In Türkiye, solar, wind, hydropower, geothermal, and biomass energy systems are all being harnessed to reduce reliance on fossil fuels, combat climate change, and promote energy security. Although İstanbul's transition to renewable energy systems remains ongoing, the city derives advantages from Türkiye's comprehensive national renewable energy framework, which has facilitated substantial investments across solar, wind, geothermal, and biomass energy sectors. As İstanbul undergoes continued urban expansion and modernization, the strategic integration of renewable energy systems (RES) will constitute a critical component in transitioning toward a more sustainable, environmentally responsible, and energy-efficient metropolitan future.

3.3. Challenges of Renewable Energy Systems

Renewable Energy Systems (RES) provide many benefits, such as reducing environmental damage and enhancing energy security. However, they also face important challenges, particularly in regions like Türkiye and Europe. One key challenge is the intermittency of renewable energy sources. Solar and wind energy depend on weather conditions, meaning energy production can vary. For example, on cloudy or windless days, solar panels and wind turbines may produce little or no energy. Intermittency in renewable generation poses challenges to grid stability and power supply continuity, especially in electricity networks with high penetration levels of renewable energy sources. To address this, energy storage solutions such as batteries and pumped- storage systems are being explored. However, both options remain expensive and require further development.

Especially, in Türkiye, another key challenge is the lack of infrastructure to fully integrate renewable energy into the grid. The increasing integration of renewable energy sources demands systematic upgrades to national power transmission and distribution infrastructure to maintain grid reliability and optimize operational performance. Sophisticated grid control technologies constitute a critical requirement for maintaining power system stability and enabling seamless renewable energy penetration at the national scale.

Furthermore, the initial financial investment for renewable energy projects, particularly wind and solar, may be extremely high. While operational costs are often minimal, the initial expenditure might be a barrier to entrance, especially for smaller businesses or local developers. In Türkiye, government incentives and financing schemes have been implemented to help overcome these obstacles, but additional efforts are required to encourage smaller-scale and decentralized renewable energy initiatives.

Another problem for Türkiye and Europe is the environmental impact of large-scale renewable energy projects. For example, the installation of wind farms and solar arrays can damage habitats, and the manufacture of renewable energy equipment, such as photovoltaic panels and wind turbines, necessitates the extraction of raw materials that are frequently mined in sensitive areas. Sustainable development methods and technologies are being emphasized to reduce these consequences, but balancing environmental preservation with the demand for clean energy remains a difficult task.

In Türkiye, biogas and biomass energy facilities present notable environmental challenges, particularly concerning water and air pollution. During anaerobic digestion, the resulting liquid by-product (digestate) can contain high levels of nutrients, heavy metals, and pathogens, posing a risk to groundwater and nearby water sources if not properly treated. Additionally, biomass combustion emits air pollutants such as Particulate Matter (PM), Nitrogen Oxides (NOx), and Carbon Dioxide (CO_2), contributing to both air quality degradation and greenhouse gas accumulation. These environmental risks are especially significant in agricultural regions, where ecosystems and public health are highly vulnerable.

To address these issues, facilities should implement advanced wastewater treatment technologies to ensure the safe management of digestate and prevent its infiltration into soil and water systems. Effective air pollution control measures—such as fabric filters, gas scrubbers, and real-time emissions monitoring—are also essential to limit atmospheric emissions. The sustainable scaling of biogas and biomass energy infrastructure in Türkiye necessitates both the fortification of environmental regulatory standards and the institutionalization of participatory governance models incorporating robust public reporting protocols and meaningful community involvement.

Additionally, geothermal energy can also cause certain environmental and social problems. Geothermal power plants are often located in regions with intensive agricultural activity. The chemical waste released by these plants can negatively affect soil quality and groundwater, leading to reduced agricultural productivity and, in some cases, crop damage. Additionally, local communities commonly report environmental concerns including odour problems, acoustic disturbances, and ground surface subsidence associated with these operations.

To ensure that geothermal resources are used sustainably and in harmony with the environment, there is a need for more effective monitoring systems, comprehensive environmental impact assessments, and transparent public information processes.

Securing community consensus is likely to encounter substantial sociopolitical barriers. While there is widespread support for renewable energy, some communities are concerned about wind farms' visual impact or the possible impacts of large-scale solar installations on local ecosystems. Engaging communities in the planning process and ensuring that renewable energy projects are implemented ethically can assist to reduce opposition and increase public acceptance.

In conclusion, while Türkiye and Europe confront considerable barriers to widespread adoption of renewable energy sources, these obstacles are not insurmountable. With continuous technical innovation, regulatory support, and infrastructural investment, renewable energy sources can play a vital part in the transition to a more sustainable and resilient energy future.

3.4. Energy Efficiency, Energy Consumption Monitoring and Behavioral Change Studies

Energy efficiency is a fundamental aspect of sustainable building design and operation, contributing to both environmental preservation and economic savings. The integration of advanced monitoring technologies and behavioral interventions has emerged as a key strategy to optimize energy use in buildings. This project introduced an innovative approach that combines real-time energy consumption monitoring with AI-driven behavioral insights to encourage more efficient energy practices among building occupants.

Through the integration of advanced sensor networks and artificial intelligence algorithms, the system facilitates granular monitoring of energy consumption patterns and generates tailored optimization strategies to enhance energy efficiency. This integrated strategy simultaneously improves energy performance while promoting occupant participation, thereby serving as a critical mechanism for realizing sustained energy conservation in diverse building typologies.

3.4.1. Global Context: Energy Efficiency, Monitoring Technologies, and Behavioral Change

In recent years, smart building technologies have become pivotal in the global push toward decarbonization, energy resilience, and sustainable urban transformation. Buildings are responsible for approximately 30–40% of global final energy use and emissions [41], making them a key goal for energy efficiency interventions. To address this, cities worldwide are increasingly investing in digital infrastructure, including real-time sensor networks, wireless communication technologies (e.g., LoRaWAN, NB-IoT), and Building Automation Systems (BAS). These infrastructures enable granular monitoring of environmental and operational parameters (temperature, HVAC runtime, air quality, occupancy) and support data-informed interventions at both system and user levels. In parallel, there has been growing recognition of the importance of behavioral change as a complementary strategy to physical retrofitting. Frameworks such as the European Renovation Wave, EN 15232[42] (building automation impact on energy performance), and IPMVP [43] emphasize the potential of AI-driven nudging mechanisms, occupant engagement platforms, and feedback loops to unlock additional energy savings—often in the range of 10–20%—without major capital investment.

Bayrampaşa pilot site provided a valuable opportunity to observe the effectiveness of the deployed technological infrastructure and AI-driven behavioral interventions in a real-world urban setting. Bayrampaşa, as a densely populated and socioeconomically heterogeneous district within İstanbul, exemplifies Türkiye's characteristic mid-20th century built environment, where persistent energy inefficiencies stemming from antiquated infrastructure present significant modernization challenges.

The real-time data collected from smart thermostatic valves, HVAC [44] (Heating, Ventilating and Air Conditioning) controllers, IAQ (Indoor Air Quality) sensors, and energy meters across multiple building types allowed for a detailed analysis of energy use patterns specific to this district. Several key insights were derived from the Bayrampaşa site:

- **High HVAC Usage During Unoccupied Hours:** Analysis revealed significant energy consumption in HVAC systems during periods when spaces were unoccupied, highlighting a major behavioral inefficiency.

- **Temperature Setpoint Patterns:** Many users exhibited a tendency to maintain consistently high indoor temperatures regardless of external weather conditions, pointing to a need for awareness-based interventions.
- **Potential for Energy Savings:** AI-based suggestions delivered through the GreenIST platform led to measurable behavior changes among users, especially those who engaged with real-time alerts and weekly summaries. Energy savings in Bayrampaşa ranged between 12% and 20% depending on building type and user engagement level.
- **User Willingness to Adapt:** The engagement rate in Bayrampaşa was among the highest across test sites, suggesting strong potential for scaling behavior change initiatives when tailored recommendations and intuitive feedback mechanisms are in place.

Overall, the findings from Bayrampaşa underscore the critical role of combining advanced sensor infrastructure with localized, behavior-driven guidance. This integrated approach not only enables technical optimization but also empowers occupants to take ownership of their energy use, thereby contributing to broader urban sustainability goals.

A comprehensive sensor network that enables real-time data collection across buildings has been implemented within the project. This infrastructure is built on LoRa (Long Range) low-power wireless technology, allowing for scalable and efficient monitoring of energy usage. The sensor ecosystem provides valuable insights into various energy consumption parameters, such as temperature, humidity, and HVAC usage, forming the basis for informed behavioral interventions.

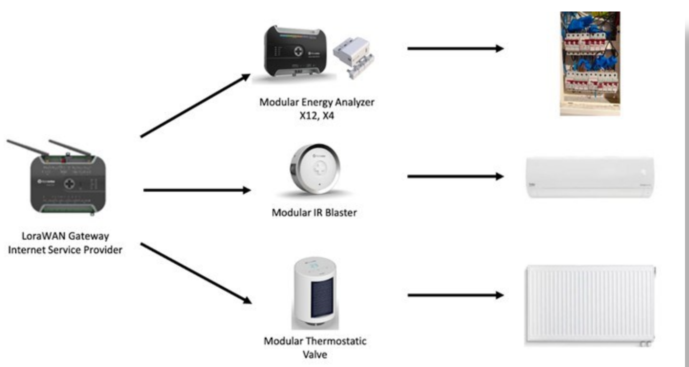


Figure 17. Project connection device diagram

At the core of the system is the LoRaWAN Gateway, which connects all the devices on site to the internet. This gateway uses LoRaWAN technology for reliable, long-range communication within the site and is equipped with an embedded LTE/4G SIM card for sending collected data to cloud-based platforms for storage and analysis.

The energy consumption data are collected with Modular Energy Analyzers, which are installed in the electrical breaker boxes of individual flats. Their primary function is to provide accurate and continuous monitoring of each flat's electricity consumption. By recording consumption data in real time, the analyzers enable detailed daily reports that reflect household energy behavior. Over time, this data reveals usage patterns that can be used to evaluate the effectiveness of energy- saving strategies. Users and building managers alike benefit from this granular insight, as it helps identify peak usage times, areas of inefficiency, and opportunities for behavioral adjustments that lead to energy and cost savings.

Complementing this, the Modular IR Blaster is a compact, intelligent device that connects to split- type air conditioning systems within each flat. It allows users to remotely control the AC units and is also equipped with sensors that monitor the ambient room temperature. This dual function supports enhanced climate control while contributing to the overall energy optimization strategy by ensuring that cooling is only applied when necessary and under efficient conditions.

In parallel, Smart Thermostatic Valves are installed on radiators in each residential unit. These valves autonomously regulate the flow of hot water into radiators by responding to the current room temperature and the user's setpoint preferences. By doing so, they maintain the desired level of comfort without wasting energy through overheating or unnecessary operation.

This intelligent heating control significantly improves energy efficiency, particularly during colder months when heating demands are high.

Together, the IR Blaster and Thermostatic Valve form a responsive thermal management system that not only enhances comfort but also contributes to the broader goal of minimizing environmental impact through smarter energy use.

Device	Function	Key Data Collected
Smart Thermostatic Valves	Zone-based control for radiator heating	Temperature, valve position
HVAC Controllers	Integration with VRF/VRV and split AC systems for centralized optimization	Temperature, humidity, runtime
Energy Consumption Meters	Real-time measurement of energy usage at device/zone level	Power, consumption, reactive load
Indoor Air Quality (IAQ) Sensors	Monitoring indoor air quality and optimizing ventilation	Air quality metrics, humidity, temperature

Table 3. Device functions and key data collected

This system enables a granular and dynamic understanding of energy use, allowing for the identification of inefficiencies and optimization opportunities. The collected data forms the foundation for the AI-driven behavioral interventions aimed at reducing energy consumption and improving overall building performance.

As part of the pilot implementation, the behavioral intervention system was deployed across a total of 75 residential apartments in Bayrampaşa. These units were selected to represent a diverse sample of occupancy patterns, heating habits, and building typologies within the district. The system installation included smart thermostatic valves, HVAC controllers, IAQ sensors, and energy meters, all integrated with the AI-powered GreenIST platform. This deployment provided a robust dataset for behavioral profiling and allowed for the validation of intervention effectiveness across a statistically meaningful user base.

Figure 18. Smart thermostatic valve installation in Bayrampaşa

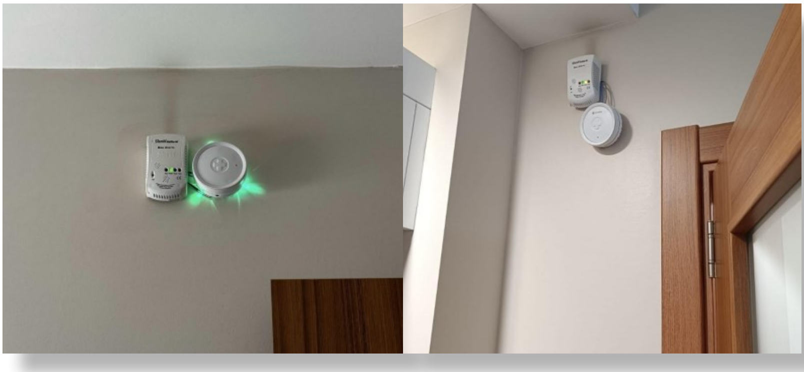


Figure 19. IAQ sensors & HVAC controllers in Bayrampaşa

Figure 20. Energy consumption meters in Bayrampaşa

3.4.2. Behavioral Interventions and AI-Driven User Guidance

Behavioral interventions have emerged as a key strategy in driving energy efficiency in residential buildings. While technological solutions such as smart sensors and automation systems are central to energy management, human behavior remains a significant factor in determining the effectiveness of these systems. To maximize energy savings and reduce carbon footprints, it is essential to influence how individuals interact with their environments and energy-consuming devices. By leveraging real- time data, machine learning, and predictive analytics, AI technologies can provide personalized nudges and recommendations that help occupants make more energy-conscious decisions.

This section explores the role of behavioral interventions in enhancing energy efficiency, focusing on the use of AI to deliver targeted, real-time feedback to building occupants. It examines the potential of these interventions to change everyday behaviors, such as adjusting heating and cooling settings, reducing unnecessary appliance use, and optimizing overall energy consumption patterns. Drawing from the Bayrampaşa pilot project, the integration of AI-powered platforms like GreenIST demonstrates how personalized guidance can drive meaningful behavior changes and lead to significant energy savings. Through this combination of technology and behavioral insight, occupants can take a more active role in managing their energy use, contributing to broader sustainability goals and reducing environmental impact.

3.4.2.1. The Role of Behavioral Interventions in Energy Efficiency

While technological upgrades and building automation systems form the backbone of modern energy efficiency strategies, an increasing body of research and policy recognizes that occupant behavior plays a critical role in shaping actual energy outcomes. Studies suggest that up to 30% of energy savings in buildings can be achieved through behavioral change alone, without major capital investment[45], [46].

3.4.2.2. GreenIST Application: Localized Behavioral Interventions Through AI

In the Bayrampaşa pilot area, behavioural interventions were implemented through the integration of GreenIST App, an AI-powered virtual assistant designed to provide real-time, personalised energy guidance to building occupants.

GreenIST App operated through a multilingual mobile application and web interface, functioning as the behavioral intelligence layer atop the physical sensor infrastructure.

Behavioral Profiling Capabilities

GreenIST app constructed dynamic energy use profiles for individual apartments by analyzing:

- Daily temperature setpoint trends (e.g., whether users lower the temperature at night)

- Frequency of manual overrides on thermostats or HVAC control apps
- HVAC activity during non-occupancy periods
- Peak usage hours and patterns associated with indoor climate preferences

These behavioral patterns were then matched to recognized inefficiencies and opportunities for savings.

Examples of Real-Time AI Nudges Delivered in Bayrampaşa

GreenIST app utilized real-time nudging techniques to encourage energy-saving behaviors among building occupants. These nudges were based on real-time telemetry data from the building's LoRaWAN-connected sensor ecosystem and were tailored to the unique contexts and usage patterns of each apartment. The following table outlines some of the key types of real-time AI nudges delivered to users in the Bayrampaşa pilot project. These nudges were designed to promote energy efficiency by providing personalized, context-specific messages to building occupants. Each type of nudge serves a distinct objective, from raising awareness to preventing energy waste and encouraging continued engagement.

Type	Example Message	Objective
Temperature Tip	"Lowering your bedroom temperature by 1°C at night could save 350 kWh/year."	Raise awareness, promote low- effort actions
Instant Alert	"The AC is still on while the room is unoccupied. Turn it off now?"	Prevent energy waste
Monthly Summary	"You've used 12% less energy this week—keep up the good work!"	Positive reinforcement, motivation
Gamification Badge	"You've completed 5 days in Eco Mode. You've earned a Green Champion badge!"	Encourage sustained participation

Table 4. Real-time AI nudges to users in Bayrampaşa

These nudges were triggered based on real-time telemetry data from the building's LoRaWAN- connected sensor ecosystem and were localized for each apartment's context and usage pattern.

Observed Outcomes in the Field

Several key outcomes were reported from the Bayrampaşa pilot:

• High Interaction Rate: Over 65% of users engaged with GreenIST messages regularly.

• Documented Energy Savings: Users who interacted with at least 3 nudges per week demonstrated 12–20% energy reductions versus baseline.

• Increased Awareness: User surveys indicated a strong improvement in awareness regarding the link between their daily actions and energy costs.

• Behavioral Shifts: A measurable change in temperature setpoints (typically 1–1.5°C lower at night) was observed among active users.

Conclusion: From Awareness to Impact

The Bayrampaşa experience demonstrates that AI-assisted behavioral interventions can complement sensor-based automation by:

• Turning passive users into active energy managers

• Unlocking low-cost, scalable energy savings

• Laying the foundation for digital literacy and climate citizenship in urban households

These results reinforce global findings that human behavior, when supported by smart technology, can be a powerful tool for sustainable transformation—especially in aging urban building stocks.

Key concepts and global practices are listed below:

• Behavioral Energy Efficiency (BEE) refers to strategies that influence how people use energy through awareness, feedback, and incentive structures.

• Real-time feedback (via mobile apps, smart displays, or web dashboards) is more effective than periodic bills or general advice[47].

• Nudging is a subtle form of behavioral intervention that gently steers users toward energy- efficient actions without restricting choice[48].

• The EU's Renovation Wave, the US DOE's BETTER initiative, and UK's Behavioural Insights Team have all emphasized digital engagement as a core element of energy demand reduction.

AI-driven guidance provides the following:

- Artificial Intelligence allows for behavioral pattern recognition at scale, enabling highly personalized feedback.
- AI systems can learn individual preferences, detect energy-wasting routines, and optimize messaging in real time.
- Emerging building standards[49] increasingly account for occupant responsiveness and behavioral interfaces.

In addition to the technological infrastructure, the project integrated GreenIST app, the AI-powered virtual assistant, to provide behavioral interventions aimed at improving energy efficiency. GreenIST delivers personalized feedback and guidance to users, helping them optimize energy consumption through real-time suggestions.

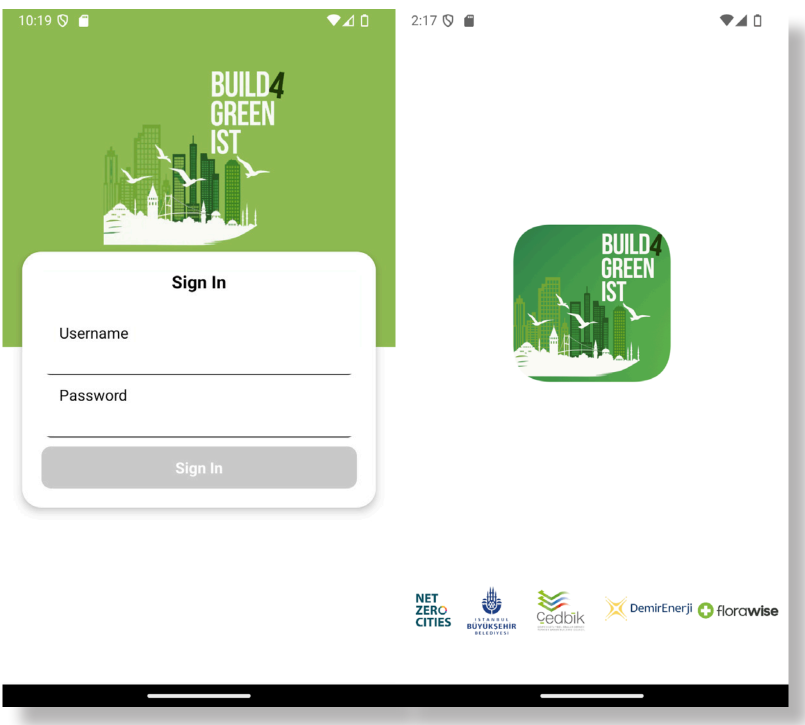


Figure 21. GreenIST app interfaces

3.4.3. Impact Evaluation of Behavioral Interventions

Evaluating the impact of behavioral interventions is crucial to understanding how effectively they influence energy consumption patterns and achieve sustainability goals. In the context of the Bayrampaşa residential buildings, behavioral interventions were implemented with the aim of encouraging energy-efficient behaviors among residents. This section explores the methodologies used to assess the outcomes of these interventions, including changes in energy usage, shifts in occupant behaviors, and the overall effectiveness in driving long-term energy savings. Through careful analysis of the data collected, the impact evaluation seeks to provide insights into the success of these behavioral strategies and their potential for scaling in similar urban settings.

3.4.3.1. Measurement and Verification Framework Using IPMVP Option D: Application in Bayrampaşa Residential Buildings

Measurement and Verification (M&V) of energy savings is a critical component in evaluating the success of energy efficiency projects. The International Performance Measurement and Verification Protocol (IPMVP) offers a standardized framework that ensures the reliable quantification and verification of energy savings. For the Bayrampaşa residential buildings, IPMVP Option D has been selected as the method for M&V due to its suitability for multi-occupant residential environments. This option allows for a comprehensive assessment of energy use across individual apartments, ensuring accurate attribution of savings. By implementing IPMVP Option D, the Bayrampaşa project guarantees that energy savings are measured and verified accurately, providing transparency and reliability in the evaluation process. Moreover, this approach facilitates continuous monitoring of energy performance and supports ongoing improvements in energy efficiency practices within the buildings.

3.4.3.2. Introduction to IPMVP Option D – Calibrated Simulation

The International Performance Measurement and Verification Protocol (IPMVP) provides globally recognized methodologies for evaluating the effectiveness of energy efficiency interventions. It defines standardized procedures for measuring energy savings by comparing baseline (pre-retrofit) and reporting period (post-retrofit) consumption, adjusted for variables such as weather and occupancy.

Among its four primary methods, Option D: Calibrated Simulation is particularly suitable for projects where:

- Pre-retrofit energy consumption data is missing, incomplete, or unreliable.
- Individual systems or components are being monitored in complex or diverse buildings.
- Large-scale retrofits or behavioral interventions are involved, requiring scenario modeling.
- A need exists to normalize variables such as weather, occupancy, or operational schedules across different time periods.

Under Option D, a detailed simulation model of the building is developed and calibrated using actual measured data, typically from a period after installation of monitoring infrastructure but before full optimization or intervention. This allows for the creation of a normalized baseline (adjusted baseline) that reflects how the building would have consumed under current conditions had no intervention occurred.

The key references include the IPMVP Core Concepts 2016 published by the Efficiency Valuation Organization (EVO), and the ASHRAE Guideline 14-2014, which focuses on the measurement of energy and demand savings.

3.4.3.3. Application of IPMVP Option D in Bayrampaşa Residential Buildings

In the scope of a smart energy efficiency project implemented in Bayrampaşa, İstanbul, IPMVP Option D was selected as the primary methodology to quantify the energy savings achieved through a combination of:

- **AI-assisted HVAC optimization:** Artificial Intelligence (AI) is used to analyze real-time data and optimize the operation of heating, ventilation, and air conditioning (HVAC) systems, adjusting them to meet occupants' requirements while minimizing energy use.
- **Smart thermostatic valve integration: S**mart thermostatic valves allow for precise control of temperature in different rooms or zones within a building, improving energy efficiency by ensuring that heating or cooling is applied only where and when it is needed.

• **Occupancy-based control via radar sensors:** Radar sensors detect the presence of people in various rooms or areas, allowing the system to adjust heating, cooling, and lighting based on actual occupancy, reducing energy waste when rooms are unoccupied.

• **LoRaWAN-enabled sensor network:** The LoRaWAN (Long Range Wide Area Network) sensor network connects a variety of environmental sensors across the building, collecting real-time data on temperature, humidity, and occupancy, which can then be used to optimize energy use.

• **Behavioral nudging via the GreenIST assistant:** GreenIST, an AI-driven virtual assistant, encourages residents to adopt energy-efficient behaviors by providing personalized feedback and suggestions, such as lowering thermostats at night or turning off appliances when not in use.

The integration of these advanced technologies with IPMVP Option D enables the project to systematically monitor and verify achieved energy savings while guaranteeing the long-term effectiveness and sustainability of implemented measures. This comprehensive approach enables a more accurate assessment of how each intervention contributes to overall energy efficiency improvements.

This methodology was applied step-by-step as follows:

Step 1: Development of the Baseline Energy Model

A whole-building energy model was created for each residential block using EnergyPlus as the core simulation engine. The model incorporated:

- Architectural characteristics (wall/roof/window U-values, infiltration rates)
- System-level HVAC data (radiator capacities, control schedules)
- Internal loads and usage profiles (based on average occupancy data)
- Weather files specific to İstanbul's historic TMY and actual 2024 data

In the absence of detailed historical consumption for some units, simulation modeling became essential to approximate pre-intervention performance.

Step 2: Calibration of the Energy Model

Using measured energy consumption data collected via LoRaWAN sensors and Modular Max devices, the simulation model was calibrated to match actual energy use observed during a defined monitoring period (February–April 2024).

Calibration Metric	Threshold (ASHRAE Guideline 14)	Bayrampaşa Model
NMBE (Normalized Mean Bias Error)	±5%	2.8%
CV(RMSE) (Coefficient of Variation of RMSE)	<15% (monthly)	11.2%

Table 5. Calibration followed ASHRAE guideline 14 performance targets

Through iterative adjustment of inputs such as thermostat schedules, internal gains, and envelope performance, the model was tuned until it aligned closely with measured values.

Step 3: Weather-Normalized Adjusted Baseline Generation

To isolate the impact of energy-saving interventions, the calibrated model was re-simulated using actual weather data from the reporting period (May–September 2024). This produced an "adjusted baseline" – i.e., how much energy would have been consumed under the same weather conditions if no intervention had occurred.

Weather data for the project was sourced from two key sources:

- MGM Türkiye Meteorological Data[50]: This data is provided by the Turkish State Meteorological Service (MGM) and offers accurate, localized weather information relevant to the Bayrampaşa area. It includes temperature, humidity, and other meteorological parameters that are essential for understanding the local climate conditions and optimizing energy consumption strategies.
- NOAA/ASHRAE IWEC Datasets: The International Weather for Energy Calculations (IWEC) datasets, provided by the National Oceanic and Atmospheric Administration (NOAA) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), offer standardized weather data for energy modeling. These datasets include historical weather information, which is used for benchmarking and simulations to assess energy efficiency improvements.

By utilizing these weather data sources, the project ensures that energy optimization strategies are tailored to both current and historical climate conditions, contributing to more accurate modeling and verification of energy savings.

Step 4: Post-Intervention Measurement and Comparison

Following implementation of the AI-enhanced control system, real-time energy consumption metrics were systematically recorded and analyzed in relation to the modified baseline parameters. Post-intervention data included:

- Room-by-room thermal demand
- HVAC valve modulation (opening percentages)
- Occupancy patterns
- User interactions with the GreenIST assistant
- The difference between the adjusted baseline and the measured consumption was calculated as net energy savings attributable to the intervention.

Step 5: Attribution Analysis – Behavioural vs. System Savings

To distinguish between behavioural savings and automated control savings, a control group was established using:

- Units where smart valves were installed but no behavioural nudges were sent
- Units with user opt-in to GreenIST alerts and tips

Behaviour-related reductions (e.g., users reducing setpoints at night following nudges) were isolated using time-series correlation between system messages and consumption drop-offs.

Step 6: Sample Results and Emissions Impact

This step presents the results of the energy efficiency interventions implemented in the Bayrampaşa project, highlighting their impact on energy consumption and emissions reduction. Through comprehensive analysis of data obtained via multiple measurement and verification methodologies, the efficacy of these interventions in achieving significant reductions in energy consumption and corresponding decreases in carbon emissions has been conclusively established. The findings provide valuable insights into the effectiveness of the strategies applied, showcasing the potential for scaling these solutions in other urban environments to achieve significant environmental benefits. Table 6. Energy Savings and Emissions Reduction Metrics presents the key results of the project, including energy savings, measured consumption, and associated reductions in CO_2 emissions. The data is indicated in Table 6.

Metric	Value
Number of buildings modelled	24 apartment blocks
Calibrated simulation engine	EnergyPlus + LoRaWAN data
Adjusted baseline (May–Sep 2024)	2,850 kWh electricity, 1200 kWh Natural gas
Actual measured consumption (same period)	2,285 kWh, 960 kWh Natural gas
Net annualized savings	(~20.2%)
(Sample data) Associated CO_2 emission reduction	0.254 tons/year (based on 0.4 kg/kWh)

Table 6. Energy savings and emissions reduction metrics

3.4.3.4. Results of Study

The implementation of IPMVP Option D in Bayrampaşa demonstrated a robust, standardized pathway for quantifying energy efficiency gains in complex residential settings with limited pre-existing data. The calibrated simulation approach enabled high-confidence savings estimates, supporting policy-level decisions and providing the following:

- A replicable framework for other districts in İstanbul
- A validation methodology for green funding mechanisms (e.g., carbon credits, ESCO contracts)
- Evidence for behavior-driven emissions reduction potential in existing housing stock

Initial pilot tests of the system have demonstrated promising results in terms of both energy savings and user engagement:

The energy savings were as follows:

- Users who engaged with the AI-driven recommendations achieved an average energy savings of 10% to 20%.
- The most significant reductions in energy consumption were observed in HVAC adjustments during unoccupied periods.

User engagement was as follows:

- A high percentage of users actively interacted with GreenIST features, such as accessing weekly reports and responding to recommendations.
- User feedback indicated that the system facilitated easier management of energy consumption and improved overall awareness of energy use.

The findings substantiate the efficacy of the integrated sensor and AI-driven methodology in delivering energy conservation while simultaneously promoting a culture of energy efficiency among building occupants.

3.4.4. Smart Energy Management for Climate-Neutral İstanbul

When implemented at scale across İstanbul's urban landscape, this energy management system has the potential to generate significant citywide energy savings. Initial projections suggest that behaviour-

based energy efficiency measures alone could lead to an estimated annual energy savings of 240 GWh. Furthermore, the widespread adoption of this system in public buildings could reduce carbon emissions by over 13,000 tons per year, contributing significantly to the city's climate-neutral goals. Increased engagement by residents in energy-saving practices would further support the transition toward a more sustainable urban environment.

The synergistic implementation of real-time energy monitoring technologies and AI-based behavioral modification strategies has exhibited considerable efficacy in improving energy performance in building operations. Key outcomes of the project include:

- Optimized energy usage through personalized user engagement.
- Long-term energy savings driven by contextual feedback and behavior modification.
- Increased community participation in energy conservation efforts.

A city-wide roll-out of the GreenIST app, supported by structured user on-boarding and continuous feedback loops, could accelerate İstanbul's transition to a more energy-efficient and sustainable future. Expanded research efforts and sector-specific pilot programs would enhance system performance while broadening its applicability, contributing substantively to the city's climate-neutral objectives.

3.4.5. Policy Guide: Scaling Smart Energy Efficiency Systems in İstanbul's Building Stock

Context and Rationale

İstanbul's urban fabric, consisting of over 1.6 million buildings, represents a critical opportunity for implementing energy efficiency measures aligned with the city's climate neutrality goals. Buildings account for nearly 24 TWh of annual energy consumption, with HVAC systems alone responsible for approximately 45% of this usage. Rapid urbanization, outdated infrastructure, and behavioural inefficiencies contribute to energy waste and carbon emissions at scale.

Behavioural and AI-supported energy efficiency systems offer a cost-effective, scalable, and citizen- centered pathway to reduce energy use and emissions while improving indoor comfort. However, widespread adoption remains limited due to structural, financial, and policy-related barriers.

Policy Objective

To foster an enabling framework that promotes the deployment and scaling of intelligent energy efficiency systems, specifically those incorporating real-time monitoring and behavioural feedback mechanisms, across public and private sector buildings in İstanbul.

Strategic Targets (2030 Horizon)

Retrofit 25,000 public and social buildings with real-time energy monitoring and AI-based guidance systems. Achieve a minimum 20% reduction in HVAC-related energy consumption in retrofitted buildings. Avoid over 500,000 tons of CO_2 emissions annually through behavior-based energy savings. Ensure citizen participation in energy awareness and demand reduction across all districts.

Policy Recommendations

- Regulatory and Institutional Reforms: Mandate energy monitoring in all newly constructed and renovated public buildings above a defined energy consumption threshold. Integrate behavioural energy efficiency tools into existing municipal energy and climate action plans. Establish a City Energy Digital Platform to centralize data from building sensors and guide citywide interventions.

- Financial Incentives and Funding Tools: Launch a Green Retrofit Fund (in collaboration with international climate finance institutions) to support municipalities and housing cooperatives. Provide performance-based subsidies or tax credits for buildings achieving >15% energy savings verified by monitoring. Enable ESCO (Energy Service Company) contracting mechanisms in municipal procurement frameworks.
- Technical Standards and Open Data Infrastructure: Promote interoperable, open-protocol systems (e.g., BACnet, MQTT) to enable vendor-agnostic scalability. Require the use of standardized tagging and ontologies (e.g., Project Haystack, Brick Schema) to harmonize building data. Support the development of a public sensor and energy data API for research and innovation purposes.
- Capacity Building and Awareness: Implement energy behavior education programs in schools, municipal workplaces, and residential cooperatives. Train building managers and facility operators on data-informed HVAC control and behavioral nudging strategies. Recognize “Energy Smart Districts” through a municipal labeling scheme that rewards innovation and participation.

3.5. Potential Impacts of Urban Transformation in İstanbul

This section examines the potential impacts of urban transformation areas in İstanbul. It focuses on identifying materiality areas for urban transformation processes, emphasizing sustainable, usable, and replicable solutions. The general urban transformation profile of İstanbul will be presented, with an emphasis on eight key criteria used to prioritize areas. These criteria include factors such as area size, population density, and the number of buildings. Furthermore, all urban transformation areas in İstanbul have been thoroughly analysed based on these criteria, and a comprehensive evaluation matrix has been developed to assess these factors collectively. Finally, based on the analysis, five urban transformation areas have been identified as priorities for the development of green/carbon-neutral buildings and regions.

3.5.1. Overview of Urban Transformation Profile in İstanbul

Urban transformation in İstanbul is a key element of the city’s development strategy, aimed at enhancing resilience, modernizing infrastructure, and ensuring sustainable urban growth. The city's ongoing challenges, such as accelerated urban growth, deteriorating infrastructure, and earthquake hazards, necessitate targeted transformation efforts aimed at elevating quality of life while concurrently tackling ecological and socio-economic issues. This process has become increasingly crucial in recent years, driven by both the magnitude of the expected earthquake, due to İstanbul's location on an active fault line, and the increasing need for urban renewal.

The migration of rural populations to İstanbul, driven by rapid industrialization and economic growth following World War II, led to significant changes in housing requirements. The proliferation of illegal settlements, driven by unmet housing requirements, subsequently transitioned into established informal settlements amid increasing migratory inflows. İstanbul, located in the 1st-degree earthquake zone, was hit by the devastating 1999 Marmara and Düzce earthquakes, which caused substantial loss of life and damaged thousands of buildings. This event marked a critical milestone in shaping the post-2000 urban planning agenda, particularly for İstanbul.

As a result of the dense urbanization in İstanbul and the potential risk of a major earthquake, an intensive urban transformation process has been underway, particularly in the past few years. Supported by legal frameworks, this transformation has become a central factor influencing the dynamism of various economic sectors in İstanbul and Türkiye. The Ministry of Environment, Urbanization, and Climate Change, along with the İstanbul Metropolitan Municipality (IMM) and affiliated organizations, have identified high-risk areas across the city, resulting in the designation of numerous large and small-scale urban transformation zones.

A central component of this transformation initiative involves the systematic renovation of an estimated 242,000 residential buildings in İstanbul, slated for completion between 2022 and 2035. This goal is part of a broader strategic initiative outlined in İstanbul's official planning documents, including the İstanbul Climate Action Plan (ICAP)[51] in 2021. The transformation plan focuses on addressing structural vulnerabilities, particularly in high-risk areas, while also improving energy efficiency and climate resilience. This transformation aligns with both earthquake risk mitigation and energy efficiency goals. Additionally, the

IMM Urban Transformation Strategy sets forth a multi-year plan for retrofitting structurally vulnerable buildings, integrating climate adaptation measures, energy efficiency, and resilience to natural disasters. The IMM Earthquake Master Plan, developed in collaboration with Boğaziçi University – Kandilli Observatory, further emphasizes the vulnerability of İstanbul's building stock, especially those constructed before 1999, and the urgent need for retrofitting in high-risk zones.

While the 242,000 unit goal primarily addresses seismic and structural transformation requirements, it is strongly linked to energy efficiency and climate goals within the ICAP framework. These buildings are expected to undergo transformations that will contribute to low-carbon, energy-efficient, and climate-resilient urban development. This large-scale urban transformation presents significant opportunities for the widespread adoption of low-carbon technologies, further advancing İstanbul's commitment to sustainable urban growth.

3.5.2. Analysis Criteria of Urban Transformation

The "Law on the Transformation of Areas at Risk of Disasters" (No. 6306) in Türkiye designates areas with hazardous or outdated structures as "risk zones" under the authority of the Ministry of Environment, Urbanization, and Climate Change. This law grants the ministry specific powers to carry out urban transformation processes. In line with this, 69 areas in İstanbul have been identified as "risky areas."[52]. Some of these areas have only been marked as risk zones, with the urban transformation process (such as demolition, reconciliation, and reconstruction) yet to begin, while others are at different stages of transformation, including construction, evacuation, demolition, and reconciliation.

Status	Value	Ratio (%)
Declared a risky area*	26	37,7%
Construction stage	21	30,4%
Evacuation and demolition process	10	14,5%
Conciliation stage	8	11,6%

Table 7. Current situations of risky areas in İstanbul

The development of carbon-neutral building designs requires that the urban transformation process has not commenced in these areas. The implementation of integrated systems or large-scale applications is inherently restricted in zones where urban redevelopment processes have already been initiated. Consequently, these 69 areas are classified into two categories: areas where carbon-neutral building designs can be fully implemented (28) and areas where only limited implementation is feasible.

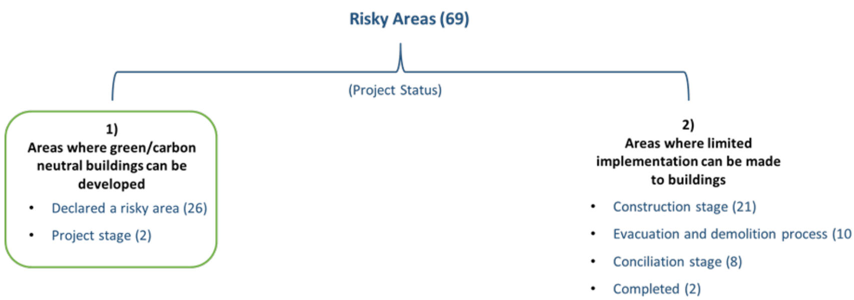


Figure 22. Distribution of current situations of risky areas in İstanbul

When prioritizing areas where green/carbon-neutral building designs can be developed and replicated, it was deemed appropriate to select from the designated Area 1. The study has developed a set of prioritization criteria to systematically evaluate and identify suitable zones within the 28 designated sites for the implementation of carbon-neutral building design strategies.

These criteria are as follows:

- Area Size
- Population Density
- Number of Existing Buildings
- Presence of Mixed-Use Function
- Public Ownership
- Private Ownership
- Renewable Energy Investments and Projects
- Proximity to E-mobility Areas

The project partners, together with the Urban Transformation Department of the İstanbul Metropolitan Municipality, conducted a joint session via the Menti program to prioritize the criteria. Participants were asked to score these criteria.

According to the results of the workshop, the most important selection criteria for determining areas suitable for the implementation and replication of green/carbon-neutral building designs are, in order: Population Density, Area Size, Number of Existing Buildings, Presence of Private Ownership, Presence of Public Ownership, Renewable Energy Investments and Projects, Presence of Mixed-Use Function, and Proximity to E-mobility Areas.

Materialization Criteria	Materiality score (1-5)
Population Density	**4.6**
Area Size	**4.3**
Number of Existing Buildings	3.6
Presence of Private Ownership	3.5
Presence of Public Ownership	3.3
Renewable Energy Investments and Projects	3.1
Having Multi-Purpose Use	2.8
Proximity to E-mobility Areas	2.6

Table 8. The scores of prioritization criteria based on workshop results.

3.5.3. Analysis of Urban Transformation Areas

Through a methodical assessment process, the 28 goal areas prioritized for carbon-neutral and green building implementation have been comprehensively analyzed and geographically mapped against predetermined parameters. İstanbul, a transcontinental megacity, exhibits a pronounced concentration of high-risk zones within its European sector, where aging residential developments and historic working-class neighborhoods are predominantly located.

- Population Density: Population densities in risky areas were examined. The lowest population density is 118 people/ha; the highest population density is 924 people/ha. Densely populated areas have the potential to reduce greenhouse gas emissions more, as the transformation will have a greater impact[52].

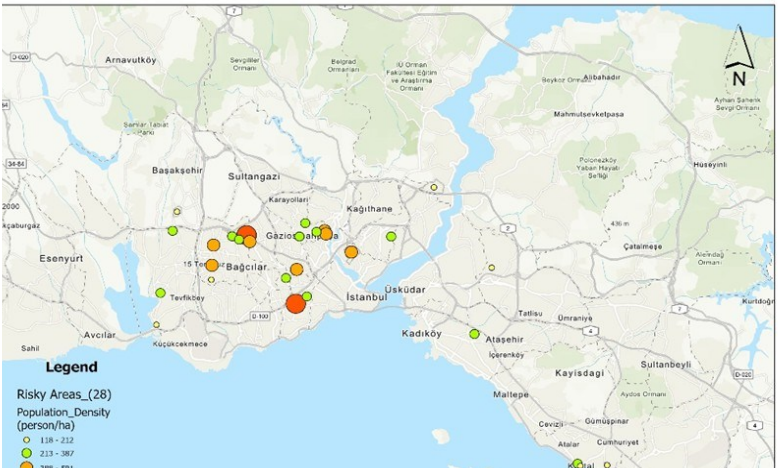


Figure 23. Population density map of risky areas in İstanbul

- **Area Size:** The sizes of the risky areas vary significantly, ranging from 0.9 ha to 140 ha. These areas have been examined and categorized into four groups based on their size. The largest risky areas are located in the districts of Beyoğlu and Sarıyer (highlighted in red), with areas of 123 ha and 140 ha, respectively [52].

The size of the area to be transformed can have a significant impact on the environmental and economic outcomes of the transformation. Extensive urban areas are recognized as having significant potential to advance the transition toward carbon-neutral cities, as they enable economies of scale and facilitate more substantial reductions in greenhouse gas emissions.

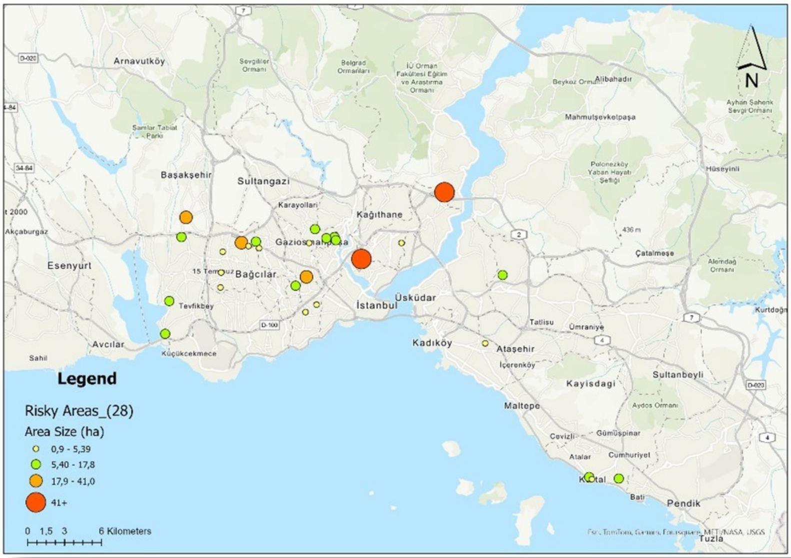


Figure 24. Area size distribution map of risky areas in İstanbul

- **Number of Existing Buildings:** The number of buildings located in risky areas and planned for transformation varies according to the size of the area. Preliminary assessments indicate that four of the designated urban transformation zones in İstanbul each contain over 1,000 buildings requiring redevelopment. Building density can also significantly affect the environmental and economic impacts of the transformation, in parallel with the size of the area. In addition to benefiting from economies of scale, more funds can be allocated to infrastructure investments such as public transportation, bicycle paths, and green spaces in projects covering more buildings [52].

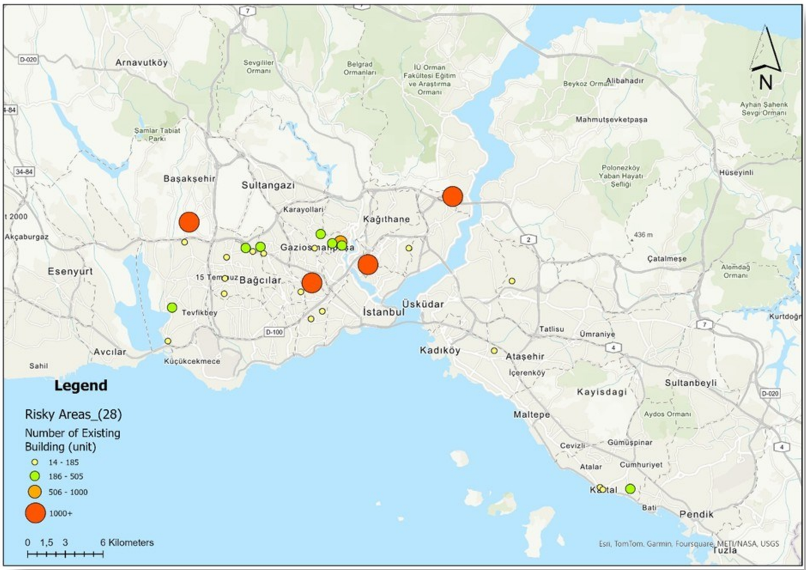


Figure 25. Number of existing buildings and map of risky areas in İstanbul [52].

- **Title:** Urban transformation areas are formed by the merger of many parcels. These parcels can have various title structures. When examining urban transformation areas in İstanbul, it is observed that there are public, private, and co-owned properties. Areas with multiple co-owned parcels are characteristics that can sometimes positively and sometimes negatively affect the transformation process. The presence of public ownership can be among the factors that accelerate the transformation process in terms of ease of authorization. On the other hand, the existence of private ownership can also be among the factors that accelerate the process by increasing the demand for transformation.

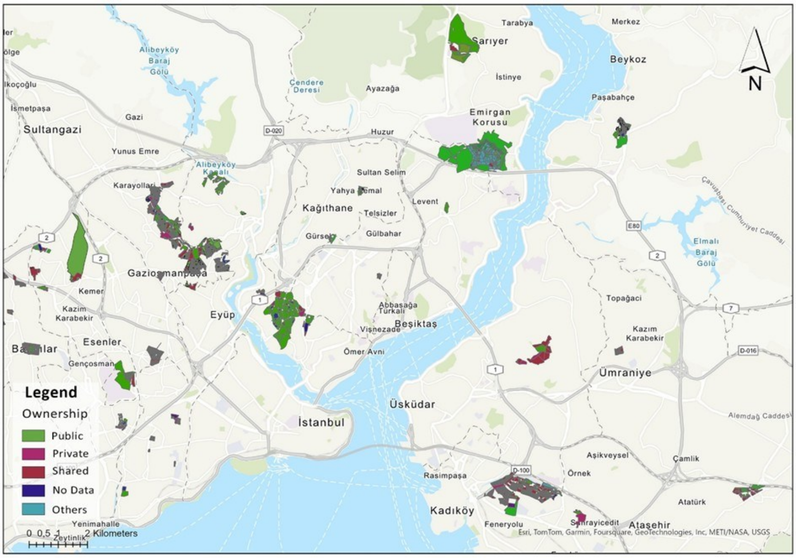


Figure 26. Ownership map of risky areas in İstanbul[52].

- **Multi-Purpose Usage:** The functional uses within the transformation areas show that some are designated exclusively for residential use, while others include a mix of residential, commercial, and public functions. The transformation of buildings with different functions can result in varying environmental and economic outcomes. Transforming single-function buildings may be more straightforward in terms of planning and implementation, but the social impacts, particularly related to community awareness and engagement, may be less predictable. The transformation of mixed-use zones, despite its inherent complexities, presents a disproportionately higher mitigation potential compared to single-function areas, coupled with enhanced opportunities for socio-economic value creation.

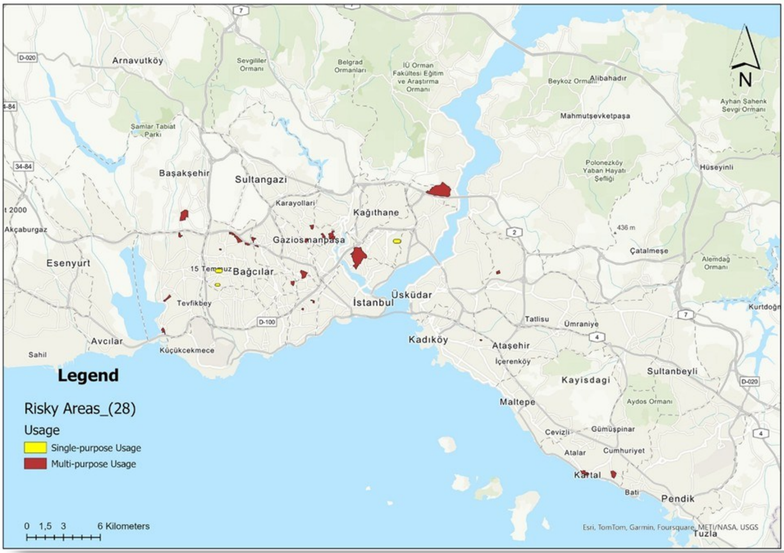


Figure 27. Usage map of risky areas in İstanbul

- **Proximity to E-mobility Areas:** İstanbul is one of the pioneer cities of Türkiye in the field of e- mobility. In recent years, important steps have been taken to promote e-mobility in the city and investments in this field have accelerated. A significant portion of the increase in the number of electric vehicles and charging stations in Türkiye is in İstanbul. According to Republic of Türkiye Energy Market Regulatory Authority data prepared for the year 2024, there are 1411 charging stations in İstanbul. E-mobility infrastructure can help reduce dependence on fossil fuels and reduce energy consumption by providing areas with facilities such as electric vehicle charging stations and bicycle parking areas. The widespread use of charging stations is also an important incentive for the widespread use of electric/hybrid vehicles. The map below shows the distribution of charging stations in İstanbul[52].

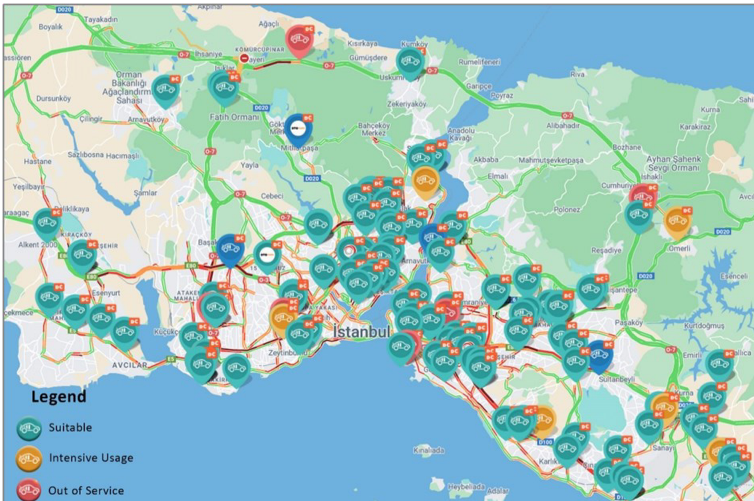


Figure 28. Distribution of e-mobility areas map of risky areas in İstanbul [52].

3.5.4. Materialization Analysis Findings

Based on the criteria mentioned above, materiality urban transformation areas have been identified in İstanbul for the transition to carbon-neutral buildings and urban designs. In determining these materiality areas, the criteria were analysed using the Analytical Hierarchy Process (AHP), and a matrix was created. The AHP is a method used to address complex decision-making problems. This method involves evaluating alternatives according to specific criteria and determining the relative importance of these criteria. As a decision-support tool, AHP provides a methodological approach to minimize arbitrariness in judgment through its mathematically derived pairwise comparison system, promoting more evidence-based policy and planning outcomes. In this matrix, all urban transformation areas were assessed according to each of the defined criteria and weighted accordingly. The materiality areas were determined by multiplying the weighting results with the materiality criteria scores. The results of the prioritization matrix are indicated Table 9.

NO	District	Neighborhood	Area Size (ha)	(K1)	K1 (4,3)	Number of Existing Building	(K2)	K2 (3,6)	Population	Population_Density (person/ha)	(K3)	K3 (4,6)	Mixed Usage (yes(2)-no(1))	K4 (2,8)	Ownership (Public yes/N-no	E-mobility Proximity (1-2-3	RESULTS
17	BEYOĞLU	FETİHTEPE,KAPTANPA	123,25	7,0	30,2	5637	9,8	35,2	65933	535	1,4	6,7	2	5,6	3,3	3	391.573
13	SARIYER	ARMUTLU	140,62	8,0	34,4	3612	6,3	22,5	24703	176	0,5	2,2	2	5,6	3,3	2	62.671
2	BAYRAMPAŞA	VATAN	23	1,3	5,6	1058	1,8	6,6	13587	591	1,6	7,4	2	5,6	3,5	2	10.709
14	BAŞAKŞEHİR	ZİYA GÖKALP	41	2,3	10,0	1013	1,8	6,3	8680	212	0,6	2,6	2	5,6	3,3	1	3.088
28	BAĞCILAR	GÖZTEPE	21,84	1,2	5,3	505	0,9	3,2	7063	323	0,9	4,0	2	5,6	3,3	2	2.505
19	GAZİOSMANPAŞA	PAZARİÇİ 2. KISIM	16,16	0,9	4,0	775	1,3	4,8	7609	471	1,3	5,9	2	5,6	3,3	1	2.071
5	ESENLER	ORUÇREİS-1	7,23	0,4	1,8	389	0,7	2,4	6681	924	2,5	11,5	2	5,6	3,5	2	1.936
18	GAZİOSMANPAŞA	PAZARİÇİ 1. KISIM	7,22	0,4	1,8	474	0,8	3,0	3283	455	1,2	5,7	2	5,6	3,3	1	546
9	KARTAL	YUKARI	11	0,6	2,7	147	0,3	0,9	4259	387	1,0	4,8	2	5,6	3,3	2	440
10	KARTAL	YUNUS	17,8	1,0	4,4	255	0,4	1,6	2352	132	0,4	1,6	2	5,6	3,3	2	421
20	GAZİOSMANPAŞA	YENİDOĞAN 1. KISIM	7,12	0,4	1,7	339	0,6	2,1	2702	379	1,0	4,7	2	5,6	3,5	1	341
12	KÜÇÜKÇEKMECE	KANARYA	9,2	0,5	2,3	302	0,5	1,9	3202	348	0,9	4,3	2	5,6	3,3	1	340
6	ESENLER	ÇİFTEHAVUZLAR	8,29	0,5	2,0	150	0,3	0,9	2845	343	0,9	4,3	2	5,6	3,3	2	300
1	BAĞCILAR	KEMALPAŞA	5,39	0,3	1,3	179	0,3	1,1	1701	316	0,9	3,9	2	5,6	3,5	2	227
15	GAZİOSMANPAŞA	BAĞLARBAŞI 2	7,56	0,4	1,9	242	0,4	1,5	2208	292	0,8	3,6	2	5,6	3,3	1	188
21	ZEYTİNBURNU	SEYİTNİZAM	2,26	0,1	0,6	118	0,2	0,7	2023	895	2,4	11,1	2	5,6	3,5	2	178
26	KÜÇÜKÇEKMECE	İKİTELLİ (ATATÜRK)	6,3	0,4	1,5	183	0,3	1,1	1946	309	0,8	3,8	2	5,6	3,3	1	125
7	GAZİOSMANPAŞA	MERKEZ	4,94	0,3	1,2	168	0,3	1,0	1543	312	0,8	3,9	2	5,6	3,5	1	97
3	ZEYTİNBURNU	MERKEZEFENDİ	3,4	0,2	0,8	128	0,2	0,8	920	271	0,7	3,4	2	5,6	3,3	2	83
4	ESENLER	TUNA	2,56	0,1	0,6	80	0,1	0,5	1151	450	1,2	5,6	2	5,6	3,3	2	65
25	BAĞCILAR	MAHMUTBEY	1,8	0,1	0,4	63	0,1	0,4	941	523	1,4	6,5	2	5,6	3,5	2	44
11	KÜÇÜKÇEKMECE	FATİH	8	0,5	2,0	123	0,2	0,8	945	118	0,3	1,5	2	5,6	3,3	1	41
27	ÜMRANİYE	ELMALIKENT	6,3	0,4	1,5	110	0,2	0,7	773	123	0,3	1,5	2	5,6	3,3	1	30
16	KADIKÖY	MERDİVENKÖY	1,55	0,1	0,4	39	0,1	0,2	434	280	0,8	3,5	2	5,6	3,3	3	18
24	BAĞCILAR	GÜNEŞLİ (THY A-C SİTE	2,4	0,1	0,6	20	0,0	0,1	1221	509	1,4	6,3	1	2,8	3,3	2	9
8	KARTAL	KORDONBOYU	3,2	0,2	0,8	19	0,0	0,1	490	153	0,4	1,9	2	5,6	3,3	2	7
22	ŞİŞLİ	FULYA	1,5	0,1	0,4	17	0,0	0,1	514	343	0,9	4,3	1	2,8	3,3	3	5
23	BAĞCILAR	BAĞLAR	0,9	0,1	0,2	14	0,0	0,1	164	182	0,5	2,3	1	2,8	3,5	2	1

Table 9. Matrix of prioritized areas [53].

3.5.5. Results of Study

Spatial analysis reveals that the districts of Beyoğlu, Sarıyer, Bayrampaşa, Başakşehir, and Bağcılar contain urban regeneration areas with the highest potential for carbon-neutral building retrofits, making them critical to İstanbul's decarbonization pathway. While the criteria of area size and population density were at the forefront in some of these areas, other factors were effective in some others. The features of these 3 areas are detailed below[52].

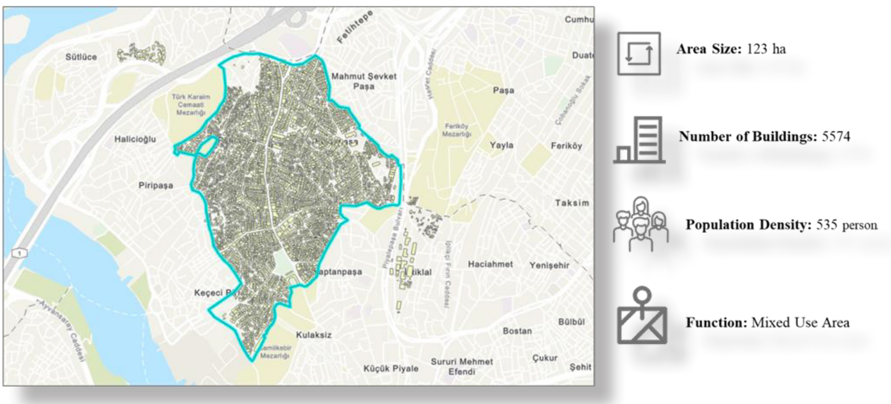


Figure 29. Beyoğlu district
(Fetihtepe, Kaptanpaşa, Keçecipiri, Piyalepaşa neighborhoods)

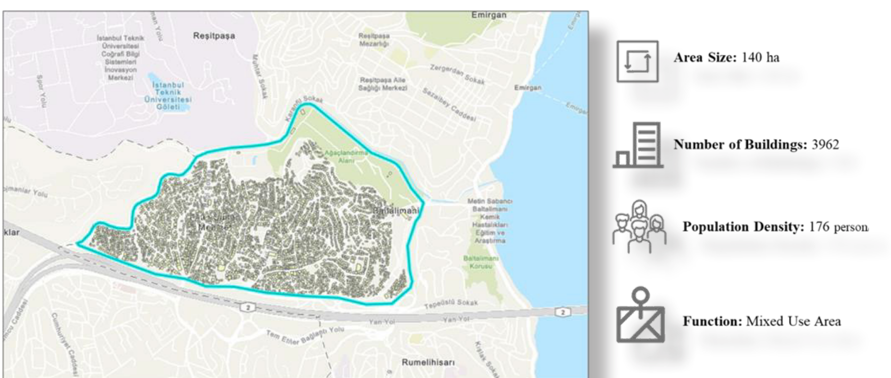


Figure 30. Sarıyer district (Armutlu neighborhood)

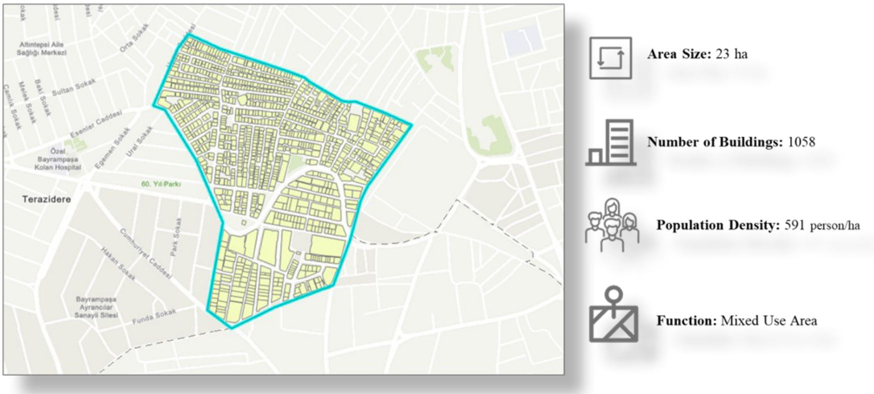


Figure 31. Bayrampaşa district (Vatan neighborhood)

This section has examined the potential impacts of the analyses conducted on urban transformation areas in İstanbul. With a focus on sustainable, functional, and replicable solutions, the study aimed to identify materiality areas to guide the urban transformation process. In this context, the general urban transformation profile of İstanbul was outlined. A structured participatory methodology, involving municipal coordination and multi-stakeholder workshops, yielded eight principal evaluation criteria for area prioritization. All urban transformation areas in İstanbul were systematically analysed based on these criteria, and a comprehensive evaluation matrix was developed to assess these factors collectively. Based on the matrix results, five urban transformation areas have been designated as materiality zones for the development of green and carbon-neutral buildings and districts. Furthermore, the findings of this study contribute to broader research on sustainable urban transformation, providing a strategic foundation for future policy development, urban planning initiatives, and decision-making processes for both public and private stakeholders. The results also serve as a reference for similar transformation projects in other metropolitan areas, facilitating knowledge transfer and best practices in urban sustainability.


GREEN FINANCING

4. Section

Green Financing Module

4.1. Overview of Green Finance

Green finance, at its core, represents a paradigm shift in how capital is mobilized and allocated, directing financial flows towards projects and initiatives that deliver positive environmental outcomes[54]. It is not a niche within traditional finance but rather a framework that seeks to integrate environmental considerations into financial decisions.

At the intersection of environmental imperatives and economic realities lies climate finance. While often used interchangeably, climate finance can be considered a subset of green finance, specifically focusing on financial resources dedicated to addressing climate change. This includes financing for mitigation efforts, such as renewable energy deployment and energy efficiency improvements, as well as adaptation measures, like building resilient infrastructure and developing drought-resistant agriculture. Green finance, however, encompasses a broader spectrum of environmental concerns, including biodiversity conservation, pollution control, and sustainable resource management. Green finance serves as a critical mechanism for directing capital investments toward dual objectives: mitigating the drivers of environmental degradation while simultaneously enhancing adaptive capacity to climate change impacts. Both concepts are inextricably linked to the overarching goal of sustainability, aiming to meet the requirements of the present without compromising the ability of future generations to meet their own requirements.

Underpinning the principles of green finance are Environmental, Social, and Governance (ESG) criteria. These non-financial factors are increasingly being integrated into investment analysis and decision- making. The “E” in ESG directly aligns with green finance objectives, evaluating how a company or project impacts the natural environment. Incorporating ESG criteria allows investors to assess environmental risks and opportunities, identify sustainable investments, and contribute to positive environmental change.

A critical aspect of realizing the potential of green finance is ensuring access to finance. This involves creating enabling environments that facilitate the flow of capital to green projects. Innovative financial instruments, such as green bonds, green loans, and blended finance mechanisms, are crucial in mobilizing public and private capital. Furthermore, capacity building and technical assistance are essential to empower stakeholders in developing a robust pipeline of green projects.

Local administrations occupy a unique and significant position in the green finance landscape. Their proximity to local environmental challenges and their ability to implement on-the-ground solutions make them indispensable actors [55]. Local authorities can play several crucial roles:

- **Policy and Regulation:** They can enact local ordinances and regulations that incentivize green practices, such as building codes that promote energy efficiency, zoning laws that favour green spaces, and waste management policies that encourage circularity.
- **Project Development and Implementation:** Local governments can initiate and lead green infrastructure projects, such as investing in public transportation, developing green buildings, and implementing local renewable energy initiatives.
- **Public Awareness and Engagement:** They can raise public awareness about environmental issues and the benefits of green finance, fostering community participation and support for sustainable initiatives.
- **Facilitating Access to Finance:** Local authorities can create platforms to connect local green projects with potential investors, potentially through special instruments like bonds or by providing guarantees for local green loans.
- **Strategic Planning and Integration:** They can integrate green finance considerations into their overall development plans, ensuring that environmental sustainability is a central pillar of local economic growth.

The benefits of active participation and leadership by local administrations in green finance efforts are crucial. Firstly, it allows for the development of tailored solutions that address specific local environmental challenges. Secondly, it fosters local economic development by creating green jobs and attracting green investments. Thirdly, it enhances the resilience of local communities to environmental risks. Finally, it empowers citizens and businesses to actively contribute to a sustainable future, fostering a sense of ownership and responsibility.

In conclusion, green finance is a multifaceted concept that extends beyond simply funding environmentally friendly projects[56]. It represents a fundamental shift towards integrating environmental considerations into the fabric of the financial system. By comprehensively examining its linkages to climate finance and sustainable development, strategically applying ESG (Environmental, Social, and Governance) criteria, mobilizing capital toward both mitigation and adaptation initiatives, promoting inclusive financial accessibility, and strengthening the capacity of local governments to assume leadership roles, we can fully realize the transformative power of green finance. This approach is essential for fostering a more climate-resilient, sustainable, and economically viable future.

4.2. Financing Models and Mobilizing Resources

Building upon the foundational understanding of green finance, the crucial next step lies in exploring the financing models and sources that can be mobilized to fuel this transformative shift. The transition towards a sustainable economy necessitates a multi-pronged approach, leveraging both public and private capital through innovative financial mechanisms [57].

The contemporary green finance ecosystem comprises multiple financing frameworks, systematically designed to align with varying project typologies and their respective risk-reward matrices. Public finance plays a foundational role, often providing initial capital for developing technologies and public projects. This can take the form of government budgets, grants, and concessional loans offered by development finance institutions (DFIs) like the World Bank and regional development banks. Private finance, on the other hand, encompasses investments from institutional investors (pension funds, insurance companies, sovereign wealth funds), commercial banks, private equity firms, and individual investors. Their involvement is crucial for scaling up green projects and bringing innovative solutions to market.

Beyond traditional public and private financing, market-based mechanisms are gaining prominence. Green bonds – fixed-income securities explicitly designated to fund environmentally sustainable initiatives – have experienced substantial market expansion, appealing to diverse investors who prioritize dual objectives of financial performance and measurable ecological benefits. Carbon markets, through mechanisms like cap-and-trade systems and carbon offsets, create a financial incentive for emissions reduction and can generate revenue streams for green projects. Environmental taxes and fees can also be levied on polluting activities, internalizing environmental costs and generating funds that can be reinvested in green initiatives.

The effective deployment of these financing mechanisms necessitates leveraging diverse funding sources, including domestic fiscal allocations, international climate finance instruments established under the UNFCCC framework – notably the Green Climate Fund (GCF) and Adaptation Fund – as well as multilateral development banks and bilateral financial institutions that provide concessional financing, grants, and capacity-building support for sustainable infrastructure projects in emerging markets. However, especially the vast pool of private capital, held by institutional and individual investors, represents the largest potential source of funding for the green transition.

A particularly potent approach to unlock private capital and enhance the feasibility of green projects is blended finance. This involves strategically combining public and philanthropic capital with private sector investment to de-risk projects, improve their financial viability, and attract commercial investors who might otherwise be hesitant to invest in purely market-rate terms[58].

The mobilization of the private sector is not merely about increasing the quantum of available funds; it also brings crucial expertise, innovation, and efficiency to the green finance ecosystem. Private sector involvement fosters the development of commercially viable green solutions, drives technological advancements, and promotes market-based approaches to environmental challenges. When private investors see clear market signals, supportive policies, and de-risked investment opportunities (often facilitated by blended finance), they are more likely to allocate significant capital to green assets. This increased private sector participation not only expands the financial resources available but also enhances the likelihood of project success through efficient management, technological innovation, and market-driven scalability.

4.3. Motivating Stakeholders

Building upon established principles of green finance, its associated financing mechanisms, and the pivotal importance of private sector engagement, several financial strategies can be effectively employed to incentivize multi-stakeholder participation in sustainable financing initiatives:

- **Risk-Adjusted Returns and Competitive Yields:** Structuring projects to offer competitive, risk- adjusted returns comparable to traditional investments. In Germany, KfW (a state-owned development bank) provides low-interest loans and grants for energy-efficient building retrofits.
- **ESG Integration and Performance Metrics:** Clearly demonstrating the positive environmental and social impact alongside financial returns through robust ESG reporting and standardized impact metrics. Green building rating systems provide standardized metrics for evaluating the environmental performance of buildings.
- **De-risking Mechanisms and Guarantees:** Utilizing blended finance structures where public or private capital provides guarantees, first-loss capital, or concessional loans can significantly reduce the risk. Development Finance Institutions (DFIs) offer partial credit guarantees to banks financing green building projects.
- **Tax Incentives and Subsidies:** Implementing tax breaks, subsidies, or feed-in tariffs for investments in green technologies to improve their financial viability. France offers tax credits for homeowners undertaking energy efficiency renovations, directly reducing the cost and incentivizing green upgrades. Morocco offers subsidies or reduced Value-Added Tax (VAT) on green building materials and technologies to make sustainable construction more affordable.
- **Green Bonds and Sustainable Finance Labels:** Clearly labelled green financial instruments provide transparency and allow investors to directly allocate capital to environmentally beneficial projects. Green bonds are increasingly being issued all over the world. Issuing municipal green bonds to finance local green initiatives is a widespread practice.
- **Grants and Seed Funding for Green Innovation:** Offering grants and seed funding specifically for pilot projects in green technologies and sustainable

solutions. As a key instrument of EU research policy, the Horizon Europe program allocates grant funding to support scientific and technological innovation in sustainable construction, with particular emphasis on pioneering green building materials and low-carbon construction methodologies.

- **Technical Assistance and Capacity Building:** Providing technical expertise and capacity- building support to develop projects and navigate the complexities. As part of its sustainable urban development mandate, the EBRD offers capacity-building support to project developers and subnational governments, enabling the effective planning and implementation of high-performance building projects.
- **Public Procurement Policies Favouring Green Solutions:** Procurement policies that prioritize environmentally friendly goods and services can create a stable demand for sustainable practices. Some cities have regulations that mandate minimum energy efficiency standards for new public buildings.
- **Carbon Pricing Mechanisms:** Implementing carbon taxes or cap-and-trade systems can create a direct financial incentive. The implementation of building-specific carbon pricing frameworks remains limited in scale; however, the sector is increasingly affected by national carbon taxation regimes and cap-and-trade systems that create financial disincentives for energy-intensive building operations.
- **Streamlined Permitting and Regulatory Processes:** Reducing bureaucratic hurdles and streamlining permitting processes for green projects can lower development costs and timelines, making them more attractive.
- **Fiscal Incentives and Rebates:** Local administrations can offer tax rebates, development fee reductions, or other fiscal incentives for green buildings. Certain municipalities in the world offer rebates on property taxes for buildings that implement green building practices.
- **Public-Private Partnerships (PPPs) with Green Focus:** Structuring PPPs that prioritize green outcomes and offer attractive risk-sharing mechanisms to mobilize private sector expertise. PPPs in some countries have been used to develop energy-efficient social housing projects, with private developers contracted to build and maintain the properties to high environmental standards.
- **Seed Funding and Grants for Local Green Initiatives:** Providing small grants or seed funding for green projects and green businesses. Local authorities in Germany often provide small grants to community initiatives that promote

energy efficiency in residential buildings, such as neighbourhood-level energy advice centers.

- **Green Mortgages and Loans:** Offering favourable terms on credit lines for green projects. Several banks across the world offer green mortgages with preferential rates for energy- efficient homes or for financing energy-saving renovations.
- **Information and Awareness Campaigns:** Educating individuals about the financial benefits of green choices can drive behavioural change and investment decisions.

Through the strategic implementation of these financial mechanisms, policymakers and financial institutions can establish a robust value proposition that incentivizes stakeholder engagement, thereby catalyzing the expansion of green finance and advancing the transition to a climate-resilient, sustainable economy.

4.4. Delivering Green Finance

The following strategic outreach and implementation mechanisms can be employed to facilitate the effective allocation of critical green finance resources to target stakeholders:

Targeted Information and Awareness Campaigns to Augment Awareness:

- *Segmentation:* Recognizing that different stakeholders (private investors, businesses, local authorities, individuals) have varying information requirements and preferences and tailoring communication channels and messaging accordingly.
- *Digital Platforms:* Utilizing websites, social media, webinars, and online portals to disseminate information about available green options, eligibility, application processes, and success stories.
- *Industry Associations and Networks:* Partnering with relevant industry associations, business networks, and environmental organizations to reach their members with targeted information sessions, newsletters, and workshops.
- *Public Awareness Campaigns:* Launching broader public awareness campaigns through traditional media and community events to educate individuals and small businesses about green finance options and their benefits.

• *Dedicated Helpdesks and Advisory Services:* Establish accessible helpdesks staffed with knowledgeable professionals who can guide stakeholders through the processes and answer questions.

Streamlined Application and Approval Processes:

• *Simplified Procedures:* Designing user-friendly application forms and processes, minimizing bureaucratic hurdles and complexity.

• *Clear Eligibility Criteria:* Clearly articulating the criteria for different green finance instruments to avoid confusion and wasted effort.

• *Dedicated Green Finance Units:* Establishing dedicated units with expertise in green finance to expedite the review and approval of green projects.

• *Standardized Documentation:* Developing standardized documentation requirements to streamline the application process and reduce the burden on applicants.

Capacity Building and Technical Assistance:

• *Workshops and Training Programs:* Organizing workshops and training sessions for businesses, local authorities, and project developers to enhance their understanding of green finance, project development, and application processes.

• *Project Development Support:* Providing technical assistance in developing robust and financially viable green options.

Leveraging Intermediaries and Local Networks:

• Financial Institutions: Partner with banks and finance institutions to extend the reach of green finance to smaller businesses and individuals.

• *Non-Governmental Organizations (NGOs):* Collaborating with NGOs to disseminate information and facilitate access to green finance.

• *Aggregators and Special Purpose Vehicles (SPVs)*: Utilizing aggregators to bundle smaller green projects into larger, more attractive opportunities. SPVs can be created to manage specific green finance initiatives.

Innovative Delivery Mechanisms:

- *Crowdfunding Platforms:* Utilizing crowdfunding to mobilize smaller investments from a wider pool of individuals for community-based green projects.
- *Revolving Funds:* Establishing revolving green funds where successful projects are reinvested, creating a sustainable funding cycle.
- *Performance-Based Incentives:* Linking incentives to the achievement of specific environmental or social outcomes.

In essence, green finance represents a paradigm shift in capital allocation, characterized by the deliberate channeling of financial resources toward environmentally positive initiatives. This approach transcends conventional financing models by proactively addressing climate change mitigation and advancing sustainable development objectives. It's intertwined with climate finance and driven by ESG criteria, finding application in crucial areas like mitigation and adaptation.

It should be noted that it's a broad ecosystem; green finance encompasses various models (public, private, market-based), sources (government, private investors, international funds), and instruments (green bonds, loans, etc.). Mobilizing private capital is essential for scaling green initiatives and requires creating attractive returns. Local administrations play a vital role in creating enabling environments, developing projects, and engaging communities in green finance efforts. Financial mechanisms should be strategically designed to align with stakeholder-specific incentives, emphasizing dual returns—both economic profitability and measurable environmental benefits—to maximize engagement and impact. To ensure optimal fund distribution, stakeholders must be engaged through strategic outreach initiatives, efficient operational frameworks, institutional capacity development, and multi-channel deployment mechanisms.

Many green investments have longer payback periods. Patience and long-term investment horizons are necessary for their success. Strong and consistent policy signals and regulatory frameworks are fundamental to creating a stable and attractive environment for such long-term life cycle considerations.

LEGAL ENVIRONMENT

5. Section

Legal Environment Module

5. Legal Environment

Existing and historical climate change legislation, building regulations, and urban regeneration policies in Türkiye and Europe play a pivotal role in advancing environmental sustainability, enhancing energy efficiency, and developing climate-resilient infrastructure. Both regions have introduced various regulations to achieve the goals of climate change mitigation, energy conservation and sustainable urbanisation. These regulations play an important role in the building sector and urban regeneration.

In the processes of designing, constructing, operating and auditing green and carbon neutral buildings, regulations and standards play a fundamental role in both promoting environmental sustainability and ensuring legal compliance of projects. This chapter analyses in detail the legal frameworks in the European Union (EU) and Türkiye, directives, regulations and policy documents that shape green building practices.

5.1. EU Legislation

In line with the objectives of combating climate change and sustainable development, the European Union has established a comprehensive legislative framework to support green building and carbon neutral practices. This framework includes a number of directives and initiatives that regulate the energy performance, use of renewable energy and environmental impact of buildings.

European Green Deal:

- This comprehensive strategy, which sets out the EU’s goal of carbon neutrality by 2050, aims to increase the energy efficiency of buildings and promote the use of renewable energy.
- The Green Deal prioritises increasing the renovation rate of buildings and reducing energy consumption.

Energy Performance of Buildings Directive - EPBD:

- This directive, which aims to improve the energy performance of buildings and reduce energy consumption, requires all new buildings to be Nearly Zero Energy Buildings (NZEB).

• It also sets energy performance standards for the renovation of existing buildings.

Renewable Energy Directive - RED:

• This directive, which promotes the use of renewable energy in buildings, aims to popularise resources such as solar, wind and geothermal energy.

• It requires that part of the energy requirements of buildings be met from renewable sources.

Energy Efficiency Directive - EED:

• This directive, which aims to increase energy efficiency and reduce energy consumption, promotes the use of energy-saving technologies in buildings.

• It includes specific targets for improving the energy performance of public buildings.

Construction Products Regulation - CPR:

• This regulation, which assesses the environmental impact and sustainability performance of building materials, sets the standards for materials used in green building applications.

Renovation Wave Initiative:

• This EU initiative to improve the energy efficiency of the building stock aims to renovate 35 million buildings by 2030.

• It aims to reduce energy poverty and the carbon footprint of buildings.

EU Taxonomy for Sustainable Activities:

• This framework, which defines sustainable investment, aims to facilitate the financing of green building projects.

• It sets out criteria for assessing the environmental performance of buildings.

5.2. Türkiye Legislation

Türkiye has established a legal framework for green building and carbon neutrality targets through legislation and policy documents issued by various institutions, primarily the Ministry of Environment, Urbanisation and Climate Change and the Ministry of Energy and Natural Resources.

Law No. 6306 on the Transformation of Areas Under Disaster Risk:

- This law, which promotes energy efficiency and environmentally friendly practices in urban transformation projects, is helping to spread green building standards.

Land Use Law:

- The legal framework governing urban development, construction, and planning in Türkiye includes provisions that, while not directly targeting environmental sustainability, encourage eco-friendly design and development through selected articles and practices.

Law No. 775 on Squatter Housing:

- Although it does not directly mention environmental sustainability, it has an indirect environmentally friendly approach that aims to create regular settlements, improve infrastructure and create healthy living spaces. It can be expected to have some positive environmental impacts, particularly through urban regeneration, protection of green spaces and infrastructure provision.

Law No. 5627 on Energy Efficiency:

- This legislation, which aims to increase energy efficiency and reduce energy consumption in buildings, makes the use of the Energy Identity Certificate (EKB) mandatory.

Law No. 5346 on Renewable Energy:

- This law, which promotes the use of renewable energy sources in buildings, aims to disseminate sources such as solar and wind power.

Environment Law:

- This law, which promotes the reduction of the environmental impact of buildings and sustainable construction, provides a legal basis for green building practices.

Energy Identity Certificate (EKB) Regulation:

- This regulation, which assesses the energy performance of buildings, sets energy efficiency standards.

Zero Waste Regulation:

- This regulation, which promotes waste management and recycling practices in buildings, provides a framework in line with green building standards

Regulation on Energy Performance in Buildings (BEP-TR):

• The regulation ensures that buildings in Türkiye comply with defined energy efficiency standards and optimise their energy use. Originating from Energy Efficiency Law No. 5627, it aims to reduce energy consumption, lower greenhouse gas emissions, and limit environmental harm.

• In order to promote Nearly Zero Energy Buildings (nSEB), the Ordinance includes provisions that specifically require new buildings to meet Nearly Zero Energy standards.

Regulation of Thermal Insulation in Buildings:

• This regulation sets out the minimum thermal insulation requirements for buildings in order to reduce energy consumption, minimise heat loss and reduce carbon emissions.

• The regulation uses the TS 825 standard as a basic reference for determining the requirements for thermal insulation in buildings. It emphasises that thermal insulation materials and components used in buildings must meet certain performance criteria[59].

Planned Areas Land Use Regulation:

• The updates of March 11, 2025 introduced important regulations to promote environmentally friendly and sustainable construction. These aim to support green projects, particularly in areas such as water and energy efficiency, green certification practices, electric vehicle infrastructure and life cycle assessments.

• As of 2026, it is mandatory to install a rainwater storage system in buildings with a tank volume of more than 7 m^3 and a plot area of more than 2,000 m^2. This water will be used for garden irrigation and toilet reservoirs.

• In accommodation establishments with more than 200 beds, shopping centres with a construction area exceeding 10,000 m^2 and public buildings with a construction area exceeding 30,000 m^2 the installation of a grey water system is mandatory for the treatment of shower and sink water for use in toilets.

• New public buildings with a total construction area of more than 10,000 m^2 to be constructed after 2026 are required to be YeS-TR certified, Türkiye's national green building certificate. This regulation aims to increase energy efficiency and reduce environmental impact.

- Building licences and occupancy permits will include information on the presence or absence of installations such as electric vehicle charging units, solar and wind energy systems. In this way, condominium owners and buyers will be able to learn which systems are present in the building through the documents, and the relevant authorities will be able to carry out their inspections effectively[60].
- From 2027, Life Cycle Assessments (LCA) will be mandatory to assess the environmental impact of the materials used in the construction of buildings and the waste generated. These analyses aim to calculate and limit the carbon footprint of buildings.

Unplanned Areas Land Use Regulation:

- This regulation governs construction activities in areas of Türkiye that lack formal zoning plans. It plays a key role in guiding development in rural and coastal regions to align with environmental sustainability and carbon neutrality objectives.
- The regulation states that solar energy systems integrated into rooftops can be constructed using metal frameworks, as long as they do not surpass 125 m^2 in size and 150 cm in height, and do not require a reinforced concrete foundation. These types of structures are exempt from building and occupancy permits, but they must comply with technical and health standards.
- As of January 1, 2027, the carbon footprints of all new buildings will be calculated and reported. This will encourage the use of low-carbon materials in the emissions trading system and support the production of sustainable buildings.
- All processes related to buildings will be digitized. By transitioning to Building Information Modeling (BIM) systems, building lifecycle data will be transferred to digital platforms. This system will make permit and approval processes faster and more transparent.

Green Certification Regulation for Buildings and Settlements:

- The primary objective of the regulation is to establish assessment and certification systems aimed at reducing the negative environmental impact of buildings and settlements by promoting the efficient use of natural resources and energy. It also defines the qualifications of professionals and training institutions involved in the process, along with the procedures and principles related to the assessment criteria.

• The regulation covers the evaluation and certification of the sustainable environmental, social, and economic performance of both existing and new buildings and settlements. This process is conducted online through the "National Green Certification System" (YeS-TR).

Regulation on the Classification and Registration of Construction Contractors:

• This regulation serves as a key policy instrument aimed at enhancing quality within the construction sector and promoting the adoption of sustainable practices. By establishing a framework for assessing the qualifications of contractors, it facilitates the implementation of environmentally responsible and sustainable construction projects.

• Following a recent amendment, contractors involved in projects awarded the National Green Building Certificate are granted an additional five percent score in the classification system. This incentive is designed to encourage green transformation and expand the number of sustainable projects with lower environmental impacts in the building sector.

Both EU and Turkish legal frameworks provide a strong foundation for the promotion of green and carbon-neutral buildings. The EU comprehensive directives, along with Türkiye national regulations, aim to enhance the energy efficiency of buildings, encourage the use of renewable energy, and reduce environmental impacts.

5.2.1. Issues for Improvement of Existing Legal Arrangements in Türkiye

The legal regulations on climate change and energy efficiency in Turkiye have a significant development potential with the increasing awareness in recent years. In this context, clarifying and making the carbon neutrality goal binding through legislation will both facilitate the fulfillment of international climate commitments and be a strong step towards environmental sustainability. The enactment of the Climate Law, which is currently in the draft stage, will contribute to Türkiye's adoption of a holistic approach in climate policies. Moreover, designing urban regeneration projects in a more integrated manner with environmental objectives offers great opportunities not only in terms of infrastructure and housing renewal, but also in terms of reducing carbon emissions and ensuring sustainable urbanization. Steps in this area will enable Türkiye to develop more effective policies to tackle the climate crisis and make its cities more resilient for the future.

While Türkiye has made significant progress in energy performance and green certificates, there are great opportunities to further strengthen progress in this area. Full harmonization with the European Union's Energy Performance of Buildings Directive (EPBD) will strengthen Türkiye's legal framework on energy efficiency and contribute significantly to reducing environmental impacts. In this context, shifting energy efficiency practices from incentive-based to more mandatory will facilitate the proliferation of green certificates and the adoption of sustainable building practices. Urban transformation projects can both provide long-term savings and support environmental sustainability by making energy performance a higher priority. Steps in these areas will increase Türkiye's alignment with international standards and accelerate the achievement of sustainable urbanism goals.

5.2.2. Recommendations for Improving Existing Legal Arrangements in Türkiye

The recommendations have been developed by taking into account the views of the relevant stakeholders of our city and evaluating the existing legal framework in a holistic manner. In this process, contributions from local governments, the construction sector, and organizations active in the fields of energy and environment have played an important role. However, it is emphasized that the existing legal arrangements need to be further improved in order to achieve Türkiye's sustainable development goals and green transformation objective. In this framework, the necessary steps and concrete recommendations for strengthening the legal framework and implementing new strategic approaches are put forward.

Recommendations	Description
Climate Law Enactment	• Making the carbon neutrality goal binding. • Requiring local governments to prepare a climate strategy.
Revision of Law No. 6306	• Urban transformation should be based on energy and carbon performance, not just physical. • Addition of the definition of “green transformation”.
New Building Code in line with the Energy Performance Building Law	• Introducing a “zero energy” obligation for new buildings • Obligation to transform buildings with energy performance class below C.
Mandatory Carbon Footprint and Life Cycle Analysis	• Measuring the carbon impact of building materials and processes in urban transformation projects.
Green Financing Law	• Encouraging the financing of low-carbon, climate-resilient and resource-efficient projects, green building and transformation projects in line with environmental sustainability goals
Green Certification Incentives	• Extra license discount, fee exemption, zoning advantage for projects with green building certificates.

Table 10. Suggestions ın the context of legal framework

5.2.3. Supporting National Strategy and Action Documents

In addition to legal regulations, Türkiye has also developed several national-level strategy and action documents on environment and energy efficiency. These documents set comprehensive targets to support the achievement of the country’s sustainable development goals by promoting environmentally friendly growth, making energy consumption more efficient, reducing carbon emissions and increasing the use of sustainable energy resources. Alongside legislation, these strategies are making a significant contribution to building the necessary infrastructure for a sustainable future, raising public awareness and achieving environmental goals.

- **Twelfth Development Plan (2024-2028)**

Türkiye's 12th Development Plan (2024-2028) takes a comprehensive approach to sustainable construction and environmental mitigation. The plan aims to encourage the design of climate- responsive and energy-efficient buildings, as well as the renovation of existing buildings. To this end, it will promote the use of certificates such as nSEB (Nearly Zero Energy Building) and YES-TR. In addition, increasing the use of district heating and heat pumps will support sustainable energy use by improving energy efficiency. Life Cycle Anaylsis (LCA) practices, which assess the environmental, economic and social impacts of buildings throughout their life cycle, also play an important role in this plan. Innovative tools such as the Digital Product Passport and the Environmental Product Declaration will be used effectively to monitor and reduce the environmental impact of buildings[61].

- **Presidency of Strategy and Budget - Medium Term Program (2025-2027)**

Under the Medium Term Programme (2025-2027), Türkiye's policy to accelerate the green transformation process includes comprehensive steps in the areas of energy and climate. In this framework, external dependency will be reduced by increasing electricity generation from renewable energy sources, developing Renewable Energy Resource Areas (YEKA) projects on the condition that domestic products are used, and making efforts to exploit offshore wind energy potential. Energy efficiency will be increased, taking into account competitiveness and domestic production, especially in energy-intensive sectors. In addition, the implementation of the National Green Certification System (YeS-TR) will be supported, as well as the dissemination of green buildings with high renewable energy use and energy efficiency priorities. The programme will also finalise the preparation of the Second National Contribution Statement and the Long-Term Climate Change Strategy 2053, in line with the objectives of reducing greenhouse gas emissions and adapting to climate change. These policies are important instruments to support Türkiye in achieving its sustainable development goals[62].

- **Republic of Türkiye Updated First National Contribution**

Türkiye's main mitigation policies for the building sector until 2030 provide a comprehensive approach to reducing environmental impacts and increasing energy efficiency. These strategies include retrofitting existing buildings, constructing energy efficient buildings and using central heating solutions in densely populated areas. It also mentions promoting the use of new technologies such as renewable energy technologies, heat pumps, combined heat and power plants, and geothermal energy in areas far from the city centre. Prevention of heat loss, use of waste heat and heat storage solutions are among these strategies. In the design and construction of buildings, the use of integrated building design, Building Information Modelling (BIM) and modular construction technologies will be promoted to increase resource and energy efficiency. It also includes the creation of zero-waste systems, the provision of incentives for the use of greywater and rainwater, and increased self-consumption of renewable energy. These policies aim to increase the use of energy efficient white goods and electrical appliances, including the implementation of building performance codes and standards in residential and commercial buildings. These policies aim to increase energy efficiency, reduce carbon emissions and ensure the environmental sustainability of buildings in Türkiye[63].

- **Türkiye 2053 Long Term Climate Strategy**

As part of Türkiye's long-term climate strategy 2053, the building sector has been identified as one of the key materiality areas for achieving the net zero emissions goal. Strategies developed within this framework include decarbonising energy used directly in buildings, expanding the practice of Nearly Zero Energy Buildings (nZEB) and increasing the use of YES-TR (Green Certification System). In line with the reduction targets, by 2025, new buildings with a floor area of 2000 m² or more will meet nSEB standards; by 2030, 30% energy savings will be targeted in public buildings; by 2033, it will be mandatory for all new buildings to have an Energy Performance Certificate (EPC) class A; and by 2043, all new buildings will be constructed as Net Zero Operational Carbon buildings. By 2053, emissions from the building sector will be close to zero, avoiding around 2 billion tonnes of CO_2 equivalent emissions over 30 years. On the adaptation side, the aim is to integrate climate change adaptation measures into energy infrastructures, in particular to increase the resilience of electricity systems and support sustainable energy use. This approach aims to increase energy security and promote climate- resilient urbanisation[64].

- **2024-2030 Climate Change Mitigation Strategy and Action Plan**

As part of the 2024-2030 Climate Change Strategy and Action Plan, a number of strategic measures have been identified for the energy and buildings sectors. In the area of electricity generation, the aim is to reduce carbon intensity and disseminate low-carbon generation technologies. In addition, a roadmap will be developed for the deployment of carbon capture, utilisation and storage (CCUS) technologies to reduce unavoidable greenhouse gas emissions. In the buildings sector, the focus will be on improving energy efficiency in existing and new buildings. Consumption will also be reduced by promoting the energy efficiency of electrical appliances. Expanding district heating and cooling systems and promoting the use of environmentally friendly design and materials through the Green Certification System (YeS-TR) are also important strategies. In addition, the digital transformation of the construction ecosystem will be achieved and the use of Building Information Modelling (BIM) tools will be promoted and supported. This measure aims to make a significant contribution to reducing greenhouse gas emissions by increasing energy efficiency[65].

- **Climate Change Adaptation Strategy and Action Plan (2024-2030)**

The Climate Change Adaptation Strategy and Action Plan (2024-2030) sets out a number of policies and actions to adapt to climate change and improve sustainability in the energy and buildings sectors. For the energy sector, it aims to build climate-resilient infrastructure, increase the use of renewable energy sources and adapt energy production systems to climate conditions. As part of the strategy to increase the adaptive capacity and resilience of cities and urban dwellers, the buildings sector will take action to increase the resilience of building roofs and facades to severe weather events, and to develop site-specific green roofs, facades and smart building applications. In addition, energy efficiency in buildings will be improved, starting with building design, efficient appliances, the use of new and efficient technologies and the spread of district heating/cooling systems[66].

- **Energy Efficiency 2030 Strategy and II. National Energy Efficiency Action Plan (2024-2030)**

The “Energy Efficiency 2030 Strategy and National Energy Efficiency Action Plan II (2024-2030)” prepared by the Ministry of Energy and Natural Resources presents a holistic roadmap to increase energy efficiency in line with Türkiye’s sustainable development and climate goals. In this context, energy efficiency is considered not only as an economic necessity but also as an environment and climate-friendly transformation tool. In particular, the building sector is among the materiality areas of the strategy, which aims to reduce energy consumption in new and existing buildings, expand green building practices and strengthen the energy identity certificate system. It is also planned to reduce carbon emissions by encouraging the integration of renewable energy systems, smart control technologies and the use of efficient equipment in buildings. The Strategy envisages the implementation of mitigation and adaptation measures that will contribute to combating climate change in line with the principles of environmental sustainability, particularly in energy-intensive sectors and urbanization. Thus, in line with Türkiye’s 2053 net zero emission goal, energy efficiency is positioned as a key policy instrument that balances economic growth with environmental responsibility[67].

SUSTAINABLE URBAN LAND USE PLANNING AND DESIGN

6. Section

Sustainable Urban Land Use Planning and Design Module

6.1. Importance of Sustainable Urban Land Use

Today's cities face global challenges such as rapid population growth, depletion of natural resources, and climate change. In this context, sustainable urban land use is critically important not only for reducing environmental impacts but also for enhancing social integration, economic efficiency, and quality of life. Transitioning planning processes from individual buildings to neighborhoods and districts plays a key role in achieving sustainable development goals.

Sustainable land use aims to optimize resource use, reduce dependency on transportation, integrate green infrastructure, and build cities resilient to disasters. Holistically considering core infrastructure topics such as energy, water, waste, and transportation during planning contributes to both emissions reduction and improved quality of life.

The transition from building scale to district scale offers many advantages in terms of sustainability:

- Energy efficiency, transportation planning, and social infrastructure can be addressed more holistically.
- Elements such as green infrastructure, public spaces, and social interaction areas can be integrated.
- It becomes possible to create resilient, flexible, and inclusive cities.

International studies show that planning at the district level creates far greater impact than isolated building performance. Therefore, as demonstrated in the Build4GreenIST project, sustainability practices at the urban scale should not be limited to building energy performance but must also encompass land use decisions, social structures, transportation networks, and infrastructure systems.

6.2. Green Districts: Certification Systems and Planning Approaches

Green certification systems developed for urban districts enable the evaluation of environmental, social, and economic criteria together in planning. These systems require the assessment of infrastructure, transportation, public spaces, natural systems, and social dynamics beyond individual buildings. They serve as comprehensive guides for local governments, planners, and practitioners.

Notable international systems include:

- BREEAM Communities
- LEED for Cities and Communities
- LEED-ND (Neighborhood Development)
- DGNB Urban District
- YES-TR Settlements

These systems share a common objective: integrating sustainability into planning from the building to the district level and creating climate-resilient urban environments. Applying these systems in cities like İstanbul can help reduce transportation-based emissions, mitigate urban heat island effects, and increase social inclusion. They also encourage local governments and developers to adopt more participatory and nature-based planning methods involving citizens.

6.3. Green Urban Transformation Potential and Nature-Based Solutions

With its unique geographical location, diverse microclimates, and rich ecosystem variety, İstanbul holds significant potential for the implementation of nature-based solutions. However, the city's environmental sustainability is increasingly threatened by rapid population growth, dense urban development, and the limited availability of green spaces. Therefore, in the context of urban transformation, it is essential not only to pursue carbon neutrality but also to integrate nature-based solutions that align with İstanbul's natural character and reinforce its local ecosystems. Coastal access to the Sea of Marmara, substantial forest areas, and urban agriculture potential provide a strong foundation for making the city more livable, resilient, and environmentally friendly.

In this context, nature-based solutions present a valuable framework for addressing İstanbul's urban and environmental challenges in a comprehensive and adaptive manner. In the face of intensifying climate-related challenges, nature-based solutions (NbS) have emerged as a strategic and holistic approach to sustainable urban and environmental planning. These solutions rely on natural processes and ecosystem services to deliver environmental, social, and economic benefits simultaneously. At their core, NbS aim to restore and protect ecosystems, enhance societal adaptation to climate change, and contribute to the mitigation of greenhouse gas emissions[68]. They embody an integrated perspective that values nature on par with socioeconomic development.

Unlike conventional “grey infrastructure” that typically relies on engineered structures, NbS prioritize “green infrastructure” that works with or mimics natural systems. For example, instead of constructing concrete seawalls to prevent coastal flooding, NbS promote the preservation and rehabilitation of marine ecosystems. Similarly, protecting and restoring forests, which serve as vital carbon sinks, helps reduce atmospheric carbon levels[68].

While initially focused on sectors such as agriculture and water management, NbS have become increasingly central in urban climate strategies. Their multifunctional nature, cost-effectiveness, and ability to generate a range of co-benefits—including improved public health, reduced energy use, and better air quality—make them highly attractive to urban planners[69]. Common urban NbS include green roofs, community gardens, green corridors, and urban green spaces, all of which not only support climate action but also improve overall urban livability.

Figure 32. Nature-based solution offers for urban resilience[68]

The World Bank’s *“Nature-Based Solutions for Resilient Cities Catalog”* provides a comprehensive framework for implementing NbS in diverse geographical and climatic contexts. The catalog outlines a variety of practices that enhance urban resilience and support long-term environmental sustainability, including:

- **Urban Forests**: Expand green space, increase carbon sequestration, enhance biodiversity, and offer residents recreational access to nature
- **Terracing and Slope Management**: Improve rainwater retention, prevent erosion, and support sustainable landscape planning in urban areas.
- **River and Stream Restoration**: Revitalize aquatic ecosystems through the reestablishment of natural water flows, reduce flood risks, and improve water quality.
- **Building-Integrated Solutions**: Encourage energy-efficient architecture with features such as green roofs, solar panels, and high-performance windows to reduce emissions and energy use.
- **Open Green Spaces and Parks**: Provide residents with natural environments that support psychological well-being, foster social interaction, and strengthen the human-nature connection.
- **Green Corridors**: Link urban green areas to promote ecological continuity, protect wildlife migration paths, and increase urban biodiversity **Urban Agriculture**: Strengthen local food security and reduce urban heat through food production projects within cities.
- **Constructed and Natural Wetlands**: Filter pollutants, manage stormwater, and create habitats that support ecological health and biodiversity.
- **Mangroves and Salt Marshes**: Reduce coastal erosion, improve water quality, and protect the habitats of marine species.

The World Bank catalog serves as a valuable guide for municipalities seeking to enhance climate resilience through context-sensitive and evidence-based NbS applications[68].

Local adaptation remains a key principle in successful implementation. For instance, a 3-hectare urban forest in Milan has demonstrated significant multifunctionality by mitigating flood risk, preserving biodiversity, and improving water quality. The system has demonstrated an annual retention capacity of approximately 11.7 metric tons of dissolved organic carbon, thereby supporting carbon sequestration initiatives[70].

Similarly, Lahore's "Freedom Forest" serves as another illustrative example—designed not only to address air pollution and extreme heat but also to advance inclusive planning principles that challenge gender inequalities and promote safety within public spaces[71].

Hamburg's multifunctional rainwater harvesting park provides yet another compelling case. Functioning both as a recreational playground and a flood mitigation system, it exemplifies how NbS can simultaneously contribute to water management, carbon capture, urban cooling, and the reduction of the urban heat island effect[72].

A Nature-Based Solution Example from İstanbul: Rainwater Harvesting Practices by Kadıköy Municipality

One of the notable urban-scale examples of nature-based solutions in İstanbul is the rainwater harvesting initiative implemented by the Kadıköy Municipality. These practices are considered significant tools within the framework of sustainable urban water cycle management and climate change adaptation strategies.

Rainwater harvesting systems have been installed in various municipal facilities, including the Ecological Life Center, Kayışdağı Service Unit, Aysel Abdullah Öğücü Female Student Dormitory, Kadıköy Design Workshop, and the Temporary Animal Shelter. Rainwater collected from rooftops is reused for secondary purposes such as garden irrigation, cleaning, toilet flushing, and vehicle washing. For instance, the system established at the Temporary Animal Shelter is projected to reduce annual water consumption by approximately 40%.

These implementations are supported not only at a technical level but also through local governance mechanisms. In 2021, a municipal council decision mandated the inclusion of rainwater and greywater collection systems in all new buildings constructed on plots of 400 m² or more. This regulation, which goes beyond national requirements, enhances the applicability of nature-based solutions in the local urban context.

As of early 2025, a total of 2,634 tons of rainwater had been harvested and reused in various municipal services. This practice promotes the use of alternative water sources in urban water management and clearly demonstrates the multifunctional benefits of nature-based solutions[73].

These examples underscore the potential of nature-based solutions to address climate challenges while simultaneously enhancing the quality of urban life. Through the integration of ecological, social, and technical considerations, NbS offer cities a robust pathway toward a more sustainable and resilient future.

6.4. Examples of Residential Area Scale Implementation and Recommendations for İstanbul

Green transformation projects carried out at the residential area scale play a critical role in observing the impact of sustainable urbanism practices on the ground. Examples from both Türkiye and Europe show that with the right planning and certification processes, social, environmental and economic benefits can be achieved together.

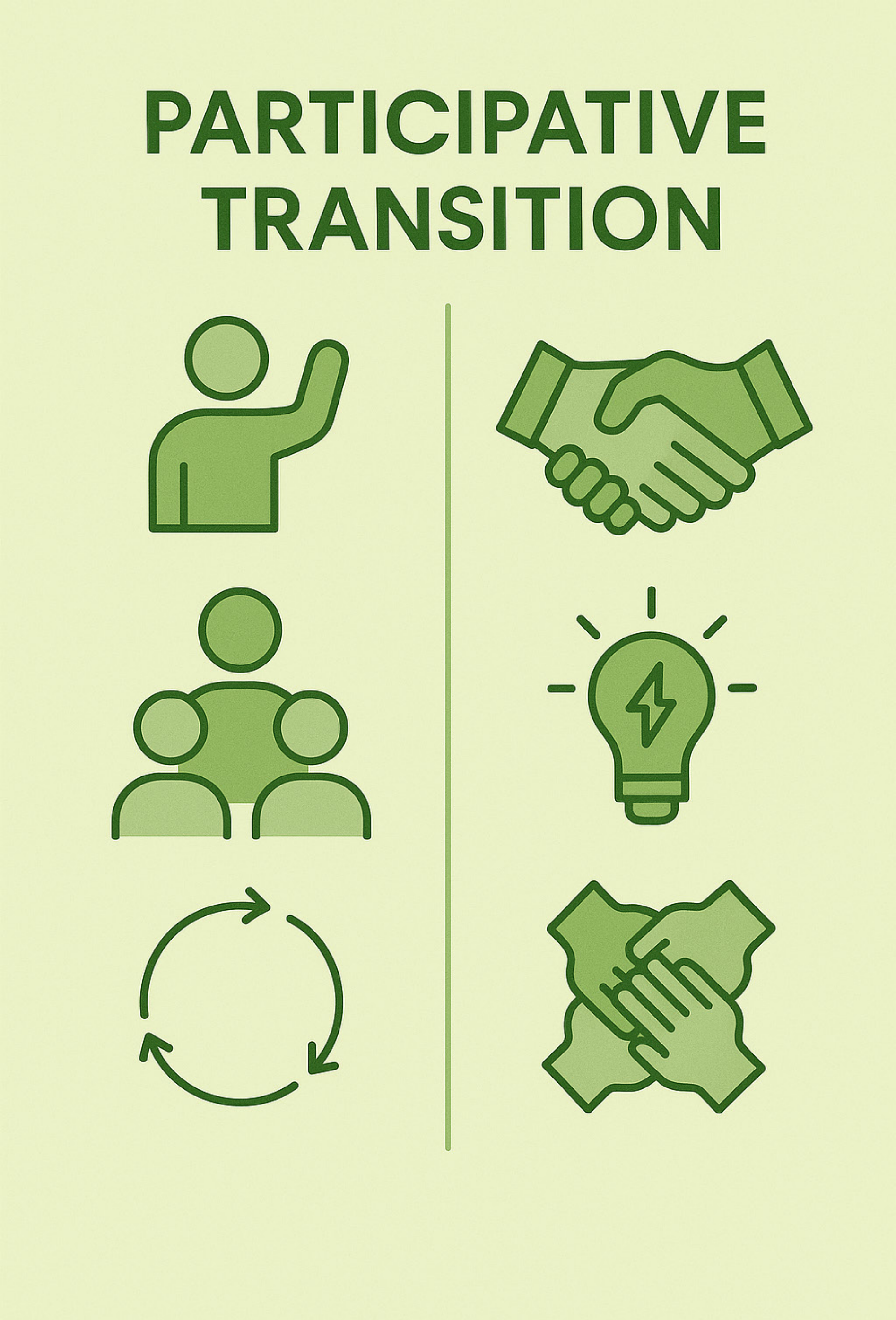
International examples include Freiburg Vauban (Germany). It was developed with a participatory planning model that exemplifies the DGNB Urban District approach, designed with car-free living spaces and energy cooperatives.

Examples in Türkiye are generally building-oriented, but some developments at the site and campus scale (e.g. ecovillage initiatives, green campus projects) offer experience in sustainability at the settlement level. In addition, domestic certification systems such as YES-TR enable the development of projects that are suitable for Türkiye's climate and urbanization dynamics

İstanbul specific recommendations:

- The integration of nature-based solutions and green infrastructure in existing urban transformation areas should be encouraged.
- Local governments should ensure that sustainability criteria are integrated into planning decisions by drawing inspiration from international certification systems as well as national systems such as YES-TR.
- As a result of urban analyses, positive energy zones and carbon neutral neighborhood pilots can be initiated in areas deemed risky in terms of transportation, density and ecosystem integrity.
- Social inclusion and implementation capability should be increased through planning processes open to citizen participation.

Sustainable urban land use is not only the planning of physical space, but also a basis for community well-being, environmental balance and economic resilience. This module of Build4GreenIST project focuses on the importance of green residential areas, national and international certification systems, nature-based solutions and İstanbul's potential in this transformation. Transitioning from the building scale to the neighborhood and district scale is a critical step towards achieving sustainability goals. In large cities such as İstanbul, this transition is envisioned to directly contribute to not only environmental but also social inclusion, resilience and quality of life. In this framework, the dissemination of holistic approaches and feasible strategies for sustainable urban planning will pave the way for green transformation.


PARTICIPATIVE
TRANSITION

7. Section

Participative Transition Module

7.1. Participation in Green Transformation

The transition to carbon-neutral cities requires not only environmental but also social and economic transformation. However, for such a major change to be effective, it is essential that citizens and other stakeholders understand, participate in, and support the process. Participatory transformation ensures this unity throughout the transition process and contributes to the formation of carbon-neutral cities from various perspectives. These include increased social awareness and consciousness, better acceptance and ease of implementation of policies, development of efforts to create solutions tailored to local requirements, and, consequently, economic contributions and new opportunities.

The participatory transformation process necessitates strong community engagement. The importance of public participation lies in enabling more accurate and locally appropriate decisions in decision-making processes, facilitating the identification of problems and the discussion of effective solutions. Additionally, this process increases the level of trust within the community and facilitates collaboration processes.

7.2. Steps of the Social Participation Process

The design of the public participation process can be defined in 6 main steps:

- Defining goals and objectives
- Identifying the goal audience and stakeholders
- Determining the level and methods of participation
- Developing a communication draft
- Implementation
- Monitoring

Institutions leading the participation process must first clearly define what they aim to achieve through participation and what kind of feedback they seek. In the initial phases of a municipal renewable energy transition project, the implementing organization must clearly articulate: the strategic goals of urban energy transformation and renewable integration; quantifiable targets for carbon emission reductions; the selection of appropriate renewable energy technologies; and the envisioned framework for community involvement.

The second step, identifying the goal audience and stakeholders, is a key part of influencing decision- making processes. It is essential to plan who will be consulted regarding the proposed or designed project, who will have a say in the process, which stakeholders will be informed, and which ones will have the greatest impact on the process. Recognizing that certain topics may require the involvement of multiple goal audiences at different levels is also important.

Various methods can be used to design this process, with stakeholder mapping being one of the most common. The purpose of this method is to determine the power and level of interest of stakeholders who may be relevant to the identified project and to assess whether they have a direct or indirect impact. Below are some examples of how this method can be applied.

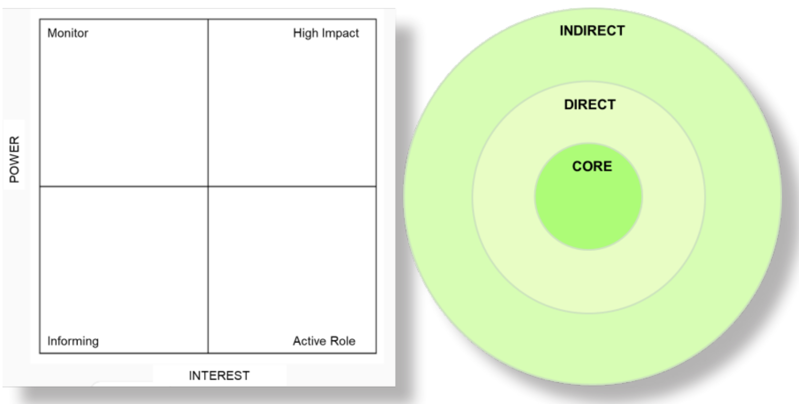


Figure 33. Stakeholder mapping and impact analysis method samples

The next step should be determining the level and methods of participation. To evaluate the degree of participation, a distinction must be made between stakeholder contributions intended to garner project support and those designed to foster sustained engagement across all project phases. Based on this, the participation method will be defined accordingly.

When determining the participation method, the following questions should be considered:

- Is there a legal obligation to use specific methods?
- Which methods have been successfully implemented in similar plans or projects in the past?
- Have relevant stakeholders had the opportunity to express their preferred methods for participation?
- What are the advantages and disadvantages of specific methods?
- Has the effectiveness of the method in reaching the relevant stakeholders been evaluated?

By addressing these questions, the foundation for the level of participation is established and structured. To enhance the effective management of the participation process, considerations such as whether sufficient time and resources are available for the efficient implementation of each activity should be taken into account. Additionally, various alternatives can be explored to enhance the creativity of participation methods and activities.

For Large-Scale Participation Events:

- Public Meetings • Town square forums, outdoor workshops
- Workshops • Collective intelligence fairs, interactive thematic workshops
- Advisory Panels • Expert + public mixed sessions, guest speaker events
- Participatory Budgeting Meetings • Project prioritization

activities For Targeted Small Group Studies:

- Focus Group Discussions • Sector-specific sessions (e.g., industry representatives, NGOs, youth groups)
- Roundtable Meetings • Thematic table rotation (different topics are discussed at each table, and participants rotate places)
- Case Studies and Role-Playing • Allowing different stakeholders to experience various perspectives

Individual Participation Methods:

- Surveys • Quick micro-surveys (via social media, email, QR code access)
- Online Brainstorming Platforms • Digital participation using tools like Miro, Mentimeter, Jamboard

• Suggestion Boxes and Bulletin Boards • Collecting ideas in both digital and physical environments

• Short Video/Writing Contests • Collecting public solution proposals in creative formats

Interactive, Creative Methods:

• Urban Exploration Tours • The public assesses areas they see as problematic or potential

• Map-based Participation Tools • Participants mark problems and solution points on a map

• Hackathons • Solution development marathons, especially with young and tech-focused participants

• Future Scenario Design • Imagining long-term visions with participants

Inclusive Decision-Making Models:

• Citizen Jury • A group randomly selected from the public evaluates the issue and develops recommendations

• Participatory Budgeting Simulation• Participants experience budget management and prioritize project proposals

• Thematic Working Groups • Specialized, ongoing stakeholder groups (e.g., energy, transportation, green spaces)

Figure 34. Inclusive decision-making model samples

According to the chosen participation method, a communication draft summarizing the topic and communication requirements is developed in the next phase. At this point, it is important to explore the demographic characteristics of the goal audience. This will help identify language barriers, transportation requirements, and other challenges to overcome in order to communicate effectively with the goal audience.

To manage this process better, it is useful to examine successful global examples where public participation processes are carried out with multiple stakeholders. Below are some examples.

UK–Bristol Energy Networks

Bristol has launched innovative projects to involve local communities in the energy transition process in line with its carbon-neutral goals. Bristol Energy Networks is a structure that encourages local people to develop their own community energy projects. Through this network, citizens actively engage in areas such as renewable energy production, energy efficiency, and the creation of community-specific energy cooperatives. For example, in some neighborhoods of Bristol, communities install their own solar panels to meet their electricity requirements while also reducing energy costs. Bristol Energy Networks sets up booths at local events to provide information about energy projects and gather feedback from the public. Additionally, they regularly organize meetings and workshops at the neighborhood level. During these events, citizens have the opportunity to share their requirements, expectations, and ideas about the projects[74].

Türkiye, İstanbul Metropolitan Municipality (IMM) "İstanbul is Renewing" Platform

"İstanbul is Renewing" is an urban transformation program launched by the İstanbul Metropolitan Municipality (IMM) to renovate the city's stock of risky and unhealthy buildings. The platform primarily targets structures located in earthquake-prone areas and aims to make them safe, resilient, and livable. Unlike traditional top-down models, this process is carried out with a participatory and transparent approach.

The "İstanbul is Renewing" platform transcends a mere individual application-based process, embodying instead a comprehensive multi-stakeholder collaboration framework that integrates public institutions, professional chambers, civil society organizations, academia, and private sector entities. This engagement with multiple stakeholders enhances the technical soundness, social acceptance, and feasibility of the projects. For example, technical consultations are held with chambers of architects and engineers; neighborhood- based requirements are identified through NGOs; and social impact assessments are conducted with the expertise of universities. In addition, partnerships with banks and cooperatives are established to ensure financial sustainability and to develop models that reduce the economic burden on homeowners. This multi-stakeholder structure supports a participatory and inclusive urban transformation approach that aims not only to renew buildings but also to strengthen the social fabric.

The platform enables residents to formally request risk assessment procedures through a digital application system if they suspect structural vulnerabilities in their buildings. These applications are reviewed by IMM's expert teams, and each step— technical analysis, on-site inspections, and one-on-one meetings with residents—is planned collaboratively. In this sense, "İstanbul is Renewing" offers a transformation model that includes the public as active participants rather than passive recipients.

A core element of the participatory approach is the active involvement of residents in the decision- making process. Transformation plans are shaped by taking into account the demands of property owners, their socio-economic conditions, neighborhood ties, and the need for a livable environment. Projects are evaluated not only on a building-by-building basis but also at the neighborhood scale, ensuring that the principle of living in place is preserved and that social ties are maintained during the transformation[75].

Sweden – Stockholm Royal Seaport Urban Transformation Project

The Stockholm Royal Seaport Project is a large urban transformation initiative involving all stakeholders, in line with Sweden's carbon-neutral city goals. In this project, local government, energy companies, the construction sector, universities, and community representatives collaborate to develop a sustainable urban area. For example, Vattenfall, an energy company, provides renewable energy solutions to meet the region's energy requirements, while the local government invests in green infrastructure, and universities conduct research in these areas. The project is a successful example of how carbon-neutral goals in urban planning can be achieved through the contributions of all stakeholders[76].

Türkiye, Nilüfer Municipality – Neighborhood Committees

In Nilüfer district, the Nilüfer City Council Women's Assembly was established to enable women living in the area to play an active role in urban governance and contribute to creating a more livable city. Similarly, the Nilüfer City Council Youth Assembly was created to increase youth participation in decision-making processes. Along with these structures, Neighborhood Committees were established in 42 neighborhoods, allowing citizens to identify the priority service requirements in their neighborhoods and directly participate in city governance.

Decisions made in the Nilüfer City Council, Women's Assembly, Youth Assembly, and Neighborhood Committees are directly brought to the agenda of the Nilüfer Municipal Council. This allows the people of Nilüfer to have a direct say in urban governance and actively participate in decisions regarding the city[77].

Ensuring the continuity of participation processes and increasing the level of trust is crucial for sustainability. Therefore, it will be beneficial to evaluate the participation both from the perspective of the implementing institution and from the participants' point of view to improve the process. To monitor the participation process, a system should be established, and participation levels must be tracked using indicators such as attendance rates at meetings, the number of participants from different sectors, feedback scores after training sessions, and average participation duration, depending on the type of participation method. A robust monitoring system should be implemented to systematically track participation levels through quantifiable indicators, including: Meeting attendance rates, Cross-sectoral participant representation, Post-training evaluation metrics, Mean engagement duration. Improvements should be made based on the results gathered from these indicators.

7.3. Challenges in the Participation Process

Participatory processes, while ensuring inclusive and fair decision-making, may encounter various challenges. One of the biggest barriers is low participation rates and uneven representation. The marginalization of vulnerable populations and disproportionate influence of vested interest groups in participatory processes undermine the representativeness and equity of outcomes, thereby limiting decision-making efficacy in addressing collective community needs. Additionally, time and resource management pose critical challenges. Participatory processes require extensive planning, organization, and feedback cycles, which can increase costs and complicate the process. Involving too many stakeholders can lead to coordination problems, while the prolonged duration of the process may result in a loss of motivation.

Another major issue is communication and information inequality. Barriers such as technical knowledge not being understood by the public, lack of trust, and language barriers can make the process inefficient. In particularly complex projects, conflicting interests between different groups can also hinder finding a common solution. Some groups may focus on environmental benefits, while others may worry about economic losses. Populist pressures can also prevent long-term projects from moving forward. Even if the process is successfully completed, it may not be sufficient for the implementation of the outcomes. If feedback from participants is not shared or the decisions made cannot be implemented, it can lead to a loss of public trust and "participation fatigue," further diminishing motivation for future projects. For an effective participatory process, transparency, inclusivity, and a results-oriented approach are essential.

To overcome the challenges faced in participatory processes, it is important to design an inclusive and accessible process. Equal representation of different groups must be ensured, and special methods should be developed for the active participation of disadvantaged groups. For example, presentations that make technical issues more understandable, facilitators, and multilingual materials can be prepared. Various participation methods — such as public meetings, workshops, surveys, and online platforms — should be used together to ensure appropriate inclusion of everyone in the process. Furthermore, in the early stages of the process, expectations should be clarified, and participants should be informed about how their feedback will be evaluated, creating a trust-based environment. This way, participants can adopt the process not just as spectators but as real actors.

Secondly, effective time and resource management planning is of great importance. While the long duration and cost of participatory processes are inevitable, steps can be taken to make the process more efficient. For example, breaking the process into smaller, manageable phases, demonstrating tangible results at each stage, and sharing these results with participants will help maintain high motivation. Using digital tools and online platforms to reach a wider audience and reduce process costs can also be an effective method.

8. Section

Modelling Framework

8. Modelling Framework: Beykoz Case Study

The Build4Greenist project focuses on the transition to carbon-neutral and green buildings, specifically addressing areas identified for urban transformation. This section of the guide involves the analysis of energy consumption and on-site energy generation potential in buildings that are planned to undergo urban transformation, including informal settlements in Çubuklu, Beykoz, İstanbul.

8.1. Beykoz District in İstanbul

Beykoz is a district located on the Asian side of İstanbul. The district has a northern coastline along the Black Sea and is surrounded by forests, rivers, and natural parks. These features make Beykoz an attractive area for nature-based activities. Beykoz is known for its viticulture and fishing, and despite the expanding urbanization of İstanbul, it has preserved a rural character. As of 2024, the population of Beykoz is approximately 245,440 people. The district covers an area of 240 km², with 65% of this area being green spaces and forests. Beykoz has a mixed climate, influenced by the Mediterranean climate and surrounding transitional climates, with mild winters and hot, dry summers. Beykoz is mainly used for residential purposes, and urban transformation projects are underway to balance urban development while preserving the natural environment.

The urban transformation area in the project covers an area of 5.6 hectares. The average age of the buildings in the area is 33 years, and all of them are used for residential purposes. The buildings are reinforced with concrete with low architectural quality. The area was declared as a "risky building area" by the Ministry of Environment and Urbanization in 2018. Therefore, the structures within the area need to be urgently demolished and rebuilt, referring to the Beykoz Urban Transformation Project. Within the total area, there are 141 independent units in 57 buildings. The average number of floors is 2, which corresponds to approximately 14,597 m² of construction area. The approximate population in the area is 460 people, with an average construction area of 228.7 m² per building.

8.2. Energy Models and Simulation Methodology

The case study compares the energy consumption levels of different scenarios for the building to be constructed after the urban transformation process in Beykoz, İstanbul. The informal settlements from the Çubuklu, Beykoz area before the urban transformation process can be seen in Figure 35 and Figure 36.

On the other hand, for a more detailed energy analysis, one building (C-02) was selected from the architectural plan of the buildings to be constructed after the urban transformation process, as shown in Figures 35, 36, and 37, and further described below. A 3D geometry and digital model of the selected building was made via IESVE software, which can be seen in Figure 36. The energy consumption and production values of the new building were analyzed across 7 different scenarios. These results were then compared to assess potential energy savings and performance within the context of urban transformation.

The analysis includes evaluating potential energy savings through the use of alternative renewable energy sources, sustainable materials, and the application of energy-efficient active system constructions. Moreover, various building scenarios for the building to be constructed are assessed to identify the most effective strategies for reducing energy consumption and promoting sustainability in the context of urban transformation.

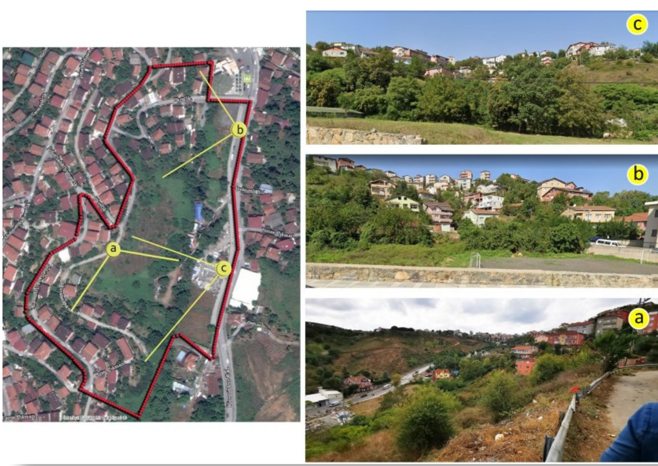


Figure 35. Site plan of the informal settlements in Çubuklu, Beykoz, İstanbul

Figure 36. Current view of the area in the Çubuklu district of Beykoz where urban renewal is planned

Figure 36 presents the site plan of the new buildings that will be constructed after the urban transformation process is conducted. In this plan, the "C-02" building (as marked in the figure) was selected due to its strategic location and orientation. The building's entrance facade faces west, and the rear, glass facade faces east. The front facade is slightly tilted towards the southwest, making it predominantly west-facing but with a minor southern tilt (southwest). This unique orientation provides both advantages and disadvantages: the west-facing front allows for more sunlight exposure during the afternoon, while the southward tilt also brings some afternoon sun, which can be beneficial for natural lighting. Additionally, the building is positioned such that its eastern facade is the only open side, with other buildings surrounding the site to the north, south, and southwest. This orientation provides the "C-02" building with more sunlight access and visibility compared to other buildings on the site, making it one of the optimal choices for selection.

Figure 37. Site plan of the buildings to be constructed after urban transformation in Çubuklu, Beykoz, İstanbul

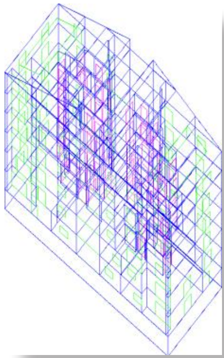
In Figure 38 and Figure 39, the top and front views of the buildings after urban transformation are presented. Specifically, in Figure 38, the C-02 building can be seen on the left side.

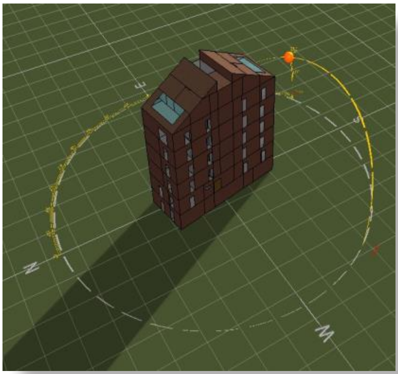
Figure 38. Top view of the buildings to be constructed after urban transformation in Çubuklu, Beykoz, İstanbul

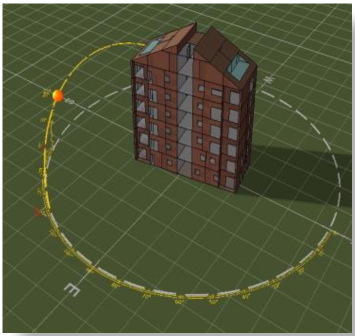
Figure 39. Front view of the buildings to be constructed after urban transformation in Çubuklu, Beykoz, İstanbul

As mentioned above, the 3D geometry and digital model of the building C-02, which will be constructed after the urban transformation, were structured via IESVE software according to its architectural plan and information and are shown in Figure 39. For modeling purposes, the building orientation was adjusted accordingly (as described above), and the climate data used was the İstanbul IWEC file from the IESVE library.

The C-02 building consists of a total of 8 storeys, with 2 basement floors and the top floor being a penthouse. The lowest basement level, which is entirely underground, is an unconditioned space designed for shelter purposes, while the remaining 7 floors are living areas that can be evaluated as conditioned space. It is assumed that there will be approximately 12 flats, with an average of 4 to 5 people residing in each. In IESVE software, the total external wall surface area of the building, including all basement and unconditioned spaces, is 1439.5 m^2, and the total floor area is 1328.5 m^2. The floor height for each story is 3 meters. Excluding the roof and basement level 2, the external wall surface area is 1197.7 m^2 (net external wall surface area was considered as 1000 m^2), and the total floor area is 1065 m^2. Excluding the flat corridors, building hallways, basement 2, and penthouse, the remaining net conditioned floor area is 758 m^2. Regarding the window areas, if the windows in the building's hallways are also included, the total window area is 258 m^2. The roof includes external openings such as terraces or voids, which are not glazed elements. However, in the IESVE model, these openings are defined as fully transparent glazing due to software constraints.


a.) 3D geometry of the C-02 building


b.) 3D front view of the C-02 building facing southwest


c.) 3D back view of the C-02 building facing northeast

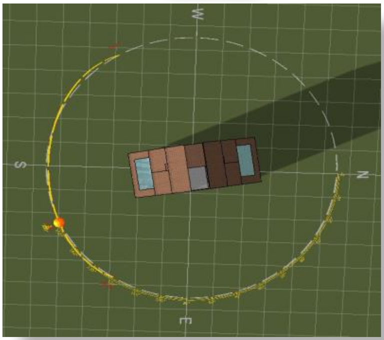

d.) 3D top view of the C-02 building

Figure 40. 3D facade views of the C-02 building

In Figure 40 solar irradiation on the C-02 building was shown, the south facade of the roof influences the highest amount of solar irradiation. Therefore, in scenarios involving PV installations, the panels are mounted on the south-facing facade of the roof.

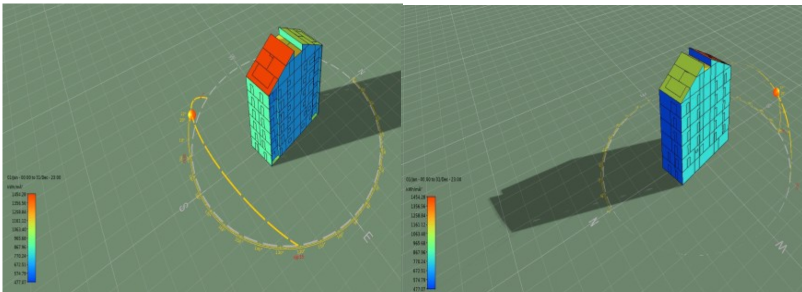


Figure 41. Solar Irradiation on the C-02 building
(up is the back view, below is the front view)

In the next steps, the energy consumption and production values of this 3D digital building model were analysed across 7 different scenarios. These results were then compared to assess potential energy savings and performance within the context of urban transformation.

8.3. Building Scenarios for Urban Transformation Area in Çubuklu, Beykoz

After the informal settlements (old buildings) in Çubuklu, Beykoz, undergo urban transformation, the new buildings will be built referring to the TS825 standard that represents C-energy label building characteristics. The European Energy Performance of Buildings Directive is being updated; the trends are evolving into net-zero energy/emission or even positive energy buildings/blocks or districts. For this reason, for the current "C-energy label" buildings, there will still be a certain level of energy consumption, which cannot be negligible. For this reason, in order to examine the base energy consumption and the potential for reducing energy consumption of the buildings to be constructed in Çubuklu, different alternative scenarios have been generated to provide a diverse set of energy- efficient, energy-flexible, and RES on-site perspectives. A total of 7 alternative scenarios (Sc) were defined for the selected C-02 building; these scenarios aim to evaluate various approaches for reducing energy consumption and improving sustainability in the built environment. Each scenario involves different combinations of energy-efficient strategies, building-integrated renewable energy system implementation, and sustainable construction materials, providing a comprehensive assessment of potential solutions for the future development of the area. Since İstanbul is a city that receives a fair amount of sunlight, PV-integrated systems have been included in renewable energy scenarios, and also an advanced PVT system has been added. On the other hand, solar-assisted heat pump systems were also proposed to sustain electrification that will guide the path to decarbonization in the near future.

Scenarios for the building to be constructed:

- **Sc0:** C-energy label base building scenario (baseline indicating the reference building according to the TS825): natural ventilation, natural gas central system (on-continuous heating, without schedule control), and individual air conditioning
- **Sc0.1:** C-energy label base building scenario (baseline indicating the reference building according to the TS825): natural ventilation, natural gas central system (scheduled heating with sets), and individual air conditioning
- **Sc1:** Passive material implementation and natural ventilation, natural gas central system (scheduled heating with set temperatures), and individual air conditioning
- **Sc2:** Passive material implementation and natural ventilation, central heat pump (HP) (air to water) usage (scheduled heating and cooling with set temperatures)
- **Sc3:** Passive material implementation and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), photovoltaic (PV) panel installation
- **Sc4:** Passive material implementation and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), photovoltaic thermal (PVT) panel installation
- **Sc5:** Passive material implementation (optimum) and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), mechanical ventilation, PVT installation and battery connection

In Table 11, the U-values of the building materials and passive implementations for the C-02 building are provided in relation to various scenarios. The scenarios represent different configurations and levels of energy efficiency applied to the C-02 building, based on its architectural design and standardizations defined by Türkiye's TS 825 (2008) standard. Although TS 825 (2008) was updated to TS 825 (2024) in April 2025, the 2008 version was taken into account due to the late announcement of the new standard, the project deadline, and the predefined task distribution in the project timeline.

The first two scenarios (Sc 0 and Sc 0.1) reflect the base conditions of the building after the urban transformation process of informal settlements. Both scenarios are created using the IESVE software, considering the base architectural design and C- energy label building standardization in Türkiye. In these scenarios, the building's external walls and windows maintain the same specifications, while in the Sc 0 scenario, the HVAC system is unscheduled, and in the Sc 0.1 scenario, the system is scheduled.

As we progress through the scenarios, additional passive and active strategies are incorporated:

- Sc 1 (only passive) introduces enhanced insulation with thicker external walls (80mm), improving the U-value of the external wall to 0.25 W/m²K. The external windows are upgraded to a lower U-value of 1.60 W/m²K by using double glazing with an argon-filled cavity. These changes aim to reduce the building's thermal losses. In Scenarios 1, 2, 3, and 4, the materials and construction elements remain consistent.
- Sc 2 (HP + passive) further integrates an air-water heat pump (HP) along with passive measures. The insulation and window U-values remain as in Sc 1.
- Sc 3 (HP + passive + PV) adds photovoltaic (PV) panels to the building's energy generation, alongside the same passive strategies and heat pump. The insulation and window U-values remain as in Sc 1.
- Sc 4 (HP + passive + PVT) integrates photovoltaic thermal (PVT) panels, combining both electricity generation and thermal energy collection alongside the same passive strategies and heat pump. The insulation and window U-values remain as in Sc 1.

- Sc 5 (opt. sc HP + passive + mech. vent + PVT + battery) is the most optimized scenario, incorporating the mechanical ventilation in addition to the heat pump (same heat pump in previous scenarios), upgraded passive measures, PVT panels, and the battery. Notably, Sc 5 upgrades the insulation of the external walls to 100 mm, enhancing the thermal performance and reducing the U-value of the external wall to 0.21 W/m²K. Additionally, Sc 5 employs triple glazing for the windows, significantly improving the thermal insulation of the glazing system, with a reduced U-value of 0.80 W/m²K.

Scenarios	External Wall	External Window	Roof	Ground	Internal Floor/Ceiling	Infiltration and Ventilation rate
Sc 0 Base on-cont. heating without control	Plaster, **Insulation (50mm),** Brickwork, Plaster; **u-value: 0.36 W/m²K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 2.42 W/m²K, g-value: 0.44**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m²K**	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast concrete; **u-value: 0.78 W/m²K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m²K**	Infiltration: **0.8 ach,** Natural Ventilation: **0.7 ach**
Sc 0.1 Base with schedule	Plaster, **Insulation (50mm),** Brickwork, Plaster; **u-value: 0.36 W/m²K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 2.42 W/m²K, g-value: 0.44**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m²K**	Gravel-Based soil: gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast **concrete; u-value: 0.78 W/m²K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m²K**	Infiltration: **0.8 ach,** Natural Ventilation: **0.7 ach**
Sc 1 only passive	Plaster, **Insulation (80mm),** Brickwork, Plaster; **u-value: 0.25 W/m²K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 1.6 W/m²K, g-value: 0.39**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m²K**	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast concrete; **u-value: 0.78 W/m²K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m²K**	Infiltration: **0.8 ach,** Natural Ventilation: **0.7 ach**
Sc 2 HP+passive	Plaster, **Insulation (80mm),** Brickwork, Plaster; **u-value: 0.25 W/m2m²K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 1.6 W/m²K, g-value:**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast	Chipboard flooring, screed, reinforced concrete, plaster; **u-**	Infiltration: **0.8 ach,** Natural Ventilation: **0.7 ach**

		0.39	board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m^2K**	concrete; **u-value: 0.78 W/m^2K**	**value: 1.86 W/m^2K**	
Sc 3 HP+passive+PV	Plaster, **Insulation (80mm)**, Brickwork, Plaster; **u-value: 0.25 W/m^2K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 1.6 W/m^2K, g-value: 0.39**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m^2K**	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast concrete; **u-value: 0.78 W/m^2K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m^2K**	Infiltration: **0.8 ach**, Natural Ventilation: **0.7 ach**
Sc 4 HP+passive+PVT	Plaster, **Insulation (80mm)**, Brickwork, Plaster; **u-value: 0.25 W/m^2K**	Double glazing, 6mm-12mm (argon)-6mm; **u-value including frame (PVC): 1.6 W/m^2K, g-value: 0.39**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m^2K**	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast concrete; **u-value: 0.78 W/m^2K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m^2K**	Infiltration: **0.8 ach**, Natural Ventilation: **0.7 ach**
Sc 5 Opt. sc HP+passive+ mech. vent. +PVT+ battery	Plaster, **Insulation (100mm)**, Brickwork, Plaster; **u-value: 0.21 W/m^2K**	Triple glazing, 4mm-16mm (argon) -4mm-16mm (argon)-4mm; **u-value including frame (PVC): 0.80 W/m2K, g-value: 0.22**	Cladding, Felt/Bitumen, Particleboard, Cavity, Felt/Bitumen, Polyurethane board, Felt/Bitumen, Particleboard; **u-value: 0.37 W/m^2K**	Gravel-Based soil, gravel, concrete, felt/bitumen, felt/membrane, reinforced concrete, cast concrete; **u-value: 0.78 W/m^2K**	Chipboard flooring, screed, reinforced concrete, plaster; **u-value: 1.86 W/m^2K**	Infiltration: **0.8 ach**, Natural Ventilation: **0.7 ach, Mechanical Ventilation:** 12 l/s/person (kitchen), 15 l/s/person (bathroom)

Table 11. U-values of building materials (outer to inner layers) and passive implementations on scenarios

In Table 12, the integration of active HVAC systems and renewable energy system specifications and efficiencies in the scenarios are presented. The seasonal efficiency is referring to a boiler or heat pump. EER refers to the energy efficiency ratio of a cooling system.

In the first C-energy label reference building scenario (Sc 0), as per the standards, the building's external materials and the heating and cooling systems are designed similarly to the Bayrampaşa KİPTAŞ housing. This includes a central natural gas heating and DHW system, with individual air conditioning units in the living rooms for cooling. The daily water requirement was assumed to be about 40 L per person. In this first base scenario, heating is continuously active and without control during the winter period (November, December, January, February, March, and April). The kitchen is set at 21°C, the living room and open-plan kitchen-living room flats are set at 22°C, the bathroom at 24°C, and the bedrooms at 22°C. As for cooling, air conditioning is available in the living room and is individually controlled for the summer period (April, May, June, July, August, September, October, and November), with a set of 24°C. Natural ventilation generally occurs in the afternoon in each room.

In Sc 0.1, the heating system is controlled to operate during specific hours, providing energy savings while maintaining a comfortable temperature. In this scenario, the heating hours for the kitchen are with a set temperature of 21°C and a setback of 20°C. In the living room or open-plan kitchen-living rooms, the set temperature is 22°C, with a setback of 20°C during the other hours. For the bathroom, the set temperature is 24°C, with a setback of 22°C during other hours. In the bedrooms, the set temperature is 22°C, with a setback of 20°C. The cooling profile for the living room or open-plan kitchen-living room in Sc 0.1 is the same as in Sc 0.

In Sc 1 (only passive), the heating and cooling systems and schedules remain the same as in Sc 0.1; the only change is the use of more insulated materials for the exterior walls and windows.

Sc 2 scenario has a central heat pump system; the heating schedule is the same as in Sc 0.1 and Sc 1, with passive scenarios for heating, but the major change is in cooling. From this scenario onwards, cooling is no longer provided by individual air conditioners but by a central heat pump system. The cooling control is now scheduled, and unlike previous cases where only the living room was cooled by air conditioning, all rooms, including bathrooms, living rooms, kitchens, and open-plan kitchen-living rooms, can now be centrally cooled. The cooling temperatures for the zones are 24°C, with a setback to 26°C.

The heating and cooling schedules for Sc 3, Sc 4, and Sc 5 are the same as those in Sc 2, with the first heat pump system scenario. There is natural ventilation in all scenarios. The only addition in Sc 3 is the inclusion of PV, in Sc 4 PVT, and in Sc 5 PVT with mechanical ventilation and battery systems.

In Sc 3, the integration of photovoltaic (PV) panels (15 panels) significantly enhances the building's renewable energy generation. The PV system has a module efficiency of 20.4%, contributing to the building's overall sustainability by generating electricity from solar power, thereby reducing the reliance on grid electricity.

Sc 4 further increases energy performance by incorporating photovoltaic thermal (PVT) systems in addition to the heat pump and passive strategies. The Photovoltaic-Thermal (PVT) system, an integrated hybrid technology that concurrently generates electricity through photovoltaic conversion and captures thermal energy for heating applications, demonstrates a module efficiency of 17.8% and a combined energy conversion efficiency of 0.712. The system is highly efficient in converting solar energy to both electricity and thermal energy, significantly reducing the building's dependence on external heating and cooling sources. The integration of PVT panels with a central heat pump system improves both electrical and thermal efficiency, ensuring a steady supply of energy for the building's HVAC requirements while lowering operating costs.

Finally, in Sc 5, the most advanced systems are integrated for a highly energy-efficient and self- sufficient building. The integration of a centralized mechanical ventilation system, with a nominal capacity of approximately 6000 m^3/h, guarantees superior indoor air quality through regulated airflow rates of 12 liters per second per occupant in kitchen areas and 15 liters per second per occupant in bathroom spaces. This system works seamlessly with the heat pump and PVT systems to provide an even higher level of comfort and energy efficiency. Moreover, battery systems with a capacity of ~12 kWh are incorporated to store excess renewable energy generated by the PVT system, enabling the building to operate independently during periods of low solar availability, further optimizing energy consumption and reducing reliance on the grid.

Scenarios	Central Heating (Natural Gas)	Central DHW system	Central Heat Pump system	Air Conditioning	Central Cooling system	PV system	PVT system	Mechanical Ventilation and Battery System
Sc 0 Base on-cont. heating without control	Central natural gas boiler, **seasonal efficiency: 0.95**, delivery efficiency: 0.89, sCoP: 0.85	Natural gas central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C	-	Individual air conditioning per flat, nominal EER: 3.125, **seasonal EER: 2.5,** delivery efficiency: 1.08, SSEER: 2	-	-	-	-
without control	boiler, **seasonal efficiency: 0.95**, delivery efficiency: 0.89, sCoP: 0.85	connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C		flat, nominal EER: 3.125, **seasonal EER: 2.5,** delivery efficiency: 1.08, SSEER: 2				
Sc 0.1 Base with schedule	Central natural gas boiler, **seasonal efficiency: 0.95**, delivery efficiency: 0.89, sCoP: 0.85	Natural gas central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C	-	Individual air conditioning per flat, nominal EER: 3.125, **seasonal EER: 2.5,** delivery efficiency: 1.08, SSEER: 2	-	-	-	-
Sc 1 only passive	Central natural gas boiler, **seasonal efficiency: 0.95**, delivery efficiency: 0.89, sCoP: 0.85	Natural gas central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C	-	Individual air conditioning per flat, nominal EER: 3.125, **seasonal EER: 2.5,** delivery efficiency: 1.08, SSEER: 2	-	-	-	-
Sc 2 HP+passive	-	Air-water Heat pump central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C	Air-water Heat pump central system heating, **seasonal efficiency: 3.8**, delivery efficiency: 0.93, sCoP: 3.54	-	Heat pump (air conditioning line) central system cooling, nominal EER: 3.38, **seasonal EER: 5.5,** delivery efficiency: 1.17, SSEER: 3.9	-	-	-
Sc 3 HP+passive+ PV	-	Air-water Heat pump central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water	Air-water Heat pump central system heating, **seasonal efficiency: 3.8**, delivery efficiency:	-	Heat pump (air conditioning line) central system cooling, nominal EER: 3.38, **seasonal EER: 5.5,** delivery	15 PV (~25.7 m²), south facing 37 tilted, module eff: 20.4%, T:	-	-

		supply temperature: **45** °C	0.93, sCoP: 3.54		efficiency: 1.17, SSEER: 3.9	42, Pmax: -0.3600, Rated Power (kW): 5.24		
Sc 4 HP+passive+ PVT	-	Air-water Heat pump central system connected, delivery efficiency: 0.95, inlet water temperature: 15 °C, hot water supply temperature: **45** °C	Air-water Heat pump central system heating, **seasonal efficiency: 3.8**, delivery efficiency: 0.93, sCoP: 3.54	-	Heat pump (air conditioning line) central system cooling, nominal EER: 3.38, **seasonal EER: 5.5,** delivery efficiency: 1.17, SSEER: 3.9	-	15 PVTs (~29.4°), south facing 37 tilted, flow rate: 31.910 l/(hm²), heat ex. effectiveness: 0.400, conversion eff: 0.712, 1st order heat loss: 5.98, 2nd: 0; module eff: 17.8%, NOCT:45,Pmax :-0.3600, Rated Power (kW):	-

Table 12. Active HVAC system and renewable energy system integration on scenarios

8.4. Analysis

A comprehensive analytical assessment was conducted on the building model slated for urban transformation, encompassing both its baseline conditions and the projected outcomes under multiple alternative development scenarios. A comparison of these scenarios was made, highlighting their energy efficiency and sustainability. Following rigorous evaluation, the optimal scenario was identified and selected, accompanied by a systematic comparative analysis of all potential scenarios that examined their respective merits, implementation challenges, and long-term implications for sustainable urban development.

8.4.1. Energy Analysis

Energy analyses of the building C-02 were presented in Table 13. Total energy consumption and generation comparisons of all scenarios for the upgraded building (C-02) model were listed. After the transformation, the building will adhere to standard insulation values, and energy consumption will be compared accordingly. Furthermore, the building will undergo additional upgrades to achieve higher energy performance levels, advancing beyond its current

C-energy classification. These improvements will include enhanced insulation measures and the integration of active systems, such as renewable energy technologies, to optimize efficiency and sustainability. These upgrades will significantly reduce energy consumption and demonstrate the benefits of active and passive interventions.

In Sc 0, with continuous heating via the central-based natural gas system and no control mechanisms, the building consumes 124.49 kWh/m². The majority of energy consumption comes from heating (43.38 MWh) and domestic hot water (DHW) usage (20.55 MWh), followed by cooling energy by individual air conditioning units (9.99 MWh~10 MWh).

In Sc 0.1, with a scheduled heating system, energy consumption is reduced to 115.89 kWh/m², showing a nearly 7% improvement due to the controlled heating times. The energy consumption for heating (36.88 MWh) is lower compared to Sc 0. Since there is not any change in the natural gas system, DHW consumption remains the same, and the cooling consumption is also similar to the previous scenario.

The transition to passive improvements (increasing wall insulation material thickness and lowering the U-value of the window) in Sc 1 results in a significant reduction in energy consumption. The total energy consumption falls to 100.61 kWh/m² (13% decrease compared to Sc 0.1). This drop is largely due to the passive design improvements that reduce heating energy consumption (24.02 MWh). However, as anticipated, there is a slight increase in cooling energy consumption (10.92 MWh). This is due to the enhanced insulation, which leads to a greater absorption of heat within the building, thereby necessitating additional cooling energy to maintain comfortable indoor temperatures. DHW consumption remains the same.

Sc 2, where the heat pump system which consumes only electricity, is introduced alongside passive improvements (same as Sc 1), shows a dramatic reduction in energy use. Total energy consumption drops to 58.68 kWh/m², a huge improvement compared to previous scenarios (49% compared to Sc 0.1). This is due to the high efficiency of the heat pump (which has a seasonal COP of 3.8), resulting in a low heating energy consumption (5.82 MWh). DHW consumption was decreased to 5.14 kWh. Total electricity consumption was calculated to be 44.51 MWh. This increase is due to the addition of the heat pump's electricity consumption, which replaced natural gas. Cooling energy consumption was found to be 10.03 MWh. The reason why the cooling energy consumption is not significantly lower compared to previous air conditioning scenarios, despite the high efficiency of the heat pump, is that cooling is provided to the rooms, kitchen, and living areas to ensure high comfort levels.

Sc 3 introduces a photovoltaic (PV) system to supplement energy requirements. The total energy consumption per m² drops to 49.94 kWh (56% decrease). This scenario benefits from both the efficient heat pump and the PV system, which generates electricity (6.63 MWh) and offsets the total energy consumption. With a net reduction in grid energy imports due to the energy generation, this scenario sees an even greater reduction in energy use, making it an ideal choice for improving sustainability.

Sc 4 builds on Sc 3 by introducing photovoltaic-thermal (PVT) panels, which combine electricity generation with heat capture, providing a more integrated renewable solution. The energy consumption is further reduced to 48.11 kWh/m² (58% decrease), with a reduction in DHW energy consumption (3.37 MWh). The PVT system offsets both electricity and heating requirements, showing the importance of hybrid systems in improving energy efficiency.

The optimal scenario, Sc 5, integrates all the aforementioned systems, with mechanical ventilation and battery storage added to further optimize energy usage. The total energy consumption is significantly reduced to 41.01 kWh/m² (64% decrease), the lowest of all scenarios. The mechanical ventilation (providing 12 L/s/person in the kitchen and 15 l/s/person in the bathroom) improves indoor air quality without causing an increase in energy consumption. The battery system ensures that excess energy generated from PV and PVT is stored and used during peak demand periods, reducing grid imports even further.

In the last column of Table 13, the energy consumption of a 2+1 flat (net area ~66 m²) is provided as an example, based on the total building energy consumption results.

Sc 0 Base on-cont. heating without control	43.38	20.55	9.99	63.93	30.49	-	94.42	-	**124.49**	8216.65
Sc 0.1 Base with schedule	36.87	20.55	9.98	57.43	30.46	-	87.89	-	**115.89**	7648.62
Sc 1 only passive	24.02	20.55	10.92	44.57	31.73	-	76.31	-	**100.61**	6640.12
Sc 2 HP+passive	5.82	5.14	10.03	-	44.51	-	44.51	-	**58.68**	3873.1
Sc 3 HP+passive+ PV	5.82	5.14	10.03	-	44.51	-6.63	37.87	-	**49.94**	3295.88
Sc 4 HP+passive+ PVT	5.82	3.37	10.03	-	43.07	-6.58	36.49	-	**48.11**	3175.07
Sc 5 Opt. sc HP+passive + mech. vent+PVT+battery	3.77	3.37	7.95	-	37.59	-6.58	31.00	31.10	**41.01**	2706.34

Table 13. Total annual energy consumption and generation comparisons of all scenarios for the upgraded building (C-02) model

- **Heating and Cooling Reductions:** As expected, scenarios incorporating passive improvements and active systems (heat pumps, PV, PVT) show a dramatic reduction in heating and cooling energy consumption. Scenarios like Sc 2 (HP + passive) and Sc 3 (HP + passive + PV) exhibit the largest reductions, with heating energy consumption falling from 43.38 MWh in Sc 0 to just 5.82 MWh in Sc 2. Cooling energy consumption is more stable, but slight reductions are still seen with the integration of more efficient systems.
- **Energy Savings per m²:** The total energy consumption per m² for the building decreases significantly across the scenarios. Sc 0 (base with continuous heating) and Sc 0.1 (with scheduling) start at 124.49 kWh/m² and 115.89 kWh/m², respectively, while Sc 5 (optimal scenario) reduces this to only 41.01 kWh/m², a 67% reduction.

- **Renewable Energy Integration:** The introduction of PV and PVT systems in Sc 3 and Sc 4, respectively, helps offset electricity and heating demands, leading to a noticeable reduction in grid reliance.
- **Mechanical Ventilation and Battery:** The inclusion of mechanical ventilation and battery storage in Sc 5 provides both energy efficiency and enhanced indoor air quality, ensuring a healthier and more sustainable living environment.

A comprehensive evaluation of the assessed scenarios demonstrates significant enhancements in energy performance through the strategic integration of passive design optimization, advanced heat pump technologies, and renewable energy systems, including photovoltaic (PV) and photovoltaic-thermal (PVT) configurations. Scenarios such as Sc 2 (HP + passive) and Sc 3 (HP + passive + PV) already show significant reductions in energy consumption, but the addition of mechanical ventilation and battery storage in Sc 5 optimizes the system further, resulting in the lowest energy consumption per m^2. This optimal scenario represents the most sustainable and energy-efficient solution for future urban housing developments, offering a model for achieving reduced energy consumption and increased energy independence.

The total greenhouse gas emissions (tCO_2, tCH_4, tN_2O, and tCO_2e) of different scenarios applied to the upgraded C-02 building model is presented in Table 14. The results clearly indicate that implementing passive design strategies, heat pumps, and renewable energy systems significantly reduces greenhouse gas emissions.

- **Baseline Scenarios (Sc 0 and Sc 0.1):** The highest emissions occur in the baseline scenarios, especially Sc 0, which operates with continuous heating and no control. It results in a total emission of 25.11 tCO_2e, largely driven by both natural gas (12.01 tCO_2e) and electricity (13.10 tCO_2e) consumption. The scheduled heating scenario (Sc 0.1) yields only marginal emission reductions, achieving a total of 23.88 (tCO_2e), thereby demonstrating the constrained efficacy of temporal load management strategies absent complementary systemic retrofits.

- **Passive Design Only (Sc 1):**

Introducing passive improvements alone (Sc 1) significantly lowers natural gas use and overall emissions to 22.01 tCO_2e, highlighting the benefit of envelope-level enhancements even without active systems.

- **Heat Pump Integration (Sc 2):** In Scenario 2, the building uses heat pumps with passive strategies, completely eliminating natural gas consumption. Total emissions drop sharply to 19.12 tCO_2e, driven solely by electricity usage, indicating a major shift toward electrification.

- **Renewables with HP and Passive (Sc 3& Sc 4):** Adding PV (Sc 3) and PVT (Sc 4) systems further cuts emissions to 16.27 tCO_2e and 15.68 tCO_2e, respectively. These reductions show the clear advantage of integrating renewable technologies to offset electrical demand.

- **Optimal Scenario (Sc 5):** The lowest emissions are achieved in Sc 5, which combines heat pumps, passive design, mechanical ventilation, and PVT systems. Total emissions are reduced to 13.36 tCO_2e, marking a 47% reduction compared to the base case (Sc 0). This makes Sc 5 the most sustainable and climate-friendly option.

Sc 5 Opt. sc HP+passive + mech. vent+PVT+battery	3.77	3.37	7.95	-	37.59	-6.58	31.00	31.10	**41.01**	2706.34

Sc 0 Base on-cont. heating without control	**Consumption**	**Greenhouse gas emissions**	**tCO2e**
Natural Gas Consumption	63932 kWh	Scope 1	12.01
Electricity Consumption	30493 kWh	Scope 2	13.10
		Total	**25.11**

Sc 0.1 Base with schedule	**Consumption**	**Greenhouse gas emissions**	**tCO_2e**
Natural Gas Consumption	57431 kWh	Scope 1	10.79
Electricity Consumption	30466 kWh	Scope 2	13.09
		Total	**23.88**

Sc1 only passive	**Consumption**	**Greenhouse gas emissions**	**tCO_2e**
Natural Gas Consumption	44574 kWh	Scope 1	8.37
Electricity Consumption	31733 kWh	Scope 2	13.63
		Total	**22.01**

Sc2 HP+passive	Consumption	Greenhouse gas emissions	tCO_2e
Electricity Consumption	44509 kWh	Scope 2	19.12
		Total	**19.12**
Sc3 HP+passive+PV	**Consumption**	**Greenhouse gas emissions**	**tCO_2e**
Electricity Consumption	37876 kWh	Scope 2	16.27
		Total	**16.27**
Sc4 HP+passive+PVT	**Consumption**	**Greenhouse gas emissions**	**tCO_2e**
Electricity Consumption	36487 kWh	Scope 2	15.68
		Total	**15.68**
Sc5 Opt sc HP+passive+mech. vent+PVT	**Consumption**	**Greenhouse gas emissions**	**tCO_2e**
Electricity Consumption	31101 kWh	Scope 2	13.36
		Total	**13.36**

Table 14. Total annual greenhouse gas emissions of all scenarios for the up graded building (C-02) model

The findings from these scenarios can serve as a pioneering guide for other cities undergoing urban transformation, offering a roadmap for sustainable development. By integrating passive design improvements, renewable energy systems, and energy-efficient technologies, cities can significantly reduce energy consumption, lower operating costs, and minimize their carbon footprint. These strategies not only enhance building performance but also promote energy independence, offering long-term environmental and economic benefits. Implementing such integrated systems in urban housing can serve as a model for creating more sustainable, self-sufficient communities, reducing reliance on external energy sources and improving overall quality of life. Additionally, this approach can inspire policy changes and the adoption of new building standards, paving the way for a greener future in urban development.

8.4.2. Economic Analysis

Economic analysis is conducted to prepare a comprehensive cost-benefit analysis (CBA) of the proposed scenarios, with the principal objective of providing the necessary quantitative analysis to assess the financial viability.

The economic analysis presented in this section evaluates the long-term sustainability of these scenarios. The analysis incorporates a detailed cost-benefit framework, considering energy cost savings, carbon emission benefits, and capital expenditures. This evaluation focuses on quantifying the economic returns derived from infrastructure investments, including reductions in electricity and natural gas consumption, improvements in carbon emissions, and enhancements to building performance.

As part of the economic analysis, the feasibility of the scenarios was evaluated using financial metrics such as IRR and NPV calculations to assess the financial impact of the proposed scenarios. In addition to determining the Internal Rate of Return (IRR) and Net Present Value (NPV), the analysis integrates sensitivity and risk assessments to measure the scenarios' resilience under varying economic conditions.

8.4.2.1. Conformance to Guidelines and Standards

The following section outlines the guidelines and standards applied in the economic analysis, ensuring that the approach adheres to recognized best practices and methodologies for cost-benefit analysis and modeling.

8.4.2.1.1. CBA Guidance

The economic analysis employed the Guide to the Cost Benefit Analysis of Investment Projects[78] as the primary framework. The EC CBA Guide is a valuable tool for assessing the financial and economic viability of infrastructure investments. It promotes the optimal allocation of funding and ensures that projects deliver good value for society. A newer version, the Economic Appraisal Vademecum 2021-2027, was published in September 2021. However, the EC CBA Guide provides sufficiently comprehensive methodology for the scope of this assessment, with divergences from other guidelines being inconsequential in this specific context.

8.4.2.1.2. Modelling Standard

The economic analysis is conducted by preparing an economic model in line with the modeling principles of the FAST Standard ("Standard"), which standardizes financial model design, promoting clarity, accuracy, and efficiency in model development.

The Standard encourages models that are

Flexible: Model allows users to run scenarios and sensitivities and make modifications over an extended period as new information becomes available

Appropriate: Model reflects key assumptions without being over-built or cluttered with unnecessary detail

Structured: Rigorous consistency in model layout is essential to retain a logical integrity over time, A consistent approach to structuring workbooks, worksheets and formulas saves time when building, learning, or maintaining the model

Transparent: Model relies on simple, clear formulas that can be understood by other modellers and non-modellers alike

8.4.2.2. Methodology

The primary objective of Cost-Benefit Analysis is to provide decision-makers with a comprehensive evaluation of both expenditures and anticipated returns on green building investments, facilitating evidence-based assessments of transition scenarios and supporting strategic investments in sustainable infrastructure and energy conservation measures.

In accordance with the EC CBA Guide, CBA requires comparing two alternative scenarios over the projection period to assess the incremental impact of these compared scenarios. For a comprehensive CBA, the following sets of assumptions are applied to account for a total of 7 alternative scenarios (Sc) defined for the selected C-02 building. These scenarios aim to evaluate various approaches for reducing energy consumption and improving sustainability in the context of urban transformation:

- **Sc 0 Base on-cont. heating without control:** C-type base building scenario: natural ventilation, natural gas central system (on-continuous heating, without schedule control) and individual air conditioning

- **Sc 0.1 Base with schedule:** C-type base building scenario: natural ventilation, natural gas central system (scheduled heating with set temperatures) and individual air conditioning
- **Sc1 only passive:** Passive material implementation and natural ventilation, natural gas central system (scheduled heating with set temperatures) and individual air conditioning
- **Sc2 HP + passive:** Passive material implementation and natural ventilation, central heat pump (HP) (air to water) usage (scheduled heating and cooling with set temperatures)
- **Sc3 HP + passive + PV:** Passive material implementation and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), photovoltaic (PV) panel installation
- **Sc4 HP + Passive + PVT:** Passive material implementation and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), photovoltaic thermal (PVT) panel installation
- **Sc5 Opt sc HP + Passive + Mechvent + PVT:** Passive material implementation (optimum) and natural ventilation, central heat pump (air to water) usage (scheduled heating and cooling with set temperatures), mechanical ventilation, PVT installation and battery connection

CBA calculations rely on projections that focus on the following key areas, which determine the economic implications of each scenario:

- **Projections of energy consumption:** This projection estimates the volume of electricity and natural gas consumed over time, including consumption for heating, DHW, cooling, and other uses.
- **Projections of electricity generation:** This projection estimates the volume of electricity generated from investments in photovoltaic (PV) panel installation, photovoltaic thermal (PVT) panel installation and battery connection.
- **Projections of carbon savings:** These projections focus on the carbon savings in tons of CO2 equivalent obtained by implementing the proposed investments.
- **Projections of investment costs:** These projections focus on the capital expenditures associated with central heating, central DHW system, central heat pump system, air conditioning, central cooling system, PV system, PVT system, mechanical ventilation, and battery system.

By comparing the projections in these scenarios, the CBA provides a clear understanding of the economic trade-offs between the selected two scenarios. It helps identify the necessary investments, operational costs, and long-term benefits of infrastructure improvements, ultimately guiding decisions on whether to proceed with major investments to meet sustainable development goals.

8.4.2.3. Cost Benefit Analysis Inputs

A cost-benefit analysis is conducted by preparing an economic model that simulates the interaction of scenario variables (e.g., energy consumption, carbon savings, electricity generation, and investment costs) and their impact on the economic analysis. The scenario projections and economic analysis results are explained in detail in the following sections

- **Time Horizon:** The economic analysis encompasses a period of 25 years (2025-2049) including the construction phase
- **Currency Unit:** The cost and benefit calculations are made in nominal TRY terms
- **Macroeconomic Inputs:** Forecast of the Central Bank of the Republic of Türkiye were used for macroeconomic projections for the 2025-2027 period. For the period after 2027, it was assumed that macroeconomic growth and inflation rates would be equal to the data from 2027
- **Discount Rate:** A discount rate of 35%, corresponding to the approximate yield on Türkiye’s 10-year TL government bonds, has been used.
- **Investment Costs:** Investment costs are defined for both the without project and with project scenarios, aligned with the scope outlined earlier and are based on a 66 m² apartment. The investment cost estimates do not include Value Added Tax.

Investment Costs	Unit	Amount	Change
Sc0	000 TL	229.0	-
Sc0.1	000 TL	229.0	0.0
Sc1	000 TL	235.0	6.0
Sc2	000 TL	323.0	88.0
Sc3	000 TL	337.9	14.9
Sc4	000 TL	439.2	101.3
Sc5	000 TL	546.9	107.7

Table 15. Scenario-based investment costs

The investment cost for the initial two scenarios reflects the base cost for the variable building elements under this analysis, such as exterior insulation, windows, and equipment. The projected investment levels demonstrate a progressive increase in each successive scenario, commensurate with the evolving cost parameters of critical building elements. Notably, the scenarios showing the largest increase in investment are Scenario 2, which introduces the central heat pump system investment, and Scenario 4 and 5, which introduce the PVT and battery systems, respectively.

- **Energy Consumptions:** For each scenario, the electricity and natural gas consumption required for heating, hot water, cooling, lighting, and equipment has been calculated on a per-square-meter basis.

The economic analysis has been conducted based on a 66 m² apartment. Accordingly, the electricity and natural gas consumption projections for each scenario have been calculated as follows.

Energy Consumption	Unit	Sc0	Sc0.1	Sc1	Sc2	Sc3	Sc4	Sc5
Natural Gas								
Heating Energy	MWh	3.775	3.209	2.090	-	-	-	-
DHW Energy	MWh	1.789	1.789	1.789	-	-	-	-
Electricity								
Heating Energy	MWh	-	-	-	0.506	0.506	0.506	0.328
DHW Energy	MWh	-	-	-	0.447	0.447	0.294	0.294
Cooling Energy	MWh	0.870	0.868	0.950	0.873	0.873	0.873	0.692
Other	MWh	1.783	1.783	1.811	2.046	2.046	2.075	1.957
Lightning	MWh	0.218	0.218	0.218	0.218	0.218	0.218	0.218
Other Equipment Electric	MWh	1.261	1.261	1.261	1.261	1.261	1.261	1.261
Pumps fan etc.	MWh	0.305	0.304	0.333	0.568	0.568	0.568	0.450
DHW/Solar Pumps Energy	MWh	-	-	-	-	-	0.029	0.029

Table 16. Scenario-based energy consumption

- **Electricity Generation:** In line with the inclusion of PV systems, Scenarios 3, 4 and 5 provide electricity to help reduce final energy consumption. Electricity generation projections for each scenario have been calculated as follows.

Electricity Generation	Unit	Sc0	Sc0.1	Sc1	Sc2	Sc3	Sc4	Sc5
Total Electricity Generation (PV)	MWh	-	-	-	-	(0.577)	(0.573)	(0.573)
Grid Import with PV Feed Battery	MWh	-	-	-	-	-	-	0.009

Table 17. Scenario-based energy production

- **Greenhouse Gas Emissions:** For each scenario, the carbon saving assumptions have been calculated in tons of CO_2 equivalent.

Greenhouse Gas Emissions	Unit	Sc0	Sc0.1	Sc1	Sc2	Sc3	Sc4	Sc5
Greenhouse Gas Emissions	tCO2e	2.186	2.078	1.916	1.665	1.417	1.365	1.163

Table 18. Scenario-based default carbon emission reduction amounts

- **Price Projections:** The impacts of energy consumption costs and carbon savings have been calculated based on electricity, natural gas, and carbon price forecasts. The projected prices for the years 2026– 2049 have been derived by applying the Turkish Lira inflation rate to the estimated prices for 2025.

Prices	Unit	2025	2030	2035	2040	2045	2049
Electricity (<240 kWh)	TL/kwh	2.6	4.5	6.7	9.8	14.4	19.6
Electricity (>240 kWh)	TL/kwh	3.9	6.9	10.1	14.8	21.8	29.6
Natural Gas	TL/m3	7.5	13.2	19.4	28.4	41.8	56.9
Carbon	TL/tCO2	4,315	7,549	11,092	16,298	23,947	32,579

Table 19. Year-based projected energy price projections

8.4.2.4. Fact Findings

The analyses conducted as part of the economic assessment have been prepared based on a comparative evaluation of all scenarios. Accordingly, each scenario has been compared with the subsequent one, allowing for the financial feasibility of each scenario to be assessed relative to the previous one. In total, seven scenario comparison analyses have been carried out across seven scenarios. Each comparison has been prepared with and without the inclusion of carbon income.

Comparison 1: Sc0 and Sc0.1

In this scenario comparison, both scenarios are based on the same investment cost assumptions. However, Scenario Sc0.1 is projected to have lower electricity and natural gas consumption. The resulting cost savings are accompanied by increased carbon revenue, leading to a positive NPV. Notably, a positive NPV is achieved in both cases — with and without carbon income. Since a consistently positive financial return is generated from the first year onward, the IRR cannot be calculated in this analysis.

Economic Impact	2025	2030	2035	2040	2045	2049
∆ in Natural Gas Cost	407	712	1,047	1,538	2,260	3,075
∆ in Electricity Cost	6	10	15	23	33	45
∆ in Capex	-	-	-	-	-	-
Subtotal	**413**	**723**	**1,062**	**1,561**	**2,293**	**3,120**
∆ in Carbon Income	463	810	1,190	1,749	2,569	3,496
Total	**876**	**1,533**	**2,252**	**3,310**	**4,863**	**6,616**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	3,540	3,542	3,545
	0.0%	3,701	3,704	3,706
	10.0%	3,863	3,865	3,868
% in Natural Gas Prices	-10.0%	3,370	3,542	3,714
	0.0%	3,532	3,704	3,876
	10.0%	3,693	3,865	4,037

IRR (%)		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	infinite	infinite	infinite
	0.0%	infinite	infinite	infinite
	10.0%	infinite	infinite	infinite
% in Natural Gas Prices	-10.0%	infinite	infinite	infinite
	0.0%	infinite	infinite	infinite
	10.0%	infinite	infinite	infinite

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	1,744	1,747	1,749
	0.0%	1,744	1,747	1,749
	10.0%	1,744	1,747	1,749
% in Natural Gas Prices	-10.0%	1,575	1,747	1,919
	0.0%	1,575	1,747	1,919
	10.0%	1,575	1,747	1,919

IRR (%)		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	infinite	infinite	infinite
	0.0%	infinite	infinite	infinite
	10.0%	infinite	infinite	infinite
% in Natural Gas Prices	-10.0%	infinite	infinite	infinite
	0.0%	infinite	infinite	infinite
	10.0%	infinite	infinite	infinite

Table 20. Comparison 1: Sc0 - Sc0.1 Economic impact and sensitivity analyses

Comparison 2: Sc0.1 and Sc1

In this scenario comparison, the Sc1 scenario includes the implementation of passive materials, resulting in an additional capital expenditure in 2025. While this leads to increased costs due to higher electricity consumption, the overall economic impact driven by the reduction in natural gas costs and the addition of carbon income results in a positive NPV. However, when carbon income is excluded, the NPV turns negative.

Economic Impact	2025	2030	2035	2040	2045	2049
∆ in Natural Gas Cost	805	1,409	2,070	3,042	4,470	6,081
∆ in Electricity Cost	(286)	(500)	(734)	(1,079)	(1,585)	(2,156)
∆ in Capex	(6,017)	-	-	-	-	-
Subtotal	**(5,497)**	**909**	**1,336**	**1,963**	**2,885**	**3,925**
∆ in Carbon Income	703	1,229	1,806	2,654	3,899	5,304
Total	**(4,795)**	**2,138**	**3,142**	**4,617**	**6,784**	**9,229**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)		% in Carbon Prices			IRR (%)		% in Carbon Prices		
		-10.0%	0.0%	10.0%			-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	585	465	344	% in Electricity Prices	-10.0%	39.5%	38.6%	37.6%
	0.0%	830	710	589		0.0%	41.4%	40.5%	39.5%
	10.0%	1,075	955	834		10.0%	43.3%	42.3%	41.4%
% in Natural Gas Prices	-10.0%	124	465	805	% in Natural Gas Prices	-10.0%	35.9%	38.6%	41.3%
	0.0%	369	710	1,050		0.0%	37.8%	40.5%	43.2%
	10.0%	614	955	1,295		10.0%	39.6%	42.3%	45.1%

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)		% in Carbon Prices			IRR (%)		% in Carbon Prices		
		-10.0%	0.0%	10.0%			-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(2,139)	(2,260)	(2,381)	% in Electricity Prices	-10.0%	19.8%	18.9%	18.0%
	0.0%	(2,139)	(2,260)	(2,381)		0.0%	19.8%	18.9%	18.0%
	10.0%	(2,139)	(2,260)	(2,381)		10.0%	19.8%	18.9%	18.0%
% in Natural Gas Prices	-10.0%	(2,600)	(2,260)	(1,919)	% in Natural Gas Prices	-10.0%	16.4%	18.9%	21.3%
	0.0%	(2,600)	(2,260)	(1,919)		0.0%	16.4%	18.9%	21.3%
	10.0%	(2,600)	(2,260)	(1,919)		10.0%	16.4%	18.9%	21.3%

Table 21. Comparison 2: Sc0.1 - Sc1 Economic impact and sensitivity analyses

Comparison 3: Sc1 and Sc2

In this scenario comparison, the Sc2 scenario involves the implementation of the central heat pump (HP), resulting in an additional capital expenditure in 2025. However, the increased costs due to higher electricity consumption cannot be fully offset by the reduction in natural gas costs and the additional carbon revenues, resulting in a negative NPV. Notably, the NPV remains negative both with and without carbon income.

Economic Impact	2025	2030	2035	2040	2045	2049
∆ in Natural Gas Cost	2,792	4,885	7,178	10,546	15,496	21,082
∆ in Electricity Cost	(4,200)	(7,348)	(10,797)	(15,864)	(23,310)	(31,713)
∆ in Capex	(87,989)	-	-	-	-	-
Subtotal	**(89,397)**	**(2,463)**	**(3,619)**	**(5,318)**	**(7,814)**	**(10,630)**
∆ in Carbon Income	1,083	1,894	2,783	4,089	6,009	8,175
Total	**(88,315)**	**(569)**	**(836)**	**(1,228)**	**(1,805)**	**(2,456)**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)		% in Carbon Prices			IRR (%)		% in Carbon Prices		
		-10.0%	0.0%	10.0%			-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(65,154)	(66,929)	(68,705)	% in Electricity Prices	-10.0%	negative	negative	negative
	0.0%	(64,777)	(66,552)	(68,327)		0.0%	negative	negative	negative
	10.0%	(64,399)	(66,175)	(67,950)		10.0%	negative	negative	negative
% in Natural Gas Prices	-10.0%	(68,110)	(66,929)	(65,749)	% in Natural Gas Prices	-10.0%	negative	negative	negative
	0.0%	(67,732)	(66,552)	(65,372)		0.0%	negative	negative	negative
	10.0%	(67,355)	(66,175)	(64,994)		10.0%	negative	negative	negative

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(69,353)	(71,128)	(72,904)
	0.0%	(69,353)	(71,128)	(72,904)
	10.0%	(69,353)	(71,128)	(72,904)
% in Natural Gas Prices	-10.0%	(72,309)	(71,128)	(69,948)
	0.0%	(72,309)	(71,128)	(69,948)
	10.0%	(72,309)	(71,128)	(69,948)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative
% in Natural Gas Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative

Table 22. Comparison 3: Sc1- Sc3 Economic impact and sensitivity analyses

Comparison 4: Sc2 and Sc3

In this scenario comparison, the Sc3 scenario involves the photovoltaic (PV) panel investment, resulting in an additional capital expenditure in 2025. With Sc3, a portion of the electricity consumption is covered through the electricity generated by the PV investment. While the reduction in electricity costs and the additional carbon revenues can offset the investment cost and result in a positive NPV, the NPV turns negative when carbon income is excluded.

Economic Impact	2025	2030	2035	2040	2045	2049
Δ in Natural Gas Cost	-	-	-	-	-	-
Δ in Electricity Cost	2,263	3,959	5,817	8,546	12,557	17,084
Δ in Capex	(14,889)	-	-	-	-	-
Subtotal	**(12,626)**	**3,959**	**5,817**	**8,546**	**12,557**	**17,084**
Δ in Carbon Income	1,070	1,873	2,752	4,043	5,941	8,082
Total	**(11,556)**	**5,831**	**8,568**	**12,590**	**18,498**	**25,166**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	1,730	2,687	3,643
	0.0%	2,103	3,060	4,016
	10.0%	2,476	3,433	4,389
% in Natural Gas Prices	-10.0%	2,687	2,687	2,687
	0.0%	3,060	3,060	3,060
	10.0%	3,433	3,433	3,433

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	40.4%	43.5%	46.8%
	0.0%	41.6%	44.7%	48.0%
	10.0%	42.7%	45.9%	49.2%
% in Natural Gas Prices	-10.0%	43.5%	43.5%	43.5%
	0.0%	44.7%	44.7%	44.7%
	10.0%	45.9%	45.9%	45.9%

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(2,421)	(1,465)	(508)
	0.0%	(2,421)	(1,465)	(508)
	10.0%	(2,421)	(1,465)	(508)
% in Natural Gas Prices	-10.0%	(1,465)	(1,465)	(1,465)
	0.0%	(1,465)	(1,465)	(1,465)
	10.0%	(1,465)	(1,465)	(1,465)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	27.9%	30.7%	33.5%
	0.0%	27.9%	30.7%	33.5%
	10.0%	27.9%	30.7%	33.5%
% in Natural Gas Prices	-10.0%	30.7%	30.7%	30.7%
	0.0%	30.7%	30.7%	30.7%
	10.0%	30.7%	30.7%	30.7%

Table 23. Comparison 4: Sc2- Sc3 Economic impact and sensitivity analyses

Comparison 5: Sc1 and Sc3

In Comparison 3, a negative NPV is obtained for Sc2 due to its high investment cost. In Comparison 4, however, it is assumed that the high cost of Sc2 has already been incurred, and the NPV is calculated based on the cost difference between Sc2 and Sc3, resulting in a positive NPV. Therefore, in order to account for the high cost of Sc2 when transitioning to Sc3, a new comparison has been prepared that considers both Sc1 and Sc3.

In Scenario Comparison 5, a significant increase in investment cost arises from the addition of photovoltaic (PV) panels and a central heat pump (HP). Although the final electricity consumption is reduced and carbon income is generated, these benefits are insufficient to offset the total investment cost, resulting in a negative NPV. This negative NPV occurs regardless of whether carbon income is included or not.

Economic Impact	2025	2030	2035	2040	2045	2049
∆ in Natural Gas Cost	2,792	4,885	7,178	10,546	15,496	21,082
∆ in Electricity Cost	(1,937)	(3,390)	(4,980)	(7,318)	(10,752)	(14,628)
∆ in Capex	(102,878)	-	-	-	-	-
Subtotal	**(102,024)**	**1,495**	**2,197**	**3,229**	**4,744**	**6,454**
∆ in Carbon Income	2,153	3,767	5,535	8,133	11,949	16,257
Total	**(99,871)**	**5,262**	**7,732**	**11,361**	**16,693**	**22,711**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(63,424)	(64,243)	(65,062)
	0.0%	(62,673)	(63,492)	(64,311)
	10.0%	(61,923)	(62,742)	(63,561)
% in Natural Gas Prices	-10.0%	(65,423)	(64,243)	(63,063)
	0.0%	(64,672)	(63,492)	(62,312)
	10.0%	(63,922)	(62,742)	(61,561)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	6.7%	6.1%	5.6%
	0.0%	7.3%	6.7%	6.2%
	10.0%	7.8%	7.3%	6.8%
% in Natural Gas Prices	-10.0%	5.3%	6.1%	6.9%
	0.0%	5.9%	6.7%	7.5%
	10.0%	6.5%	7.3%	8.0%

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(71,774)	(72,593)	(73,412)
	0.0%	(71,774)	(72,593)	(73,412)
	10.0%	(71,774)	(72,593)	(73,412)
% in Natural Gas Prices	-10.0%	(73,773)	(72,593)	(71,413)
	0.0%	(73,773)	(72,593)	(71,413)
	10.0%	(73,773)	(72,593)	(71,413)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative
% in Natural Gas Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative

Table 24. Comparison 5: Sc1- Sc3 Economic impact and sensitivity analyses

Comparison 6: Sc3 and Sc4

In this scenario comparison, Scenario Sc4 involves the implementation of a photovoltaic thermal (PVT) panel system, leading to an additional capital expenditure in 2025. While the natural gas consumption remains unchanged, the system contributes to a reduction in electricity costs through energy generation, and it also results in an increase in carbon revenues. Nevertheless, the aggregate financial benefits—comprising both energy expenditure reductions and carbon credit revenues—remain insufficient to completely amortize the initial capital outlay. As a result, the scenario yields a negative NPV. Importantly, the NPV remains negative both when carbon income is included and when it is excluded.

Economic Impact	2025	2030	2035	2040	2045	2049
∆ in Natural Gas Cost	-	-	-	-	-	-
∆ in Electricity Cost	474	828	1,217	1,789	2,628	3,576
∆ in Capex	(101,331)	-	-	-	-	-
Subtotal	**(100,857)**	**828**	**1,217**	**1,789**	**2,628**	**3,576**
∆ in Carbon Income	224	392	576	847	1,244	1,692
Total	**(100,633)**	**1,221**	**1,794**	**2,635**	**3,872**	**5,268**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(72,389)	(72,189)	(71,989)
	0.0%	(72,311)	(72,111)	(71,911)
	10.0%	(72,233)	(72,033)	(71,833)
% in Natural Gas Prices	-10.0%	(72,189)	(72,189)	(72,189)
	0.0%	(72,111)	(72,111)	(72,111)
	10.0%	(72,033)	(72,033)	(72,033)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative
% in Natural Gas Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(73,258)	(73,058)	(72,858)
	0.0%	(73,258)	(73,058)	(72,858)
	10.0%	(73,258)	(73,058)	(72,858)
% in Natural Gas Prices	-10.0%	(73,058)	(73,058)	(73,058)
	0.0%	(73,058)	(73,058)	(73,058)
	10.0%	(73,058)	(73,058)	(73,058)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative
% in Natural Gas Prices	-10.0%	negative	negative	negative
	0.0%	negative	negative	negative
	10.0%	negative	negative	negative

Table 25. Comparison6: Sc3- Sc4 Economic impact and sensitivity analyses

Comparison 7: Sc4 and Sc5

In this scenario comparison, the Sc5 scenario involves the implementation of battery connection, resulting in an additional capital expenditure in 2025. While natural gas consumption remains unchanged, electricity costs decrease, and carbon revenues increase. Nevertheless, the cumulative energy cost reductions and carbon credit earnings remain inadequate to offset the required capital investment, resulting in a negative net present value (NPV) for the project. This negative NPV occurs regardless of whether carbon income is included or not.

Economic Impact	2025	2030	2035	2040	2045	2049
Δ in Natural Gas Cost	-	-	-	-	-	-
Δ in Electricity Cost	1,606	2,810	4,129	6,067	8,915	12,129
Δ in Capex	(107,730)	-	-	-	-	-
Subtotal	**(106,124)**	**2,810**	**4,129**	**6,067**	**8,915**	**12,129**
Δ in Carbon Income	869	1,521	2,234	3,283	4,824	6,563
Total	**(105,254)**	**4,331**	**6,364**	**9,350**	**13,739**	**18,692**

Sensitivity Analysis (Including Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(70,318)	(69,639)	(68,960)
	0.0%	(70,015)	(69,336)	(68,657)
	10.0%	(69,712)	(69,033)	(68,354)
% in Natural Gas Prices	-10.0%	(69,639)	(69,639)	(69,639)
	0.0%	(69,336)	(69,336)	(69,336)
	10.0%	(69,033)	(69,033)	(69,033)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	4.0%	4.5%	5.0%
	0.0%	4.3%	4.8%	5.3%
	10.0%	4.6%	5.1%	5.5%
% in Natural Gas Prices	-10.0%	4.5%	4.5%	4.5%
	0.0%	4.8%	4.8%	4.8%
	10.0%	5.1%	5.1%	5.1%

Sensitivity Analysis (Excluding Carbon Income)

NPV (TL)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	(73,689)	(73,010)	(72,331)
	0.0%	(73,689)	(73,010)	(72,331)
	10.0%	(73,689)	(73,010)	(72,331)
% in Natural Gas Prices	-10.0%	(73,010)	(73,010)	(73,010)
	0.0%	(73,010)	(73,010)	(73,010)
	10.0%	(73,010)	(73,010)	(73,010)

IRR (%)

		% in Carbon Prices		
		-10.0%	0.0%	10.0%
% in Electricity Prices	-10.0%	1.0%	1.7%	2.3%
	0.0%	1.0%	1.7%	2.3%
	10.0%	1.0%	1.7%	2.3%
% in Natural Gas Prices	-10.0%	1.7%	1.7%	1.7%
	0.0%	1.7%	1.7%	1.7%
	10.0%	1.7%	1.7%	1.7%

Table 26. Comparison7: Sc4- Sc5 Economic impact and sensitivity analyses

Summary

A comparison of all scenarios reveals that, excluding carbon income, all except Comparison 1 result in a negative NPV. This indicates that the projected reductions in energy consumption costs alone are insufficient to justify the additional investment costs associated with each scenario.

Including carbon income in the analysis alters the analysis. In addition to Comparison 1, two more comparison (Comparison 2 and Comparison 4) show a positive NPV, indicating that these scenarios become financially viable with the support of carbon revenues. It is noteworthy that despite Comparison 3 yielding a negative NPV, Comparison 4 becomes financially feasible due to the assumption that the substantial investment cost of Sc2 has already been absorbed. To further explore this situation, Comparison 5 was conducted between Sc1 and Sc3. The results again show a negative NPV, reinforcing the financial limitations of these scenarios under current assumptions.

Scenario analysis	Unit	NPV (Excl. Carbon Income)	NPV (Incl. Carbon Income)
Comparison 1: Sc0 > Sc0.1	TL	1,747	3,704
Comparison 2: Sc0.1 > Sc1	TL	(2,260)	710
Comparison 3: Sc1 > Sc2	TL	(71,128)	(66,552)
Comparison 4: Sc2 > Sc3	TL	(1,465)	3,060
Comparison 5: Sc1 > Sc3	TL	(72,593)	(63,492)
Comparison 6: Sc3 > Sc4	TL	(73,058)	(72,111)
Comparison 7: Sc4 > Sc5	TL	(73,010)	(69,336)

Table 27. Net present values of scenario comparisons

8.4.2.5. Economic Commentary

Seven distinct alternative scenarios (Sc) have been systematically formulated to evaluate a range of strategic interventions targeting energy efficiency optimization and sustainability enhancement, with specific application to urban regeneration contexts. Each scenario represents a unique combination of energy efficiency measures, renewable energy system implementations, and sustainable construction materials. Collectively, these scenarios enable a holistic assessment of potential intervention strategies for sustainable long-term urban development and environmental enhancement within the designated study area.

To assess the financial feasibility of these scenarios, an in-depth analysis has been conducted to identify the adjustments required to bring each scenario to a breakeven point in terms of Net Present Value (NPV). Thus, a switching value analysis has been applied as a key tool in this evaluation.

The switching value of a given variable represents the threshold at which the NPV of a project becomes zero. In other words, it is the critical value that a parameter must reach for a previously non-viable scenario to become financially feasible. This analysis provides insight into the sensitivity of each scenario to key variables, helping stakeholders better understand the magnitude of change needed for financial viability.

The switching value analysis primarily focuses on five key variables that significantly impact the economic outcome of the investment:

- **% Change in Capital Expenditures (Capex):** This refers to the percentage reduction in upfront investment costs required to reach breakeven. The adoption of strategic cost-containment approaches—such as economies of scale through bulk purchasing, implementation of standardized material specifications, and rigorous competitive tendering procedures—could enhance the project's financial feasibility by reducing capital expenditures.
- **Number of Capex Payments:** This evaluates the impact of distributing investment costs over multiple payment periods rather than a single upfront payment. The adoption of structured payment deferrals or installment-based financing mechanisms serves to mitigate early-stage fiscal constraints, improve liquidity management, and consequently increase the project's operational and financial feasibility.
- **% Change in Electricity Prices:** Changes in electricity prices directly affect the cost savings derived from energy efficiency improvements and renewable electricity generation. An increase in electricity tariffs improves the payback of energy-saving measures, thus positively affecting the NPV.
- **% Change in Natural Gas Prices:** Similar to electricity, changes in natural gas prices influence the economic value of consumption savings. A rise in natural gas tariffs would enhance the benefits of measures that reduce gas usage.
- **% Change in Carbon Prices:** The financial benefit from reduced carbon emissions is dependent on the prevailing carbon pricing mechanism. An increase in the carbon price enhances the revenue generated from emission reductions, improving the overall financial viability of the investment.

Accordingly, the results of the switching value analysis are presented in the table below:

Switching Values (Scenarios including Carbon Income)	% in Capex Amount	# of Capex Payment	% in Electricity Prices	% in Natural Gas Prices	% in Carbon Prices
Comparison 1: Sc0 > Sc0.1	n.a.	n.a.	n.a.	n.a.	n.a.
Comparison 2: Sc0.1 > Sc1	n.a.	n.a.	n.a.	n.a.	n.a.
Comparison 3: Sc1 > Sc2	Infeasible	Infeasible	-375%	564%	1454%
Comparison 4: Sc2 > Sc3	n.a.	n.a.	n.a.	n.a.	n.a.
Comparison 5: Sc1 > Sc3	-83%	23.1	-775%	-35%	698%
Comparison 6: Sc3 > Sc4	-96%	99.5	3603%	No Impact	7611%
Comparison 7: Sc4 > Sc5	-87%	29.4	1021%	No Impact	1887%

Table 28. Results of switching value analyses of scenario comparisons

According to the data presented in this table, no adjustments to the input assumptions are necessary for Comparison 1, Comparison 2, and Comparison 4, as each of these scenarios demonstrates a positive NPV, indicating financial viability under the current conditions.

In contrast, Comparison 3 experiences operational losses every year because the increase in energy consumption costs surpasses the gains from carbon revenue. This imbalance renders the capital expenditures associated with this scenario financially unfeasible.

However, sensitivity analysis suggests that with substantial improvements-such as significant reductions in capital expenditure (Capex), extended investment repayment periods, or favorable changes in energy unit prices—some of the less viable scenarios could approach breakeven. For instance, a reduction in Capex by approximately 87%, or an extension of the Capex repayment duration to as long as 23 years, could bring Comparison 5 into the feasibility zone.

8.4.2.6. Conclusion and Establishing Links to a Green Finance Framework

Despite these theoretical possibilities, the magnitude of these required changes is considerable. Therefore, from a practical standpoint, achieving breakeven for some scenarios under the current market and investment conditions is highly unlikely, underscoring the need for either technological advancements or policy incentives to improve economic outcomes for these scenarios.

However, it is crucial to acknowledge that a purely KPI-based economic analysis, while providing valuable insights, may not fully capture the comprehensive value and implications of these building improvements for several key reasons.

Firstly, the inherent long lifespans of buildings necessitate a life cycle cost perspective that extends beyond the immediate net present value. While quantifying all aspects of these long-term costs can be challenging, factors such as reduced maintenance, increased durability, and potential for higher property value over time are not adequately reflected in a solely NPV-focused analysis.

Secondly, even substantial negative net present values of certain variations may appear relatively small when juxtaposed with the overall asset value of the residential buildings. This scale can sometimes lead to an underestimation of the long-term financial implications and missed opportunities for value enhancement.

Thirdly, while a negative NPV might seem unfavourable, its impact on the residents' monthly utility bills might be manageable, potentially making the improvement more palatable from an affordability standpoint, even if it doesn't yield a positive return on investment according to standard financial metrics.

Furthermore, this economic analysis often overlooks financially unquantifiable externalities that hold significant societal value. Benefits such as reduced healthcare costs due to improved indoor air quality, decreased environmental impact from lower energy consumption, enhanced welfare through more comfortable living conditions, and the intrinsic value of occupant comfort are not factored into the NPV calculations.

Finally, the pursuit of immediate profit maximization in every incremental improvement can overshadow significant non-monetary value from an individual's perspective. Aspects like increased comfort, improved aesthetics, and a sense of well-being, while not directly translating to financial returns in the short term, can hold considerable personal value and contribute to overall quality of life.

Therefore, while the KPI-based economic analysis provides a crucial financial lens, a holistic evaluation of building improvement scenarios must also consider these longer-term, less quantifiable, and individual-centric factors to arrive at truly informed decisions.

To further support the adoption of these building improvements, it's essential to consider the broader context of green finance.

As previously highlighted in this guide, green finance seeks to direct financial flows towards projects with positive environmental outcomes, integrating environmental considerations into financial decisions. In the context of building improvements, this aligns with the goals of energy efficiency, reduced environmental impact, and sustainable resource management.

To better support these improvements, green finance strategies such as the following requirements to be integrated into the effort:

- Utilizing green finance mechanisms: Explore green bonds, green loans, and blended finance to mobilize capital, especially for complex projects. Blended finance can de-risk projects and attract private investment.
- Leveraging local policy: Local authorities should enact supportive policies like energy-efficient building codes and zoning laws that favour green initiatives.

- Incentivizing investment: Implement financial motivators such as risk-adjusted returns, ESG integration, de-risking mechanisms, tax incentives, grants, and green finance labels.

By incorporating green finance tools and local policy support, policy makers can create a more favourable context for investing in sustainable building improvements.

8.5. Results of Study

The analysis of the C-02 building within the Beykoz urban transformation project demonstrates significant improvements in energy efficiency, sustainability, and environmental performance across the various scenarios evaluated. The study focused on assessing the impacts of different energy-saving strategies, the integration of renewable energy systems, and the use of advanced technologies. The results underline the potential for considerable reductions in both energy consumption and greenhouse gas emissions, highlighting the effectiveness of adopting a comprehensive approach to building design and operation.

The results indicate that the transition from base scenarios (Sc 0 and Sc 0.1) to more energy-efficient configurations, such as Sc 1, Sc 2, Sc 3, Sc 4, and Sc 5, yields substantial reductions in energy consumption. Notably, in Sc 2, which integrates heat pump systems and enhanced passive design measures, heating energy consumption decreased dramatically from 43.38 MWh in Sc 0 to 5.82 MWh. This reduction is attributed to the high efficiency of the heat pump system, which significantly reduces the demand for traditional heating sources. Furthermore, the integration of photovoltaic (PV) and photovoltaic-thermal (PVT) systems in Sc 3 and Sc 4 resulted in additional energy savings, further lowering the building's total energy consumption. Specifically, Sc 3 achieved a reduction in energy use to 49.94 kWh/m2 square meter, while Sc 4 reduced energy consumption to 48.11 kWh/m2 per square meter, demonstrating the substantial benefits of renewable energy systems in optimizing energy performance.

The optimal scenario, Sc 5, which combines all energy-saving technologies—heat pumps, passive design improvements, PV and PVT systems, mechanical ventilation, and battery storage—achieved the lowest energy consumption, reducing total energy use to 41.01 kWh/m2 square meter, a 67% reduction compared to the base case. This scenario demonstrates the highest level of energy efficiency and sustainability, providing a model for future urban housing developments.

In terms of greenhouse gas emissions, the implementation of energy-efficient systems and renewable energy technologies resulted in significant reductions. In the baseline scenarios (Sc 0 and Sc 0.1), total emissions were 25.11 tCO_2e and 23.88 tCO_2e, respectively, primarily driven by natural gas and electricity consumption. However, the introduction of heat pumps in Sc 2 reduced emissions to 19.12 tCO_2e, and the addition of renewable energy systems in Sc 3 and Sc 4 further reduced emissions to

16.27 tCO_2e and 15.68 tCO_2e, respectively. The optimal scenario, Sc 5, demonstrated the most substantial reduction, achieving a total emission of 13.36 tCO_2e, representing a 47% decrease compared to the base case.

The financial analysis highlights that the price difference between natural gas and electricity in Türkiye is more significant than in the European Union, primarily due to the country's natural gas subsidy policies. As a result, the transition to energy systems is currently not economically viable. However, if national policies are adjusted to improve access to renewable energy systems and make them more affordable, and if electricity prices are reduced or the subsidy on natural gas is removed, the payback periods for energy-efficient investments would shorten, leading to quicker returns for households.

These findings hi0ghlight the significant environmental and economic advantages of adopting integrated energy strategies in urban transformation projects. The results indicate that by incorporating energy-efficient systems, passive design measures, and renewable energy technologies, urban buildings can reduce their energy consumption and greenhouse gas emissions, contributing to a more sustainable urban environment. Furthermore, the study suggests that policy adjustments, such as reducing electricity prices and facilitating easier access to renewable energy technologies, would accelerate the adoption of these systems, making energy-efficient investments more feasible and shortening the payback periods for households. Overall, this study provides a robust framework for guiding future urban development, offering a pathway toward creating more energy-efficient, self- sufficient, and environmentally sustainable communities.

9. Conclusion

The transition to green and carbon-neutral buildings is a critical component of achieving sustainability and climate resilience in Türkiye, particularly in urban areas such as İstanbul. The Build4GreenIST project provides an essential framework to facilitate this transition, integrating key elements including sustainable construction, renewable energy, green finance, legal alignment, participative governance, and advanced urban planning practices. The comprehensive approach outlined by the project serves as a strategic roadmap, offering guidance to stakeholders across public institutions, the private sector, and local communities, in their efforts to meet climate objectives and transform urban environments in a sustainable and efficient manner.

In the transformation process for green and carbon neutral buildings in Türkiye, legal regulations and national strategic documents stand out as powerful tools that complement each other. To align with Türkiye's 2053 net-zero emission goal, enhancing the environmental performance of buildings during planning, design, and construction is not only regulated through zoning, energy efficiency, and environmental legislation but also guided by strategic documents and action plans that establish long-term objectives and implementation frameworks. The adoption of nSEB standards, YES-TR certification, BIM technology, renewable energy integration, and zero-waste systems will play a pivotal role in substantially reducing the carbon footprint of the construction sector. Therefore, the harmonised implementation of legislation and strategies will enable the construction of more resilient, efficient and climate-sensitive cities with economic, social and environmental benefits.

It is also of utmost importance to study this issue at the provincial scale in more depth and in accordance with local dynamics and within this framework, the climate action plans and strategic documents developed for major metropolitan municipalities—including İstanbul—establish an implementation architecture that demonstrates substantial alignment with Türkiye's national sustainability objectives and carbon neutrality commitments, while serving as a foundational mechanism for vertically integrated climate governance.

However, successful implementation of this transformation requires not only the development of strategies and regulations, but also their effective implementation. Harmonising legal frameworks and national strategy documents with local requirements and contexts is critical, especially in urban transformation areas such as Beykoz.

The operationalization of strategic frameworks into tangible interventions, effective enforcement of statutory climate regulations, and robust functioning of compliance mechanisms will constitute critical determinants in realizing long-term carbon neutrality and sustainable energy objectives. Overcoming the institutional, technical and financial obstacles encountered in implementation should be supported by capacity building, awareness raising and incentive systems. Thus, an effective and sustainable transformation process that not only sets targets but also achieves them can be realised.

Addressing institutional, technical and financial challenges through capacity building initiatives, awareness raising campaigns and the establishment of incentive systems will be crucial in overcoming these barriers. Furthermore, the active participation and engagement of all stakeholders, from citizens to decision-makers, will play an important role in securing broad societal support for green transformation.

Adoption of the identified strategies and legal framework not only at the technical and administrative level but also by citizens, practitioners and decision makers plays a critical role in achieving the targets in a long-term and sustainable manner. Social ownership of this transformation will be possible through an inclusive and participatory structure. Consequently, the appropriate and equitable structuring of financial and social incentive mechanisms – at both individual and institutional levels – will constitute a critical instrument for addressing the economic and behavioral obstacles to transformational change. In this way, green transformation can be transformed from a mere policy objective into a way of life that is embraced and shared by the whole society.

In conclusion, although Türkiye is still in the early stages of transition to green and carbon-neutral buildings, the Build4GreenIST project provides a basic framework for meaningful and effective change. This transition can be achieved through the implementation of appropriate policies, financial mechanisms and participatory governance structures. The project establishes a scalable framework that can be adapted by other urban centres, while positioning Türkiye to advance its transition toward sustainable and climate-resilient urban development. Successful realisation of this vision will require sustained and coordinated efforts at both national and local levels to ensure that the built environment evolves in line with the country's sustainability goals.

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The future will flourish together!

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DEPARTMENT OF ENVIRONMENTAL PROTECTION AND DEVELOPMENT

DIRECTORATE OF CLIMATE CHANGE