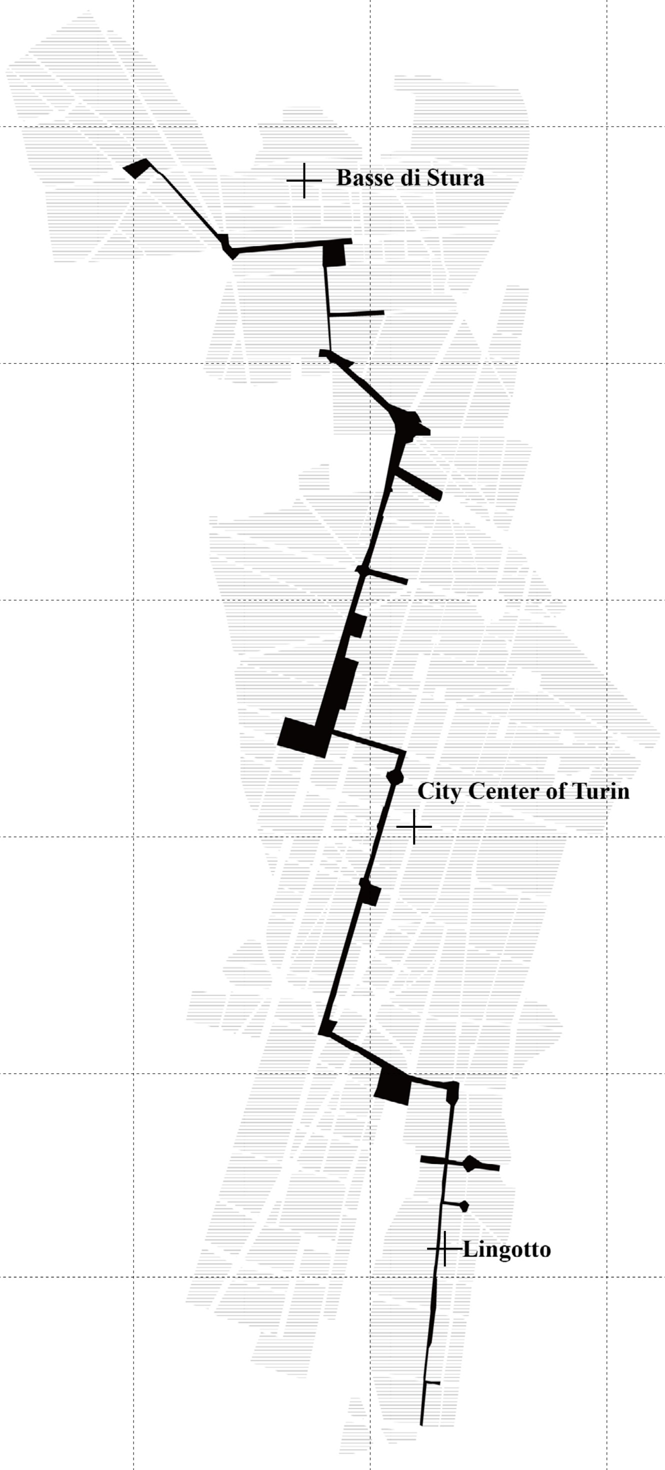
Designing Renewable Energy Community in Basse di Stura:

A Multidisciplinary Approach to Urban Regeneration through the Integration of Urban Design and Sustainable Technologies



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A Multidisciplinary Approach to Urban Regeneration through the Integration of Urban Design and Sustainable Technologies

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Acknowledgement

As I type these words, my postgraduate journey draws to a close, and my association with architecture spans nine years. Along the way, there have been no dramatic turning points, yet perseverance and growth have been constant companions. From initial confusion about this unfamiliar major, to gradually developing an interest, and finally discovering the true joy of design, I still consider the final two years of my undergraduate studies as the most focused and confident period in my architectural education.

Driven by my passion for architecture, I embarked upon my professional journey. Though I participated in numerous projects, I found myself increasingly adrift amidst the tug-of-war between aspiration and reality, uncertain of what I truly pursued. Ultimately, after two years in the profession, I chose to resign and set out once more upon a quest to find answers.

In September 2023, I set foot upon Italian soil. Over the subsequent two years of study, I encountered a wealth of new knowledge, gradually refining my academic framework. This, in turn, gave rise to further curiosity and questions. But this time, I no longer felt lost; instead, I approached the exploration of this world with greater composure and resolve. Thus, I finally arrived at this moment—a moment that felt as if I could rediscover and understand myself again.

Perhaps I still cannot clearly articulate what this journey has changed within me, but I know this: to have encountered and received the help and support of so many people along the way, I suppose I can count myself a rather fortunate person.

First and foremost, I would like to extend my most sincere gratitude to my thesis supervisor, Professor Mario Artuso. Throughout the more than six months of writing this thesis, you provided invaluable guidance with rigour and patience, offering constant encouragement and support. This enabled me to maintain confidence amidst difficulties and uncertainties, ultimately completing the thesis successfully.

My gratitude also extends to Professor Roberto Pagani, whose lectures broadened my academic horizons, helping me discover both a research direction and a passion amidst my initial lack of confidence. I would also like to thank Professor Michele Bonino, whose lectures equipped me with knowledge that enabled more confident thinking and practical application during the thesis design phase.

Of course, I must thank my parents, who granted me freedom and boundless support, enabling me to stand upon their shoulders and gaze upon a wider world. Thank my boyfriend, Zhang Shaoqiu, who has accompanied me unwaveringly through these nine years of both companionship and hardship with architecture, bringing me warmth and beauty. And I must also thank my little cat, Lizi, who accompanied me all the way from China to Italy, offering me endless comfort and happiness.

Abstract

Since the concept of renewable energy communities (RECs) was first proposed, many scholars and practitioners have consistently emphasized its significance as a citizen-led initiative in promoting low-carbon energy transitions. However, few studies have explored how such communities can be conceived and developed from an urban design perspective, enabling them to serve as an effective spatial pathway for sustainable urban regeneration.

This study adopts an urban design perspective to re-examine the concept of RECs within the context of urban design, and to explore their relationship with sustainable urban regeneration. The objective is to investigate how spatial planning and design strategies can be employed to achieve the efficient and sustainable development of RECs. The research first reviews and analyses the current state of studies in this field, based on which the Basse di Stura area in Turin is selected as the case study for in-depth research and practice. Through case analysis, conceptual design, and feasibility assessment, the study gradually develops and presents a comprehensive and practicable urban design scenario and strategy.

The findings of the research indicate that incorporating the planning and layout of renewable energy systems (RESs) into the urban design stage can significantly create favourable conditions for their application and ensure flexibility and sustainability for future development. Throughout the research, the study emphasised the importance of fostering synergy between technological advancement and urban design, and identifies the main obstacles and challenges faced during the design and feasibility assessment stages, providing valuable references for academia and policymakers. Furthermore, the study highlights the critical significance of integrating RESs into urban design for achieving sustainable urban development and low-carbon transitions.

Keywords : urban design, renewable energy system, renewable energy community, sustainable urban development, urban regeneration, Turin.

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1.Introduction

At the *2015 United Nations Climate Change Conference*, 196 parties jointly signed the *Paris Agreement*[1], whose core objective is to limit the global temperature increase to below 1.5 °C above pre-industrial levels (Anna Kracher, 2021; United Nations, 2015a). However, according to statistics from the European Commission, the energy systems of EU member states still rely heavily on fossil fuels, which account for approximately 75% of the EU's total greenhouse gas emissions(European Commission, 2020). With the continued advancement of global urbanization and the increasingly severe climate and energy challenges, the demand for low-carbon energy systems and the attention paid on renewable energy have been steadily increasing. In order to transform the existing energy structure and establish a low-carbon energy system, it is essential to transition from the current inflexible, large-scale centralized energy systems to a more decentralized and adaptable renewable energy systems (Goldthau, 2014; International Energy Agency, 2021; Saintier, 2017). In this context, renewable energy communities (RECs), as a new type of energy self-sufficiency model that breaks away from the traditional centralized energy pattern, have been gaining increasing attention from both academia and governmental authorities (Robinson, 2022).

[1] The Paris Agreement was hailed by Obama as 'our best chance to save our only home.' However, global progress toward carbon neutrality remains slow. Despite the attention given to energy technology, the lack of binding obligations and enforcement mechanisms has also contributed to this delay. For further discussion on the policy level, particularly an analysis of the limitations of enforcement mechanisms, see the research by (Tørstad et al., 2025; Zhang et al., 2025).

With the continuous progress and development of society, the utilization of renewable energy and its related technologies has become increasingly mature. At the same time, the United Nations' *2030 Agenda for Sustainable Development* has identified the urban environment as one of its key areas of focus, aiming to promote sustainable urban regeneration and development through advances in urban planning (United Nations, 2015b, 2016). Urban regeneration, defined as the transformation and development of existing cities through a series of interventions to address urban challenges and resolve pressing issues, can be seen as a comprehensive strategic approach to promote sustainable urban development in the current context (Barosio Michela et al., 2016; Stouten Paul, 2010). As highlighted by the C40 Cities Climate Leadership Group's Reinventing Cities initiative, urban regeneration should not only focus on improving spatial and environmental quality but also promote urban decarbonization and resilient regeneration. The key entry point to achieving decarbonization lies in promoting the low-carbon transformation of energy systems by addressing the energy structure. In this regard, RECs, characterized by energy self-sufficiency and low-carbon emissions, can be seen as an effective path to sustainable urban regeneration and decarbonization (Carra et al., 2023).

1.1 Problem Statement

In theory, RECs can be regarded as an effective approach to achieving sustainable urban regeneration and urban decarbonization. However, in current practice and academic research, there are still very few cases in which the design of RECs has been systematically integrated into urban design projects. Existing studies indicate that, as the core component of RECs, renewable energy systems (RESs)—although technologically mature—can still suffer from reduced supply quality if they are not properly planned and arranged (Paatero & Lund, 2007; Passey et al., 2011). Furthermore, since urban managers and designers rarely incorporate the layout and design of energy systems into overall planning during processes of sustainable urban regeneration and urban design, subsequent efforts to establish RECs often face limitations in installation conditions due to the absence of early-stage planning. This not only reduces the efficiency of energy supply, but may also damage the quality of urban space and the living experience of residents, and even leading to the emergence of 'unsightly urban patches'[2] (Ramirez Camargo & Stoeglehner, 2018). Therefore, urban design is not only the vehicle for promoting the effective implementation of renewable energy technologies in urban spaces, but also the foundation for building mature, high-performance RECs and advancing sustainable urban development.

[2] The 'unsightly urban patches' refers to certain haphazardly planned facilities or structures within cities, which, due to spatial constraints or the absence of systematic planning and design, appear like patches on a garment. Whilst they serve a certain purpose for the whole, they simultaneously appear disorderly and discordant.

Against this backdrop, how to integrate urban design with renewable energy technologies to build efficient RECs that promote sustainable urban development and decarbonization has become a pressing issue that urgently needs to be addressed.

1.2 Research Definition

This study aims to explore the relationship between urban design and RECs, review the current state of research in this field, as well as identify gaps and shortcomings in existing research. Based on this, the study analyses the urban design process and outcomes of RECs, and propose strategies and methods for integrating RES planning into the urban design stage, with the aim of providing guidance for relevant practices. At the same time, this study seeks to draw the attention of both the academic community and government bodies, thereby providing theoretical foundations and practical support for the development of more comprehensive planning and urban design methods.

The literature review, case analysis, conceptual design, and feasibility assessment of this thesis are all organized around the following three core questions. *Question 1* focuses on the definition of RECs and their relationship with urban design, aiming to clarify and define the research subject and scope through the exploration of this question.

Q1: What is a renewable energy community, and why is urban design essential to its development?

Question 2 builds upon *Question 1* and further explores how to intervene from an urban design perspective to create an efficient REC after clarifying the relationship and importance between RECs and urban design. This question forms the core of the entire study and requires a systematic design methodology that is validated through case studies and a complete design process.

Q2: How can renewable energy system design be incorporated into the urban design process to facilitate the creation of renewable energy communities?

Although previous studies have repeatedly demonstrated the importance of this topic, the feasibility of the research theme itself and the rationality of the proposed design approaches still need to be further verified. Therefore, *Question 3* aims to explore how to assess the feasibility and rationality of the design process and outcomes of the selected cases through quantitative analysis.

Q3: How to evaluate the feasibility of the conceptual design?

1.3 Methodology

To clarify the research subject and achieve the established objectives, this study first conducted a systematic literature review of relevant fields to clarify and refine the research goals while identifying gaps in existing research. The literature analysis revealed that Italian cities face certain challenges in terms of urban development patterns and energy structures, but at the same time it also possess advanced experience in the development of RECs, related technologies and urban design. Based on these research findings, Basse di Stura which is in the northern part of Turin, Italy, was selected as the study site. To ensure the scientific rigor and relevance of the subsequent design strategies and approaches, two representative cases were selected for in-depth analysis and comprehensive research based on the site analysis results. On this basis, a REC urban design proposal was developed and proposed for Basse di Stura, aiming to provide a set of reference design strategies and methods. Subsequently, a quantitative assessment of the design outcomes was conducted to evaluate and validate the feasibility of the proposed scenario.

The overall research approach and framework of this study can be summarised in the following five steps:

1. Literature review
2. Analysis of the current status of the study area
3. Case study analysis
4. Conceptual design
5. Feasibility assessment

1.4 Scope and Limitation

The significance and importance of the research object have been elaborated many times in the preceding text, but how to specify it and conduct in-depth research and design on this basis still requires careful consideration. According to a report by the EU Building Stock Observatory, most buildings in Europe are residential buildings, and in Italy, nearly 90% of the buildings are residential, about half of which are old buildings with high energy consumption (Energy & Strategy Group, 2022). Although Italy faces severe challenges in building energy consumption, the country has abundant renewable energy resources such as solar and geothermal energy (The World Bank & Solargis, 2025), making it well-suited for renewable energy development. Moreover, there is an urgent need to promote sustainable urban regeneration. Accordingly, this study selected the Basse di Stura, as the research object, aiming to demonstrate how to construct a REC from an urban design perspective by completing a series of urban design proposals for the REC in this area.

Since this project focuses on the urban design phase, the overall design does not involve detailed architectural design of individual buildings or the detailed engineering design of RESs. Therefore, during the conceptual design presentation stage, specific architectural details and RES designs will not be shown; instead, only the preliminary overall spatial layout and form of the community will be presented. For this reason, in the subsequent feasibility assessment stage, it will not be possible to conduct precise building energy consumption simulations or renewable energy production simulations.

To ensure the rationality and reliability of the quantitative results, relevant calculations will be carried out based on validated reference values.

1.5 Organization of the Thesis

Chapter 1 introduces the background and significance of the study, clarifies the research objectives and direction, defines the research scope and limitations, and outlines the structure of the thesis.

Chapter 2 defines the core concepts involved in the study, explores the relationships between these definitions to further clarify the research direction, and identifies the gaps and shortcomings in this field through literature review and data analysis.

Chapter 3 building on the preceding analysis of the research status, further clarifies the research objectives and conducts an in-depth analysis of the current state of research based on these objectives.

Chapter 4 selects case study subjects according to the characteristics of the research objectives, carries out an in-depth analysis, and summarizes design experiences and methods that can be used as references.

Chapter 5 develops a conceptual design for the research subject, explaining the design rationale, design process, and final outcomes.

Chapter 6 conducts a quantitative analysis of the design outcomes presented in *Chapter 5* to assess the feasibility and implementation potential of this design method in terms of renewable energy utilization.

Chapter 7 presents the conclusions of the study and provides recommendations and directions for future research.

For clarity, the author made an limited use of AI-assisted translation and Grammarly for language editing; see the software disclosure after the References.

2.Literature Review

As the world's urbanisation process continues to advance and climate and energy challenges intensify, cities have become key locations for promoting sustainable global development and addressing climate change and energy issues(International Energy Agency, 2021; Sancino et al., 2022; United Nations, 2019).RECs are emerging as a new model that promotes local energy autonomy and encourages community in achieving energy self-sufficiency, attracting increasing attention from government departments and academics(Robinson, 2022).

With the increasing depth of academic research on RECs, the related energy utilisation and building retrofitting technologies have become more mature. However, from an urban design perspective, research on integrating spatial planning, urban form, and energy use and deployment to build efficient RECs remains relatively limited. Urban design is not only about the functionality and aesthetics of a city, but to some extent, it also plays a key role in the future sustainable development of a city(Carmona, n.d.; Ziafati Bafarasat, 2023). Nevertheless, research that integrates urban design with the development of RECs remains in its early stages, with a lack of established theoretical framework and systematic knowledge structure. Therefore, it is necessary to conduct a systematic review and analyse of existing studies in this interdisciplinary field from the perspective of urban design, in order to better identify its developmental trends, research gaps, and structural limitations, thereby providing a theoretical foundation and direction for further research.

Since the term 'renewable energy community' has been defined and understood in various ways in existing studies (Bauwens et al., 2022).In order to define the research content and direction of this paper clearly, this chapter first defines the key concepts such as 'renewable energy community', 'urban regeneration' and 'urban design', and explores the inherent relationship between them. Based on this, this chapter further reviews and compares the current state of research in this interdisciplinary field through literature screening and data analysis. It then explored the potential value of urban design in the development of RECs and identified opportunities for future research, thereby providing a theoretical basis and direction for ongoing academic research.

2.1 Renewable Energy Communities: A Path to Sustainable Urban Regeneration

2.1.1 Renewable Energy Community from the Perspective of Urban Design

The concept of energy communities is nothing new; they have existed in remote areas where fuel is scarce and expensive long before the energy transition (i.e. the shift towards decentralized renewable energy production) became a mainstream trend(Lowitzsch et al., 2020).

Today, in response to the challenges posed by climate change, the European Union(EU) has developed the *Clean Energy Package*[3] , which aims to achieve carbon-neutral[4] by 2050(Ahmed et al., 2024; Gandhi et al., 2020).The 'Clean Energy Package' emphasizes that by 2030, the energy market should be reformed, and in the EU's energy structure 30% of energy should come from RESs[5] (Ahmed et al., 2024; Müller et al., 2017).Within this framework, the EU has introduced and established two types of energy community frameworks called Renewable Energy Communities (RECs) and Customer Energy Communities (CECs).The concept of RECs was introduced by the Renewable Energy Directive II (RED II)2018/2001 , which focuses on the use of renewable energy(European Union, 2018).

However, there are no precise definitions of what exactly the RECs are, either in academic research or in public discourse[6] (Bauwens et al., 2022). Even after the concept of RECs was introduced to the general public's awareness, its definition remained limited to energy types and sources. Given the multidimensional nature of RECs, divergent interpretations persist among the public. With the development of time and the continuous application and practice of RECs, today's RECs have gradually evolved into a complex system with 'multi-purpose', 'multi-content', and 'multi-stakeholder', which makes the concept of RECs even more difficult to define (Robinson, 2022).

Although it is not possible to define and understand the meaning of RECs directly from the explanation of the terminology, as there are already many mature RECs in existence, it is possible for us to study and define them by studying their functions, operational models, participants and their roles, etc. From a broader perspective, there are two ways of understanding RECs in academic research and public discussion: from the perspective of social organization, RECs are cooperative organizations composed of citizens, businesses, local organizations, and government agencies that engage in one or more energy-related functions within a specific region to produce, share, and use renewable energy(Robinson, 2022).From a spatial-territorial point of view, RECs are an area where renewable energy can be produced, shared, and used by the above organizations working together. There is no specific definition of this area; it can be a residential area, a village, or a part of a city.

[3] The Clean Energy Package adopted in 2019 proposes an adaptation of the European energy policy framework to facilitate the transition away from fossil fuels toward cleaner energy.

[4] Carbon-neutral refers to achieving a net-zero carbon footprint by balancing the amount of carbon dioxide emitted with an equivalent amount of carbon offset or removed from the atmosphere. This is typically achieved through energy efficiency, renewable energy use, and carbon offset projects.

[5] Renewable Energy Systems here refers to an energy system that utilizes renewable energy sourcesto generate electricity, heat, or fuel, aiming to reduce dependence on fossil fuels and minimize environmental impact.

[6] In the study by Bauwens et al, 183 definitions of renewable energy communities were identified, highlighting the diversity and complexity of concepts in this field. For more details, refer to their article (Bauwens et al., 2022)

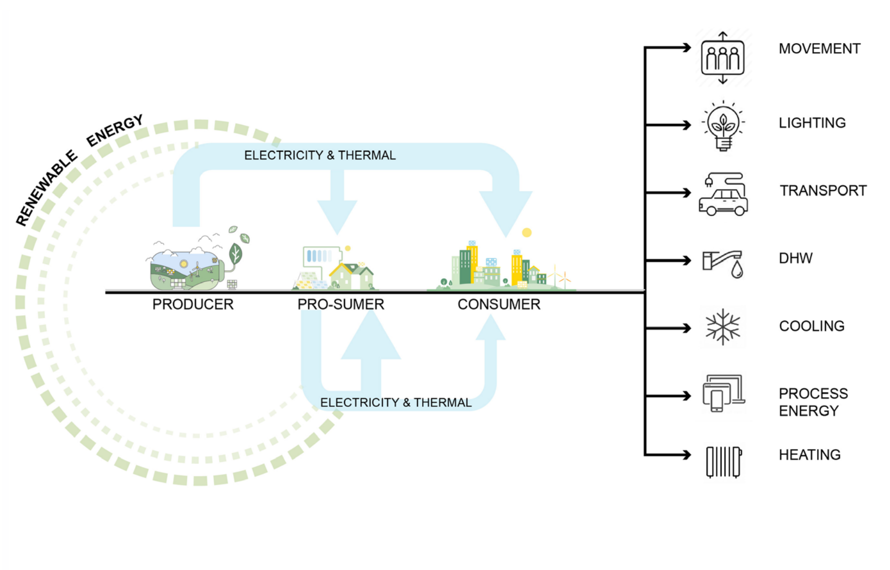

Figure 1 The relationship between producer, consumer, and prosumer
Source: Created by the author.

Since this research focuses primarily on how RECs are constructed at the urban design level, the following analysis will focus on analysing and understanding RECs from a spatial-territorial perspective. Observations of maturely operating RECs in RES indicate that RECs will primarily fulfil the following different functions: providing energy support to consumers and prosumers, generating and supplying energy, and delivering energy through the transmission and distribution network(Caramizaru, n.d.; Robinson, 2022). Therefore, they can be directly divided into three major functional areas: producer, consumer, and prosumer, with the relationships between the three shown in Figure 1.

Producers refer to individuals or entities responsible for generating renewable energy. In urban contexts, this typically includes centralized renewable energy facilities, such as solar farms, that convert natural resources like solar, wind, or biomass into electricity or thermal energy. Consumers refer to those individuals or groups that consume energy from renewable energy sources. In the urban context, this usually refers to residential buildings or neighbourhoods that are unable to install energy-producing equipment such as solar panels or small wind turbines due to geographic or physical constraints. Prosumers combine the functions of both producers and consumers, as they not only generate part of their own energy for self-consumption but also feed excess energy back into the community's energy network for use by consumers(Chaudhry et al., 2022; Milčiuvienė et al., 2019). Together, these three roles complement and support one another, enabling the spatial layout and operational functionality of RECs.

In summary, from an urban design perspective, a REC refers to an area that achieves energy self-sufficiency, low carbon emissions, socio-economic benefits, and environmental sustainability by integrating renewable energy technologies (such as solar, wind and geothermal) with urban spaces and buildings.

2.1.2 Sustainable Urban Regeneration

The term 'urban regeneration' originated from the slum clearance and housing reconstruction programs implemented in the United Kingdom after World War II. Since the urban renewal approach at that time primarily focused on demolition and rebuilding, the academic community often defined it as *Urban Reconstruction* or *Urban Renewal*(Ding Fan & Wu Jiang, 2017; Xiaoshu & Di, n.d.).Over the course of nearly a century of subsequent development, this term has gradually evolved into *Urban Redevelopment, Urban Renaissance, and Urban Revitalization*[7]. By the 1980s, due to the impact of the energy crisis and global economic downturn, cities that had relied heavily on manufacturing experienced rapid decline. This led to widespread urban problems such as high concentrations of unemployed workers, urban decay, and inner-city hollowing[8]. In response, governments in Europe and North America adjusted their urban development strategies to old city redevelopment which focused on restructuring the economy—this marked the adoption of the urban regeneration model(Ding Fan & Wu Jiang, 2017). Around 2010, the term 'urban regeneration' began to be increasingly widely used, reflecting people's efforts to interpret and solve urban issues through more sustainable approaches(Stouten Paul, 2010).

Since then, urban regeneration and sustainable development have become two interrelated and intertwined key issues in policy agendas, planning practices, and academic research. The United Nations' 2030 Agenda for Sustainable

[7] The historical development and conceptual evolution of the term 'urban regeneration'can be referenced in the seminal work of(Stouten Paul, 2010)which systematically examines the contextual shifts during thirty years of modernization in Rotterdam. Additionally, the critical analysis by (Ding Fan & Wu Jiang, 2017)on the theoretical genealogy of urban regeneration offers further valuable theoretical insights for this study.

[8] Inner-city hollowing refers to the loss of population, functions, and spatial vitality in central urban districts due to suburbanization, deindustrialization, and disinvestment. A closely related and more widely used concept is urban shrinkage; for further discussion, see (Haase et al., 2014; Martinez-Fernandez et al., 2012; Pallagst et al., 2013).

Development places particular emphasis on urban environments through its eleventh goal, which focuses on sustainable cities and communities. The New Urban Agenda further advances this goal by promoting the development of urban planning as a key tool for driving sustainable development, aiming to collectively achieve the goal of '*make cities inclusive, safe, resilient, and sustainable*'(Carra et al., 2023; United Nations, 2016).

Therefore, from both the historical development of the term 'urban regeneration' and its current trajectory, it can be understood as a comprehensive strategic approach undertaken within existing cities. It involves a series of integrated actions that restore and replace large areas of abandoned or deteriorated urban fabric. These actions are intended to address practical urban issues while also responding to evolving urban challenges. At the same time, by incorporating sustainable transformation and development strategies, it seeks to achieve lasting improvements in the economic, physical, social, and environmental conditions of the region, thereby ensuring its long-term sustainability (Barosio Michela et al., 2016; Rojek, 2016; Stouten Paul, 2010). This process typically involves: redeveloping lost economic activities, revitalizing weakened social dynamics, reintegrating socially isolated areas, restoring degraded environmental quality and ecological balance, and ultimately achieving sustainable development for cities and regions. In general, urban regeneration—whether viewed from a spatial-territorial perspective or a strategic urban development standpoint—is a means of addressing urban problems and promoting sustainable development by transforming adverse conditions into favourable ones.

2.1.3 Renewable Energy Communities and Urban Regeneration in the Current Context

In 2019, the C40 Cities Climate Leadership Group[9] launched the *Reinventing Cities*[10] initiative aiming to promote decarbonization and resilient regeneration by renovating and reusing underutilised urban land through sustainable projects (Carra et al., 2023). As noted above, the United Nations 2030 Agenda also emphasises the sustainable development of cities and their public spaces, as well as the importance of sustainable and efficient use of natural resources, in its Sustainable Development Goals (United Nations, 2015b). Therefore, under the influence of today's global landscape, achieving sustainable development of cities and regions through urban regeneration requires not only considering economic sustainability and social sustainability—two of the three pillars of sustainable development[11] —but also a focused attention on the critical issue of environmental sustainability. This specifically includes the previously mentioned concepts of 'urban decarbonization' and the transformation of urban energy systems.

It is worth noting that, according to the report by the EU Building Stock Observatory[12](BSO), the majority of buildings in Europe are residential buildings, particularly in Italy, where approximately 90% of the building area is used for residential purposes. Moreover, over 50% of these residential buildings were constructed before the 1970s—that is, before the introduction of building energy efficiency regulations (Energy & Strategy Group, 2022). These data indicate that in Italy, more than half of the residential building stock suffers from low energy efficiency. Therefore, when carrying out urban regeneration in EU countries—particularly in Italy—it is essential to fully consider the specific characteristics of the existing building stock and to develop new strategies that are better aligned with the renewal and development of urban residential structures. This involves exploring how urban environments, communities, citizens, and energy systems can cooperate and evolve together in a sustainable manner.

[9] C40 Cities Climate Leadership Group is a network of 96 cities, representing one twelfth of the global population and one quarter of the global economy. Created and led by cities, C40 focuses on combating the climate crisis by driving urban action to reduce greenhouse gas emissions, mitigate climate risks, and enhance the health, well-being, and economic opportunities of urban residents.

[10] Reinventing Cities is an initiative led by C40 Cities aimed at promoting sustainable development and highlighting innovative solutions to address environmental and urban challenges.

[11] Three pillars of sustainable development are: environmental sustainability (protecting natural resources), economic sustainability (promoting long-term economic growth), and social sustainability (ensuring social equity and quality of life).

[12] EU Building Stock Observatory is an official platform of the European Commission that provides data and indicators on the energy performance, renovation, and characteristics of buildings across EU Member States. If needed, the database can be accessed at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/eu-building-stock-observatory_en.

As discussed earlier regarding RECs, from an urban design perspective, RECs are characterized by energy self-sufficiency, low carbon emissions, potential socio-economic benefits, and environmental sustainability. These are precisely the goals that urban regeneration projects in the EU—especially in Italy—need to consider and strive to achieve. Moreover, within the framework of RECs, both citizens and residential buildings play crucial roles. Hence, from a holistic perspective, RECs can be regarded as one of the effective pathways toward achieving the sustainable development goals of urban regeneration. By integrating urban regeneration with RECs, it is possible not only to advance the green transformation and sustainable development of energy systems in regenerated urban areas, but also to improve urban environmental quality from multiple dimensions, support the transition to a low-carbon economy, ultimately achieving a win–win outcome for the environment, economy, and society.

2.2 Urban Design as a Foundational Element in Renewable Energy Community Planning

To establish a mature and efficient REC, two key issues must first be addressed: (1) How can local renewable energy sources be efficiently identified and utilized? (2) How can an efficient RES be established within the REC site?

Renewable energy refers to energy sources derived from nature whose regeneration rate is faster than their consumption rate. Common types of renewable energy currently include solar energy, wind energy, biomass energy, and biogas (Lowitzsch et al., 2020). To effectively harness these resources, a variety of application technologies have emerged, such as wind turbines and solar photovoltaic panels, many of which have already been deployed on a large scale. However, improper planning can lead to a decline in the quality of energy supply and increased demands on related infrastructure, including the power grids and energy storage systems (Paatero & Lund, 2007; Passey et al., 2011; Ramirez Camargo & Stoeglehner, 2018). As a result, to utilize these technologies efficiently, it is essential not only to consider the spatial suitability for equipment installation but also to assess the potential of the renewable energy and conduct spatial analysis of the site to determine the optimal location for equipment placement.

With the accelerating pace of global urbanization, the analysis and exploration of renewable energy in urban environments has evolved beyond the traditional single-dimensional integration of geographic information. It has developed into a systematic research approach based on multiple spatial factors, including the analysis and consideration of diverse parameters such as building morphology within and around the site, the layout of public spaces, and the characteristics of the natural environment (Akrofi & Okitasari, 2022; Ramirez Camargo & Stoeglehner, 2018). Taking solar energy utilization as an example, it is necessary to conduct comprehensive solar radiation simulations of buildings and public spaces within the site. This enables the precise calculation of effective radiation areas, thereby guiding and optimizing the layout and design of photovoltaic systems to maximize solar energy capture efficiency. However, since renewable energy is directly sourced from nature, its power generation is inherently unstable. Such fluctuations may lead to a range of issues, including reduced reliability of the power system, and in some cases, the underutilization or even abandonment of renewable energy generation equipment. For example, in 2017, approximately 49.2 terawatt-hours (TWh) of wind and solar power generation were abandoned in China (Ren et al., 2019). For this reason, in order to enhance the stability of renewable energy, improve system cost-effectiveness and flexibility, and reduce maintenance costs for the community, it is essential to fully consider the complementarity between different types of renewable energy sources. This means that when establishing a REC, it is necessary to conduct a detailed assessment of the types and quantities of renewable energy available on site, followed by a scientifically sound and rational combination of these resources. For example, research conducted by Ramirez Camargo and his team on standalone power systems for ten households demonstrated that integrating small wind turbines into an existing photovoltaic system significantly reduced both the total system cost and the required energy storage capacity (Camargo et al., 2019). This clearly shows the advantages and rationality of integrating multiple types of renewable energy sources based on their resource complementarity. Of course, for further enhancing the performance of RESs, dynamic regulation mechanisms can also be introduced into system design—for instance, by integrating energy storage devices with smart grid systems to enable the dynamic storage and regulation of energy within the grid.

It is important to note that efficient RESs are not evenly distributed across cities or regions (Bridge et al., 2013). As mentioned earlier, due to differences in land use characteristics, building layout, and public space planning between cities and regions, even in areas with similar natural resource conditions, the distribution of renewable energy within specific sites may vary significantly. Therefore, in practical planning, it is necessary to closely integrate the layout of renewable energy installations with the specific characteristics of the site, and to carry out a comprehensive design accordingly. In addition, another key factor contributing to this uneven distribution is the differing patterns of energy supply and demand density (W/m^2) between renewable energy sources and energy consumers. The energy density per unit area (W/m^2) of renewable energy sources is relatively low compared to traditional fossil fuel-based power generation. This lower energy density necessitates more efficient use of space (Lowitzsch et al., 2020; Smil Vaclav, 2015). Thus, when designing and deploying RESs, it is essential to consider not only the types and availability of renewable resources but also to comprehensively assess the potential impact of these technologies on the surrounding urban environment. For example, although Italy has abundant solar energy resources, its building stock is predominantly residential, with more than 50% of residential buildings constructed before the 1970s (Energy & Strategy Group, 2022). This implies that the traditional approach of installing solar panels on building rooftops may not be suitable in all cases. To maximize solar energy utilization, alternative solutions such as solar farms may need to be considered. However, such technologies often require large areas of land and have a more significant impact on the urban environment. This is particularly true for facilities like biogas plants, which have stricter requirements for their surrounding environments.

In summary, establishing a mature and efficient REC requires not only a deep understanding of the characteristics of renewable energy sources but also the

integration of emerging technological trends with constantly changing market demands. However, relying solely on the advancement of energy technologies is not enough to ensure their successful implementation. The key lies in comprehensive planning and design that integrates these technologies with the spatial layout and environmental characteristics of the city.

Urban design aims to create liveable and functional environments for living and working environments by planning, designing, and organizing urban spaces. It seeks to optimize the use of urban space and promote the sustainable development of the social, economic, and environmental dimensions of the city (Xiaoshu & Di, n.d.). As noted in the previous sections, whether it concerns the analysis and utilization of renewable energy, the installation of related technical infrastructure, or the planning and layout of basic RESs, all of these processes are linked to the unified planning and design of urban space. Through well-considered and forward-looking spatial planning and design, a solid foundation for sustainable development can be ensured for the future. Hence, urban design is not only the spatial carrier for the implementation of energy technologies but also the fundamental basis for establishing mature and efficient RECs and promoting their sustainable development.

2.3 Limitations in Current Research on Urban Design in Renewable Energy Communities

The previous two sections respectively define RECs and urban regeneration, followed by an in-depth examination of their interrelation and respective connections to urban design. Against the backdrop of global sustainable development and low-carbon transition, sustainable urban regeneration and RECs have increasingly attracted scholarly attention as important pathways toward achieving sustainable cities. However, existing literature on sustainable urban development and renewable energy utilization primarily focused on achieving efficient use of energy through sustainable technologies and energy-saving renovations of buildings. Few studies have approached the topic from the perspective of urban regeneration, specifically exploring how the integration of urban design and sustainable technologies can contribute to the development of RECs. In particular, although some studies have explored the integration of renewable energy in urban design, most of them have focused on the application of solar energy. For example, Kanters & Wall, 2016) examined the critical solar-related decisions that need to be considered at different stages of the urban design process. Systematic reviews and reflections on how to integrate different types of renewable energy through urban design strategies are even more limited. It is worth noting that the limited existing studies in this field have not yet fully utilized scientometric analysis methods or large-scale datasets to evaluate the impact, application, and evolution of this research field (Akrofi & Okitasari, 2022). Given this background, this chapter aims to clarify the current state of academic research in relevant fields through the collection and analysis of literature data, identify future research directions, and combine the findings of this chapter with subsequent case studies and design explorations to ultimately propose perspectives and methods for better integrating renewable energy into the urban design process.

2.3.1 Methodological Framework and Literature Screening

In order to conduct a more scientific and systematic analysis of how to design and establish a mature and efficient REC from an urban design perspective, this chapter follows the PRISMA[13] reporting framework and makes appropriate adjustments to the data collection, screening, and analysis process, as illustrated in Figure 2.

However, the overall procedural framework retains the four core steps: identification of literature, screening, data extraction and analysis, and final synthesis of results (Moher et al., 2010).

Phase 1: Literature identification. To systematically and comprehensively retrieve literature related to the research topic, this study selected the SCOPUS database as the source for literature retrieval. Before conducting the identification process, search parameters were set based on the research topic, with keywords limited to 'Urban Design' and 'Renewable Energy Community'. Subsequently, a document type filter was applied to the initially identified literature, restricting the selection scope to the following types: Article, Review, Book, and Book Chapter. Since research in this field is not limited to a specific region and the overall number of relevant literature remains relatively limited, no additional restrictions were placed on the language of the documents. However, to ensure that even the initially screened literature maintains a strong relevance to the topic, subject areas such as Agricultural and Biological Sciences, Chemical Engineering, Chemistry, Medicine, Neuroscience, Biochemistry, Genetics and Molecular Biology, Business, Management and Accounting, Mathematics, as well as Economics, Econometrics and Finance were excluded.

Phase 2: Literature Screening. Due to the relatively small number of results obtained from the initial screening, this study used two sets of screening methods in order to analyze the literature data more systematically and accurately:

The first method involved secondary keyword screening of the retrieved literature. The selected keywords included: Renewable Energy, Sustainable Development, Urban Planning, Energy Community, Renewable Energy Community, Sustainable City, Urban Design, and Urbanization. After screening with this set of keywords, a total of 131 publications were obtained.

The second method further narrowed the scope of the keyword, using only Urban Design and Renewable Energy Community for screening, initially selecting 11 publications. To ensure the high relevance of the screening results, this group of documents was reviewed manually, and 10 documents that met the research criteria were finally selected.

All screened publication data were exported in CSV format for subsequent visualization analysis using Python and VOSviewer. By comparing and analysing the datasets obtained through the two different screening methods, this study aims to draw more comprehensive and accurate research conclusions.

2.3.2 Data Analysis

In the data analysis phase, this study conducted a series of analyses on the two final datasets obtained through retrieval and screening. These analyses included publication trend analysis, keyword co-occurrence analysis, document type analysis, research field analysis, and national cooperation network analysis.

The first step was to analyse publication trends. In the previous section, two datasets were obtained through two different screening methods: the

[13] PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting framework is a widely adopted set of guidelines designed to improve the transparency and completeness of systematic reviews by providing a structured flow diagram and checklist for reporting the process of study identification, screening, eligibility, and inclusion(Page et al., 2021).

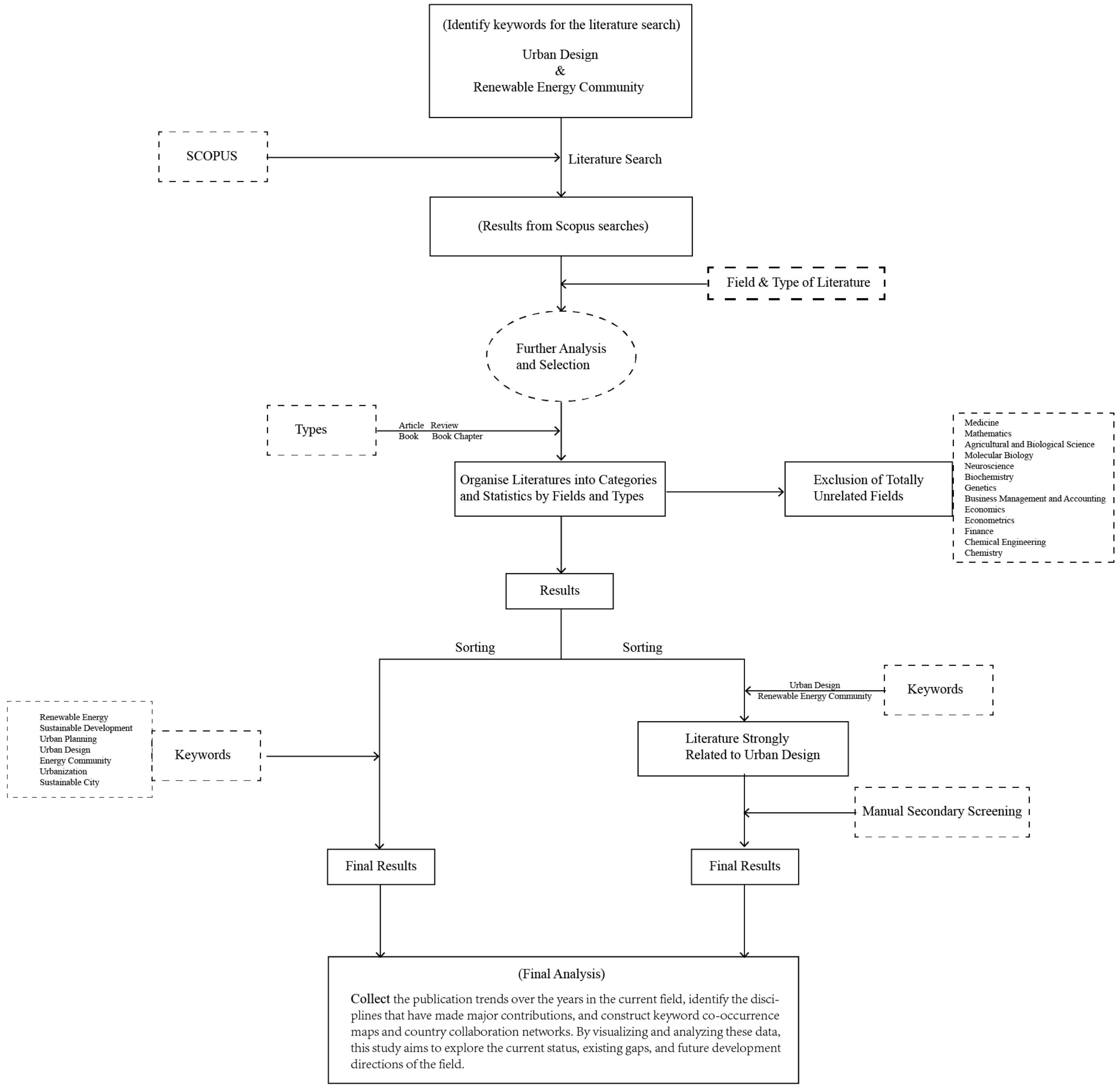

Figure 2 Literature Processing Workflow: Retrieval to Analysis
Source: Created by the author.

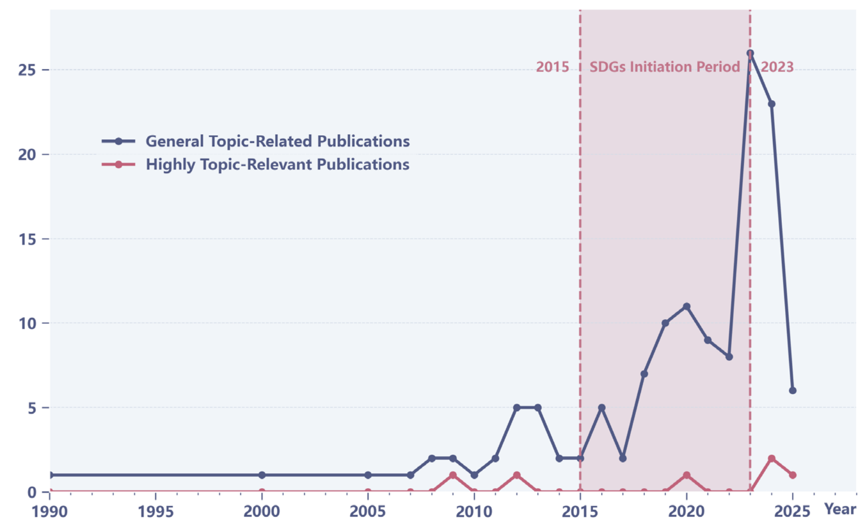

Figure 3 Publication Trends
Source: Created by the author.

first method resulted in 132 publications, while the second method yielded 10 publications. For the sake of clarity, these two datasets were referred to respectively as General Topic-Related Publications and Highly Topic-Related Publications. The results retrieved from the SCOPUS database were then imported into Python, where custom scripts were used to visualize the data and generate a line chart, as shown in Figure 3.

Overall, the General Topic-Related Publications have shown a steady annual growth trend. Before 2015, the growth in publication volume was slow, and it even experienced a certain degree of decline at times. However, since the United Nations released the Sustainable Development Goals (SDGs) in 2015, the number of publications in related fields has grown at a noticeably faster pace. Although there was a brief decline between 2016 and 2017 (possibly due to immature technologies and a lag in research development), another notable decline started in 2020, which is likely caused by the outbreak of the COVID-19 pandemic. Nevertheless, driven by major international events such as the 26th United Nations Climate Change Conference (COP26)[14] held in Glasgow in 2021, the overall publication trend has continued to rise rapidly.

[14] COP26, held in Glasgow in 2021, produced the Glasgow Climate Pact, highlighting the critical need for accelerated energy efficiency measures, emissions reductions, and a coal phase-down to achieve climate goals.

It should be mentioned that the data in this article was collected up to 24 April 2025, so the number of publications in the recent year is comparatively low. As further illustrated in Figure 3, due to the small sample size and the scattered distribution of publication years, the development trend of Highly Topic-Related Publications is less apparent in the chart.

In summary, with the increasing global focus on sustainable development and energy conservation and emission reduction, within the framework of sustainable development and renewable energy, the number of studies related to RECs and urban design is growing, and the academic community is paying increasing attention to this field. However, based on the data and trends of the Highly Topic-Related Publications, it is evident that the research field focusing on the close integration of urban design and RECs has not yet received sufficient attention in the academic community.

In the analysis of literature data, keyword co-occurrence is useful for identifying existing research themes within a specific field, as well as understanding how these themes have evolved and extended over time (Akrofi & Okitasari, 2022).

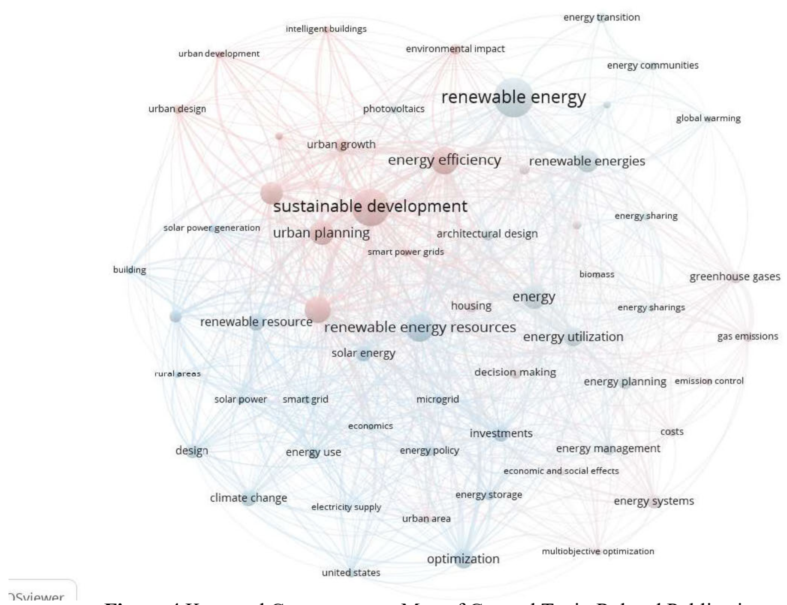

Figure 4 Keyword Co-occurrence Map of General Topic-Related Publications
Source: Created by the author.

By using VOSviewer, the keyword co-occurrence network extracted from the data can be directly visualized, clearly presenting the relationships between topics. Figure 4 Shows the keyword co-occurrence network analysis based on the data from the General Topic-Related Publications. In this figure, each node represents a keyword, and the size of the node indicates the frequency of that keyword occurrence in the literature. The lines between nodes represent co-occurrence relationships where keywords appear together in the same publication, while different colors indicate different research themes.

From the visualisation results shown in Figure 4, Renewable Energy, Sustainable Development, and Urban Planning are the most frequently occurring and most central keywords in the entire network. This highly coincides with the keywords initially proposed, proving the accuracy of the selected literature. In terms of research topics, keyword clusters centred on renewable energy mainly focus on the efficient use of energy, innovation and optimisation of energy technologies. Clusters centred on sustainable development and urban planning cover research directions related to urban construction, such as urban growth and smart grid building design.

Overall, the entire keyword network is highly interconnected and intertwined, which reflects that, under the guidance of sustainable development goals, research in fields such as renewable energy and urban design has gradually converged and integrated. Energy conservation and emission reduction, urban intelligence, and energy optimisation are now hot topics in academia.

Next, when looking at the keyword co-occurrence network analysis based on

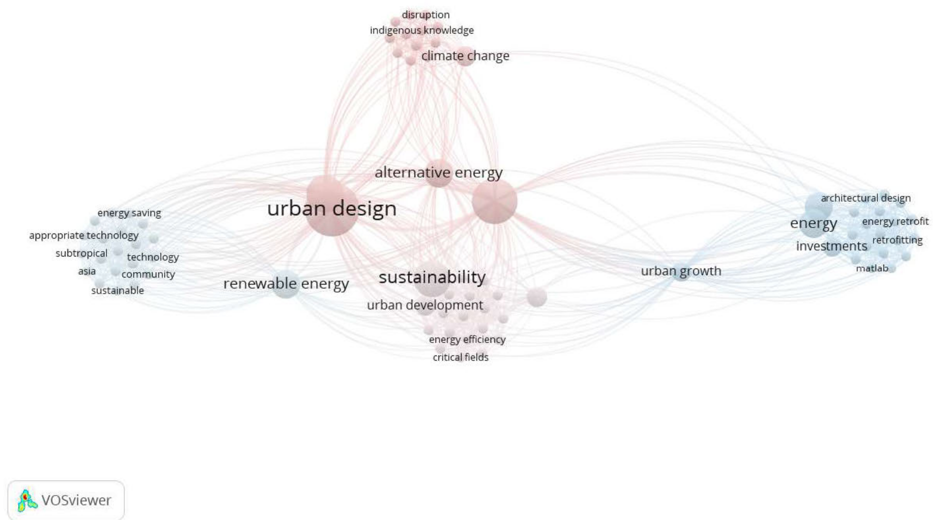

Figure 5 Keyword Co-occurrence Map of Highly Topic-Related Publications
Source: Created by the author.

Highly Topic-Related Publications dataset, as shown in Figure 5, that when the literature is limited to those strongly related to urban design and renewable energy communities, urban design becomes the centre of the entire network. In general, although the keyword network structure is relatively dense and exhibits a certain degree of correlation and interconnection, compared with Figure 4, its network density is relatively low, indicating that the number of existing literature and the degree of crossover in research fields strongly related to urban design and renewable energy communities are limited.

From the analysis of research topic clustering, it can be observed that even when the literature is strongly related to both urban design and RECs, the primary focus still lies on energy-related topics. The cluster centred on urban design mainly explores issues such as climate change, disruption change, and indigenous knowledge. This suggests that the research direction focusing on the integration of urban design and RECs is still in its early stages of development.

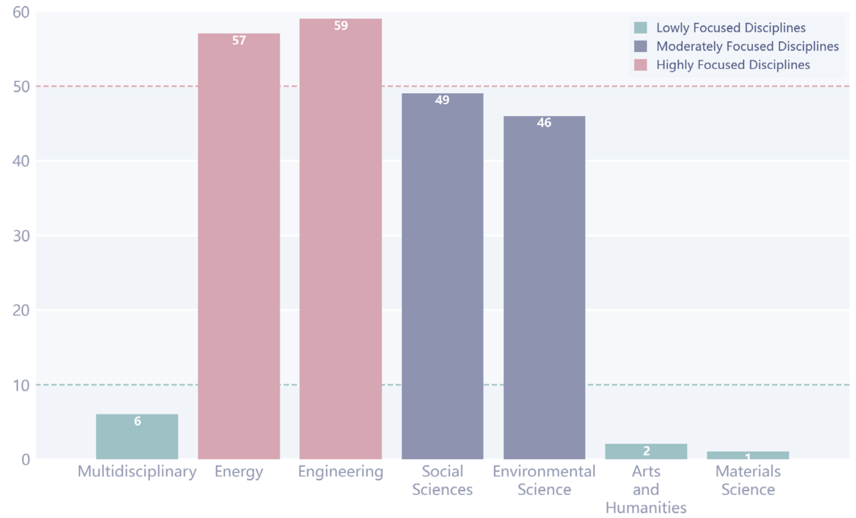

Figure 6 Subject Areas of General Topic-Related Publications
Source: Created by the author.

To validate the results of the keyword co-occurrence network analysis, this study conducted a subject area analysis on the two final sets of retrieved literature. The analysis began with the General Topic-Related Publications dataset, and the visualization results generated by Python are shown in Figure 6.

As can be seen from the bar chart, under the guidance of the Sustainable Development Goals, the interdisciplinary field of renewable energy and urban design remains primarily centred on the energy and engineering disciplines, which have contributed the most research findings. This is followed by social sciences and environmental sciences, which indicate that research in this field is gradually expanding to social and environmental issues. In contrast, multidisciplinary, arts and humanities, and materials science have received relatively little attention in this field.

This distribution trend is consistent with the results of the keyword co-occurrence network analysis based on General Topic-Related Publications

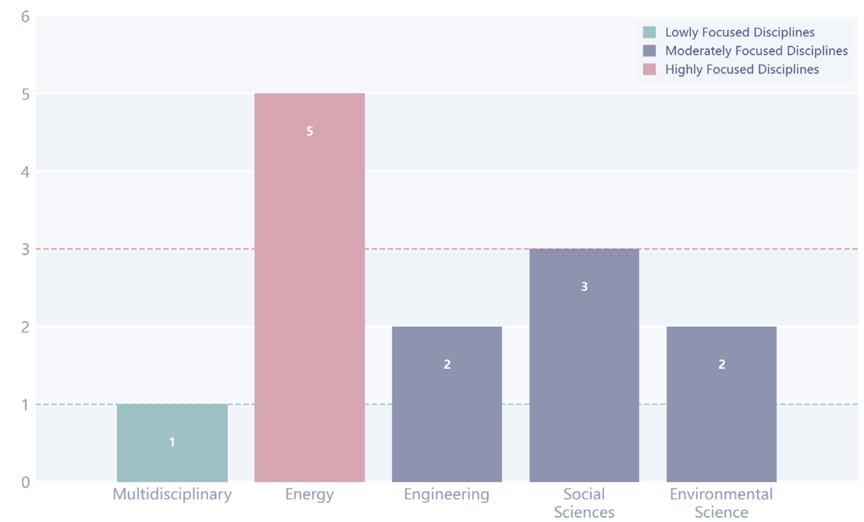

Figure 7 Subject Areas of Highly Topic-Related Publications
Source: Created by the author.

mentioned earlier, that is, energy remains the main hotspot in the academic community in this research direction.

Interestingly, even though the selected literature is already strongly related to both urban design and RECs, the research results are still mainly dominated by the energy discipline, as shown in Figure 7. This may be attributed to the fact that the core focus of RECs is on energy-related issues. However, this result also reinforces the earlier conclusion drawn from the keyword co-occurrence network analysis, namely that the research field integrating urban design with RECs is still in its early stages of development.

At the beginning of the literature screening, this study limited the literature types to Article, Review, Book, and Book Chapter in order to ensure the authority of the data and the systematic nature of the research. After getting the final datasets, to further analyse the structure and depth of research development in this field, both datasets were imported into Python for the visualization of the distribution of literature types. Figure 8 and Figure 9 respectively show the

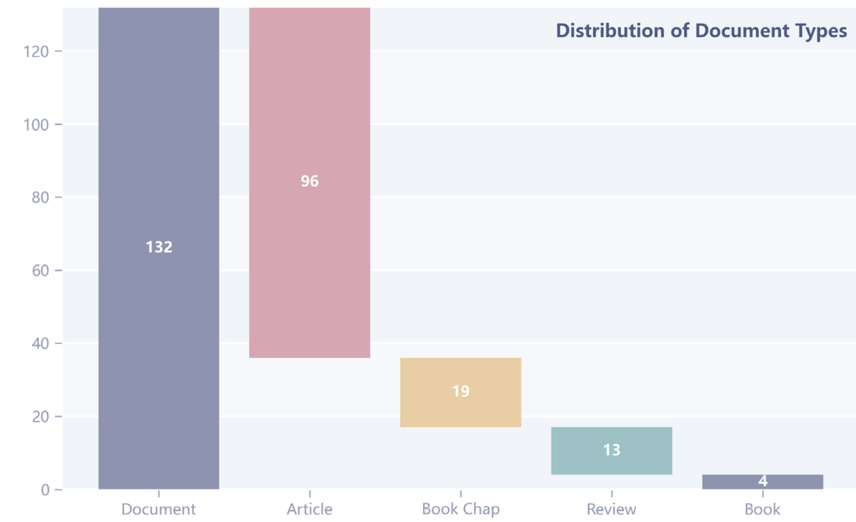

Figure 8 Document Type Distribution of General Topic-Related Publications
Source: Created by the author.

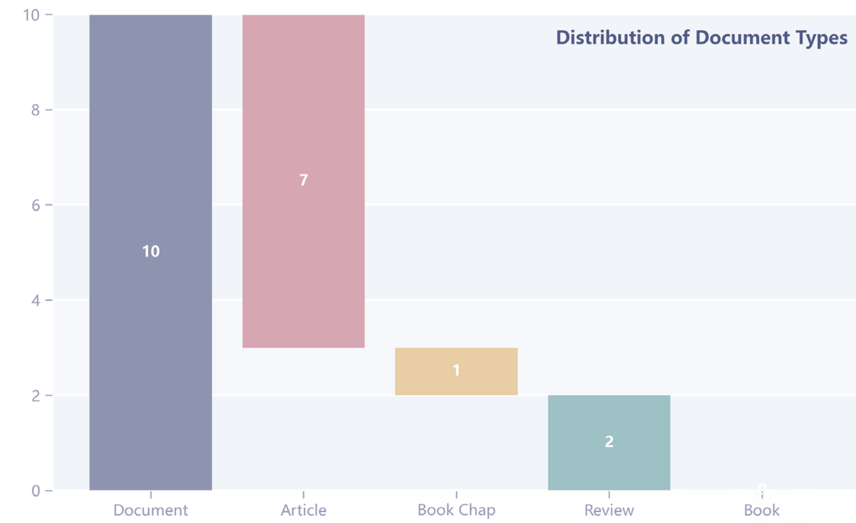

Figure 9 Document Type Distribution of Highly Topic-Related Publications
Source: Created by the author.

analysis results for each dataset.

As shown in Figure 8, among the 132 identified publications, the majority are journal articles, totalling 96. In addition, relevant research can also be found in book chapters and review papers. Monographs are relatively rare, with only four books included in the total of 132 publications.

This indicates that, under the guidance of the Sustainable Development Goals, there is frequent academic exchange in the research fields related to renewable energy and urban design. Although the number of review papers is limited, it still reflects a certain degree of accumulation within this broad research field. Moreover, the fact that book chapters rank just below journal articles indicates that this research field exhibits a strong interdisciplinary character under current conditions, which is consistent with the findings from the earlier keyword co-occurrence network analysis. Finally, the presence of only four monographs suggests that, even when the scope of related research is broadened, the academic community has yet to establish a systematic and in-depth body of knowledge in this field.

A similar pattern can also be observed in the document type distribution of the Highly Topic-Related Publications cluster. As shown in Figure 9, among the 10 publications identified, the Article is the most common type, with a total of 7. The number of book chapters and review papers is almost the same, with 1 and 2 respectively. No relevant monographs were found within this cluster.

From the previous analysis, it can be concluded that academic research in the fields that are related to renewable energy and urban design under the guidance of the Sustainable Development Goals—as well as in the more specialized area that closely integrates urban design with Renewable Energy Communities—remains insufficiently systematic and mature in its development.

To explore international collaboration models within these two research areas and to identify research hotspots that may serve as references for deeper cooperation and future studies, this paper conducted a national collaboration network analysis based on the two sets of selected publications, as illustrated in Figure 10 and Figure 11. Similar to the keyword co-occurrence maps, each node in these two figures represents a country, with larger nodes indicating that the country has published more literature in the respective field. The lines connecting the nodes represent the strength of collaboration between countries—thicker lines indicate more frequent collaboration, while thinner lines suggest less interaction between the two countries. As shown in Figure 10, in the General Topic-Related Publications group, there are obvious regional clustering characteristics, such as the European cluster and the North American cluster. Although cross-regional cooperation exists, it is not close, and scholars mainly conduct scientific research cooperation within the same large regional cluster. The core countries that drive the development of this field—the United States, Italy, and China—also show obvious regional clustering characteristics. It is noticeable that the node size of Italy in the entire cooperation network is close to that of the United States, making it the most active European country in the entire network. Furthermore, Italy not only maintains close collaborations with several other European countries but also actively participates in the broader global academic research network with countries such as the United States and China.

However, when conducting a national cooperation network analysis of the Highly Topic-Related Publications research group, due to the early stage of development in this field, the number of scholars participating in the research was relatively small, and related research was mainly limited to the domestic scope, with no extensive international cooperation yet established. Therefore, when importing the relevant data into VOSviewer for visualisation, no obvious cooperation network was generated, as shown in Figure 11. However, from

the size and depth of the nodes representing different countries, it can be seen that, as in the previous data analysis, the countries most active in academic research in this field are still the United States and Italy, with Italy performing the most outstandingly and having the highest academic activity. This result is consistent with the previous analysis conclusions and further confirms Italy's core position in related research fields such as urban sustainable development and energy transition.

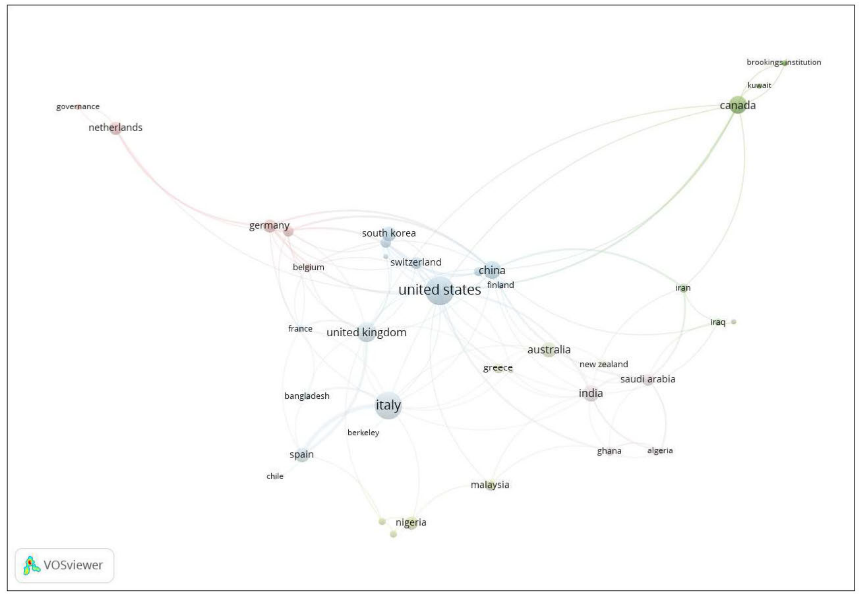

Figure 10 Country Collaboration Network of General Topic-Related Publications
Source: Created by the author.

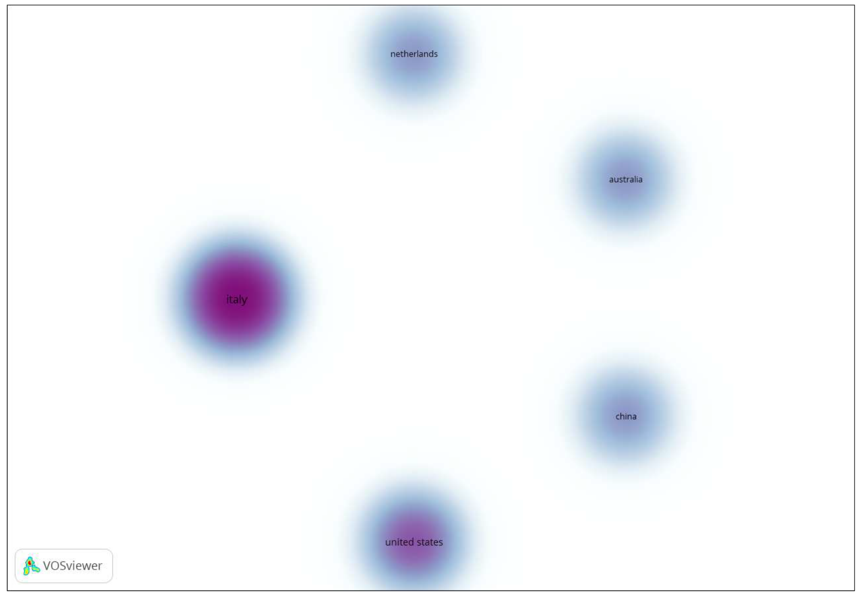

Figure 11 Country Collaboration Network of General Topic-Related Publications
Source: Created by the author.

2.3.3 Research Gap and Future Research Directions

After analysing the two sets of selected literature data, three key gaps and shortcomings were identified in the relevant research field. These differences are reflected in the topics covered by academic research, geographical scope, and theoretical basis.

By combining the keyword co-occurrence analysis and subject area analysis of the two sets of data, it is clear that, regardless of the strength of the relevance between the literature and the cross-disciplinary field of urban design and RECs, the focus of the research is all centred on how to utilise and optimise renewable energy technologies. In comparison, there are few scholars who explore how to promote the construction and development of RECs through spatial planning and design from the perspective of urban design.

Taking solar energy, the most mature and widely used renewable energy technology, as an example, academic research on tools and technologies related to solar energy development and utilisation has achieved significant results. As of 2018, more than 200 solar energy-related design tools have been developed to support the optimisation, evaluation, and application promotion of solar energy systems (Jakica, 2018; Peronato et al., 2018). Moreover, many cities have become proficient in using solar design tools to create customized 2D or 3D solar maps for their urban environments. However, the academic community still lacks effective methodologies for integrating these research findings into traditional urban planning or urban design processes (Akrofi & Okitasari, 2022; Lungren Marja & Dahlberg Johan, 2018).

Achieving global sustainable development cannot rely solely on technological research. In the context of accelerating global urbanization, cities are not only engines of economic growth but also serve as key areas for addressing major challenges such as climate change, energy transition, and the pursuit of sustainable development (International Energy Agency, 2021). Therefore, urban designers and scholars from related fields should actively participate in this global wave of transformation and propose solutions to address the gaps and shortcomings that currently exist in the intersection field of urban design and RECs research.

In theory, either urban design or the design and construction of the REC, these two disciplines should be studied in different cities and regions, and there should not be any obvious regional differences. However, from the diagram of the national cooperation network, it can be clearly observed that the current research on RECs related to urban design is mainly concentrated in North America and Europe, while research from the Global South and Asia is relatively scarce. This phenomenon may be related to the uneven distribution of global scientific research resources. Given that this field is still in its early stages of development, the current national collaboration network shows three major regional clusters dominated by developed countries in North America and Europe: the North American cluster, the European cluster, and the Asian cluster centred around China. Cooperation and communication between these clusters are relatively limited. From the current stage of development, these regional differences and the research gaps in certain countries should be viewed as a normal phenomenon, rather than a negative factor. On the contrary, they reflect the early stage of development in this field and the potential for future expansion.

It is particularly worth noting that, as shown in Figure 11, when the research focuses specifically on designing RECs from an urban design perspective, the number of countries that participate in the research further decreases, and no effective international cooperation network has been formed yet. Research efforts are mainly concentrated in a few countries, such as the United States, Italy, and China. As mentioned earlier, when explaining the concepts of urban design, urban regeneration, and RECs, ‘Renewable Energy Communities can serve as an important means for achieving sustainable urban regeneration’, while ‘urban design is the core foundation for building efficient, mature RECs and promoting their sustainable development’. As a result, from a global perspective, conducting sustained and in-depth research

on designing and building RECs from an urban design perspective, while promoting broader and deeper international collaboration, will become an indispensable component in achieving the global Sustainable Development Goals. In addition, it is also important to note that Italy plays an active and key role in the overall cooperation network and research contributions. Therefore, future research can critically analyse the existing cases and research results in Italy to gain a deeper understanding of its experience and practices in urban sustainable development and REC construction. At the same time, by enhancing cooperation and exchanges with Italian scholars, it may be possible to provide new perspectives and theoretical support for the development of this interdisciplinary field, thereby further promoting in-depth research on the integration of urban design and renewable energy.

As for theoretical research, since research on RECs related to urban design is still in its early stages of development, a relatively mature knowledge system and theoretical framework has not been formed yet. which can be clearly seen from the analysis of the distribution of publications by subject area in Figure 8 and Figure 9. As an emerging interdisciplinary field of study, it not only focuses on traditional areas such as urban development, design, and cultural context, but also integrates multiple emerging technological fields such as energy and technology, and encompasses various aspects including policy regulations and economic development. It particularly emphasises the pursuit of balance between urban space, residents’ lives, and environmental sustainability. Therefore, although in-depth research in this field may face certain complexities, it also holds significant exploratory value and academic interest.

The establishment of a mature knowledge system and theoretical framework can significantly promote the systematisation and in-depth development of academic research in this field. From the analysis of the distribution of disciplines, it can be further noted that energy and engineering-related fields have already conducted extensive research at the technical level. Urban design and related disciplines should also actively participate in the exploration of this interdisciplinary field to promote its rapid development, especially to address the current research limitations caused by the lack of urban design theory support, and to help RECs play a greater role in the process of sustainable urban development.

2.4 Summary

It is estimated that by 2050, the global urban population will exceed 70%, leading to a significant increase in demand for cities and urban infrastructure, energy, and so on (International Energy Agency, 2021). Cities, as the largest consumers of energy and key drivers of global sustainable development and solutions to climate change and energy issues, are crucial to addressing the current global climate and energy crisis (International Energy Agency, 2021). Integrating the development of RECs with urban design provides a more comprehensive and innovative solution to achieving sustainable urban regeneration. However, based on the analysis of the literature data in this chapter, although research in fields related to urban design and RECs has been ongoing for decades, the integration of the two—designing and establishing RECs from an urban design perspective—is still in its early developmental stage and has not yet attracted widespread attention in academia. (Li et al., 2021) pointed out in their study that addressing increasingly complex urban issues requires the dynamic adoption of more practical and adaptive strategies and measures. Therefore, in response to the shortcomings identified in this study, such as issues related to academic research topics, regional distribution, and theoretical foundations, future scholars should conduct in-depth exploration into these areas. They should integrate urban design concepts with the development of RECs to continuously enrich and refine the knowledge system of this interdisciplinary field, promoting both its theoretical and the development of RECs to continuously enrich and refine the knowledge system of this interdisciplinary field, promoting both its theoretical and practical development, and better serving the sustainable transformation and high-quality development of cities.

Finally, it is important to note that all of the above analyses are based on the screening methods and processes outlined above, and therefore may contain a certain degree of bias. For example, due to the limited scope of the keywords, some relevant studies may not have been included in the final database. Therefore, although this study has revealed, to some extent, the gaps in the academic research topics and theories related to the design and development of RECs from an urban design perspective, the conclusions drawn should still be interpreted with caution and the limitations of the data itself should be fully considered.

3.Site Analysis of Basse di Stura: *Context, Opportunities and Challenges*

Through the analysis of the literature review, this study recognises the key role of urban design in the construction of mature and efficient RECs, while also pointing out the gaps and shortcomings in academic research within this field. In order to solve this research gap, this study attempts to develop a conceptual design and preliminary technical analysis for selected typical sites, aiming to establish a systematic design process that integrates sustainable energy technologies with urban design at its core. It is hoped that this method will provide a comprehensive framework for future related research.

Currently, Europe, and especially Italy, faces significant challenges in addressing sustainable urban regeneration and energy transition. In Italy, 90% of buildings are residential, and more than half of these residential buildings were constructed before the introduction of building energy efficiency regulations (Energy & Strategy Group, 2022). However, according to the regional analysis of the academic collaboration network in the literature review, Italy stands out for its high research activity and international collaboration in this field. In this context, to better illustrate the significant role of urban regeneration in sustainable development and to gain more comprehensive theoretical support, this study selects a brownfield site in the northern part of Turin—Basse di Stura—as the focus for research and conceptual design.

3.1 Site Context and Sense of Place

Basse di Stura is located in the northern part of Turin, Italy, in the transition zone between the urban built-up area and the surrounding farmland(Figure

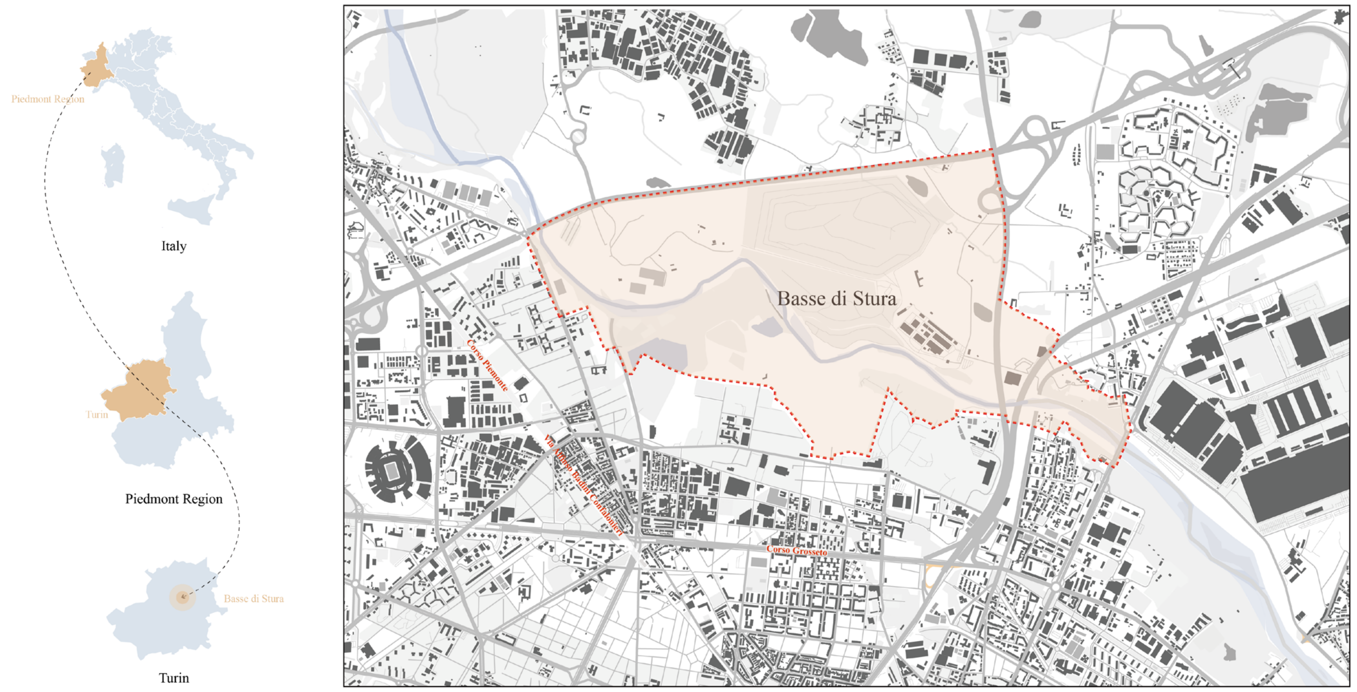

Figure 12 Site Analysis of Basse di Stura
Source: Created by the author.

12). The entire site is surrounded by large agricultural areas to the north and east, adjacent to a densely populated residential area to the west, and dotted with industrial and commercial facilities to the south. The total area of the site is approximately 5.19 square kilometres, and the Stura di Lanzo river flows through it. Figure 13 illustrates the defined boundary and land area of the Basse di Stura region (Regione Piemonte et al., 1999).

Historically, Basse di Stura was a low-lying area prone to flooding along the river. During the Middle Ages, frequent flooding caused by the Stura di Lanzo led to several changes in the river's course, as can be seen in Figure 14. As a result, the area lacked stable human settlements for a long time. Starting in the 16th century, residents gradually built villages in relatively higher areas, and in the following centuries, the area was mainly used for agricultural production. (Politecnico di Torino – Dipartimento di Architettura e Design, 2025; Regione Piemonte et al., 1999). In the mid to late 20th century, with the urban expansion and industrialisation of Turin, the Basse di Stura area was gradually developed into a site for large-scale municipal landfill operations, along with several gravel and sand quarries that supplied construction materials to the city. Therefore, the function of this area has changed from agricultural production to a central location for waste disposal and stone supply for the city of Turin. This can be seen in Figure 15, which shows the basic topographyand geological distribution map based on a 1994 land survey, where the once productive agricultural areas have been replaced by a large number of car dismantling plants and vehicle warehouses. (Pantaloni Giulio Gabriele, 2020; Politecnico di Torino – Dipartimento di Architettura e Design, 2025; Regione Piemonte et al., 1999).

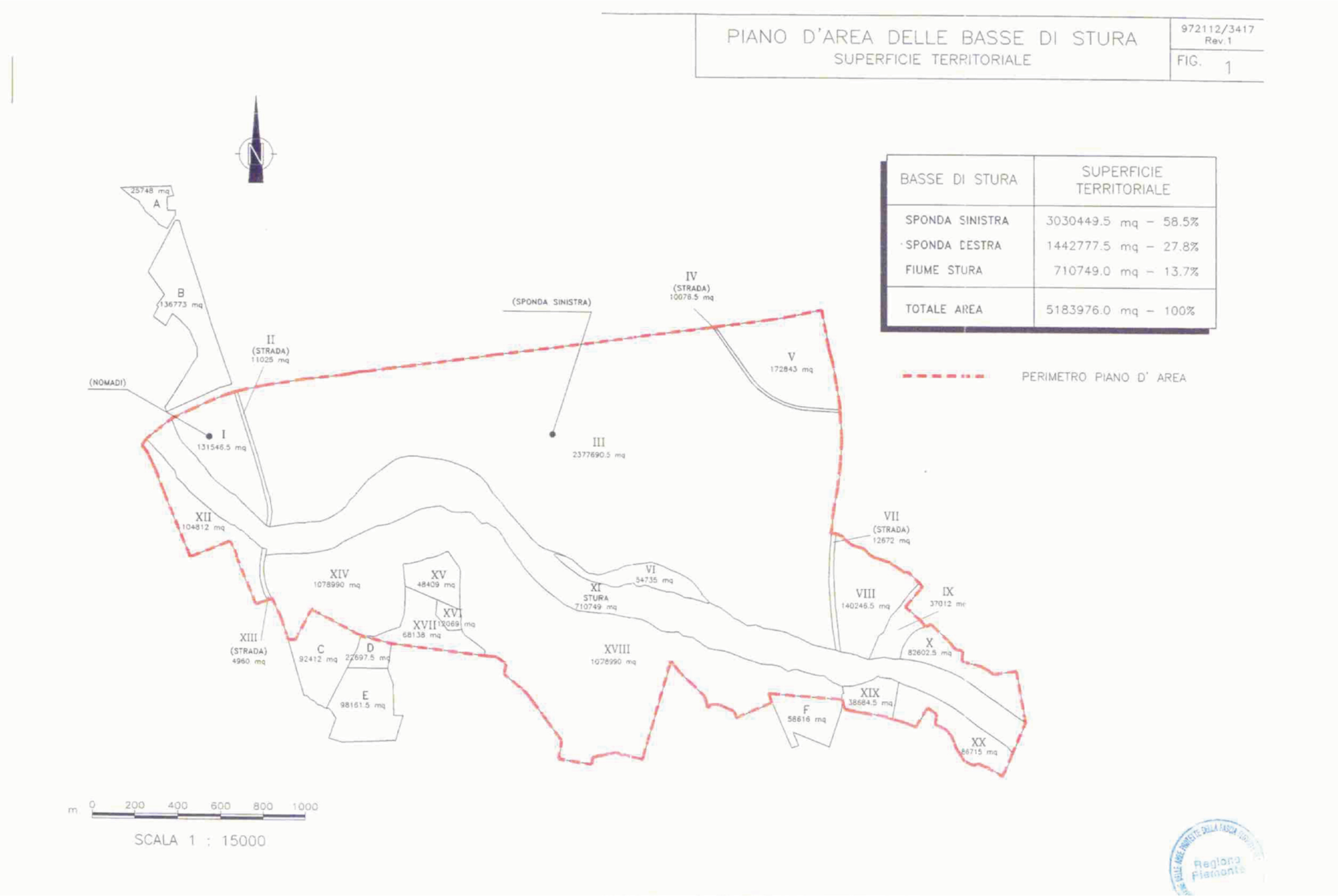

Figure 13 Area Plan of the Basse di Stura – Territorial Surface
Source: (Regione Piemonte et al., 1999).

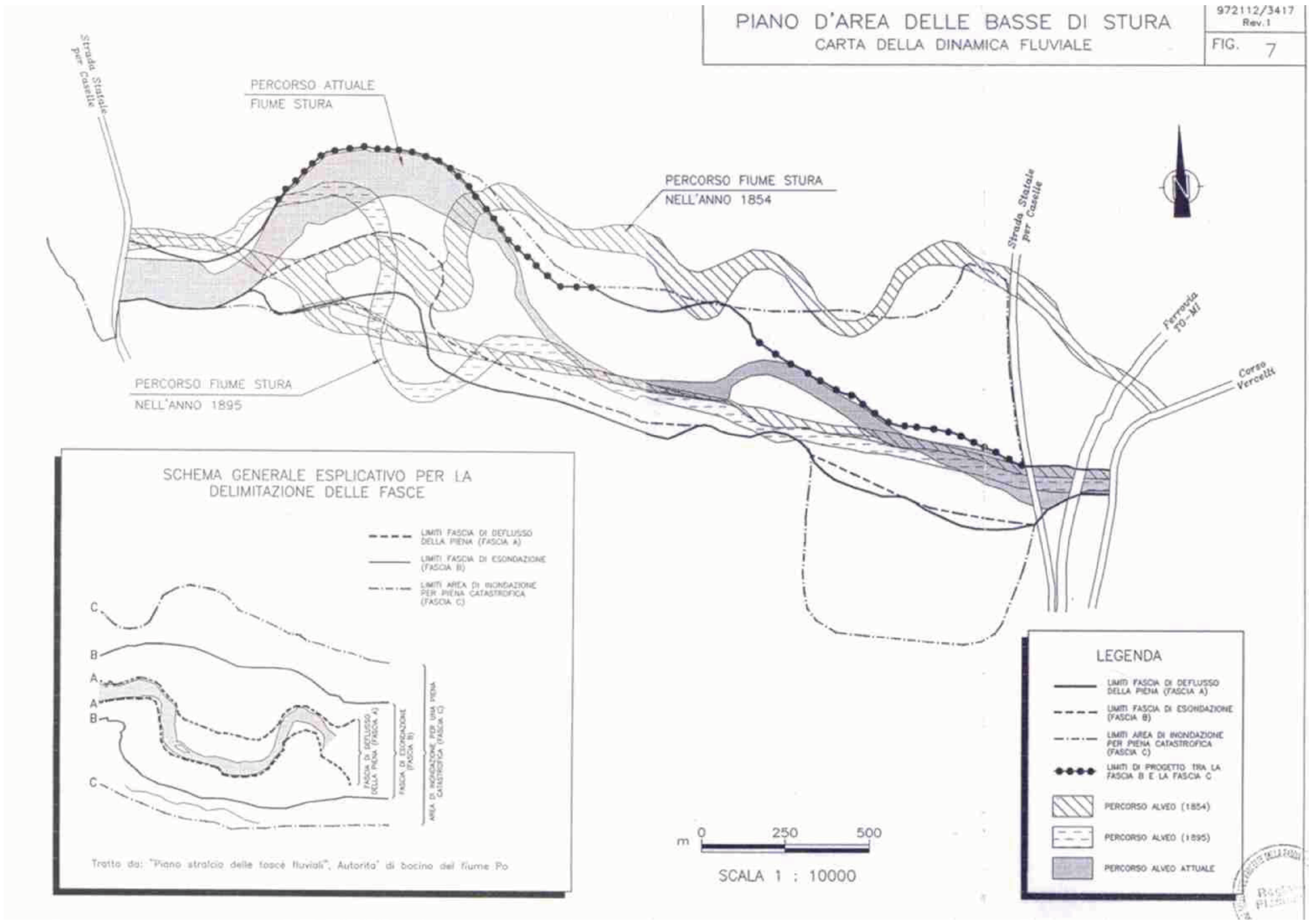

Figure 14 River Dynamics Map of the Stura in the Basse di Stura Area (1854–1999)
Source: (Regione Piemonte et al., 1999).

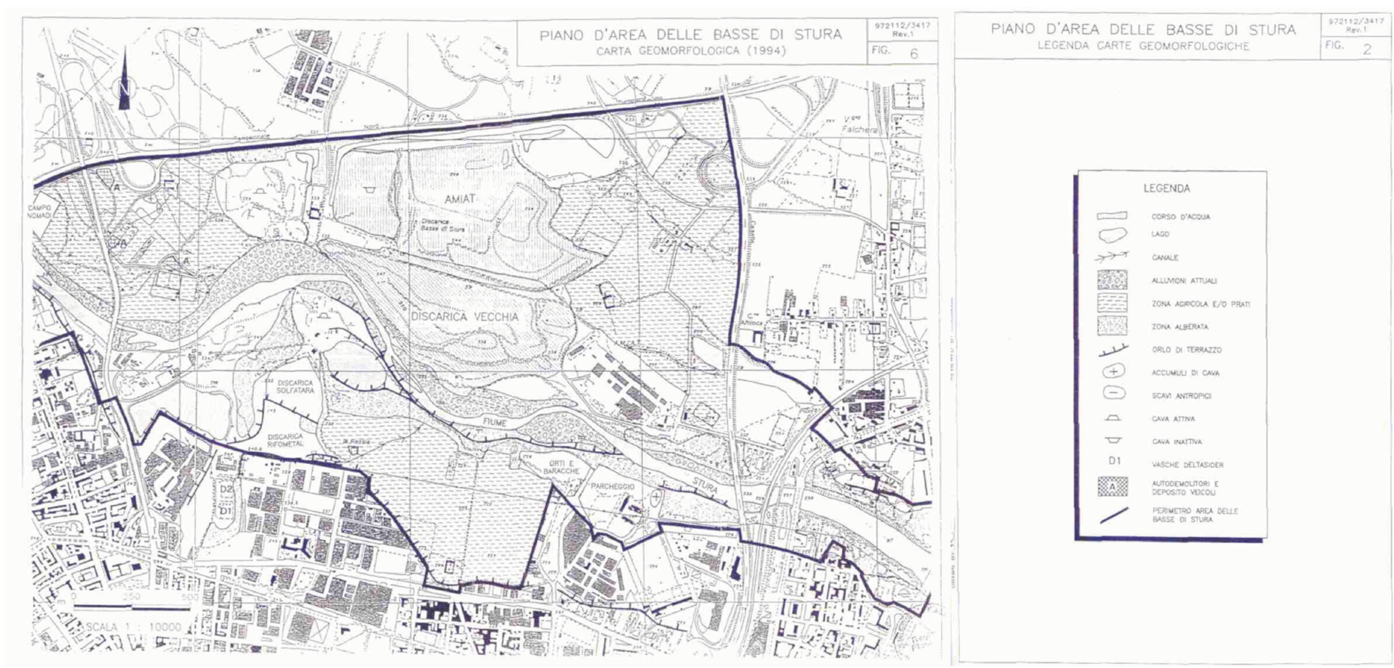

Figure 15 Basse di Stura Area Plan – Geomorphological Map (1994)
Source: (Regione Piemonte et al., 1999).

3.2 Land Use and Built Form

Due to multiple functional transformations throughout its historical development, the land use in the Basse di Stura area has gradually evolved into a highly mixed pattern. As shown in Figure 16, the land use zoning map, each functional update in the Basse di Stura area has retained some traces of the previous phase, resulting in the current land use status that includes agricultural land, abandoned industrial land, and natural river wetlands, and presenting a diverse and complex spatial structure. Among these, the *P.E.R.A*[15]. area is the most complex and closely related to the city(Regione Piemonte et al., 1999).

According to the geographical analysis of the *P.E.R.A.* area in the Basse di Stura by (Pantaloni Giulio Gabriele, 2020) (as shown in the Figure 17), the existing land use in the region can be broadly categorized into six types: built-up land, quarrying and waste disposal areas, agricultural land, urban green spaces, natural vegetation cover, and water bodies.

The built-up land accounts for approximately 16% of the entire site and mainly consists of a small number of residential and industrial buildings, which are scattered across the area. As a result, no continuous urban blocks have been formed. The quarrying and waste disposal areas account for approximately 23% of the entire site. Most of the quarries are no longer in operation, leaving behind large areas of exposed land and deep pits. The agricultural land that occupies approximately 26% of the Basse di Stura area includes orchards, arable land and some pastures. Although some farmland has been left idle due to urbanisation, large areas of arable land are still used by nearby farmers in a scattered manner(Pantaloni Giulio Gabriele, 2020; Regione Piemonte et al., 1999).

Surrounding the agricultural land are urban green spaces and natural vegetation, which occupy 13% and 17% of the area, respectively. The urban green spaces consist of two main parts: one is the greenbelt preserved along city roads and flood control embankments, and the other is the ecological green space created from the transformation of the former landfill site. The landfill site within the area covers nearly 100 hectares. It was put into use after World War II, ceased receiving waste in 2009, and was recently completed with soil cover and greening, becoming an important ecological restoration area within the site(Amiat Gruppo Iren, 2023; Pantaloni Giulio Gabriele, 2020; Politecnico di Torino – Dipartimento di Architettura e Design, 2025).

In addition, the site contains two artificial lakes formed by historical sand extraction activities, covering approximately 5% of the total area. Although the water bodies are somewhat polluted, dense vegetation has naturally grown along the shores, creating a unique ecological landscape in the area(Pantaloni Giulio Gabriele, 2020).

The various types of land use described above are interwoven within the site, creating a complex and unique spatial layout. Although residential and industrial/commercial buildings are relatively rare in this area, and no large-scale urban communities have formed, the site is bordered to the west by a large, developed residential area and surrounded to the south by extensive industrial and commercial land. In this spatial context, if the site boundaries are moderately expanded in the planning process to include the surrounding urban built-up areas within the overall consideration for future RECs, this diverse

[15] *P.E.R.A.* (Piano Esecutivo di Recupero Ambientale, 'Executive Plan for Environmental Remediation') is a planning instrument introduced in Turin's new General Regulatory Plan (PRG). It applies particularly to degraded areas such as Basse di Stura, requiring the remediation of polluted sites, environmental restoration, and safe land reuse before any park development or urban regeneration project can be implemented(Regione Piemonte et al., 1999).

Surrounding the agricultural land are urban green spaces and natural vegetation, which occupy 13% and 17% of the area, respectively. The urban green spaces consist of two main parts: one is the greenbelt preserved along city roads and flood control embankments, and the other is the ecological green space created from the transformation of the former landfill site. The landfill site within the area covers nearly 100 hectares. It was put into use after World War II, ceased receiving waste in 2009, and was recently completed with soil cover and greening, becoming an important ecological restoration area within the site(Amiat Gruppo Iren, 2023; Pantaloni Giulio Gabriele, 2020; Politecnico di Torino – Dipartimento di Architettura e Design, 2025).

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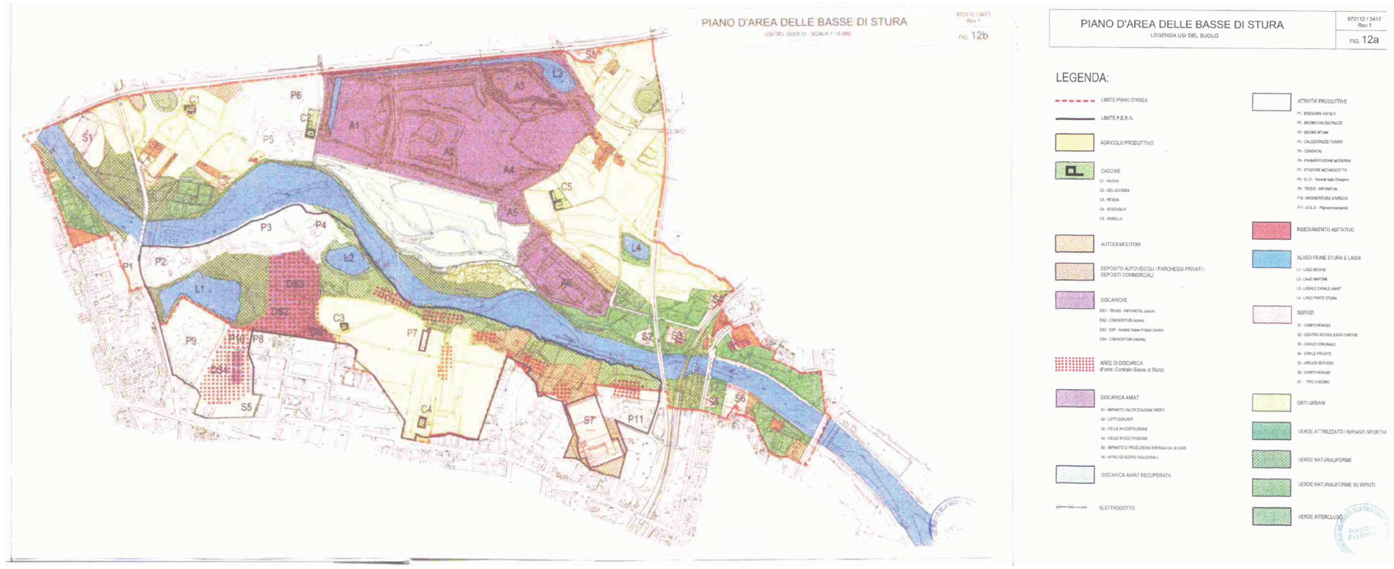


Figure 16 Land Use Map – Basse di Stura Area Plan (Scale 1:10,000)
Source: (Regione Piemonte et al., 1999).

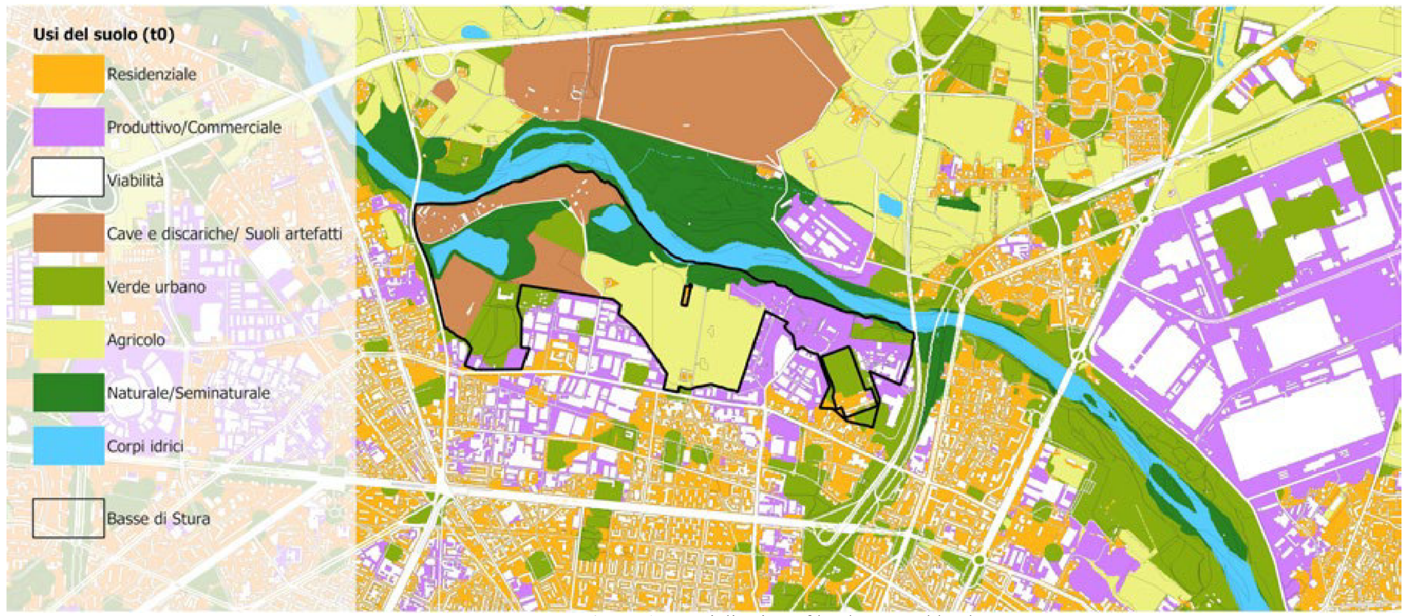


Figure 17 Spatialisation of land uses and land cover
Source: (Pantaloni Giulio Gabriele, 2020).

The various types of land use described above are interwoven within the site, creating a complex and unique spatial layout. Although residential and industrial/commercial buildings are relatively rare in this area, and no large-scale urban communities have formed, the site is bordered to the west by a large, developed residential area and surrounded to the south by extensive industrial and commercial land. In this spatial context, if the site boundaries are moderately expanded in the planning process to include the surrounding urban built-up areas within the overall consideration for future RECs, this diverse and overlapping spatial structure would no longer be a limitation. Instead, it could be transformed into a design advantage, providing more possibilities and flexibility for subsequent spatial organization, functional layout, and energy system integration.

3.3 Assessment of Renewable Energy Potential

In order to design an efficient REC in Basse di Stura, it is necessary to understand not only the current land use but also the potential for renewable energy development.

According to the data report jointly released by the World Bank and Solargis in the Global Solar Atlas[16] (as shown in the Figure 18), the Turin region possesses abundant solar energy resources, with an annual average photovoltaic output (PVOUT) of 1,409.4 kWh/kWp. This means that for every 1 kilowatt peak power (kWp) of photovoltaic modules installed, approximately 1,409.4 kilowatt-hours of electricity can be generated annually on average. Additionally, Turin demonstrates outstanding performance in terms of solar radiation intensity. When photovoltaic panels are installed at the optimal tilt angle of 38° facing south, each square metre can receive approximately 1,700.5 kWh of total solar radiation energy per year (referred to as the optimal tilt angle total radiation, GTI_opt). Of this, the portion of sunlight directly used for electricity generation, known as direct normal irradiance (DNI), averages 1,476.3 kWh per square metre annually. (The World Bank & Solargis, 2025). Therefore, it can be concluded that Turin not only enjoys abundant sunlight but also has stable solar radiation, making it highly suitable for the deployment of photovoltaic power systems and other solar-related distributed renewable energy projects.

[16] The *Global Solar Atlas* is an online platform by the World Bank and IRENA that provides solar resource data to help assess solar energy potential worldwide.

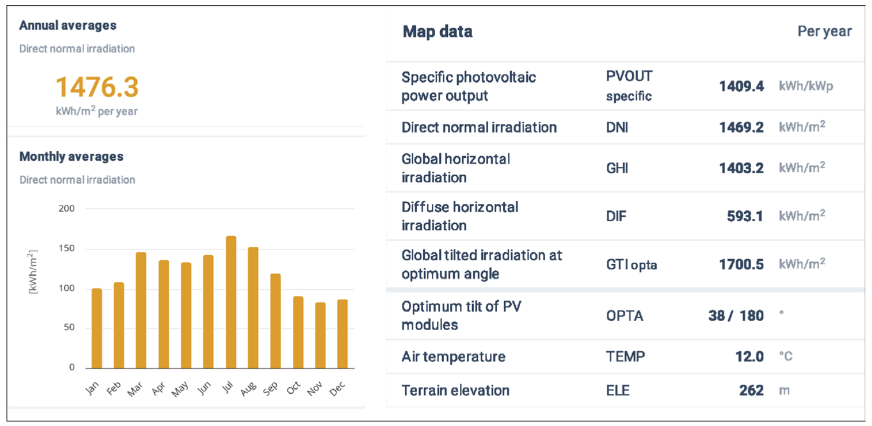


Figure 18 Solar Energy Resource Assessment in Turin (Global Solar Atlas)
Source: (The World Bank & Solargis, 2025).

As shown in Figure 19 and 20, according to data from the Global Wind Energy Resource Database, the average annual wind power density in the optimal wind energy zone of Turin is only 29 W/m², and the annual average wind speed at a height of 100 meters is generally below 2.3 m/s. This indicates

that the region has a climate dominated by light winds. This wind speed is far below the technical and economic feasibility threshold for wind power generation, indicating that the overall wind energy development potential of the region is low. Although small wind turbines can be installed in local areas to utilise gusts or seasonal local winds, their utilisation value is significantly lower than that of solar energy. Therefore, wind energy is not considered a priority energy type in the planning of the renewable energy system for Basse di Stura, and no dedicated wind power generation facilities are required.(World Bank Group et al., 2023).

Regarding the biomass energy potential of the Basse di Stura region, due to its long history as a municipal landfill, a large accumulation of organic waste has built up within the site, providing favorable conditions for biogas power generation. Since 1994, the company Amiat has been collecting and generating electricity from biogas at this site, with the produced electricity being sufficient to meet the power needs of approximately 15,000 households. Even though the landfill ceased operations in 2009, biogas generated from the decomposition of waste is expected to continue to be released for more than 20 years.(Amiat Gruppo Iren, 2023). Therefore, for a significant period of time in the future, biogas power generation will remain one of the important forms of renewable energy in the region. However, since the system has already been integrated and is being stably operated by a company, with the related facilities now being well-established, biomass energy is no longer considered as a primary focus in the design phase of this study.

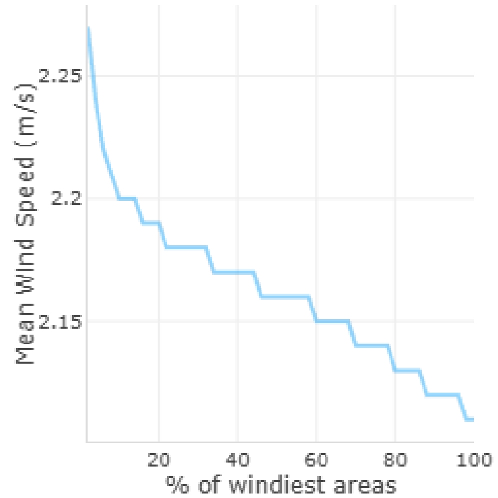


Figure 19 Mean Wind Speed Distribution by Percentile of Windiest Areas in Turin
Source: (World Bank Group et al., 2023).

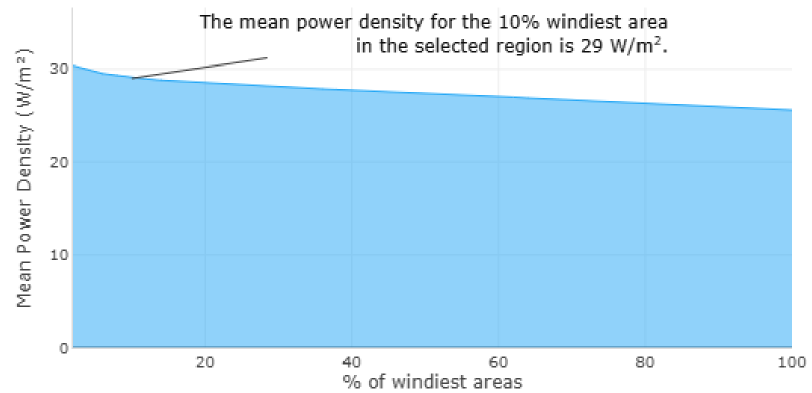


Figure 20 Mean Wind Power Density Distribution by Percentile of Windiest Areas in Turin
Source: (World Bank Group et al., 2023).

Finally, since Turin is located in northern Italy, the average heating period lasts approximately 162.1 days per year (2617 degree days, according to DPR 412/93, as shown in the Figure 21)(President of the Republic of Italy, 1993). Therefore, how to effectively address heating demand within the REC planned for the Basse di Stura area becomes a key issue that requires careful consideration.

According to research on geothermal resources in the Piedmont region by (Casasso Alessandro et al., 2021) , as shown in the Figure 22, the annual unit heat energy potential (Q_{BHE}) of Turin is approximately 8 to 12 MWh/year, which belongs to the medium-high heat energy utilisation level.

From the team's analysis of the geothermal potential of the Piedmont region, it can be seen that Turin not only has high geothermal energy extraction potential (>10.5 MWh/year) but also sufficient residential density(see Figure 23). Therefore, in this study, Turin is considered a 'highly promising geothermal development area,' particularly suitable for shallow geothermal energy utilisation (such as closed-loop ground-source heat pumps)(Casasso Alessandro et al., 2021).

Additionally, from the official planning documentation for the *Piano d'Area delle Basse di Stura*[17] the subsurface analysis map (Figure 24) of the Basse di Stura region reveals that the subsurface structure exhibits strong overall continuity, with no abnormal fractures or faults throughout the entire 100-metre depth. The layers are well-defined and of moderate thickness.The gravel and sandstone layers provide excellent thermal conductivity, while the deeper

[17] The *Piano d'Area delle Basse di Stura*, compiled by the Piedmont Region's Department of Territorial Planning and Natural Parks, provides detailed information on the Basse di Stura area in northern Turin and is a valuable reference for further research on this site. Interested readers may refer to (Regione Piemonte et al., 1999) for more information.

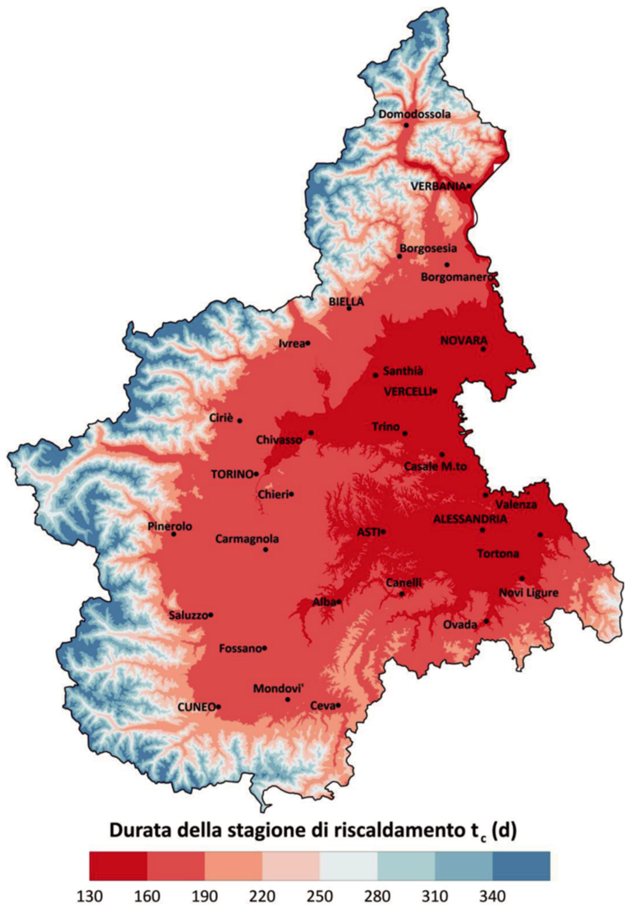


Figure 21 Estimated Duration of the Heating Season in Days
Source: (Casasso Alessandro et al., 2021).

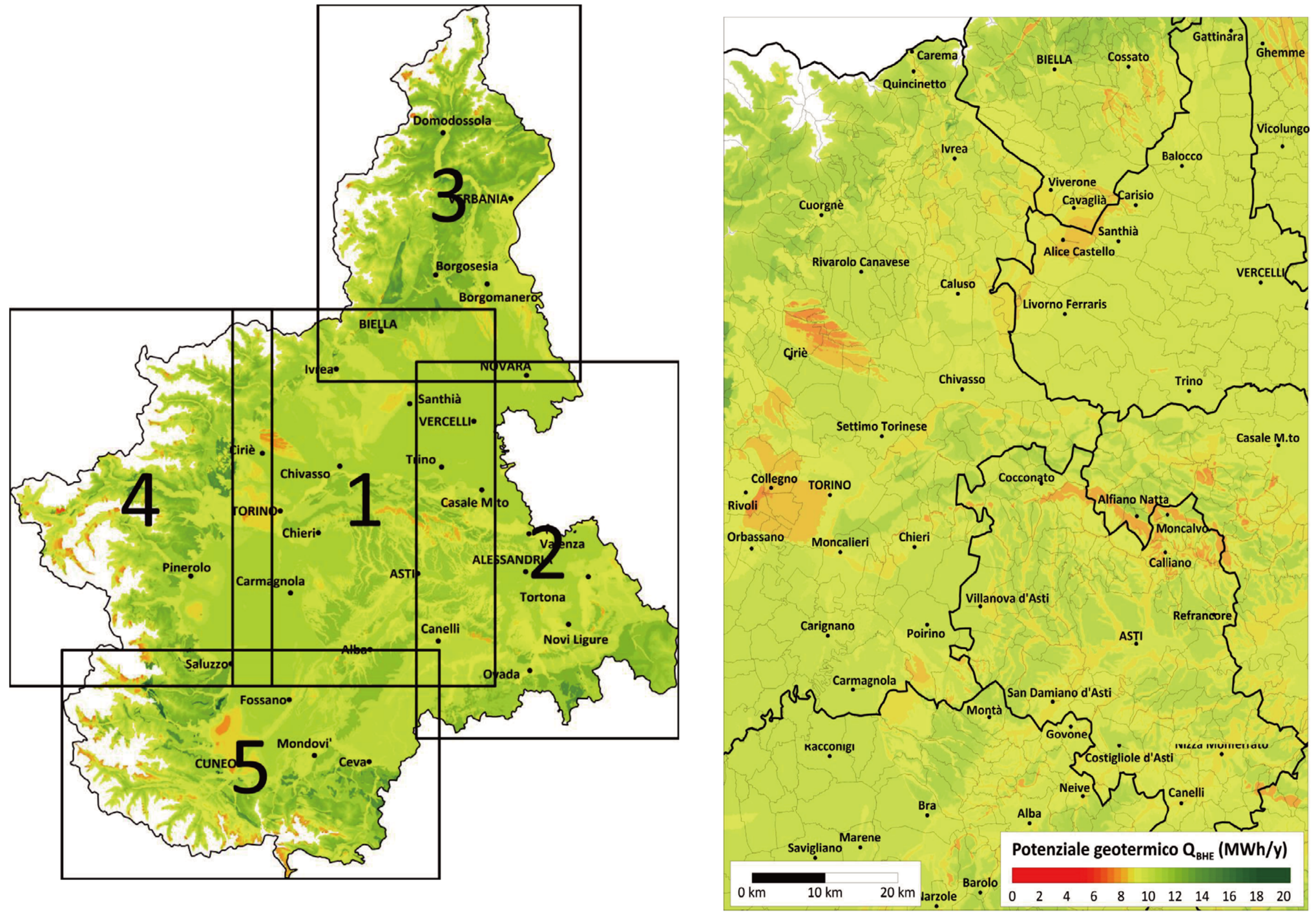


Figure 22 Map of Closed-Loop Geothermal Potential (Q^{BHE}): Central Piedmont Detail (AT, CN, TO, VC, BI, AL)
Source: (Casasso Alessandro et al., 2021).

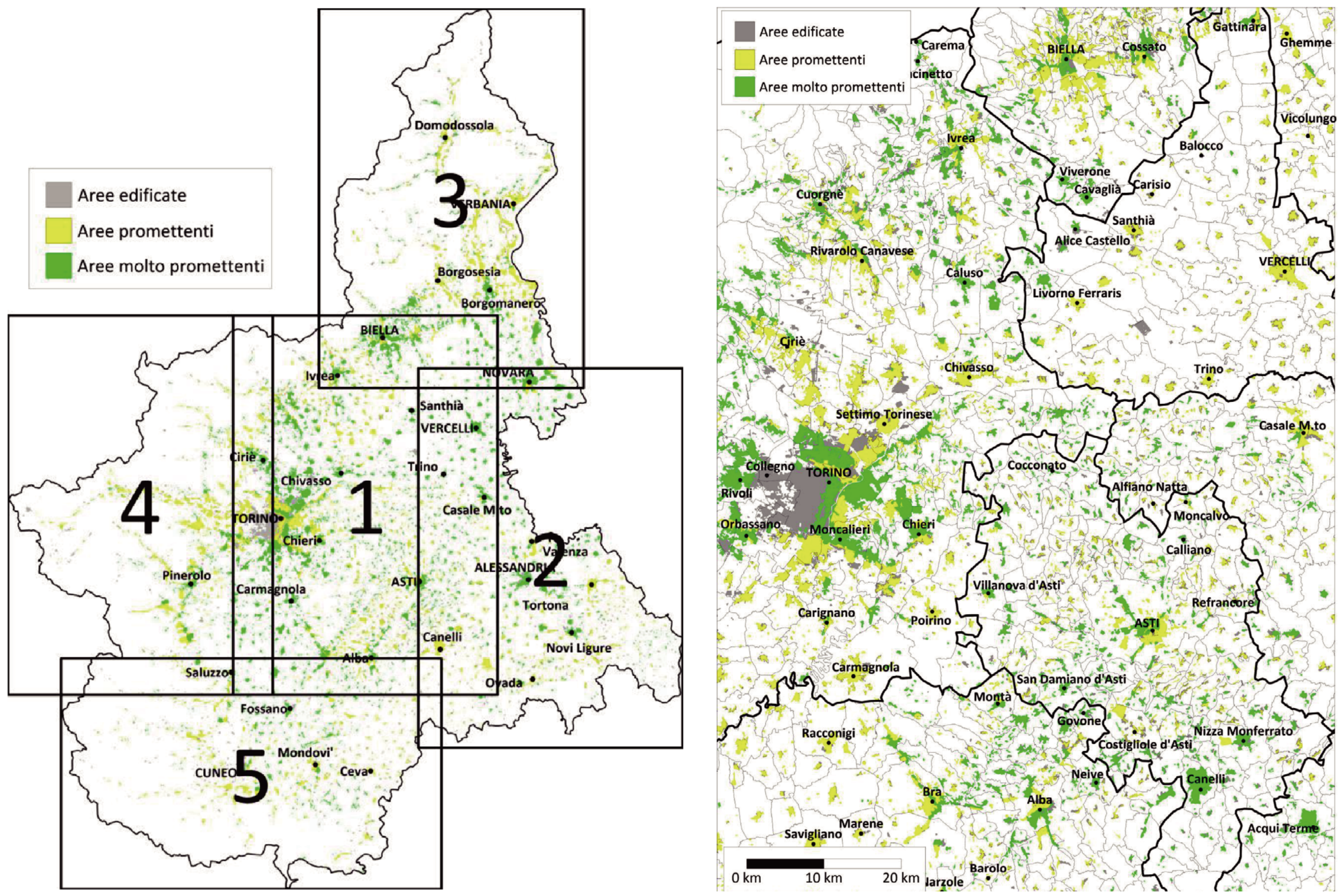


Figure 23 Map of the Most Promising Areas for Geothermal Energy: Central Piedmont Detail
Source: (Casasso Alessandro et al., 2021).

sandstone-rich silt layers enhance heat exchange potential. These geological conditions make the area highly suitable for geothermal energy utilisation. Therefore, considering the heating demand, geothermal potential, and geological conditions of the Basse di Stura region, the deployment of geothermal heating systems in this area is both necessary and appropriate(Regione Piemonte et al., 1999).

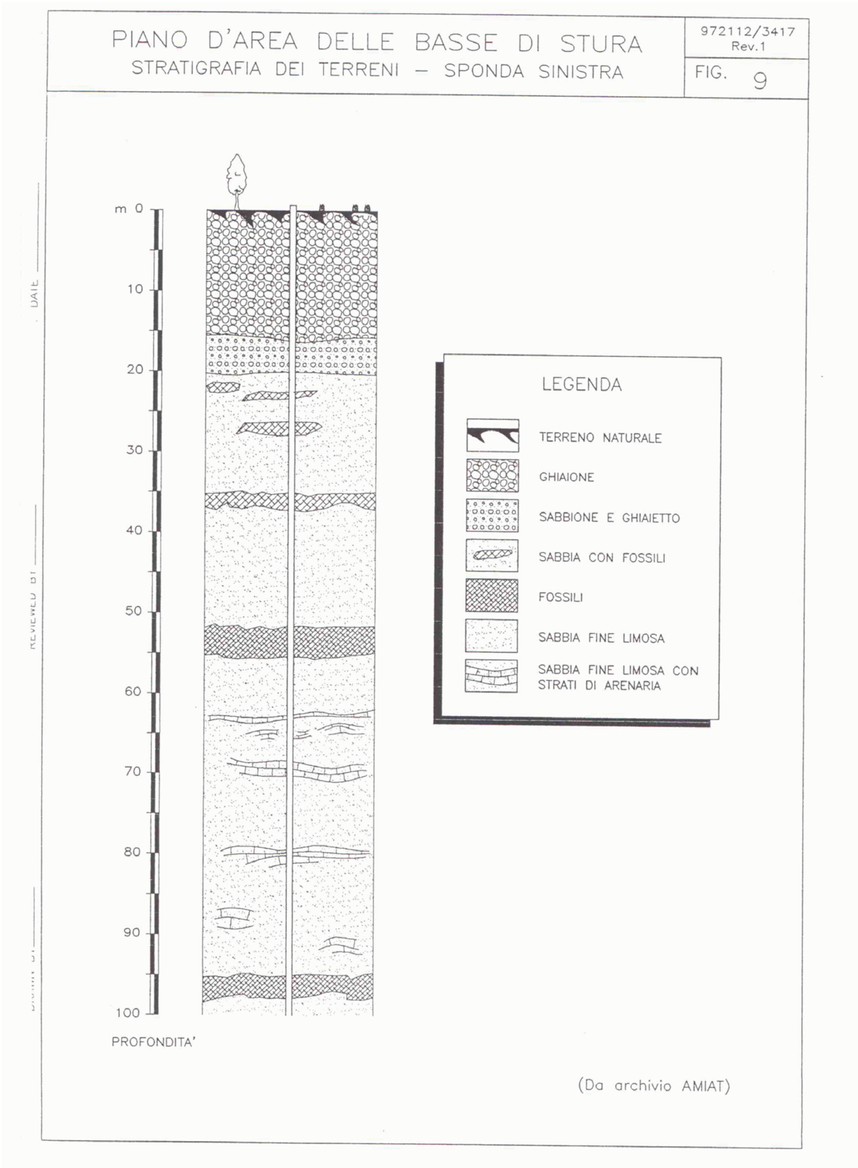


Figure 24 Subsurface Stratigraphy of Basse di Stura – Left Bank Section
Source: (Regione Piemonte et al., 1999).

3.4 Opportunities and Challenges for Urban Renewal and Renewable Energy Communities

After a systematic analysis of the area's current conditions, land structure, and renewable energy potential, it is clear that Basse di Stura faces numerous challenges in its future development, but also holds significant opportunities. Due to the large amount of undeveloped or abandoned open spaces in Basse di Stura, there is a high degree of flexibility and freedom in both reallocating its functions and installing renewable energy facilities. More importantly, the area possesses excellent solar energy resources, making it an ideal location for the development of photovoltaic energy systems. Thanks to its open terrain and unobstructed environment, Basse di Stura can accommodate large-scale photovoltaic systems, such as solar farms, at a relatively low cost. The orientation and tilt angle of the solar panels can also be flexibly adjusted based on the characteristics of different plots to maximize sunlight exposure and energy generation efficiency. In addition, the artificial lakes and green areas that have already been created within the site provide a good foundation for subsequent ecological integration design, helping to create sustainable urban spaces that balance energy use and ecological restoration.

However, despite the abundant natural resources and the solid foundation for biogas energy provided by the abandoned industrial land and the ecologically restored landfill site in Basse di Stura, the historical background of these areas inevitably brings environmental risks, such as soil and groundwater contamination. These potential contamination issues mean that updating and redeveloping the site, while maintaining the existing ecological restoration achievements, will require higher technical standards and face greater engineering challenges. On the other hand, although the site overall exhibits an open, low-density land use pattern, its land types are mixed, and the spatial distribution is scattered, with different land uses lacking organic integration. Therefore, to establish an efficient REC in this area, it is necessary not only to integrate diverse land resources but also to restructure the spatial layout and establish a systematic infrastructure and functional zoning. It is particularly noteworthy that the area currently lacks a mature public space system, and its connection to the surrounding urban areas is relatively weak. Which means that to transform Basse di Stura into a core area for an efficient energy community, it is essential to integrate it with the overall urban spatial network and design a new public space system. This will not only help achieve spatial connectivity at the urban level but also facilitate the formation of a stable and efficient energy flow and sharing network, thereby enhancing the overall spatial cohesion and sustainability of the community.

Finally, although existing data indicate that the geological strata in this area are relatively stable and have good overall thermal conductivity, some fossil layers and silt layers at a depth of approximately 30–60 metres may have low permeability (as shown in Figure 24). In addition, the distribution of groundwater has not been clearly identified in the current data. Therefore, if a geothermal system is to be installed in this area, further hydrogeological data needs to be collected and studied to more comprehensively assess its feasibility.

In summary, Basse di Stura possesses abundant development potential while also facing challenges such as environmental pollution, spatial fragmentation, and insufficient connectivity with surrounding urban areas. As a result, establishing a mature and efficient renewable energy community in this region requires an urban design approach that integrates the internal land types of the site while considering its relationship with the surrounding urban space.Given the absence of large-scale residential buildings within the site, it is necessary to first define a reasonable scope for the renewable energy community based on the surrounding urban spaces and existing buildings. Subsequently, a new network of public spaces and energy systems should be gradually developed to ultimately achieve a livable, aesthetically pleasing, functionally complete, and energy-self-sufficient REC.

4.Urban Design Strategies for Renewable Energy Communities: *Case Studies and Approaches*

4.1 From Context to Comparison: Choosing the Cases

According to the analysis and evaluation in the previous chapter, it is clear that although Basse di Stura already possesses certain spatial potential and renewable energy resources, the question of how to make good use of and design its urban space and energy infrastructure, and ultimately how to efficiently deploy renewable energy systems to achieve truly sustainable regeneration and development, remains a complex and challenging issue.

In order to explore possible answers to this question, this study selects two representative cases for analysis. By examining their design concepts, strategies, and subsequent development processes, the aim is to extract practical research approaches and applicable design methods, providing a foundation for identifying more context-appropriate design directions for subsequent project phases.

To better identify cases suitable for guiding the development of a REC in Basse di Stura, key project features were first defined: brownfield, solar, geothermal, community, sustainable, renewable energy, urban design, and urban planning. To ensure that the selected cases are both representative and complementary for comparative analysis, two projects were chosen following a process of keyword screening and project evaluation: BedZED (Beddington Zero Energy Development) in the United Kingdom and Masdar City in Abu Dhabi.

BedZED in the UK was conceived in 1997 and completed in 2002. In 2003, it was recognized as a 'model for future mass housing.' Similar to Basse di Stura, the community was developed on a brownfield site. Its goal was to create a vibrant neighborhood free from fossil fuel consumption, powered by two RESs: a combined heat and power (CHP) plant and solar photovoltaic panels(Chance, 2009; Schoon Nicolas, 2016). Since this case was built relatively early and is still in use today, and given its high similarity to Basse di Stura, analysing this case not only provides insights into its design concepts and methods but also offers valuable lessons from its current usage status.

Unlike BedZED and Basse di Stura, Masdar City is an entirely new urban development project which located in the United Arab Emirates, with no similarities to the former in terms of site conditions or geographical context. However, it is the world's first planned carbon-neutral and sustainable eco-city. Its masterplan was formulated in 2006, only a few years after BedZED (completed in 2002), but the project is still under construction today(Zhu et al., 2012).

By analysing the planning and design of Masdar City, we can see how to carry out sustainable design correctly. Since the city mainly uses solar energy as its renewable energy source, similar to Basse di Stura, it is necessary to combine solar energy systems with dense urban areas. Therefore, by analysing this case, we can learn how to plan and deploy renewable energy systems from a more sustainable and advanced perspective, as well as how to deal with the relationship between passive design, urban design, active design and renewable energy systems(Masdar City, 2023b).

Although these two cases differ in several aspects—including geographic location, development stage, technological approach, and spatial strategy—it is precisely these differences that make them complementary and comparable in the analytical process. By sorting out their commonalities and differences, it is not only possible to extract general experiences applicable to the site under study, but also to identify the adaptability and limitations of design strategies in different contexts. Hopefully, through a comprehensive analysis of these two cases, a more comprehensive, reasonable, and forward-looking design approach and methodology can be constructed and applied to subsequent designs.

4.2 Case Study

4.2.1 BedZED in Beddington, UK

Figure 25 Original sitemap
Source: (Schoon Nicolas, 2016).

BedZED[18] was built on a brownfield site in Sutton, South London(Figure 25), which had previously been used by a sewage treatment company before being abandoned and left as an undeveloped plot(Chance, 2009) . The project was designed by architect Bill Dunster and developed by the Peabody Trust. It was conceived in 1997 and completed in 2002. The initial intention was to achieve a fossil fuel-free operational model, significantly reducing carbon emissions from residents' daily lives while providing energy for the community through renewable energy sources. At the same time, the project aimed to create a vibrant, high-quality living environment and foster close social connections among residents through spatial planning and architectural design. The BedZED community consists of 82 residential units, approximately 1,500 square meters of live-work space, and around 1,000 square meters of commercial space. It is the first large-scale, mixed-use sustainable community project in the United Kingdom (BioRegional Development Group, 2002; Chance, 2009; Zhu et al., 2012).

[18] BedZED: 'Bed' for the suburb of Beddington and 'ZED' for zero energy development.

In the past, sustainable planning and design were often oversimplified as building-level energy-saving technologies or low-energy solutions. However, the BedZED design team believed that a truly sustainable community must not only improve energy performance but also prioritize the quality of the community environment and residents' subjective experience. As they pointed out, if planning and design fail to create an attractive and comfortable space where people can live easily and interact with one another freely, it becomes difficult to foster a genuine sense of community with green lifestyles, and the community's energy-saving and emission-reduction goals are unlikely to be achieved(BioRegional Development Group, 2002). Therefore, the project team adopted a systematic and integrated design approach across all aspects of the development—from community environment and building form to renewable energy infrastructure—aiming to achieve environmental sustainability while also creating a high-quality, livable space that promotes a strong sense of belonging(Schoon Nicolas, 2016; Zhu et al., 2012).

From the perspective of the BedZED design team, apart from buildings themselves, cars are the largest source of energy consumption and CO_2 emissions within the community. To address this issue, they proposed a spatial organization strategy that integrates residential, commercial, and community functions (as shown in the Figure 26). According to the team's assessment, if residents adopt sustainable modes of transportation such as public transport, walking, and cycling, it is possible to reduce fossil fuel consumption from cars by approximately 50%. Therefore, they believe that the key to achieving sustainable transportation in the communities lies in reducing dependence on private vehicles from the outset. By constructing a mixed-use urban structure that integrates various functions enables residents to meet their daily living and working needs nearby, thus encouraging them to actively choose alternative modes of transportation instead of cars (BioRegional Development Group, 2002; Zhu et al., 2012).

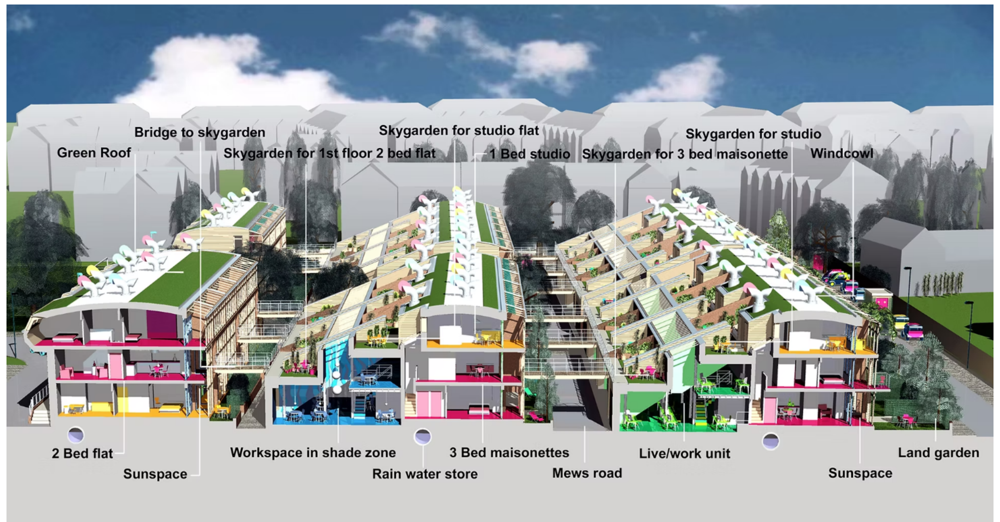


Figure 26 BedZED Sectional Perspective
Source: ZEDfactory, 'BedZED', https://www.zedfactory.com/bedzed.

In the design of the BedZED community, residential, office, and commercial spaces are organically integrated, providing residents with convenient living services and nearby employment opportunities while effectively alleviating commuting pressure and reducing reliance on private vehicle travel. The community adopts a 'family zone' design concept, where vehicle speeds are strictly limited to near-walking levels within this area, giving pedestrians and cyclists absolute priority, thereby creating a people-centric, safe, and pleasant street environment(BioRegional Development Group, 2002). The project aimed to further encourage residents and community staff to reduce their reliance on private cars through this spatial system.

In addition to its functional mix and pedestrian-priority spatial strategy, BedZED has also optimised the community's parking system. The entire community has only about 81 parking spaces, far below the standard configuration for suburban residential developments in the UK. Although this approach seemed quite radical at the time, it was made possible by the excellent public transport accessibility of the area.BedZED is surrounded by three bus routes, and the Hackbridge train station, approximately 600 metres from the community, offers frequent commuter services to Sutton and central London. The nearest tram stop is also just a 15-minute walk away, effectively covering the main areas of south London.This transportation infrastructure provides residents with diverse travel options, ensuring that despite certain restrictions on car use within the community, its connectivity to the outside world and residents' daily commuting needs are adequately met. (BioRegional Development Group, 2002; Chance, 2009).

The BedZED project team found that by reducing the proportion of land allocated to roads and parking spaces, the floor area could be increased by over 100% compared to traditional suburban development models in the same area.The saved land resources were effectively converted into community green spaces and courtyards, significantly improving the quality of the living environment. Of the 82 residential units in the entire community, 71 are equipped with private gardens. This high proportion of green open spaces not only enhances the ecological attributes of the community but also further improves the quality of life and overall liveability for residents (BioRegional Development Group, 2002; Chance, 2009; Schoon Nicolas, 2016).

In terms of architectural design, in addition to the mixed-use development and the provision of private gardens, the BedZED design team also implemented several passive solar design strategies specific to the UK's climatic conditions. These measures aimed to enhance indoor comfort while reducing building energy consumption (as shown in the Figure 27) (BioRegional Development Group, 2002).

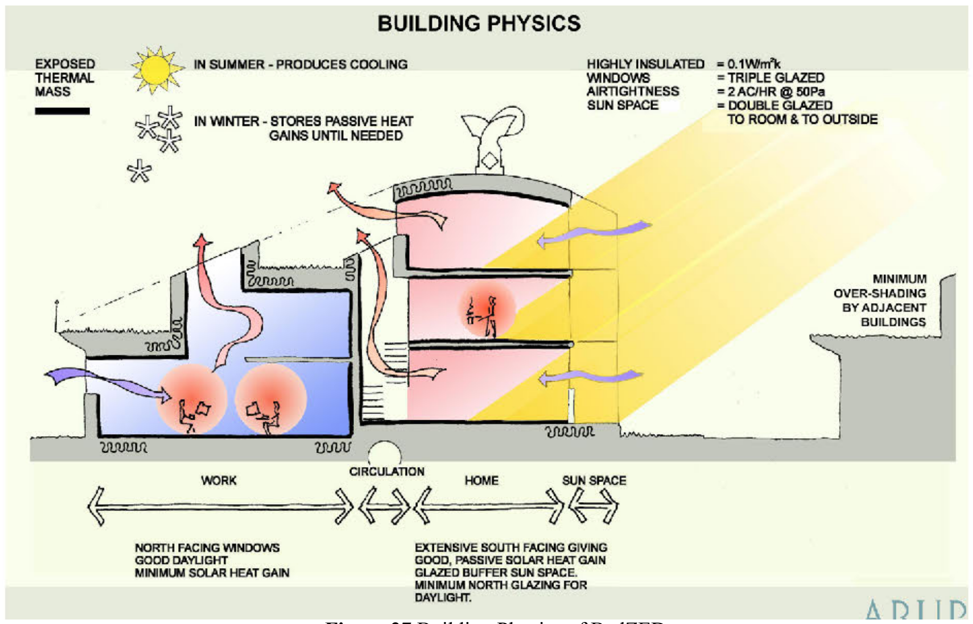


Figure 27 Building Physics of BedZED
Source: (BioRegional Development Group, 2002).

In the BedZED community, most residential units feature a 'sunspace' on the south side of the building, equipped with large glass façades. These sunspaces, approximately 1.2 meters deep, and are distributed along each floor. When there is sufficient sunlight, the sun space is heated. Once the temperature rises to a comfortable level, residents can open the double-glazed doors and windows connecting the sun space to the interior, allowing warm air to flow naturally into the room. This achieves solar gain and reduces the energy demand for heating in winter.

Additionally, the building incorporates a passive ventilation system: in winter, cold air is expelled from the interior through the principle of rising warm air, helping to maintain indoor warmth; in summer, cooler external air is used for natural ventilation and cooling, maintaining a stable indoor thermal comfort level. Through these passive strategies, BedZED aims to maximise the use of natural environmental conditions and minimise energy consumption during building operations (BioRegional Development Group, 2002; Schoon Nicolas, 2016; Webb Steve & Downie Paul, 2023).

Of course, simply reducing transportation and building energy consumption is not enough to make BedZED a truly sustainable community. To achieve comprehensive sustainable development, the community must also rely on RESs to provide a stable energy supply. During the initial construction phase, the design team installed a wood chip-fired CHP unit in a dedicated auxiliary building within the community to simultaneously provide electricity and heating for the community. However, due to the immaturity of the technology at the time and concerns from municipal planners about noise impacts, the unit frequently experienced shutdowns, modifications, and maintenance during its operation. Ultimately, the system was dismantled in 2005 and replaced with three traditional natural gas boilers. It was not until 2017 that the natural gas equipment was replaced with biomass boilers, enabling the community's energy system to return to a renewable energy pathway and continue pursuing its original sustainable development goals(Chance, 2009; Schoon Nicolas, 2016; Webb Steve & Downie Paul, 2023).

Although it experienced setbacks during the implementation of the CHP system, BedZED has maintained stable operation in terms of solar energy utilisation. From the very beginning of the design phase, the photovoltaic system was integrated into the building. By optimising the roof slope, the system not only improved the solar radiation reception efficiency of the rooftop photovoltaic modules but also enhanced the solar gain effect of the 'sunlight space' on the south side of the building. Through this strategy, the photovoltaic system achieves dual benefits at the building level: on the one hand, it provides clean energy for residential use, and on the other hand, it feeds excess electricity back into the local grid on sunny days, enabling local energy sharing and circulation(BioRegional Development Group, 2002; Chance, 2009; ZEDfactory, n.d.; Zhu et al., 2012).

It is worth noting that BedZED was equipped with electric vehicle charging infrastructure a decade before plug-in electric vehicles became widespread in the UK, demonstrating strong forward thinking. Fifteen years after the system was installed, the photovoltaic system still maintains a zero-carbon power generation capacity of approximately 30,000 kWh per year, proving its long-term sustainability in terms of performance stability and environmental benefits(BioRegional Development Group, 2002; Chance, 2009; Schoon Nicolas, 2016).

Despite numerous adjustments and setbacks during its construction and operation, according to statistics published by BioRegional in 2012, compared to surrounding conventional communities, BedZED has reduced its heating energy use by 81%, electricity consumption by 45%, and residents' annual car travel distances were 64% lower than the UK average(BioRegional, 2012; Zhu et al., 2012). Although the emergence of certain issues was closely related to the technical conditions and stage of development at the time, the overall effect of the project was undoubtedly significant and serves as a typical case study that continues to provide valuable reference for the design and implementation of sustainable communities around the world.

4.2.2 Masdar City in Abu Dhabi

Figure 28 Regional Context of Masdar City in Abu Dhabi
Source: (Masdar City, 2024).

Masdar City is located in the desert heartland of the Emirate of Abu Dhabi in the United Arab Emirates, situated between the city centre of Abu Dhabi and Abu Dhabi International Airport (as shown in Figure 28). It is the world's first sustainable eco-city to be planned and built as a comprehensive development. In 2006, the Abu Dhabi government officially announced the launch of the Masdar City project, aiming to propose innovative solutions to global climate change and to create an international model for 'the world's most sustainable eco-city.'(Zhu et al., 2012; Ziqi & Beiqi, 2024).

The city covers a total area of approximately 1,460 acres and was master-planned by Foster + Partners. The city is composed of two square-shaped zones connected by a linear park, forming a clear and coherent spatial structure (as shown in the Figure 29). According to the proposal, the city is expected to accommodate more than 50,000 residents, 1,500 businesses and approximately 60,000 employees once completed, with the aim of forming a sustainable urban complex that combines residential, office, scientific research and industrial functions(BBC News, 2008; Zhu et al., 2012).

The overall construction of Masdar City is divided into several phases, with work officially commencing in 2008 and completion originally scheduled for 2020. However, due to external factors such as the global financial crisis, the project has experienced repeated delays, and the overall completion date has been postponed several times. To present, the city remains under continuous construction, with completion expected around 2030 (BBC News, 2008; Ziqi & Beiqi, 2024). Notably, Masdar's masterplan is designed with a high degree of flexibility, allowing emerging technologies to be integrated at various stages of construction and enabling timely responses and adjustments to issues identified in already developed areas. This flexibility and freedom not only enhance the adaptability of urban systems, but also provide strong support for their long-term sustainable operation(Masdar City, 2023a; Ziqi & Beiqi, 2024).

Masdar City is planned as a compact, emerging metropolis with high building density, but overall, the city will be dominated by low-rise buildings. Situated in the desert region of the United Arab Emirates, the city faces extreme summer temperatures that can reach up to 50°C, posing serious challenges to sustainable urban development. But as a new city starting from scratch, Masdar still has a high degree of freedom in its planning and design phase. Therefore, at the beginning of the design, the project team made climate adaptability one of the core considerations, striving to minimise heat absorption by the building surface through spatial layout and form control. At the same time, they utilised the prevailing wind direction to guide cool air to flow effectively through the city and naturally into residential areas, thereby alleviating the impact of extreme heat on the urban living environment(Hassan et al., 2016; Masdar City, 2023b; Zhu et al., 2012).Masdar City adopts an integrated grid

Figure 29 Master Plan of Masdar City
Source: (Foster + Partners, 2014).

street layout with its main axis running southeast-northwest (as shown in Figure 30). This layout helps reduce the exposure time of streets and building façades to direct solar radiation, thereby lowering the overall heat load in the urban environment. However, for residents who live in the extreme heat of Masdar, this strategy is still insufficient to significantly improve thermal comfort(Haobo et al., 2022; Hassan et al., 2016; Zhu et al., 2012).

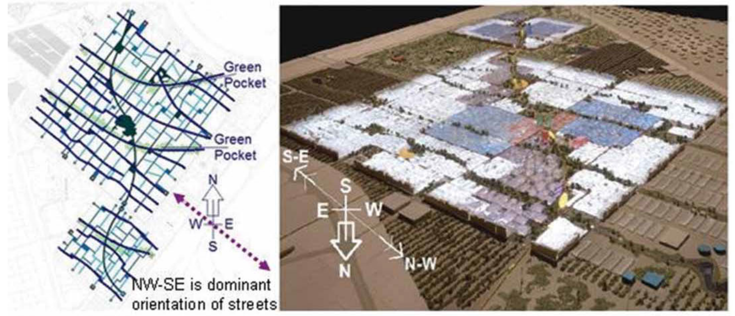


Figure 30 Street Network Analysis of Masdar City
Source: (Hassan et al., 2016).

To further enhance the shade effect at the street level, the project design team proposed a creative architectural interface design solution, as illustrated in the Figure 31 below. The ground floors of buildings on both sides of the street are cantilevered outward to create sheltered walkways, while the undulating building façades and the overhanging photovoltaic panels together form a multi-layered shading system. This strategy effectively increases the amount of shade on the street without affecting pedestrian and vehicle traffic. More importantly, the design also takes into account the city's ventilation performance. The changing shape of the building boundaries helps guide natural winds from the north and northwest, creating effective cross-ventilation channels that further improve thermal comfort in the building and street space(Hassan et al., 2016; Masdar City, 2023b; Zhu et al., 2012).

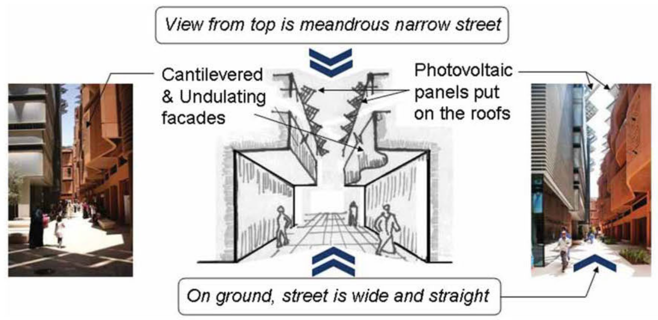


Figure 31 Street Space Analysis of Masdar City
Source: (Hassan et al., 2016).

When designing the architecture for the entire city, in addition to considering building orientations that harmonise with the road network structure and cantilevered designs that enhance shade, Masdar's planning team also conducted in-depth research into local Arab traditional architecture. They found that the courtyard typology—commonly used in both residential and public spaces in the Arab world—offers significant advantages in regulating outdoor thermal environments. By setting up transition spaces of different scales and characteristics, this courtyard system can guide air pressure changes, encouraging breezes to flow from high-density areas to low-density areas, thereby enhancing natural ventilation within the city(Haobo et al., 2022; Hassan et al., 2016).

Given the limited wind energy potential in the region where Masdar is located, the design team extended the courtyard logic by integrating it into building clusters and reinterpreted the traditional Arab architectural elements such as 'wind catchers', from a modern context. The team creatively installed several large-scale wind towers (as shown in the Figure 32 and Figure 33) in urban public squares of the city and combined them with courtyard and landscape designs. It can not only improves the microclimate of the city, but also provides residents with pleasant outdoor public spaces, creating conditions for outdoor social activities for local residents (Hassan et al., 2016; Masdar City, 2023b).

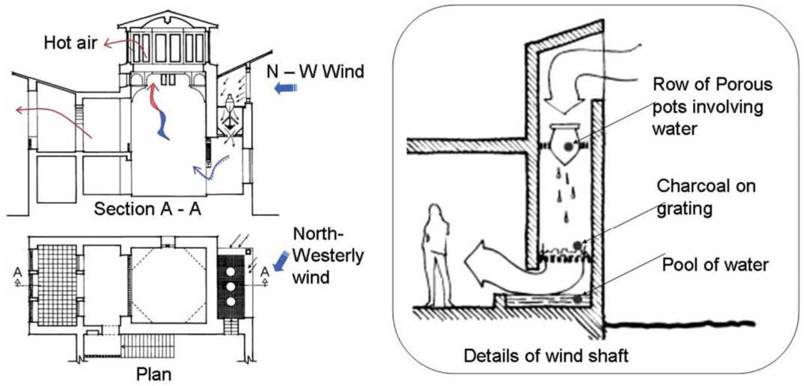


Figure 32 Sectional Diagram of a Traditional Windcatcher and Its Passive Cooling System[19]
Source: (Hassan et al., 2016).

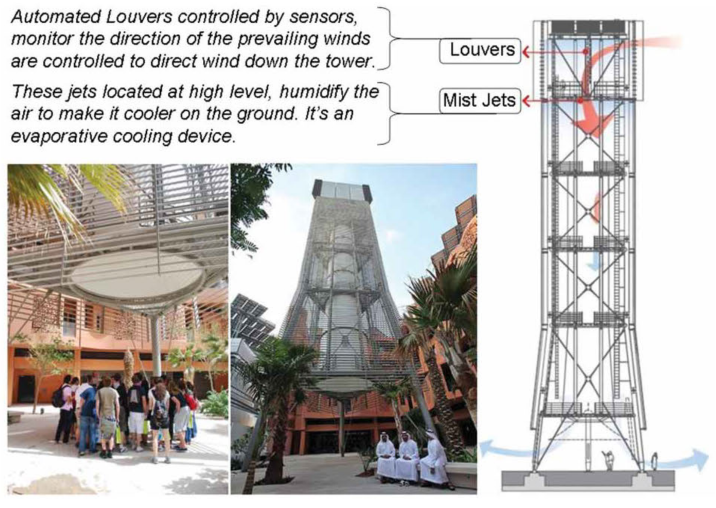


Figure 33 Contemporary Wind Tower Design in Masdar City[20]
Source: (Hassan et al., 2016).

In terms of overall functional planning, Masdar City shares similarities with the BedZED project—both place a strong emphasis on functional diversity and mixed-use development. Masdar's design team has organically integrated residential, commercial, educational, and entertainment functions within the same area, which forms a highly composite urban spatial structure (as shown in the Figure 34)(Hassan et al., 2016; Zhu et al., 2012).

As a modern, future-oriented sustainable eco-city, Masdar has fully integrated various passive design strategies into every building, such as optimising building orientation at the master planning level, enhancing shading systems, and improving building envelope airtightness, to minimise reliance on external energy sources. At the same time, the design team has further introduced a number of active design measures, including efficient mechanical and electrical systems, adjustable active shading devices, and intelligent energy management technologies, thereby significantly reducing the city's overall consumption of energy and water resources (Masdar City, 2023b, 2023a). According to Masdar's official *Masdar City White Paper*, the implementation

[19] A traditional windcatcher is based on a simple technique. Porous pots of water convert dry air into humid air, and charcoal on a grating increases the flow of air into indoor spaces. Here, windcatchers were only used to affect the inside of buildings.

[20] The windcatcher in Masdar City involves complex technology to control the orientation of the wind and the quality of the air. Windcatchers are used in public spaces alongside buildings.

of comprehensive passive design strategies has reduced approximately 43% in operational energy demand compared to global sustainable development baseline standards(Masdar City, 2023b). The United Arab Emirates boasts abundant solar energy resources, with an average of 360 sunny days per year. To further advance the sustainable development goals of Masdar City and meet its remaining energy needs, the design team integrated photovoltaic systems into the urban planning at an early stage, strategically deploying renewable energy systems to ensure low-carbon and stable energy supply(Hassan et al., 2016; Masdar City, 2023b; Ziqi & Beiqi, 2024).

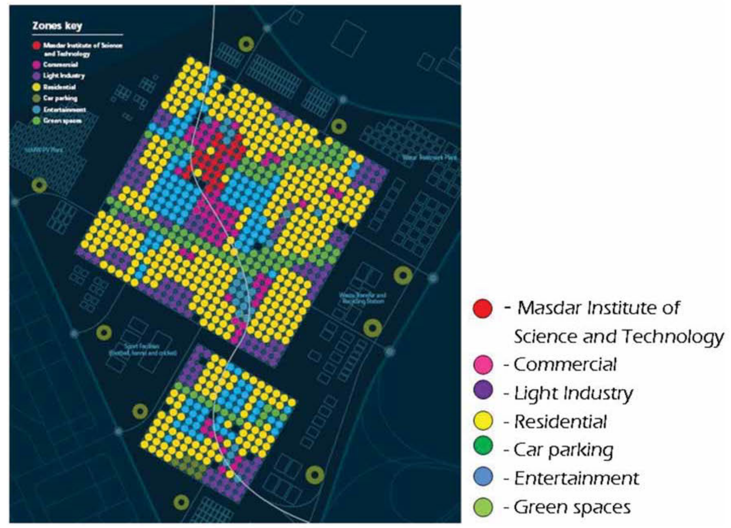


Figure 34 Functional Zoning and Mixed-Use Structure of Masdar City
Source: (Hassan et al., 2016).

Firstly, at the architectural level, Masdar City flexibly integrates photovoltaic systems into its building design. Unlike traditional rooftop installation methods, in order to maximise the use of the region's abundant solar energy resources, the design team optimised the PV panels not only as energy facilities but also as part of the building structure.The panels are smartly embedded into the building facades and roof structures, and by adjusting their installation angles and positions, they are able to enhance power generation efficiency while also providing effective shade for urban streets and public spaces (as shown in the Figure 35). Thanks to this highly integrated design strategy, the building's integrated photovoltaic system can generate 104% of its own electricity demand each year, and the excess electricity will be fed back into the local grid, enabling the building to achieve its energy positive output target at the building level(Masdar City, 2023b; Zhu et al., 2012).

Figure 35 Solar Panel Arrays Mounted Above Building Roofs in Masdar City
Source: (Masdar City, n.d.).

In addition to building-integrated photovoltaic systems, Masdar's design team also systematically planned and designed parking lots in the city. They integrated photovoltaic panels with the carport structure (as shown in the Figure 36), enabling it to provide shade and cooling for parked vehicles while simultaneously generating clean energy to support the city's power system or charge electric vehicles. This dual-function design strategy not only improves the efficiency of urban space utilisation but also further expands the application possibilities of renewable energy in various urban scenarios(Masdar City, 2023b; Zhu et al., 2012).

Figure 36 A carport integrated with photovoltaic panels in Masdar City's car park
Source: ((Masdar City, 2023b).

As mentioned before, Masdar City is positioned as a high-density, compact emerging metropolis. Although all new buildings are designed with greater flexibility and PV systems are widely integrated into building structures, not all building types or orientations are equally suitable for efficient PV application. To ensure a stable urban energy supply while minimizing disruption to the high-density urban environment, the design team planned from the outset to construct a large-scale centralized solar power plant with a capacity of 10 megawatts. According to data from the *Masdar City White Paper – From Vision to Reality: Masdar City's Journey to Net-Zero*, the total PV systems—including those installed on rooftops, parking lot canopies, and the centralized solar farm—generate approximately 13 million kilowatt-hours of clean electricity annually, accounting for about 37% of Masdar City's total energy demand(Masdar City, 2023b; Ziqi & Beiqi, 2024).

Although Masdar City is still under construction, as a newly established city rising from scratch in an arid desert environment, it offers valuable lessons and inspiration for rapid urbanisation through its forward-thinking planning concepts and integrated design strategies. By systematically integrating passive design, active systems, and renewable energy technologies, Masdar presents a referential model for shaping efficient, liveable, and low-carbon cities of the future.

In studying this project, we can regard Masdar as an experimental ground for exploring sustainable urban development approaches and technologies. Only by deeply understanding their design concepts and practical methods, and then internalising and recreating these strategies in the context of our own country and local conditions, can we truly develop more scientific, reasonable, and forward-looking sustainable design solutions for ourselves.

4.3 Comparative Analysis and Key Insights

Through the analysis of two typical cases, BedZED and Masdar City, it can be seen that although they have significant differences in project background, geographical environment, and development scale, as important representatives of contemporary sustainable urban practices, both aim to create resource-saving and environmentally friendly living environments, demonstrating different levels and paths of exploration. In order to more comprehensively understand their design logic and practical strategies, this section will focus on the following five points:

1. Project background and development conditions
2. Functional organization and spatial layout
3. Strategies for integrating RESs
4. Community behaviour guidance and mobility patterns
5. Actual operational performance

In terms of project background and development conditions, BedZED was built on a brownfield site in Sutton, south of London, while Masdar City was developed on a completely new piece of land on the outskirts of Abu Dhabi, with the ambition of creating an entirely new ecological metropolis(Zhu et al., 2012). As such, these two projects differ significantly in development scale, site conditions, and climatic context. BedZED is a relatively small-scale project surrounded by well-established public transportation and residential areas. Although these existing infrastructures provide convenience for residents, they also impose certain constraints on planning and design. At the same time, as a project located in the UK, BedZED needs to pay more attention to heat preservation and sunlight utilisation in its architectural design, with an emphasis on building insulation and passive daylighting.In contrast, Masdar City, as a completely new development project starting from scratch, offers greater spatial and design flexibility. Its transportation system, building layout, and energy systems can all be freely coordinated and planned within an overall framework. as Masdar City is located in a hot and arid desert environment, the project, while benefiting from an abundance of sunlight, must also place a high priority on design strategies such as insulation, sun protection, and reducing direct solar radiation(BioRegional Development Group, 2002; Masdar City, 2023b; Zhu et al., 2012).

Although the two projects were launched in a relatively short timeframe—BedZED was completed in 2002, while Masdar City broke ground in 2006—there are significant differences in their implementation progress and sustainability. BedZED is one of the earlier sustainable community experiments. Although its design concept was forward-thinking, it was limited by the technological conditions at the time, and some of the design plans revealed discrepancies between actual application and expected goals during long-term operation. This will be discussed in more detail in the 'Project Performance' section below(Webb Steve & Downie Paul, 2023).In comparison, the Masdar City project is large in scale and has a long construction cycle. This characteristic requires the project team to remain open to new technologies and methods while also being capable of making adjustments and optimisations at different stages, so as to continuously respond to issues that arise during construction and make improvements(Ziqi & Beiqi, 2024).

In terms of functional organization and spatial layout, despite their significant differences in background conditions and development scale, both BedZED and Masdar City tend to a compact urban form characterized by high density and low-rise buildings. For BedZED, this layout was influenced by both site constraints and the urban character, as well as the community-oriented nature of its setting. Located in the land-constrained southern part of London, the project is surrounded by predominantly low-rise buildings, and maintaining a low skyline helps the project blend harmoniously with its surroundings. Additionally, the compact layout reinforced community bonds and fostered a sense of community belonging through enhanced spatial proximity and interaction(BioRegional Development Group, 2002; Schoon Nicolas, 2016). While Masdar City chose the same architectural form, it was more out of a comprehensive consideration of climate adaptability and cultural responsiveness. The project drew on the low-rise architectural style of traditional Arab cities and effectively addressed the extreme heat and sandstorms of desert regions through high-density layout, optimising street ventilation and shade conditions to improve overall microclimate comfort(Hassan et al., 2016).

At the functional organisation level, neither project adopts traditional single-function zoning, but instead promotes mixed-use development, organically integrating multiple urban functions such as residential, office and commercial. This layout not only aligns with the project's intention to encourage walking and green travel, but also enhances convenience while boosting community employment and daily vitality(BioRegional Development Group, 2002; Hassan et al., 2016; Zhu et al., 2012).

Similarly, perhaps because of the alignment of their development goals—namely, to create resource-efficient, sustainable, and people-friendly living environments—both projects advocated walking and cycling, restricted car use, and emphasised the creation of public spaces to encourage active social engagement among residents from the outset. Although their specific strategies differ, BedZED and Masdar City both demonstrate a strong commitment to low-carbon transportation and community interaction(BioRegional Development Group, 2002; Zhu et al., 2012).

Although the specific strategies differ, both BedZED and Masdar City demonstrate a strong commitment to promoting low-carbon transportation and enhancing community interaction. BedZED establishes 'Home Zones' to restrict vehicle speed, improving safety for walking and cycling. It also provides safe and convenient cycling infrastructure, reduces the number of parking lots, and introduces car-sharing services to further discourage private car use. In addition, the project includes public spaces such as community squares and sports fields to encourage neighborhood interaction and community activities(BioRegional Development Group, 2002; Chance, 2009).

In contrast, Masdar City has implemented a systematic traffic management strategy on a larger scale. The project features a car-free zone in the city centre, with narrow, winding streets designed to reduce vehicle speeds, while a convenient public transport system enhances connectivity between different functional zones(Hassan et al., 2016; Zhu et al., 2012). In terms of urban spatial organisation, the project incorporates multiple courtyards and public open spaces of varying scales. These not only optimise microclimates and enhance ventilation but also provide residents with comfortable outdoor activity spaces, further fostering social interaction at the community level.(Hassan et al., 2016).Overall, although their differing approaches, both projects prioritize pedestrian-friendly environments and high-quality public spaces, reflecting a shared vision of integrating low-carbon lifestyles into spatial design.

Regarding the selection of renewable energy sources and system construction, both projects use solar energy as their primary energy source, which reflects the maturity of solar energy technology and its accessibility. As the world's most widely used renewable energy source, solar energy is still considered the first choice even in BedZED, where solar radiation is relatively limited.

In addition to solar energy, BedZED initially planned to build a wood chip-fired CHP system to provide both heat and electricity for the community. However, due to technical limitations at the time and local authorities' concerns about the system's noise impact on the community, the CHP plant was replaced by three natural gas boilers in 2005. Eventually, in 2017, the system was upgraded to a cleaner biomass boiler, which reintergrating renewable energy into the community's energy system(BioRegional Development Group, 2002; Webb Steve & Downie Paul, 2023). And in Masdar City, where solar energy resources are extremely abundant, the solar energy naturally became the dominant form of energy. Photovoltaic panels are widely installed on building rooftops and facades, and the project also includes the development of centralized solar power plants and solar-shaded parking structures to maximize energy output and meet the city's operational demands. Due to limited local wind energy resources, which are insufficient for efficient clean energy production, the design team did not consider wind energy as a primary source of electricity. Instead, wind was utilized mainly for improving the urban microclimate, such as through the incorporation of wind towers, to reduce the heat load on buildings(Hassan et al., 2016; Masdar City, 2023b).

According to statistics provided by BioRegional in *The BedZED Story: The UK's First Large-Scale, Mixed-Use Eco-Village*, the BedZED community has shown significant energy savings and lifestyle changes in its early stages of operation: Compared to neighbouring traditional communities, BedZED has reduced its heating energy consumption by 81%, electricity consumption by 45%, and residents' annual average car mileage by 64% compared to the UK average. These figures objectively demonstrate that the community has achieved positive results in energy conservation, emissions reduction, and green transportation. This was further confirmed by interviews with residents in the report—most households believed that BedZED had successfully promoted the practice of green lifestyles, bringing them a very pleasant living experience(BioRegional, 2012; Schoon Nicolas, 2016). However, the 2023 report, Revisit BedZED, presents a different picture. After two decades of actual use, BedZED's performance has gradually deviated from the original vision. In terms of RESs, the community has undergone several transitions—from a CHP system to gas boilers, and finally to biomass boilers. Although biomass was once viewed as a clean and viable energy source, growing global concerns about air pollution have increasingly called into question its sustainability. The community later explored geothermal heat pumps as an alternative to biomass heating, but the implementation was constrained by local geographic conditions and limitations in technological maturity(Schoon Nicolas, 2016; Webb Steve & Downie Paul, 2023).

On the architectural level, the south-facing sun room and the wind tower on the roof were originally considered the core highlights of the passive design and formed an important part of the sustainable living vision initially envisioned. However, a series of problems arose during actual use. A 2006 study revealed that, in order to reduce costs, the developer eliminated the planned high-level ventilation openings. As a result, while the sunspaces could provide solar heat during winter, upper-floor units suffered from severe overheating in summer. Meanwhile, although the wind cowls facilitated natural ventilation in the summer, they introduced large amounts of cold air during winter. Although residents could manually close the vents, doing so often left the interiors with no ventilation at all. To address the thermal comfort imbalances caused by the passive system, the design team invested considerable effort to address the overheating problem. However, they neglected to consider heating requirements under low-temperature conditions during the initial design phase, resulting in some residents having to install gas heating systems on their own(Webb Steve & Downie Paul, 2023).

Furthermore, at the overall community planning level, although BedZED promoted mixed-use development and reduced parking provisions, it intended to create a closed-loop system of 'live–work–commute' within the community, while also encouraging walking and low-carbon travel, the reality is far more complex than expected. Residents' places of employment and daily life needs cannot be fully aligned with the original design assumptions, commercial spaces were gradually converted into purely residential units, and the shortage of parking frequently led to neighborhood disputes. Clearly, whether in terms of energy systems, architectural technologies, or community operation logic, BedZED's utopian vision has not been fully realized(BioRegional Development Group, 2002; Chance, 2009; Schoon Nicolas, 2016; Webb Steve & Downie Paul, 2023). Nevertheless, we cannot deny that BedZED holds pioneering significance in the development of sustainable cities and communities. As the UK's first large-scale ecological community experiment, it has provided valuable experience for subsequent urban regeneration projects and prompted designers and developers to critically reflect on the gap between idealism and reality. As Gregory noted in The Architectural Review: 'go to BedZED, then wake up and help us all live the dream'(Webb Steve & Downie Paul, 2023).

Compared to BedZED, Masdar City which is still under construction, has continuously incorporated the most advanced technologies and methods at each stage of its development. Thanks to its inherent flexibility, the project, as repeatedly mentioned above, has been able to actively respond to various issues encountered during construction and make ongoing improvements. As a result, its overall performance and operational effectiveness appear to be quite outstanding. According to Masdar City's own 2023 ESG report, as of that year, the city had reduced its energy use intensity by 36% compared to the ASHRAE baseline[21] , and reduced its water consumption by 18% compared to the Estidama PBRS baseline[22] . Furthermore, 27% of the city's energy demand was met by renewable sources. The city continues to make progress toward its long-term sustainability goals for 2050(Masdar City, 2023a).

To more clearly illustrate the similarities and differences between the two cases across key design dimensions, the comparative results are summarized in Table 1.

[21] The ASHRAE baseline refers to the reference building model defined in ASHRAE Standard 90.1 (2007), Appendix G, which specifies minimum energy performance requirements. The actual baseline value varies depending on building type, size, and climate zone, and is determined through energy simulation.

[22] The Estidama Pearl Building Rating System (PBRS) baseline is Abu Dhabi's green building reference standard, setting minimum requirements for energy, water, waste, and materials, against which building designs are evaluated for Pearl certification.

Table 1 Comparative Analysis of Urban Design Strategies and Sustainability Performance: BedZED and Masdar City

Design Dimensions	BedZED	Masdar City
Location	Beddington, UK	Abu Dhabi
Site context	Brownfield redevelopment	Greenfield new development
Construction timeline	Concept initiated in1997,completed in 2002	Launched in 2006, the project remains under construction and expected to be completed by 2030
Project scale	1.7 hectares	591 hectares
Functional organization	Mix-used development	Mix-used development
Types of renewable energy used	Solar PV,biomass heating, combined heat and power(CHP)	Solar PV, passive wind cooling system
Passive design strategy	South-facing sunspace, souble glazing windows/doors,passive ventilation inside the house	Shaded street grid,natural ventilation,high-performance building envelopes,reflective feades,integrated shading,minimized east-west glazing
Active design strategy	\	High-efficiency MEP systems,condesate water recovery,active shading devices,advanced building management systems
Behavioal guidance	Walking-friendly design,restricted parking,limited car use,promotes sustainable lifestyles	Encourages walking and cycling,car-free city center,promotes outdoor social interaction and community participation
Actual performance	Achieved an 81% reduction in space heating demand and a 45% drop in electricity use compared to nearby conventional communities	Compared to baseline standars,achived 30.6% reduction in energy use intensity(ASHRAE),18.3% water savings(Estidama PBRS); 27% of energy from renewables; 57% waste reduction through recycling

4.4 Design Principles Derived from the Cases

Through a horizontal comparison of multiple design dimensions, it can be seen that although BedZED and Masdar City have completely different urban contexts and development paths, both are actively exploring the future vision of sustainable urban development in their own ways. This section aims to identify design concepts within the differences and commonalities of the two cases that can be extracted, translated, and further expanded. The goal is to provide foundational strategic references and design insights for building RECs in different urban environments and spatial scales.

In the previous section, when analysing the design strategies and techniques of the two projects, it can be seen that both BedZED and Masdar City opted for a low-rise, high-density development model. This strategy is closely related to the traditional architectural forms of each region and also reflects a response to energy conservation needs. However, this apparent consistency is not sufficient to demonstrate that low-rise buildings have a natural advantage over high-rise buildings in terms of energy conservation, nor does it prove that high-density urban spaces play a decisive role in energy conservation and emission reduction. Therefore, when planning RECs or similar sustainable urban regeneration projects, the choice of development model must be based on a comprehensive evaluation of functional requirements, surrounding environmental context, and specific usage scenarios.

Furthermore, another commonality between the two projects is their emphasis on prioritising walking, restricting motor vehicle use, and promoting community interaction and mixed-use urban development. These goals are all aimed at creating a more friendly, beautiful, and sustainable future cityscape. It is worth noting that although the concepts are similar, the two projects have adopted different strategies to achieve them. BedZED did not propose an overarching redesign of the street network; instead, it aimed to limit car usage indirectly through measures such as designating 'home zones' and reducing the number of parking spaces. In terms of functional integration, its approach leaned more toward an idealized utopian model—envisioning a self-contained community where residents could meet both work and daily life needs within the neighborhood, thereby minimizing travel and energy consumption. However, in practice, there is still a certain gap between this concept and the complexity of real life(BioRegional Development Group, 2002; Webb Steve & Downie Paul, 2023; Zhu et al., 2012).

In the context of shaping new urban spaces, adopting a mixed-use development model is by no means inappropriate. Since Jane Jacobs famously proposed in *The Death and Life of Great American Cities* that 'diversity is the natural condition of cities,' urban design concepts has gradually shifted from the functional zoning advocated by the *Athens Charter* toward integrated and mixed-use approaches. Over the past few decades, mixed-use land has become a central principle of planning theories such as 'compact city' and 'new urbanism.' It is now widely regarded as a vital strategy for improving land use efficiency, enhancing urban vitality, and promoting spatial sustainability(Haobo et al., 2022; Jacobs, 1961; Mumford, 1992).

However, the actual operation of BedZED turned out to be very different from the original plan. The commercial space that was originally designated was converted into residential use after many years, and the number of motor vehicles in the community increased instead of decreasing. Residents even fought over parking spaces on the streets. This discrepancy was largely due to the design team's excessive immersion in their idealised vision of a future utopia, while neglecting the actual conditions of the project. Due to the small size of the community itself, even if commercial and office functions are incorporated into the space, its capacity and service scope will be insufficient to meet the actual living and employment needs of all residents. On this basis, the imposition of rigid and inflexible control measures such as parking restrictions will inevitably lead to disorder and space utilisation tensions in subsequent operations(Webb Steve & Downie Paul, 2023).

It is important for designers to recognize that, no matter how promising the vision may be, any urban design strategy aimed at shaping human behavior should retain a certain degree of adaptability and flexibility in order to respond to future uncertainties and the diverse needs of residents. Design proposals should be advocacy-oriented rather than overly prescriptive, and should be grounded in the actual behaviors and preferences of local residents. For example, encouraging non-motorized travel should come through enhancing pedestrian networks, improving the quality of public spaces, and increasing accessibility, rather than simply reducing car-related infrastructure. Similarly, fostering community engagement should be achieved by creating public places that truly meet the needs and spirit of the community, rather than relying solely on the construction of sports facilities or plazas as evidence of 'providing social spaces.'

In this regard, Masdar City offers a more instructive example. During the planning and design of Masdar City, the design team also made encouraging walking and cycling an important goal and established a motor vehicle-free zone in the city centre. However, although this measure appears similar to BedZED's 'restrict motor vehicles' strategy, there are fundamental differences between the two in terms of implementation and spatial logic(Masdar City, 2023b; Zhu et al., 2012).

Firstly, the Masdar project does not ban motor vehicles from the entire city, instead establishing car-free zones in the core area. This allows for the promotion of green travel while ensuring freedom and diversity of movement throughout the city. Secondly, from the very beginning of the planning stage, the project systematically incorporated walking and cycling into the core of its spatial organisation. By constructing continuous, beautiful and safe pedestrian walkways that are closely connected to public spaces, the project further encourages people to choose non-motorised modes of transport. Based on this, Masdar is also equipped with an efficient and convenient green public transport system, providing residents with diverse and flexible travel options. This comprehensive approach, from conceptual advocacy to spatial guidance and public service facility support, constitutes a more practical and sustainable way to achieve the goal of 'green travel'(Hassan et al., 2016; Masdar City, 2023b; Zhu et al., 2012).

In the organisation of urban functional spaces, Masdar also continues the strategy of mixed development, with the aim of increasing the diversity of urban functions so that citizens can work, study and meet their daily needs within a smaller radius, thereby reducing commuting distances and the frequency of motor vehicle use(Hassan et al., 2016). Compared to BedZED, Masdar has the advantage of a larger urban scale and stronger development capacity, which allows it to attract and accommodate a significant concentration of office and commercial functions—thus providing the necessary functional support for achieving a truly walkable urban lifestyle(Hassan et al., 2016; Masdar City, 2023a).

To sum up, whether it is the renovation and upgrading of renewable energy communities or their development from scratch, it is crucial to adopt a systematic and forward-looking approach during the urban design stage. Designers should not unilaterally project their own wishes onto residents' behaviour. Instead, they should give users sufficient freedom and guide the gradual formation of green lifestyles by optimising spatial structures and improving infrastructure. Only in this way can design concepts be truly transformed into sustainable urban realities.

In terms of planning and design for renewable energy systems, both projects demonstrated a certain degree of preliminary planning awareness. However, the process of multiple replacements of the BedZED community heating system shows that the effectiveness of its renewable energy system was not entirely satisfactory(Chance, 2009; Schoon Nicolas, 2016). This can be partly attributed to the immaturity of renewable energy technologies at the time, as well as the design team's limited understanding of its performance and operational mechanisms.

Initially, the team selected a CHP system, which was installed in an auxiliary building adjacent to the residential area. Thus, even if the equipment itself does not have technical faults, the noise generated during its operation may interfere with residents' daily lives due to improper location and layout. Moreover, subsequent reports did not mention whether the design team conducted adequate research on local renewable energy conditions during the early planning phase, indicating a certain lack of consideration regarding resource adaptability. This oversight may be one of the reasons why, after several adjustments, the community ultimately resorted to installing a biomass boiler in the original CHP location(Chance, 2009; Schoon Nicolas, 2016; Webb Steve & Downie Paul, 2023).

By comparison, Masdar City shows a more systematic and forward-looking strategy in the design of its energy system. In the beginning of the project, the design team has conducted a detailed assessment of the renewable energy resources in the area, especially solar energy resources. They have developed a multi-scale plan, including rooftop photovoltaic systems that are integrated with buildings, photovoltaic carports that are combined with car parks, and a centralised photovoltaic power station that is located on the outskirts of the city (Masdar City, 2023b, 2024). This comprehensive photovoltaic system not only maximises solar energy utilisation efficiency but also allows for future expansion and adjustment by organically integrating with the urban spatial structure(Masdar City, 2023b).

While the potential for wind energy is relatively limited in the Abu Dhabi region, the Masdar design team neither completely ignored it nor invested heavily in wind power equipment. Instead, they incorporate wind energy into the overall passive design system, combining the orientation of streets, building forms, and public space layout to guide natural winds passing through urban spaces, thus optimising microclimates, improving ventilation efficiency, and enhancing the comfort of outdoor spaces. This kind of passive strategy not only enhances the environmental performance of the building and urban space, but it also indirectly promotes the outdoor activities and public interaction among residents by improving the accessibility and livability of outdoor spaces, and thus further supporting the overall walkability of the city(Hassan et al., 2016; Masdar City, 2023b).

By analysing the two projects, it is clear that although Masdar City, a modern city hailed as the 'city of tomorrow,' was developed at around the same time as BedZED, the two cities present very different urban landscapes. In addition to differences in objective conditions such as project positioning and investment, the key factor behind this difference lies in the fact that the Masdar design team reserved sufficient flexibility for future development at the beginning of the planning stage. This forward-looking response to uncertainty has enabled the project to continuously adjust its strategy in the face of challenges during implementation and achieve dynamic optimisation through technical and spatial means. It can be seen that although both projects have undergone continuous revisions and improvements during their construction and use, Masdar seems to be evolving in an orderly trial process, While the adjustment of BedZED is more like a passive response(Webb Steve & Downie Paul, 2023; Ziqi & Beiqi, 2024).

Finally, since this research focuses on exploring the construction of RECs from an urban design perspective, the integration of sustainable urban renewal and renewable energy community design strategies will also focus primarily on the organisation, structure, and operational logic of urban spaces. Through a critical analysis of the BedZED and Masdar City case studies, several key design insights can be summarized as follows:

First, at the conceptual design level, designers should keep an open and flexible mindset and treat sustainability principles as a core concept throughout the entire planning process. In practice, this not only means that adequate resource research and systematic deployment have to be carried out in the early stages of the project, it is also necessary to reserve a certain amount of space and flexibility for the future development of the project so that it can be adjusted in a timely and dynamic manner during operation, thereby achieving long-term adaptability and evolution.

Secondly, in order to create a more pleasant living environment and further encourage walking and cycling to reduce energy consumption, the overall road system should be optimised. Taking into account the characteristics of the site environment and usage requirements, an efficient and user-friendly pedestrian and non-motorised traffic system should be developed to enhance accessibility and mobility on a human scale.

Third, at the level of energy systems, a full assessment and planning of renewable energy resources should be completed at the beginning of the project, and integrate their spatial deployment organically with the urban structure. This should not only pursue maximum technical efficiency, but also avoid negative impacts on residents' lives, achieving a symbiotic state of 'energy as environment.'

Fourth, it is important to focus on the construction of ecological infrastructure and urban public spaces, and optimise the microclimate of cities through passive strategies such as green spaces and shade. If possible, integrate the use of resources such as wind energy into passive strategies for cities. while meeting daily functional needs, improve the outdoor comfort and sense of belonging of residents.

Finally, adopting a mixed-use development strategy. it will not only enhance the functional diversity and convenience of the community, but also stimulate the vitality and resilience of the urban space, and provide social and economic support for the establishment of a sustainable community.

It should be emphasised that sustainable urban regeneration and REC development are not a fixed model; however, it needs to be flexibly adjusted according to the geographical, social, and policy context of each project. Therefore, the above strategies are only a basic reference framework for designers and decision-makers, hoping to promote more accurate and feasible sustainable urban design practices in different project contexts.

To give a clearer picture of the core ideas and key points of the above design strategy, the comparative results are summarized in Table 2 below.

Table 2 Guiding Principles for Renewable Energy Communities

Design Focus	Masdar City
Flexibility and Adaptability in Overall Plann	Flexibility and adaptability should be embedded at the planning stage to allow for systemic adjustments and long-term resilience throughout project development and operation.
Walkable and Bikable Street Networks	Urban mobility systems should be designed to prioritize safe, accessible, and pleasant pedestrian and cycling routes to promote low-carbon transportation modes.
Early Integration of Renewable Energy System	Renewable energy potential should be assessed early and spatially integrated into the urban fabric to maximize efficiency and minimize disruption.
Passive Design and Public Space Optimization	Passive design strategies such as greenery, wind corridors, and shading can enhance microclimatic conditions while improving the usability and attractiveness of public spaces.
Mix-used Development and Spatial Diversity	Mixed-use development increases land-use efficiency, enhances accessibility, and contributes to vibrant, resilient urban environments.

5.Designing a Renewable Energy Community in Basse di Stura: *Conceptual Proposal*

5.1 Rationale for Site Selection and Redefinition

In Chapter 3, this paper systematically analysed the historical evolution, current land use, climatic conditions, and renewable energy and site development potential of the Basse di Stura area. The results of this chapter show that, although there are a few scattered buildings in the Basse di Stura area, they are not sufficient to form a complete and continuous urban community(Pantaloni Giulio Gabriele, 2020; Regione Piemonte et al., 1999).

While in Chapter 2, when defining and characterising RECs, this paper describes them as: 'From an urban design perspective, RECs refer to areas that achieve energy self-sufficiency, low carbon emissions, and possess certain socio-economic benefits and environmental sustainability by integrating renewable energy technologies (such as solar, wind, and geothermal energy) with urban space and the built environment.' Furthermore, in the literature review section, this paper not only explores the conceptual implications of RECs but also further analyzes their relationship with sustainable urban regeneration.

Based on the above research, this study argues that 'RECs represent an effective pathway for achieving the goals of sustainable urban regeneration.' Therefore, the focus of this research is placed on urban edge or neglected areas, aiming to promote not only energy self-sufficiency through the establishment of RECs, but also sustainable regeneration of these peripheral urban zones at both spatial and social levels.

Therefore, to ensure greater methodological rigor and consistency with the preceding research findings, this study redefines the site boundary of the Basse di Stura area prior to the design development. Specifically, based on the original study area shown in Figure 37, the boundary of the site has been extended westward to Corso Piemonte and southward to Corso Grosseto, and part of the surrounding built-up and relatively mature urban space has been included in the overall consideration. This adjustment outlines a preliminary structure for the proposed renewable energy community, as illustrated in Figure 38.

The core logic behind this boundary adjustment is to ensure that the site has a certain functional foundation for the future community design(such as a comprehensive residential or mixed-use area) while avoiding the excessive expansion of the research problem due to the inclusion of too many complex urban elements, so that the integrity and applicability of the design research can be developed within a controllable range. This approach enhances the comprehensiveness and applicability of the design investigation within a manageable framework. As Kevin Lynch noted in *The Image of the City*: 'Such edges may be barriers, more or less penetrable, which close one region off from another; or they may be seams, lines along which two regions are related and joined together' (Lynch Kevin, 1960). In this study, the arterial roads surrounding Basse di Stura can be interpreted both as 'barriers' that delineate regions and

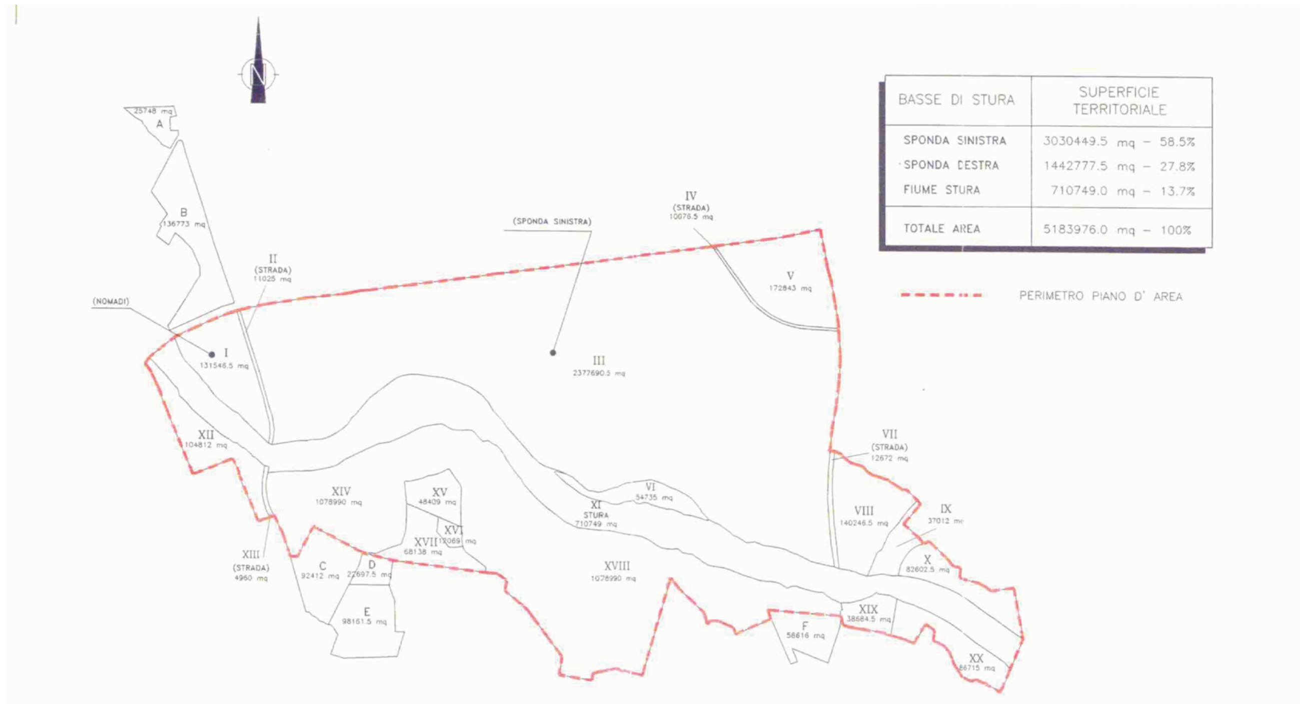


Figure 37 Area Plan of the Basse di Stura – Territorial Surface
(Same as Figure 13, re-shown for comparison with New Site Boundary of the Basse di Stura)
Source: (Regione Piemonte et al., 1999)

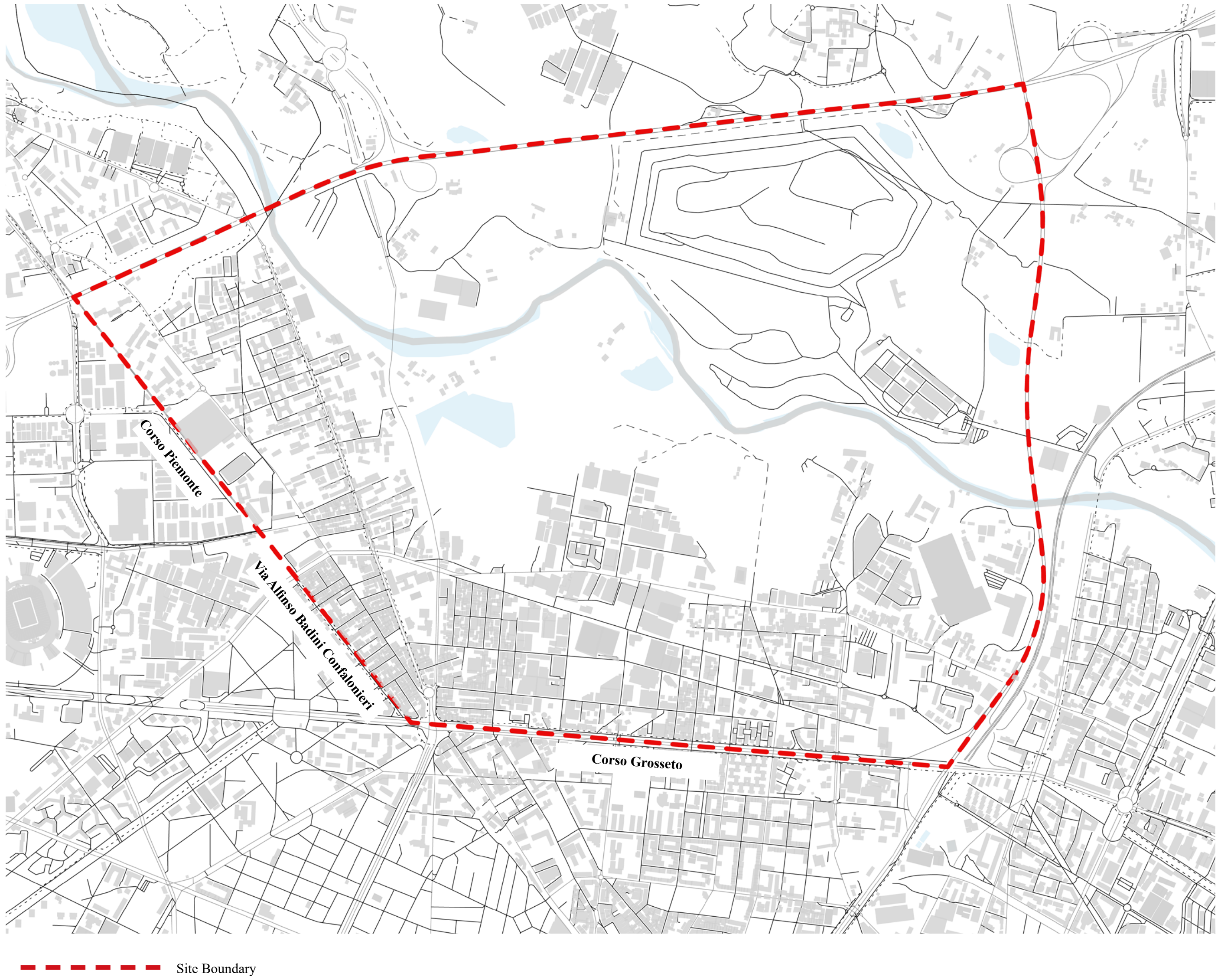


Figure 38 The New Site Boundary of the Basse di Stura Renewable Energy Community
Source: Created by the author.

as ‘seams’ that connect adjacent urban fabrics.

In the process of defining new boundaries, this research makes full use of these four main roads as natural spatial dividing lines to clearly define and delimit the scope of the renewal study for Basse di Stura. It must be emphasised that, although the definition includes some existing residential, industrial and commercial areas, the overall urban space is still fragmented due to the location of the area on the northern edge of Turin, and planning and development are still immature, with a large number of industrial facilities such as waste disposal plants scattered throughout the area(Pantaloni Giulio Gabriele, 2020; Politecnico di Torino – Dipartimento di Architettura e Design, 2025). Therefore, despite the apparent inclusion of built-up urban zones, Basse di Stura fundamentally retains its character as an ‘underutilized urban fringe area.’

5.2 Understanding the Site Context

Upon establishing the revised site boundary, this section conducts an analysis of the current conditions of the newly designated Basse di Stura Renewable Energy Community (hereinafter referred to as BdsREC), in order to better understand the internal characteristics of the site, its relationship with the surrounding urban fabric, identify existing constraints, and explore its development potential.

Jane Jacobs, in her book *The Death and Life of Great American Cities* (1961), emphasized that the essence of a city lies in its diversity, and the key to achieving diversity is the mixing of functions(Jacobs, 1960). Therefore, by analysing the existing functions of buildings within a site, one can not only determine whether the area possesses diverse functional types but also help designers assess the rationality of the existing functional layout, thereby identifying potential issues such as functional deficiencies and misaligned distributions(Dinç & Gul, 2022; Park et al., 2023). Only in this way can more targeted and reasonable reference criteria be provided for subsequent design decisions.

To better understand the existing building types within the BdsREC site, this research conducted a functional analysis of the built environment, as shown in the Figure 39. The analysis shows that the area is mainly composed of residential buildings, followed by commercial and industrial structures. Notably, many of the commercial buildings are large-scale car deales or wholesale businesses, which, although they are classified as commercial buildings, their forms are mainly warehouses or factory-style facilities.

Due to the site’s location on the northern urban fringe of Turin, the industrial buildings are mainly composed of auto repair shops and waste treatment plants. These types of buildings can negatively impact the surrounding residential environment, traffic systems, and overall quality of life. Although some of these structures are concentrated in specific zones, a number are interspersed within residential areas, further amplifying their disruptive effects.

In addition to the above-mentioned functional buildings, there are also some old or abandoned buildings scattered throughout the site. These buildings not only weaken the overall image of the urban space, but also pose potential safety hazards such as structural instability and illegal occupation, posing a threat to the surrounding environment.

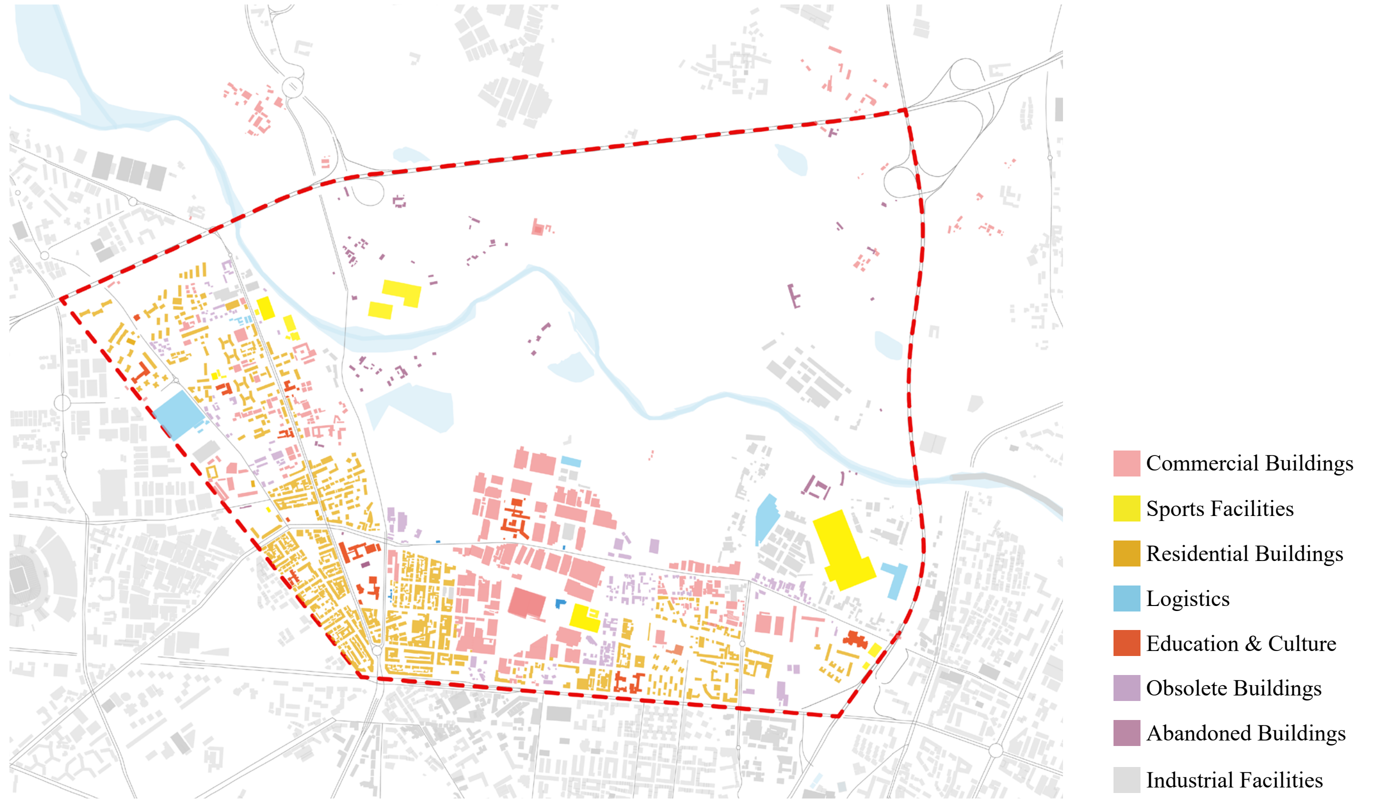


Figure 39 Function Anaysis
Source: Created by the author.

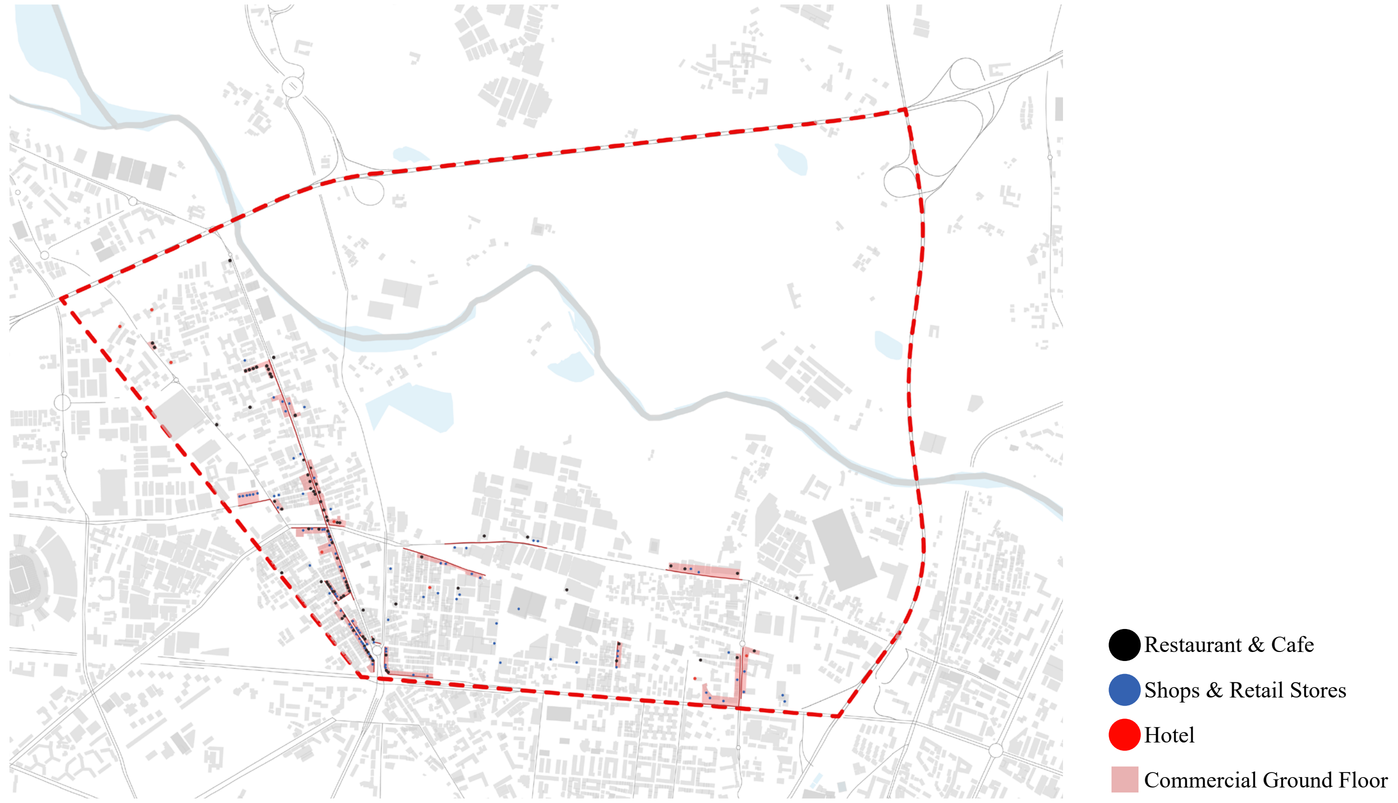


Figure 41 Map of Retail, Hospitality and Street-Level Commerce
Source: Created by the author.

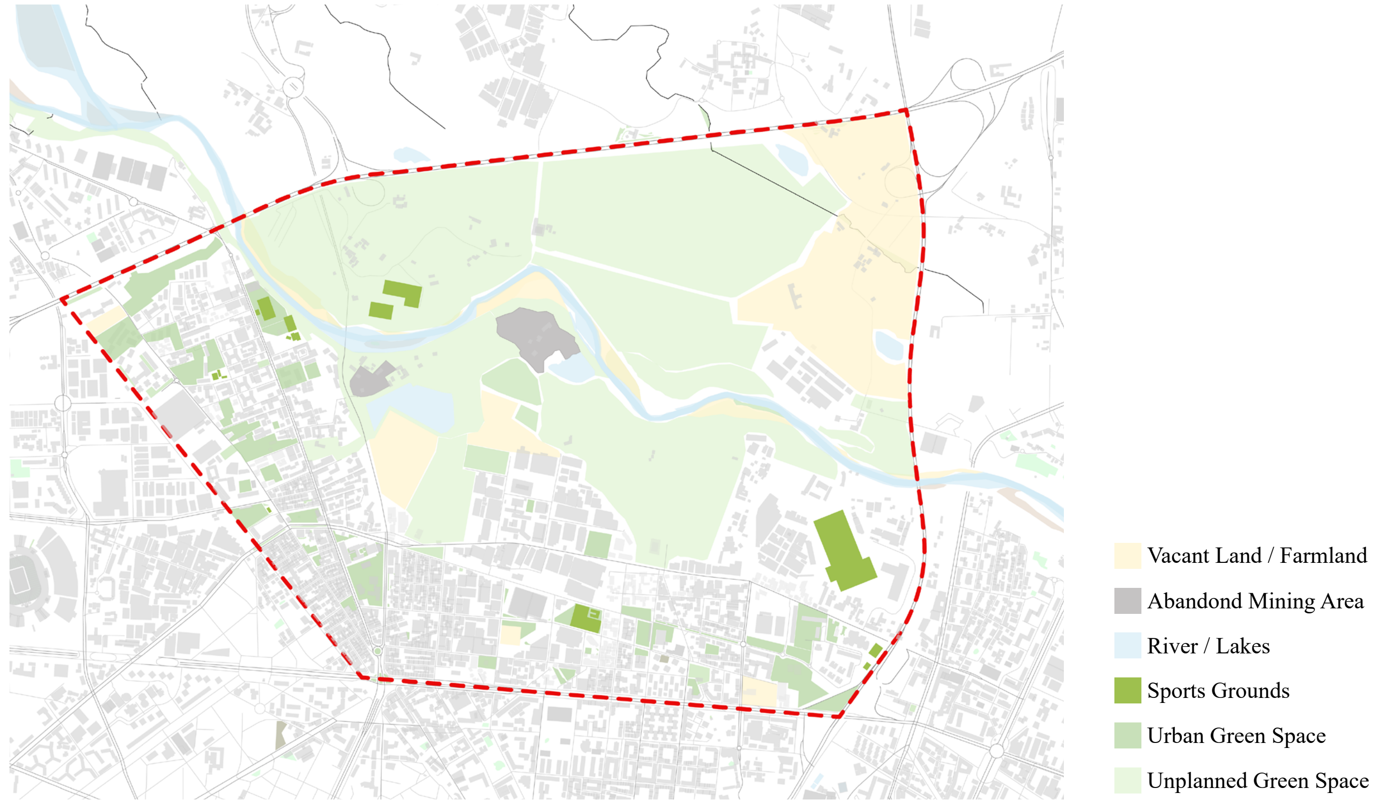


Figure 42 Distribution of Public Space and Green Area
Source: Created by the author.

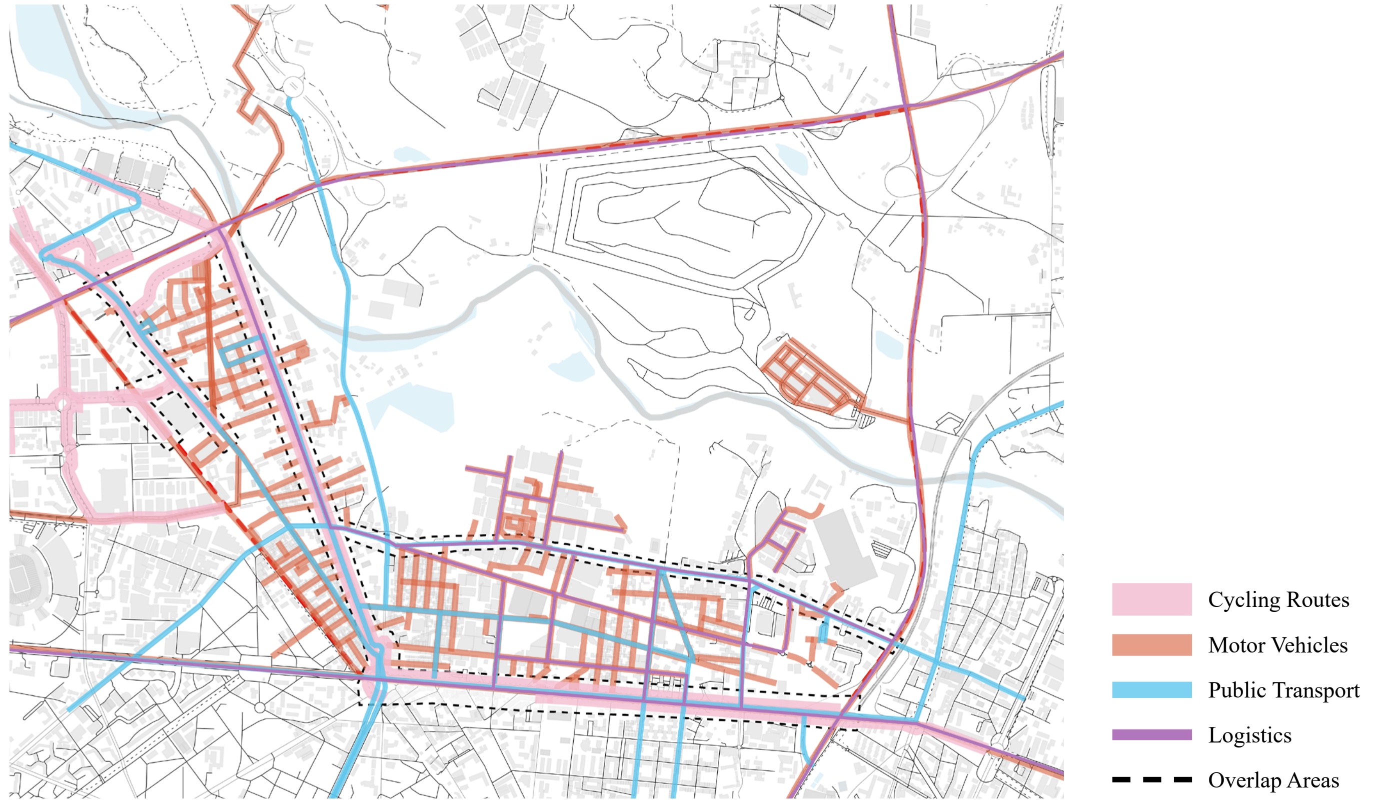


Figure 43 Mobility Network Analysis
Source: Created by the author.

Fortunately, even under the above conditions, there are still a few public buildings for education and culture, as well as sports facilities scattered throughout the community. These spaces can provide not only essential services and convenience for residents but also enrich the activities within the community to a certain extent, enhancing the overall quality of life and the diversity of public life within the area.

In 2010, Carlos Moreno, a professor at the Sorbonne University in Paris, proposed the concept of the '15-minute city.' The idea aims to ensure that urban residents can access six essential functions—living, working, shopping, healthcare, education, and leisure—within a 15-minute walk or bike ride from their homes (as shown in Figure 40) (Moreno et al., 2021). Among these, ground-floor commercial spaces, as the services closest to residents, not only fulfil the function of meeting residents' daily needs but also serve as an important vehicle for realising the '15-minute living circle.' By analyzing the spatial distribution and business types of these commercial units, it is possible not only to assess the convenience of a community but also to further judge the quality of its street space and the social vitality within the community(Graells-Garrido et al., 2021; Horton et al., 2024; Jacobs, 1960).

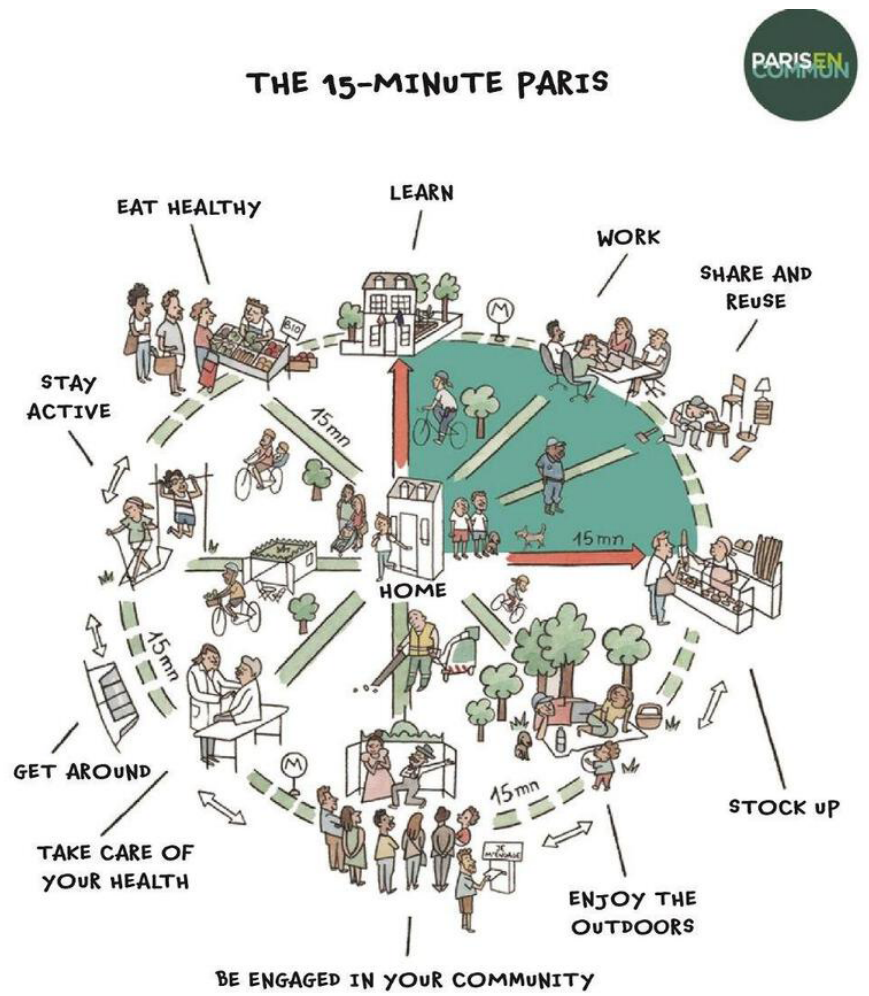


Figure 40 Illustration of the 15-minute Paris
Source: Created by Carlos Moreno

To further explore the convenience and 'activity level' of the community, this study analysed the distribution of street-front commercial locations and business types within the BdsREC. In order to identify the commercial types that have the greatest impact on the area and are most closely related to residents' daily lives, the study selected three key business types for analysis: restaurants/cafés, retail stores, and daily service facilities (such as pharmacies,

barbershops, laundromats, etc.). The study also attempts to identify continuous commercial streets to evaluate the spatial distribution characteristics of commercial activities within the community.

As shown in Figure 41, the western part of the BdsREC features a relatively high concentration of residential buildings with an organized layout, resulting in a greater number of street-level commercial spaces that exhibit clear linear and continuous distribution patterns. In contrast, the southern part of the community, which is dominated by industrial, commercial, and logistics-related buildings, has a much sparser distribution of commercial activities. Even where there are stretches of continuous commercial frontage, they often lack spatial coherence. Overall, the commercial space within the community presents a rather fragmented layout.

Moreover, in terms of quantity, restaurants and cafés account for the largest share among the three selected commercial types, followed by retail shops, while daily service facilities are the most underrepresented. This indicates that even though there is already a certain amount of commercial space available in the area, there is still an uneven distribution of business types. Therefore, subsequent design work should not only reasonably plan the layout of commercial spaces in terms of geographical location, but also fully consider the number and types of different commercial businesses to promote the balanced development of community functions.

Green and open public spaces are critical indicators for evaluating the spatial structure of a community or urban area, as well as the overall quality of life of its residents. As Christopher Alexander pointed out in *A Pattern Language*, people need green open spaces to fulfill their need for rest and connection with nature. At the same time, green spaces also help regulate the urban microclimate. Therefore, analyzing the distribution and area of green spaces not only provides guidance for future landscape design and planning, but also contributes to promoting low-carbon development in the area through well-designed landscape systems(Alexander, 1977).

Public open spaces are important vehicles for promoting social interaction among community residents. For people living in communities, they not only need high-quality public spaces, but also require these spaces to be easily accessible and convenient to use. Therefore, combining a comprehensive analysis of public spaces and green spaces within the community can help designers sort out their spatial structures, identify existing problems, and maximise the effective integration of the two through design, thereby creating efficient, pleasant community public spaces that truly serve residents. Such designs not only provide the community with a beautiful living environment and improve the quality of life for residents, but also inject new vitality and appeal into the community(Aram, Solgi, et al., 2019; Kifayatullah et al., 2025).

As shown in the analysis diagram of public and green spaces in the community (Figure 42), although the area contains a considerable amount of green and public open spaces, these are primarily concentrated in the northern and eastern part of the site, where open land is more available. In contrast, the western and southern parts—where buildings are more densely distributed—contain only a limited number of green or public spaces, scattered irregularly among the built environment. In addition, most of these spaces are green areas that have formed naturally without systematic planning, and some of them are even still used as farmland. Therefore, in subsequent planning and design, it is necessary not only to optimise and integrate existing green spaces and public spaces, but also to systematically add a new batch of public activity spaces that are more in line with the actual needs of residents, in conjunction with new community layouts and architectural planning.

The final part of this section focuses on the analysis of traffic circulation in the site. In urban systems, the road network serves as the structural framework of the city, which can provide the spatial foundation for buildings and urban form(Tian et al., 2019). With the development of technology, automobiles have already become an essential part of urban life, which can offering greater efficiency and convenience in connecting different parts of the city. However, this kind of convenience on private cars has also introduced a range of challenges, particularly in areas where vehicles and pedestrians share the road, such as noise pollution and safety risks, which directly affect residential environments and reduce overall comfort(Babisch, 2006). In addition, the high level of motorisation in cities is often followed by increased energy consumption and carbon emissions, which not only prevents cities from low-carbon transformation, but may also lead to land use dispersion, thus increasing transportation costs and further worsening environmental pollution and carbon emissions (Botteldooren et al., 2011; Kadakath et al., 2025).

In its 2022 report, the World Health Organization pointed out that a major shift toward walking and cycling can effectively address many of the problems caused by current transport models—including air pollution and greenhouse gas emissions (World Health Organization, 2022). This makes walking and cycling (hereafter referred to as active mobility) one of the most effective strategies for addressing urban challenges.

Apart from reducing the burden on the environment, active travel can also significantly enhance the vitality of community streets. This kind of 'vibrancy' can be reflected not only in resident interaction and community activities but also in the economic vitality carried by the street(Litman, 2003). As discussed earlier in the analysis of ground-floor commercial space, a rich and active retail environment can stimulate public interaction, while a pleasant, comfortable, and convenient active travel system further draws people into public streets(Jacobs, 1960; Litman, 2003).

Todd Litman's research on the economic value of walking shows that, in New York City, the redesigned streets that are oriented toward pedestrians and public transport can significantly increase retail revenue and greatly reduce commercial vacancy rates (Litman Todd, 2024).Therefore, how to optimize existing urban transportation systems, reduce car dependence through thoughtful design, and encourage active mobility among citizens—thereby promoting sustainable development and building greener, more vibrant, and more efficient communities—remains a crucial issue in urban regeneration and design.

In order to identify solutions and provide a solid foundation for future design and optimization, this study analyzed four types of transportation routes—bicycle, automobile, public transit, and logistics—within the BdsREC and its surrounding areas during the site analysis phase.

As shown in the analysis diagram(Figure 43), the community exhibits a relatively well-connected road network and high spatial accessibility, with public transportation routes covering most of the area. However, cycling paths suffer from poor continuity and insufficient convenience. More notably, various

traffic flows are highly overlapping: not only do cycling lanes, vehicle lanes, and public transport routes intersect and intertwine, but the presence of numerous industrial, commercial, and logistics buildings within the community also results in a significant volume of heavy freight traffic flowing through the area. Compared to the conventional urban traffic structures, this high-intensity traffic mix can not only lead to more severe noise and environmental pollution issues but also further increase traffic safety risks for the residents(W. E. Marshall & Garrick, 2010).

It should be highlighted that, in addition to the densely built-up areas in the west and south, the northern part of the community contains expansive open land, including farmland, vegetation, and a river running through the site, offering rich natural and landscape resources. However, these assets have not been systematically planned, and the lack of connectivity with southern urban areas has resulted in spatial fragmentation. The absence of adequate urban roads and walking/cycling infrastructure has created a physical and functional divide between these adjacent zones, weakening overall spatial integration.

Therefore, it is important to systematically integrate and optimise the road network in this area in subsequent designs. By planning a reasonable and efficient transportation system, it will reduce residents' dependence on private cars, at the same time increasing walking and cycling areas and improving public transportation routes, ensuring that the residents of the community can have convenient and efficient travel experiences, while also participating more actively in low-carbon modes of transportation such as walking and cycling(Banister, 2008; Pucher & Buehler, 2010).

At the same time, In addition, the design should also focus on connectivity between the northern and southern parts of the community. By optimising roads and slow traffic systems, the connections between the resource-rich northern area and the southern urban space can be established to fully develop the landscape and ecological value of the area and better serve the surrounding residents. By doing this will not only promote low-carbon development in the community and improve environmental quality, but also enhance residents' comfort and revitalise the community.

5.3 Strategy of Urban Transformation

After systematically analysing the current status of building functions, ground-floor commercial use, green and public spaces, and traffic flow within the BdsREC, it can be concluded that the community currently faces the following core issues:

1. Imbalance in building functions hinders sustainable community development.
2. Insufficiency and fragmentation of ground-floor commercial spaces result in a lack of vibrant and continuous commercial streets.
3. Ineffective allocation of green and public spaces limits their ability to serve community needs.
4. Disorganization and inefficiency in the traffic system, coupled with an incomplete road network, reduce overall accessibility and connectivity.

In response to the issues mentioned above, we must recognise that urban renewal and development in BdsREC cannot only rely on natural evolution to achieve a sustainable, structurally appropriate, and high-quality urban environment. It is only through clear planning guidance and systematic design strategies that the community can be effectively transformed and developed in a more efficient, green and liveable direction.

Building on the analysis of the two case studies—BedZED and Masdar City—presented in Chapter 4, this study summarizes the key design strategies and principles as outlined in the Table 3. These include not only mixed-use development, promotion of active mobility, and the integration of renewable energy systems, but also emphasize the importance of passive design and flexible, adaptable urban structures.

Based on this, and in response to the challenges currently faced by BdsREC and its future development goals, this paper attempts to combine the design concepts summarised above with the actual conditions of the site, to further sort out and construct a set of design methods and frameworks that are more suitable for local characteristics. It is hoped that through these strategies, urban design can be used as a tool to reconfigure the spatial and functional systems of the region, guiding it toward a more efficient, greener, and more energy self-sufficient future. At the same time, this study also aims to provide a practical methodological reference for the planning and design of renewable energy communities in other urban contexts.

Table 3 Guiding Principles for Renewable Energy Communities(Same as **Table 2**)

Design Focus	Masdar City
Flexibility and Adaptability in Overall Plann	Flexibility and adaptability should be embedded at the planning stage to allow for systemic adjustments and long-term resilience throughout project development and operation.
Walkable and Bikable Street Networks	Urban mobility systems should be designed to prioritize safe, accessible, and pleasant pedestrian and cycling routes to promote low-carbon transportation modes.
Early Integration of Renewable Energy System	Renewable energy potential should be assessed early and spatially integrated into the urban fabric to maximize efficiency and minimize disruption.
Passive Design and Public Space Optimization	Passive design strategies such as greenery, wind corridors, and shading can enhance microclimatic conditions while improving the usability and attractiveness of public spaces.
Mix-used Development and Spatial Diversity	Mixed-use development increases land-use efficiency, enhances accessibility, and contributes to vibrant, resilient urban environments.

According to the design principles proposed in Table 3 and the summary of the current issues of the BdsREC in the previous section, this article summarises the design concepts into three core directions: (1) activating mixed-use functions and local vitality; (2) emphasizing green open spaces and ecological connectivity; and (3) integrating RESs to establish a self-sufficient community system.

The first strategy is 'activating mixed-use functions and local vitality'. Whether it is the imbalance in functional structure shown in the above analysis of building functions or the problem of insufficient and scattered commercial space reflected in the analysis of ground floor commercial space, the underlying cause is closely related to the lack of effective mixed-use development within the community. As noted above, an imbalanced building functional structure that is not beneficial to community development and the insufficient number of commercial spaces on the ground floor that lack a systematic layout will not only weaken the convenience of community residents' lives, but may also further affect the vitality and safety of the community(Jacobs, 1960; Strano et al., 2007). the functional configuration of the building should be considered as an integrated system with the geographical location and business distribution of the ground floor commercial space, thereby more comprehensively and efficiently stimulating the functional mix and regional vitality of the community.

Green open space and ecological connectivity are not new concepts in urban design and have been widely addressed in past planning practices. However, in the context of this project, it is important to clarify that ecological connectivity refers not only to the physical accessibility between urban or community public spaces and natural ecological areas, but also to the internal coherence of spatial and mobility systems within the community.

As demonstrated in the earlier analysis of green/public space and traffic circulation in the BSD Renewable Community, both the spatial distribution of open spaces and the organization of the transportation network exhibit significant imbalances and fragmentation. Hence, during the design process, it is necessary to combine the above-mentioned overall review of the functional structure of community buildings and comprehensively plan diverse and appropriate green open spaces. At the same time, the realisation of ecological connectivity should also be reflected in the improved accessibility within the community. Not only should residents be able to easily reach green spaces such as community centre parks, but road optimisation should also take into consideration road classification, clear and efficient traffic flow, and the continuity and convenience of walking and cycling networks. Although this design phase does not include a detailed proposal for the large green area in the northern part of the community, its future integration and the flexibility of the overall development framework must still be considered. Only through such a holistic and forward-looking approach can this neglected urban fringe area be transformed into a truly sustainable and livable REC.

Finally, considering the special characteristics of RESs, the author focused on this aspect as an independent and important point in the overall design. Based on the findings, designers can predefine appropriate system types and their spatial deployment. However, as evidenced by the multiple replacements of RESs in the BedZED project and the controversies they sparked, it is clear that integrating renewable energy systems into urban design at an early stage and establishing a flexible and forward-thinking energy system are critical to the long-term sustainability of RECs (BioRegional Development Group, 2002; Schoon Nicolas, 2016; Zhu et al., 2012). Therefore, in the planning and design of renewable energy communities, it is essential to first conduct preliminary research on the types of energy available and the resource conditions within the site, and based on this, predefine the system type and spatial layout. Through this proactive and systematic energy planning, sufficient and independent design space can be reserved for future engineering interventions, demonstrating respect for professional expertise. It also avoids the common issue of renewable energy infrastructure compromising the quality and usability of public space due to inadequate spatial integration.

The three design strategies—activating mixed-use functions and vibrancy, enhancing green connectivity and open spaces, and integrating renewable energy systems—are distinct yet interdependent. By organically overlapping these three elements and incorporating them into a unified spatial intervention framework, designers can systematically respond to the core development issues of the area from an urban design point of view and provide ideas and methods for future energy-oriented community planning and practice.

To ensure the effective implementation of the BdsREC project and translate the previously proposed concepts into tangible urban spaces, this study simplifies the spatial and developmental structure of the community based on the integrated design strategies. By thinking about how to effectively integrate complex design concepts into simplified real-world community space networks, we can further summarise an efficient and feasible implementation path that relies on the existing spatial layout while taking into account development goals and site characteristics.

As demonstrated in the previous sections, from the analysis of the overall spatial structure of the community and various aspects of the current site conditions to the emphasis on renewable energy systems in the design strategy phase, the entire planning process revolves around three fundamental elements: functional zoning, the spatial structure of the street network, and key development nodes for renewable energy. As illustrated in the Figure 44, these three basic elements form the basis of the preceding design strategy and also represent the key development directions that need to be considered based on the current site conditions. Combining these three core elements with a comprehensive design strategy enables designers to start from the regional scale and promote the organic integration of community spatial structure, functional distribution, and energy infrastructure while coordinating the layout of the street network, functional organisation, and energy system configuration as depicted in Figure 45.

Of course, the design strategies and basic elements outlined above are not sufficient to design an efficient and truly implementable REC. To achieve a more systematic and comprehensive design concept, this paper further integrates the key points of the strategies with the three core elements mentioned above and reorganises them logically to form the nine key design points shown in Figure 46. These principles include:

1. Develope Multifunctional Communities
2. Enhance Connectivity
3. Diversify Areas for Future Development
4. Create Climate-Adaptive Communities
5. Promote Walkable and Permeable Environments
6. Design with a Green-Oriented Approach
7. Strenghthen Clarity in Spatial Structure
8. Establish Distinctive, Community-Serving Nodes
9. Define zones for producers, consumers, and prosumers

Through this set of logically clear and mutually supportive key points, the design will not only help to systematically solve the current problems faced by BdsREC and promote its transition to sustainable development, but also help designers clarify their design ideas, ensure that the final results are effectively implemented, and truly create a sustainable, environmentally friendly and vibrant renewable energy community for residents.

5.4 Conceptual Design Proposal

After clarifying the design approach and summarizing the key strategies and principles, this section integrates all previous analytical findings to formally initiate the urban design proposal for the BdsREC.

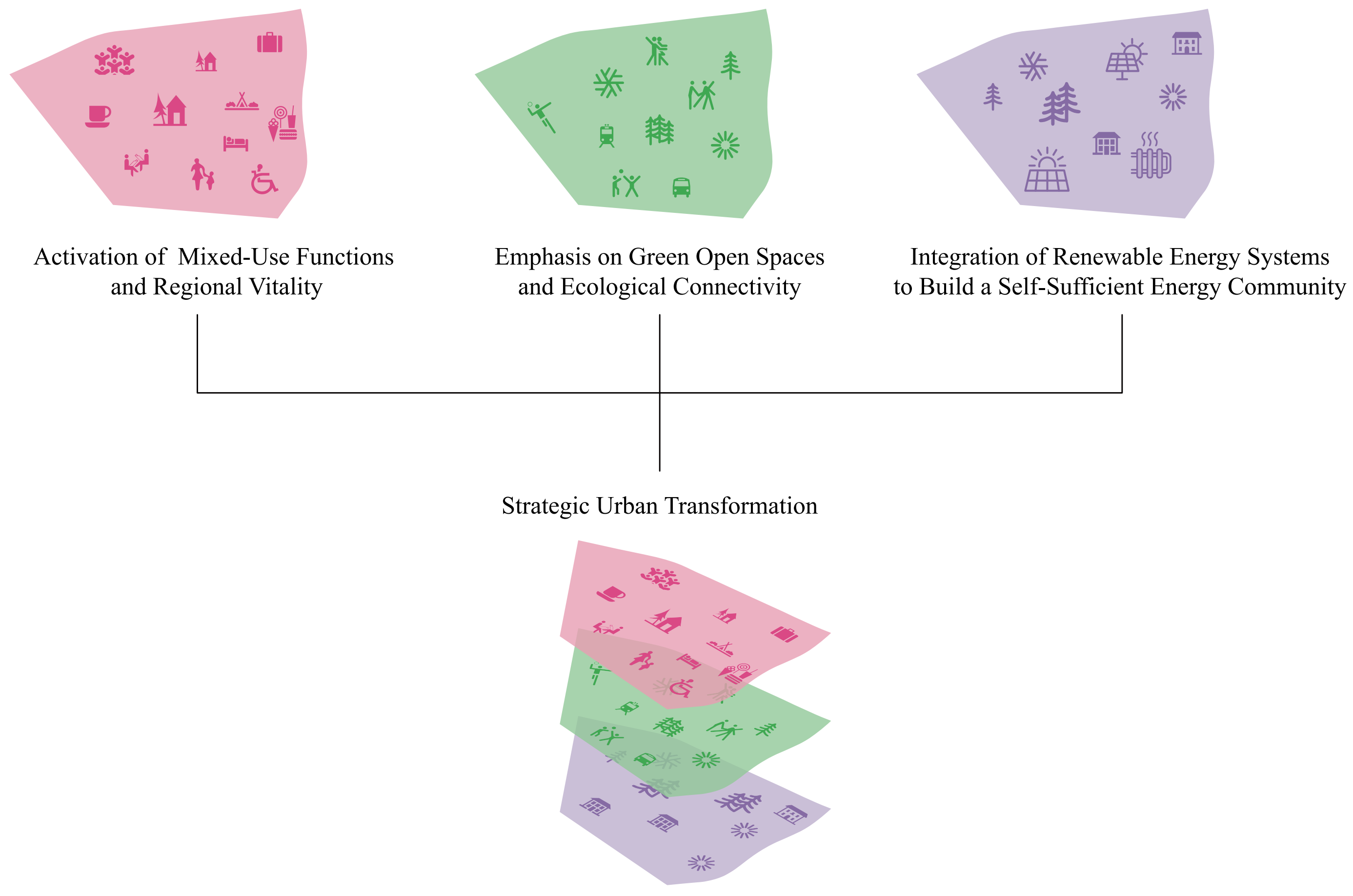


Figure 44 Strategic Urban Transformation
Source: Created by the author.

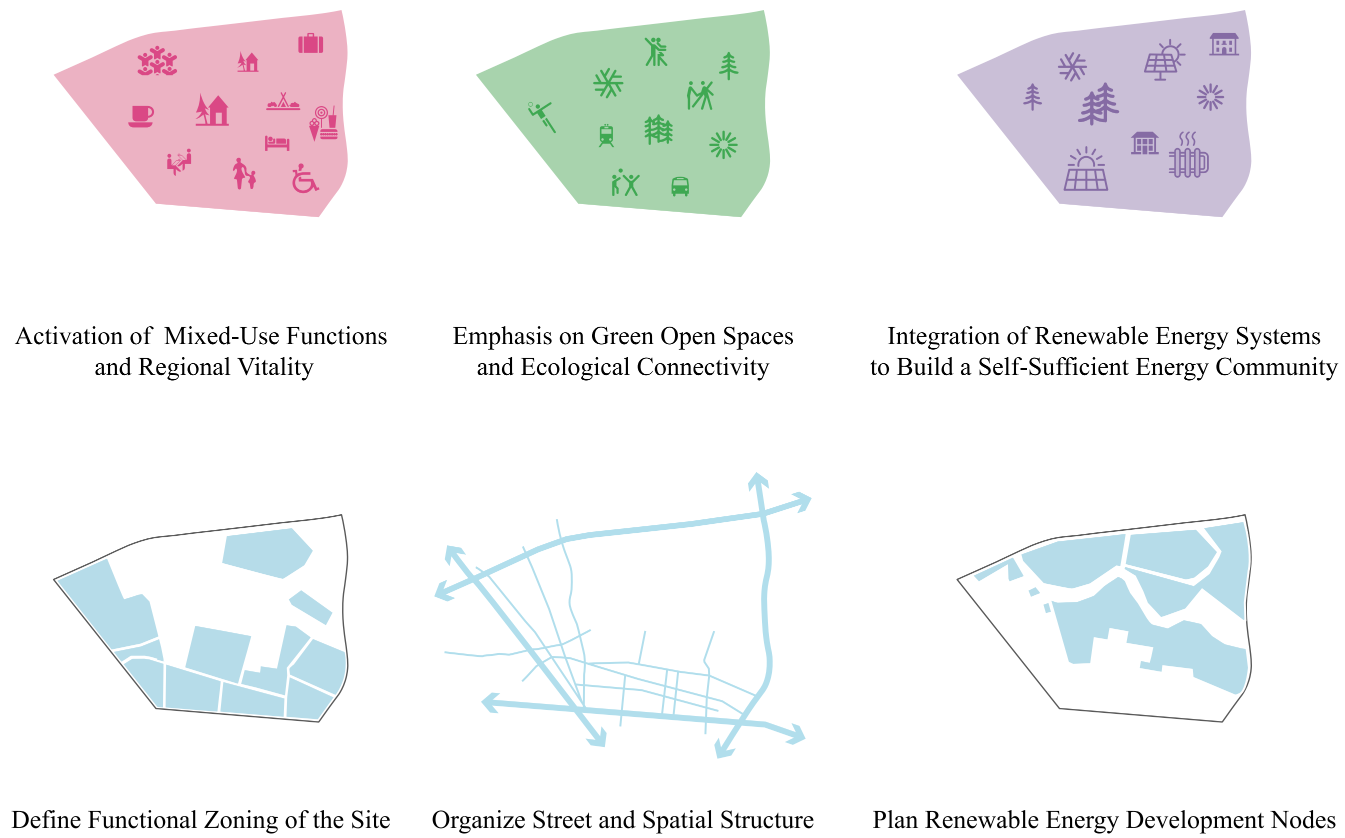


Figure 45 Approach:Integrated and Area-Based
Source: Created by the author.

Figure 46 Key Directions of Urban Design
Source: Created by the author.

As identified in the previous analysis of the BdsREC, a portion of the site includes industrial buildings, logistics and storage facilities, as well as dilapidated or abandoned structures(Pantaloni Giulio Gabriele, 2020). Before advancing the design of a mixed-use development, this phase involves relocating industrial and certain logistics buildings(especially those embedded within residential areas)to other parts of the city, and demolishing degraded or abandoned structures. The spatial morphology before and after the relocation/demolition process is illustrated in the Figure 47 and Figure 48.

This preliminary clean-up work has established a clear framework for subsequent urban design: unfavourable functional elements that hinder the future development of the community have been removed, and issues related to the imbalance of building functions and structures have been resolved. This has cleared the way for the integration of new functional spaces and laid a solid foundation foundation for future development.Additionally, this round of cleanup has freed up a significant amount of potential open space within the community. This allows for sufficient space to accommodate new functional buildings while providing greater flexibility and freedom for the reconstruction of the overall spatial structure and the design of the public space system.

After completing the building clean-up and revealing the internal spatial structure of the community, the design team first optimised and restructured the internal road network. This design step was based on the following considerations:

Firstly, as Kevin Lynch emphasised, streets are not only paths for urban traffic, but also key elements in shaping the image and sense of order of a city(Lynch Kevin, 1960). In urban spaces, the road network serves as the basic framework and circulatory system(Tian et al., 2019). Its organisational structure not only determines the operational efficiency and accessibility of internal transportation but also directly influences the rational allocation of subsequent building layouts and public spaces(Hillier, 2007; S. Marshall, 2004).

Secondly, as shown in the traffic flow analysis above, the community's current transportation system is highly mixed and structurally fragmented. If it is not optimised and reorganised at the design stage, any subsequent design interventions may result in spatial conflicts due to the chaotic road network, or even trigger new usage and management issues(S. Marshall, 2004; W. E. Marshall & Garrick, 2010). Therefore, a clear and efficient transportation system is a prerequisite for rational spatial organisation, separation of vehicles and pedestrians, and sustainable urban operations.

Based on these considerations, I systematically restructured the road network using the cleared spatial framework. On the one hand, unreasonable and redundant roads will be removed. On the other hand, a clearer grid-type road structure will be introduced while retaining the original accessibility, improving the efficiency and simplicity of the overall transportation network, and ensuring that the convenience of existing buildings and residents' travel is not affected. The optimised road system is shown in Figure 49.

In the initial design phase, this research has already systematically sorted out and optimised the existing chaotic and inefficient road network. The focus of the next phase of design should be to further respond to global sustainable development goals and the growing demand of residents for high-quality public spaces and natural environments. In the process of rapid urbanisation, the urban heat island effect has become a widely recognised issue. As noted

Figure 47 Existing Morphology Map of Basse di Stura
Source: Created by the author.

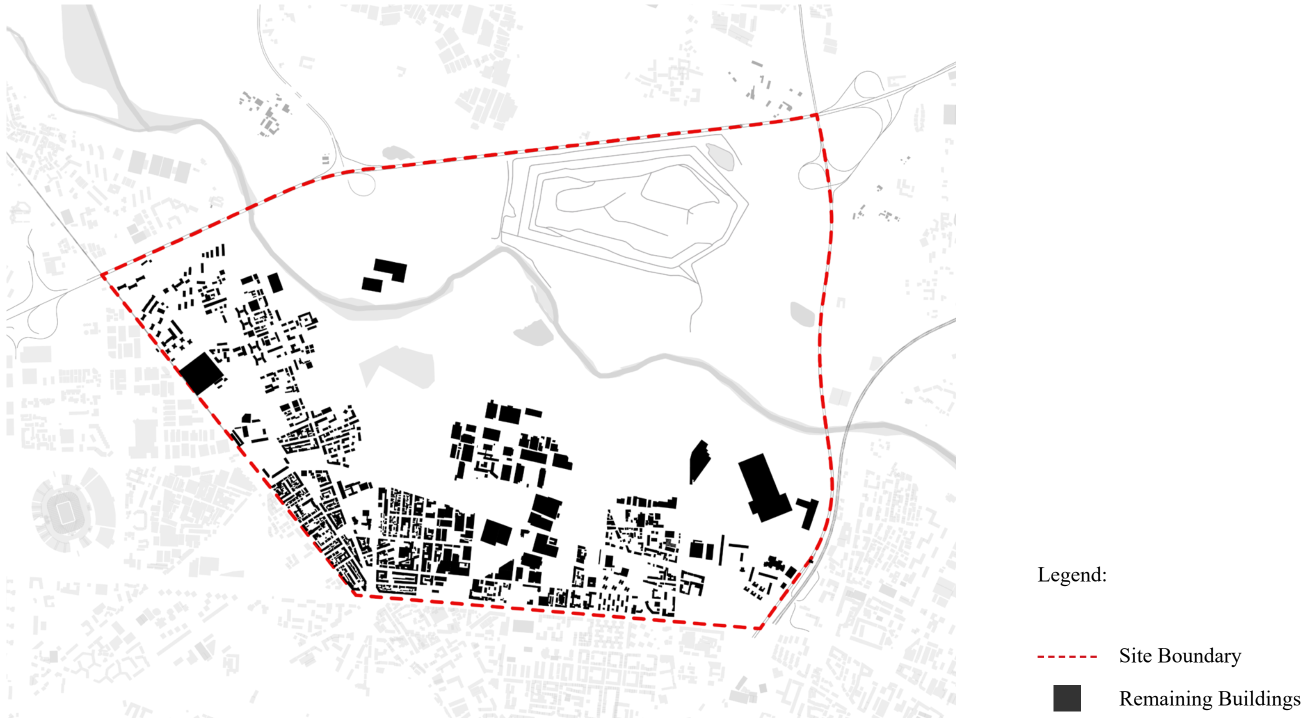


Figure 48 Post-Demolition Morphology Map
Source: Created by the author.

Figure 49 New Road Network
Source: Created by the author.

Figure 50 Integrate the Green Loop in to Basse di Stura
Source: Created by the author.

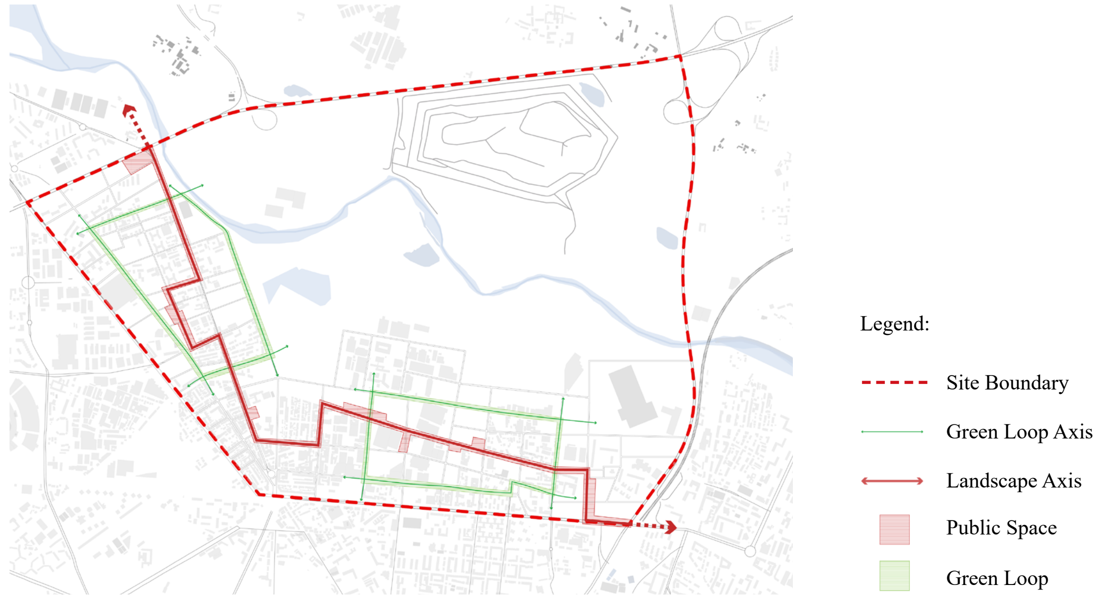


Figure 51 Integrate the Landscape Axis in to Basse di Stura
Source: Created by the author.

in the study 'Urban green space cooling effect in cities' by Farshid Aram et al., even a small pocket park of just 300 square meters can reduce the surrounding temperature by approximately 1°C(Aram, Higueras García, et al., 2019). Similarly, in an interview-based study titled *How can cities use green spaces to mitigate the effects of extreme heat on vulnerable residents?* by Jodi Heckel and Professor Fang Fang from the University of Illinois at Urbana-Champaign, it was highlighted that shaded urban surfaces can be up to 20°F cooler than those exposed to direct sunlight(Heckel, 2023). It can be seen that planning continuous and organised green corridors in communities can not only help optimise the overall spatial landscape and enhance the experience of residents, but also has important ecological significance in regulating the microclimate and alleviating the urban heat island effect(Aram, Higueras García, et al., 2019; Aram, Solgi, et al., 2019; Tzoulas et al., 2007).

Moreover, as Christopher Alexander proposed in his book *A Pattern Language*, he introduced the concept of a 'community corridor,' advocating for the gradual development of a central walkway in each neighborhood to connect major activity nodes—ensuring that every point in the community lies within a ten-minute walking distance(Alexander, 1977). Similarly, Jane Jacobs expressed a similar view in her classic book *The Death and Life of Great American Cities*, noting that parks isolated from pedestrian traffic tend to be empty and unsafe, while parks embedded in busy traffic routes are more likely to become active focal points for the community(Jacobs, 1960). Green corridors can effectively integrate multiple public spaces into a larger, coherent system, encouraging people to pass through, stay and use various spaces in their daily lives. Therefore, green corridors in urban spaces not only play a significant role in terms of ecology and landscape, but also serve as important links that connecting public spaces in communities, stimulating public life and injecting new vitality and possibilities into communities(Alexander, 1977; Gobster & Westphal, 2004; Hunter et al., 2021).

Based on the above considerations and combining the linear distribution of buildings in the community, in order to achieve a balanced layout of green spaces, two green corridors were incorporated into the site after re-planning the community road network (as shown in the Figure 50). These corridors connect large open spaces with existing green areas while staying as close as possible to high-density residential zones. The intention is to maximize residents' access to nature, allowing them to enjoy the pleasant landscapes and comfort that green environments provide.

Finally, as Ian McHarg proposed in his book *Design with Nature*,that 'urban development should be guided by natural corridors functioning as an open space network'(McHarg, 1971). The author also hopes that through the preliminary planning and guiding design of green corridors, the functional positioning and development direction of the surrounding community spaces can be clarified in advance, thereby ensuring the consistency and coherence of the overall design in the future.

After the introduction of the green corridors, as shown in the Figure 51, a certain sense of spatial cohesion has emerged within the community. However, due to the zigzag distribution of the densely built-up areas, the overall layout still exhibits a degree of fragmentation. A living urban organism must weave together its natural setting and social fabric. Similarly, to create a truly 'vibrant community,' it is essential to consider the spatial continuity and coherence of

the entire area. During the design process, the natural environment, architectural complex and public spaces should be organically linked and integrated to form a unified and harmonious whole(Fang et al., 2021; Kim & Kaplan, 2004; Mumford, 1937).

To connect the entire community more cohesively and to systematically organize the layout of different building types and spatial functions—while avoiding spatial disorder during the transition toward mixed-use development—a winding landscape axis was designed to traverse the site and link the two green corridors (as shown in the Figure 51). Through this guiding linear landscape structure, the author hopes to integrate community spaces while using this as a basis for arranging a series of accessible public spaces that serve residents. On the basis of enhancing spatial connections, this axis also aims to create diverse landscape nodes that attract and encourage residents to stroll, linger and interact along the axis, thereby stimulating community vitality and promoting social interaction.

Following the site analysis and the step-by-step refinement of the urban spatial structure—driven by existing conditions and design objectives—including the reconfiguration of the road network, the integration of green corridors, and the introduction of a continuous, meandering landscape axis, a new structural framework for the community has been established. In order to more clearly show the relationship between the various design elements, the author superimposed and integrated the above design results, and on this basis carried out further planning and spatial design work.

From the community's overall spatial structure point of view, the eastern and northern areas are currently underdeveloped, consisting primarily of farmland and natural landscapes. Given the significant development gap between these two zones, the community's construction can be divided into two phases. The areas with urban voids resulting from demolition are designated as 'development zones,' while the underutilized, still-natural areas are marked as 'future development zones.' This division helps to concentrate the resources of the community in the early stages, which can help to improve existing space and infrastructure, while strengthening the foundation for community development and leaving sufficient space and flexibility for subsequent development. And this kind of gradual regeneration strategy can not only help to ensure the systematic and continuous design, but also enhance the long-term adaptability and resilience of the entire community.

In the preceding section, the author has already discussed in detail the importance of green corridors and landscape axes as well as their design concepts, while the key role of the road network in the overall community structure design has also been emphasised. To deepen the design and provide a rational basis for the subsequent layout of building clusters and public spaces, the author first conducts a preliminary planning of the road hierarchy within the community.

The primary roads are designed as the structural network that maximally connects the entire site. By establishing clear priorities in road classification, the design aims to direct vehicular traffic efficiently and reduce large-scale pedestrian–vehicle conflicts caused by disorganized road planning. Considering the noise and air pollution typically associated with motor vehicles, some segments of the main roads intentionally overlap with green corridors, allowing greenery to buffer the negative impacts on residential zones.

Secondary roads run between neighbourhoods, which simplifies the main traffic system without affecting local accessibility within the community. When planning secondary traffic axes, the future development direction of the community was also taken into consideration, ensuring that they are vertical to the main roads and extend to undeveloped areas.The resulting grid-like road system not only simplifies navigation within the community, enhances overall accessibility, and effectively avoids traffic congestion, but also leaves room for future expansion.

In addition, the mixed development model of transportation networks and green corridors also achieves coordinated development with motor vehicle traffic while encouraging active modes of transportation such as walking and cycling. It is particularly worth noting that in the design of this road system, in order to avoid the recurrence of mixed traffic and continue the concept of integrating green spaces and transportation systems, this study has renovated the main vehicular roads, as shown in the Figure 52. As shown in the figure, by leveraging the more spacious conditions created after the removal of buildings, the renovated main roads have been widened by 2 metres on both sides to accommodate bicycle lanes, with a 1.5-metre-wide pedestrian walkway on the outer side of the bicycle lanes, and street trees planted between them. This design ensures pedestrian safety while enhancing the comfort of cycling and walking through an optimised road structure, which further encourages green modes of transportation.

In the early stages of planning and design, the importance of green spaces, public open areas, and community activities was emphasized multiple times. While the previous structural framework included a comprehensive landscape system and the preliminary layout of public spaces along the landscape axis, these measures alone are not sufficient to meet the diverse needs of residents. To enhance the living experience and deepen spatial perception and memory within the community, it is essential to design distinctive places 'landscape nodes' that encourage residents to step out of their homes and engage in communal activities. As Kevin Lynch pointed out, in some cities, nodes are often the most prominent spatial elements and the most memorable parts of people's memories; they not only help to strengthen the clarity of the urban structure but also significantly improve the legibility of the urban space(Lynch Kevin, 1960). Based on this, the author has identified five landscape nodes of varying sizes along the landscape axis, taking into account the existing layout of open spaces, public spaces, and green corridors in the development area. by establishing these nodes, the aim is to further improve the community's public space system and, at the same time, provide more targeted guidance and support for future building layout and spatial design.

After the overall design framework of the community has taken shape, further optimization of the layout and planning of ground-floor commercial spaces is essential. As (Jacobs, 1960) and (Yang et al., 2023) in the early stages of planning and design, the vitality of a city largely depends on the liveliness and activity of its street spaces. Rich and attractive ground-level commercial spaces can give a city a sustained and vibrant dynamic atmosphere(Mehta, 2009). Although the street spaces within a community are not as diverse as those in the city's core commercial areas, they can still create attractive and vibrant spaces through reasonable ground-level commercial planning, thereby enhancing the daily experience of residents and stimulating community vitality.

Given the relatively limited demand for commercial types and quantities

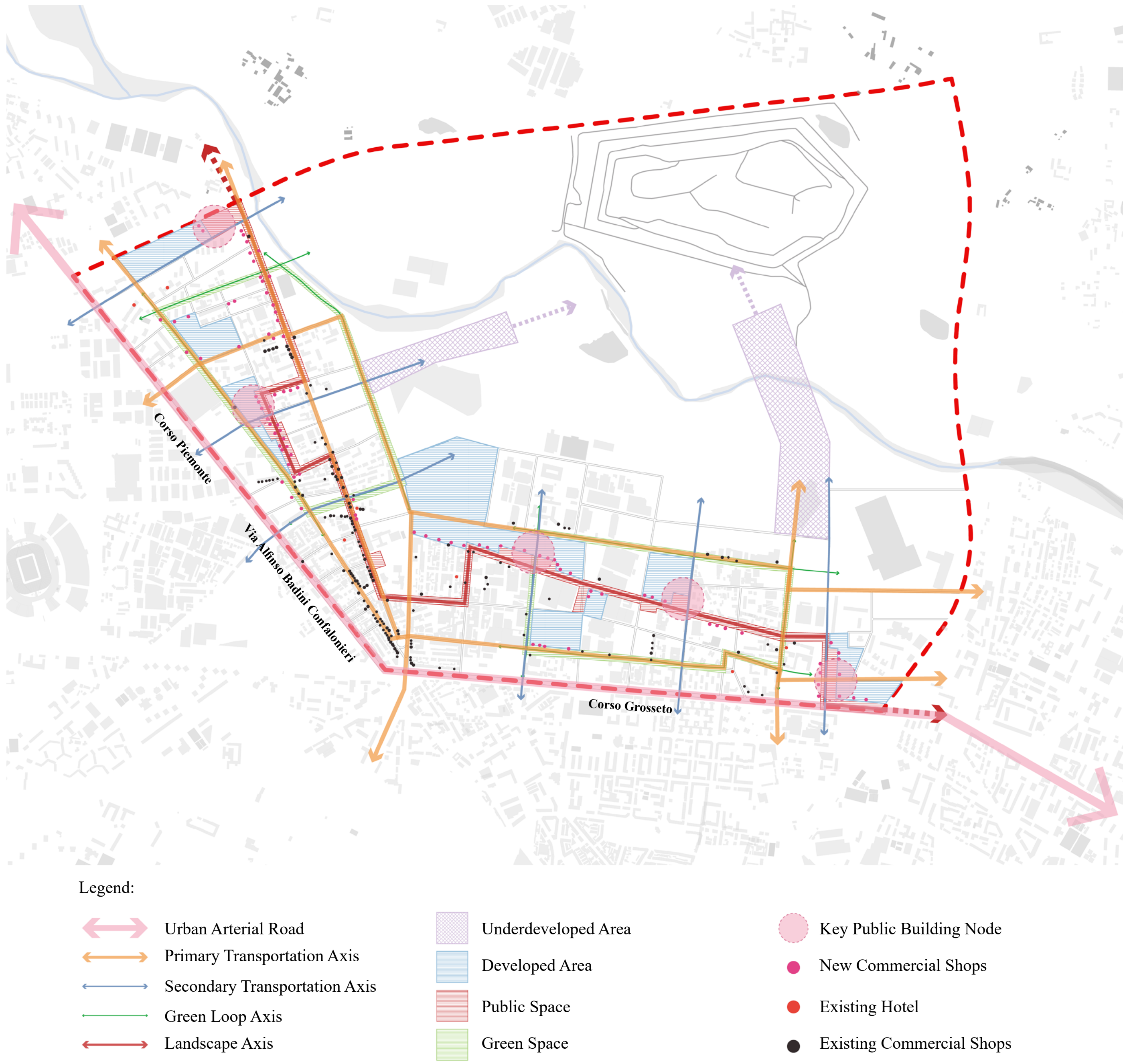


Figure 53 Post-Redevelopment Urban Structure of the Community: Roads, Green Corridors, and Public Spaces
Source: Created by the author.

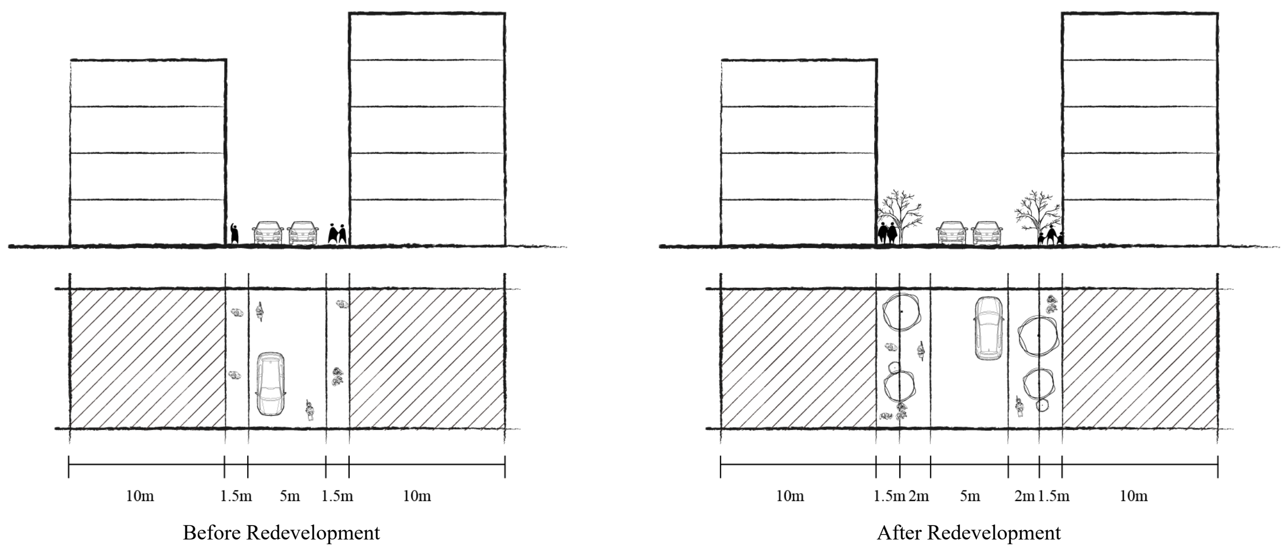


Figure 52 Comparative Analysis of Street Structure Before and After Redevelopment
Source: Created by the author.

within the community, and it has been mentioned several times above that the landscape axis should be used to connect the entire community, so in the new round of ground-floor commercial planning and design, the first consideration is to lay out the commercial space along the landscape axis. Although in the previous design, the author has enhanced the attractiveness of the landscape axis to residents by setting up public spaces and landscape nodes, hoping to maximise the value of the space, these measures are still unable to fully guarantee that the actual results will meet expectations. Therefore, in the planning of ground-floor commercial spaces, the landscape axis remains the core focus. It aims to meet the daily needs of residents while maximising the attraction of foot traffic and creating a rich, diverse, and vibrant community atmosphere by integrating natural landscapes, public spaces, landscape nodes, and commercial spaces in a multi-dimensional manner.

In addition, in order to ensure that all residents within the community can enjoy convenient services at minimal cost, this research also gave full consideration to the convenience of secondary areas within the community during the design process. Small commercial spaces were appropriately inserted between several secondary public spaces and green spaces and residential buildings. this not only allows residents to meet their daily basic needs within walking distance, but also enhances the frequency and efficiency of secondary public spaces through the combination of commercial and green spaces(Mehta, 2009).

Through the design above, this research hope to strengthen the public dynamics of the landscape axis while ensuring the overall spatial continuity of the community and also the convenience for residents' daily lives. The driving effect of the landscape axis will gradually spread to the surrounding urban spaces of the community, thereby achieving balanced development of the entire community. Finally, the author integrates and overlays the previous achievements of the planning to form the preliminary community concept structure shown in the Figure 53. This figure is not only a comprehensive display of the preliminary design strategies and achievements, but also provides a clear basic framework for subsequent more detailed spatial planning and architectural design. Future specific design work, such as building layout and sustainable energy systems, will also be carried out step by step based on this framework.

After determining the preliminary urban design framework for the BdsREC, the next step will be based on this framework to carry out specific design at the architectural level, organically embedding new buildings into the community as a whole. However, before formally starting the architectural design phase, it is necessary to first establish a set of new design strategies that fit the characteristics of this community, so as to provide clear guidance and direction for the subsequent architectural layout and spatial organisation.

Many architectural theorists believe that before undertaking urban design, the first task is to understand the logic behind the creation of architecture. As Gianfranco Caniggia noted, 'When the form being sought appears to arise naturally from the environment, as if the architect's personal intentions have been absorbed by history, the design study can be considered complete.' He believes that a successful design should give people the impression that the architecture is a natural continuation of the current environment(Caniggia & Maffei, 2001).

Similarly, Aldo Rossi emphasized in his book *The Architecture of the City*

that permanent structures in cities (such as monuments, municipal buildings, and street networks) not only carry historical memories but also profoundly influence future urban development(Rossi et al., 1984). Therefore, before undertaking architectural and urban design, it is crucial to carefully interpret and understand the existing types and structures of the city and use this as a basis to guide subsequent design. This will ensure that even if a new building is constructed, it will still respect and continue the continuity of the urbanspatial structure. And this kind of spatial continuity also ensures that the local architecture will not fall behind the times while naturally integrating into the urban environment, thereby avoiding a sense of strangeness and alienation among residents.

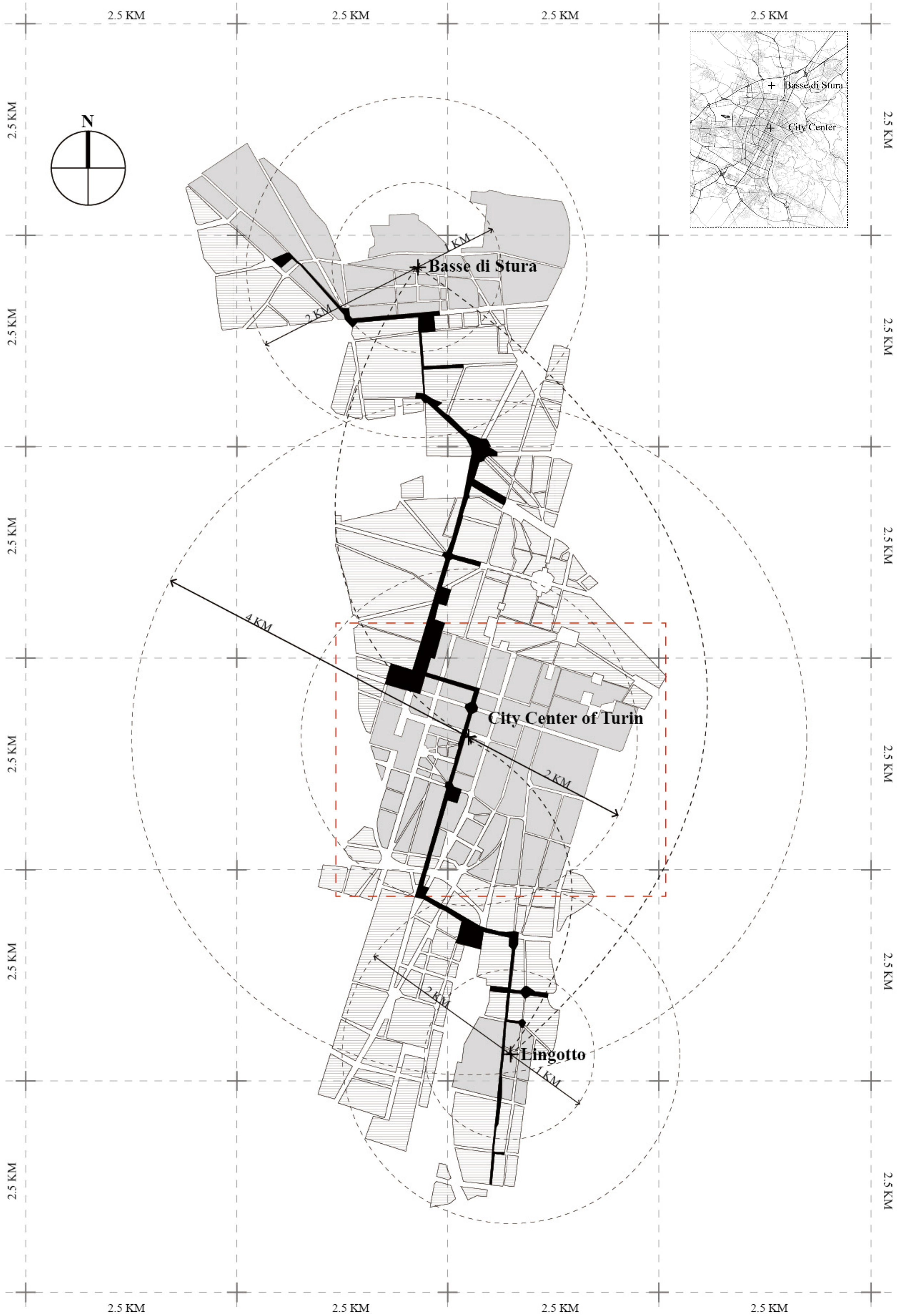
For a city with such a rich historical heritage as Turin, its existing city centre is not only a hub for commercial activities and historical buildings, but also an important microcosm of the city's spatial structure and development. Over time, Turin's city centre has matured in terms of building types, neighbourhood texture and public space networks, becoming an important place that carries the collective memory of its citizens(Bernardi et al., 2024; Colombino & Vanolo, 2017).

As a brownfield site located on the northern edge of Turin, Basse di Stura feels somewhat disconnected from the main city centre in terms of spatial structure, architectural composition, and transport network. As urban design theorist Giancarlo De Carlo pointed out, urban fringe areas should not be viewed as a 'blank canvas', but rather as an 'organic offshoot' of the city, which can extend naturally towards its boundaries(Charitonidou, 2021). Similarly, Bill Hillier emphasized that when newly designed urban areas or peripheral zones fail to connect with the city's primary street network, they often suffer from low pedestrian traffic and social isolation(Hillier, 2007). Therefore, when designing an area like Basse di Stura, it is important not only to consider the residential experience and functional needs within the site itself, but also to address its relationship with the broader urban fabric. Ensuring a natural transition from the city core to its edges enhances both the coherence and the accessibility and legibility of the area.

When introducing the concept of the 'Analogous City,' Aldo Rossi proposed that architects and urban designers can draw upon familiar urban forms, using known spatial models as analogies to guide the development of new urban areas—thereby ensuring spatial continuity(Matsui, 2022; McEwan, 2020). By analyzing and understanding the morphology of Turin, and using the structural characteristics of the city center as a reference for the architectural design of BdsREC, the collective urban memory and 'DNA' embedded in the minds of Turin's citizens can be effectively integrated into this peripheral site. This approach not only preserves physical and visual continuity with the existing urban fabric, but also allows BdsREC to naturally merge into Turin's broader urban evolution and narrative over time(Cataldi et al., 2002; Kropf, 1996).

Before formally starting the architectural design, an initial analysis of the urban morphology of Turin was conducted. As shown in Figure 54, Basse di Stura is located at the northernmost tip of Turin, about 6 kilometres from the city centre. Moving towards the city centre from Basse di Stura, the density of the neighbourhood gradually increases. Further south is a newer urban area, including Lingotto, which has retained its original grid-like urban structure while moderately reducing the density of the neighbourhood(Pantaloni

Figure 54 Initial Morphological Extraction of Turin: Key Spatial Axes and Urban Nodes
Source: Created by the author.



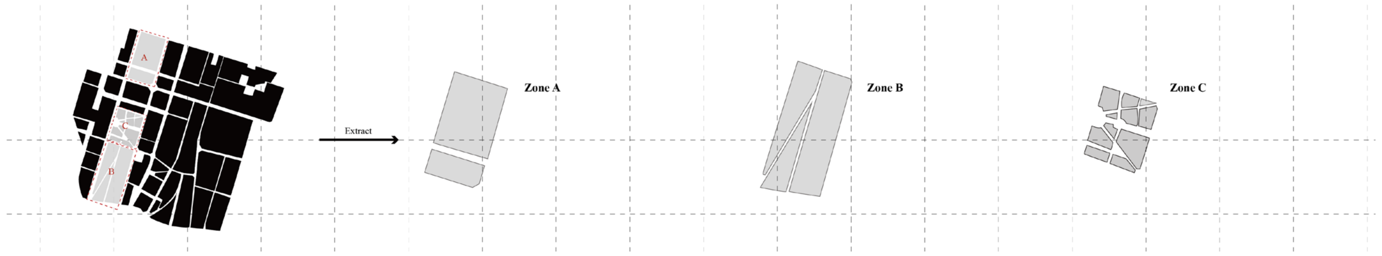


Figure 55 Morphological Zoning and Spatial Extraction of Urban Blocks in the Turin City Center
Source: Created by the author.

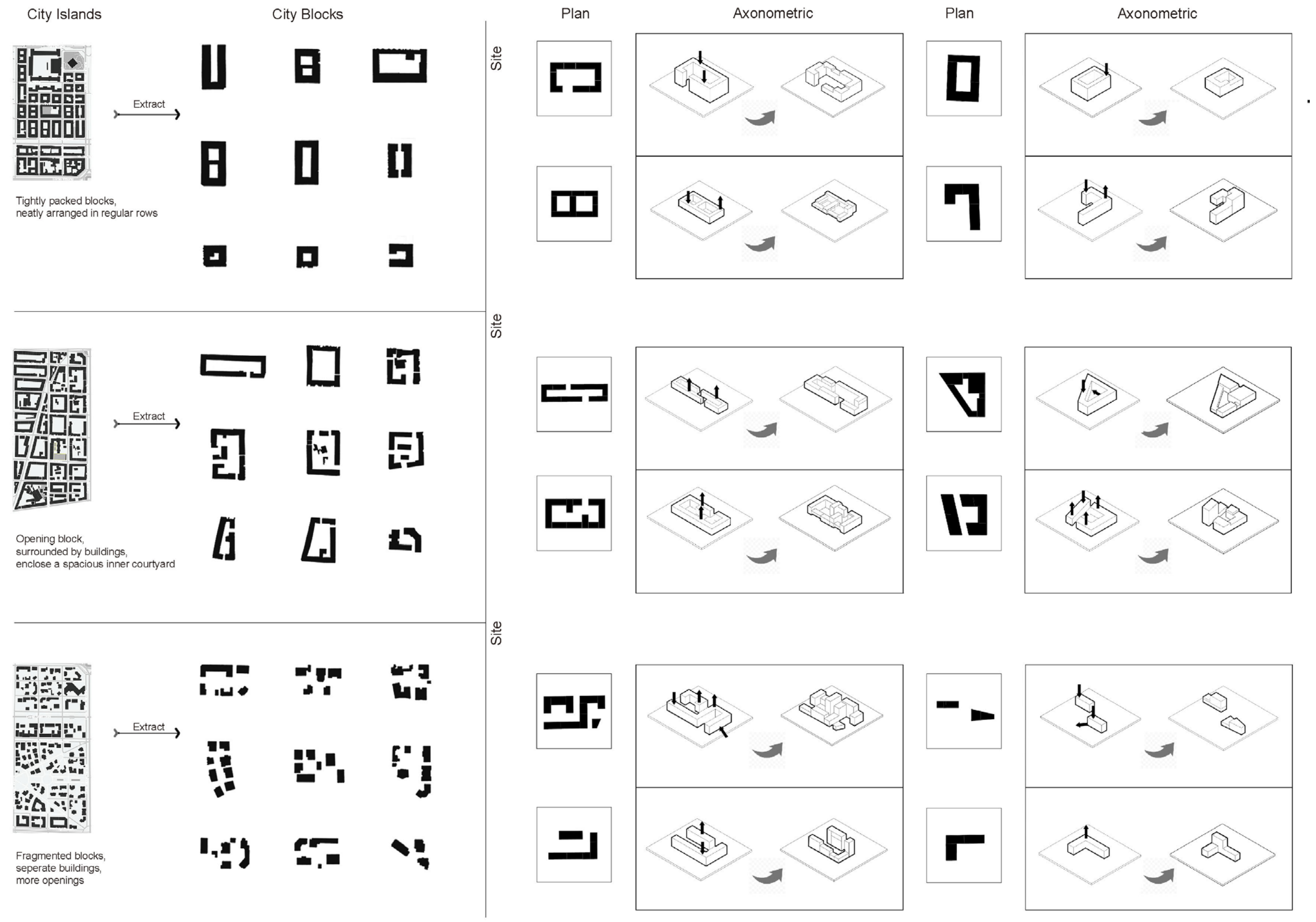


Figure 56 Detailed Morphological Analysis of Selected Urban Blocks
Source: Group work drawing, created by Wanyu Peng (Architecture and computational design, Politecnico di Torino, 2024).

Giulio Gabriele, 2020; Regione Piemonte et al., 1999). It can be seen that when conducting overall urban planning for the BdsREC district, there is no need to strictly adhere to the density and form of the historic district in the city centre. Instead, based on respect for its spatial logic, appropriate adjustments and evolution should be made in line with the actual needs of modern urban development, so that it better aligns with modern architectural functions and urban renewal directions.

In order to gain a deeper understanding of Turin's urban morphology, the author conducted a more detailed analysis of the city centre. The study found that even as the most mature and historically representative area of the city, the city centre has developed three neighbourhood patterns with different structural densities over the course of its long evolution.

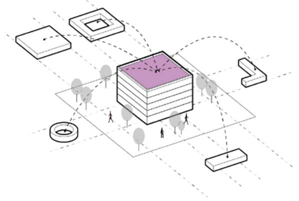
On this basis, this study selected the three representative areas marked A, B, and C in the figure as the objects of analysis(see Figure 55). It is hoped that through comparative studies of diverse forms, a spatial structure that meets urban development logic and is adaptable can be refined to guide subsequent architectural and urban design work.

Figure 56 shows the detailed analysis of these three areas. It can be seen that although there are significant differences in building density and openness between the three areas, when their building forms are abstracted, it is not difficult to see that they are essentially derived from a basic enclosed courtyard structure.Although this configuration is relatively simple in terms of logic and form, the right side of the figure clearly demonstrates that under the influence of different regional and environmental conditions, this basic form can evolve into a variety of architectural forms, both preserving the morphological characteristics of historic districts and possessing the flexibility to adapt to the needs of contemporary urban development.

The development and transformation of basic architectural forms can follow countless trajectories. To provide a clear set of guidelines for future architectural design in the Basse di Stura area—ensuring that the community meets the demands of a renewable energy district while avoiding rigid imitation of outdated historical forms—an analysis of Turin's urban morphology was first conducted. Based on the findings of this analysis and aligned with future development goals, a series of design principles have been established, as shown in the diagram. These principles are intended to offer architects sufficient creative freedom while ensuring that the long-term evolution of the community remains grounded in the original planning vision and spatial logic.

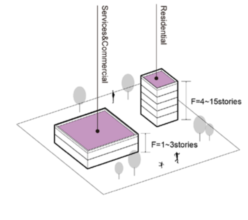
Based on the morphological analysis and the development goals of the BdsREC community, seven key architectural design guidelines have been formulated, as shown in the Figure 57:

1. Architectural design must respect the local urban morphology, using fundamental forms derived from Turin's typological patterns as the basis for spatial composition and transformation.
2. Building height should be appropriately regulated: commercial and public service buildings are limited to 1–3 stories, while residential buildings should range from 4 to 15 stories.
3. To minimize mutual interference and ensure a high-quality living environment, a minimum distance of 6 meters must be maintained between adjacent buildings.
4. Building height should be guided by landscape elements: when the landscape is located on both sides of a building cluster, the central buildings should be tallest and gradually decrease in height toward the edges; when the landscape lies at the center of the site, the opposite approach should be applied.
5. To promote walkability and expand green space within the community, a setback of at least 4 meters should be maintained between buildings and block boundaries to accommodate future pedestrian paths and public spaces.
6. In cases where adjacent existing buildings prevent the formation of continuous public space through setbacks, reducing building volume and opening corners of the site can help create urban green areas and public open spaces.
7. In the specific design process, the architectural form can be moderately adjusted according to the characteristics of the site, functional requirements, and landscape location, while maintaining the overall continuity of the Turin morphology and providing residents with the best possible views and public space experience.



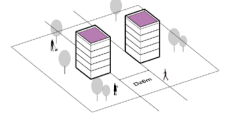
Architectural design must respect the local urban morphology, using fundamental forms derived from Turin's typological patterns as the basis for spatial composition and transformation.

Guidline 1



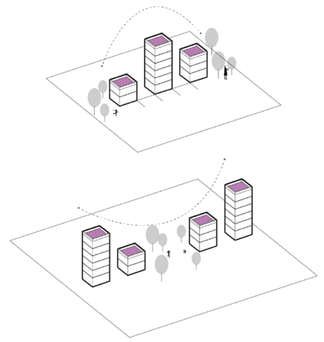
Building height should be appropriately regulated: commercial and public service buildings are limited to 1–3 stories, while residential buildings should range from 4 to 15 stories.

Guidline 2



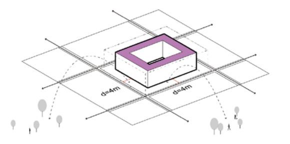
To minimize mutual interference and ensure a high-quality living environment, a minimum distance of 6 meters must be maintained between adjacent buildings.

Guidline 3



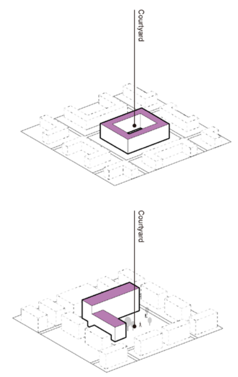
Building height should be guided by landscape elements: when the landscape is located on both sides of a building cluster, the central buildings should be tallest and gradually decrease in height toward the edges; when the landscape lies at the center of the site, the opposite approach should be applied.

Guidline 4



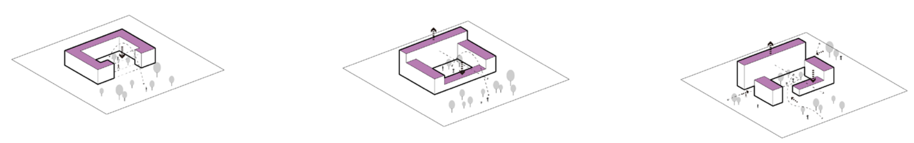
To promote walkability and expand green space within the community, a setback of at least 4 meters should be maintained between buildings and block boundaries to accommodate future pedestrian paths and public spaces.

Guidline 5



In cases where adjacent existing buildings prevent the formation of continuous public space through setbacks, reducing building volume and opening corners of the site can help create urban green areas and public open spaces.

Guidline 6



Architectural form may be flexibly adjusted based on site conditions, functional needs, and landscape orientation. While maintaining consistency with Turin's overall morphological character, such flexibility should enhance residents' access to quality views and convenient public space.

Guidline 7

Figure 57 Design Guidelines for New Buildings in Basse di Stura
Source: Created by the author.

Finally, based on the preceding analysis and design guidelines, the new urban morphology of BdsREC is illustrated in the Figure 58. The contrast between new and old architectural forms can be observed in the diagram. Overall, although the new buildings are larger in scale than the existing ones, their visual impact is not jarring, as they respect Turin's urban form. Furthermore, considering the lack of systematic planning and precise positioning during the early stages of development in this area, its original architectural forms, types, and spatial experience differ significantly from other mature areas in Turin, especially the historic city centre. As analysed above, the introduction of new buildings, through the introduction of similar architectural forms, aims to inject elements deeply rooted in Turin's urban 'DNA' into this peripheral area, thereby creating a sense of order and familiarity in this previously disorderly urban fringe area(Cataldi et al., 2002).

At the beginning of this study, it is proposed that RECs are an important means of achieving sustainable urban regeneration and that urban design is the foundation for establishing renewable energy communities. Through urban planning and design, the layout and scale of renewable energy facilities can be determined in advance to ensure that they can be connected to the grid efficiently and reliably. If this is not done in advance during the urban design stage, insufficient space or environmental constraints in the city will often result in inadequate development of renewable energy facilities. Moreover, this can lead to costly and visually unappealing retrofits—such as awkwardly squeezing temporary solar or wind installations into existing urban spaces. These makeshift 'band-aid' solutions not only compromise the overall quality of urban spaces but can also negatively affect the cityscape(Paatero & Lund, 2007; Passey et al., 2011).

As mentioned in the previous case study, Masdar City took into consideration the layout of renewable energy systems during the initial planning and design stages. For example, rather than simply installing solar panels on rooftops, the solar panels were integrated into the overall design of the building facades. At the same time, the city's centralised solar power plants were planned and located in the suburbs, which not only enabled large-scale centralised power generation but also avoided interference with residential areas. As a result, Masdar City achieved a coherent and comprehensive sustainable urban design(Masdar City, 2023b; Zhu et al., 2012; Ziqi & Beiqi, 2024).

However, before initiating the design process, it is essential to clarify that energy demand, energy potential, and available space for installing renewable energy facilities are not equal across different areas within the community. Therefore, there are three distinct functional roles in the planning of a renewable energy community: producer, consumer, and prosumer, which combines both production and consumption functions(Chaudhry et al., 2022; Milčiuvienė et al., 2019). Based on this, before proceeding with the overall planning and design of the community's renewable energy system, it is essential to first complete the overall functional zoning to enable targeted and efficient renewable energy layout design in subsequent stages.

In the preliminary analysis of the Basse di Stura area, the community was clearly divided into three areas: the north and east are open farmland and natural landscapes, the south is a commercial and warehouse area, and the west is a residential area. These three zones correspond well with the functional categories discussed earlier.

Among these, open farmland and natural landscape areas are suitable for the concentrated planning and construction of solar photovoltaic power plants, designated as energy producer zones; The southern commercial and warehousing zone, after the demolition of industrial warehousing buildings, will see the construction of new buildings, and the existing commercial establishments are primarily large-scale wholesale businesses. This area also possesses significant potential for the installation of renewable energy facilities and has been designated as a producer zone. Meanwhile, the western residential district, characterized by a dense concentration of often older buildings, has limited capacity for renewable energy equipment and is thus identified as the primary consumer zone. The relative positions and spatial distribution of these three functional zones are illustrated in Figure 59.

After establishing the renewable energy functional zoning of the community, the next step is to carry out more detailed and systematic planning and deployment of energy equipment within each designated area.

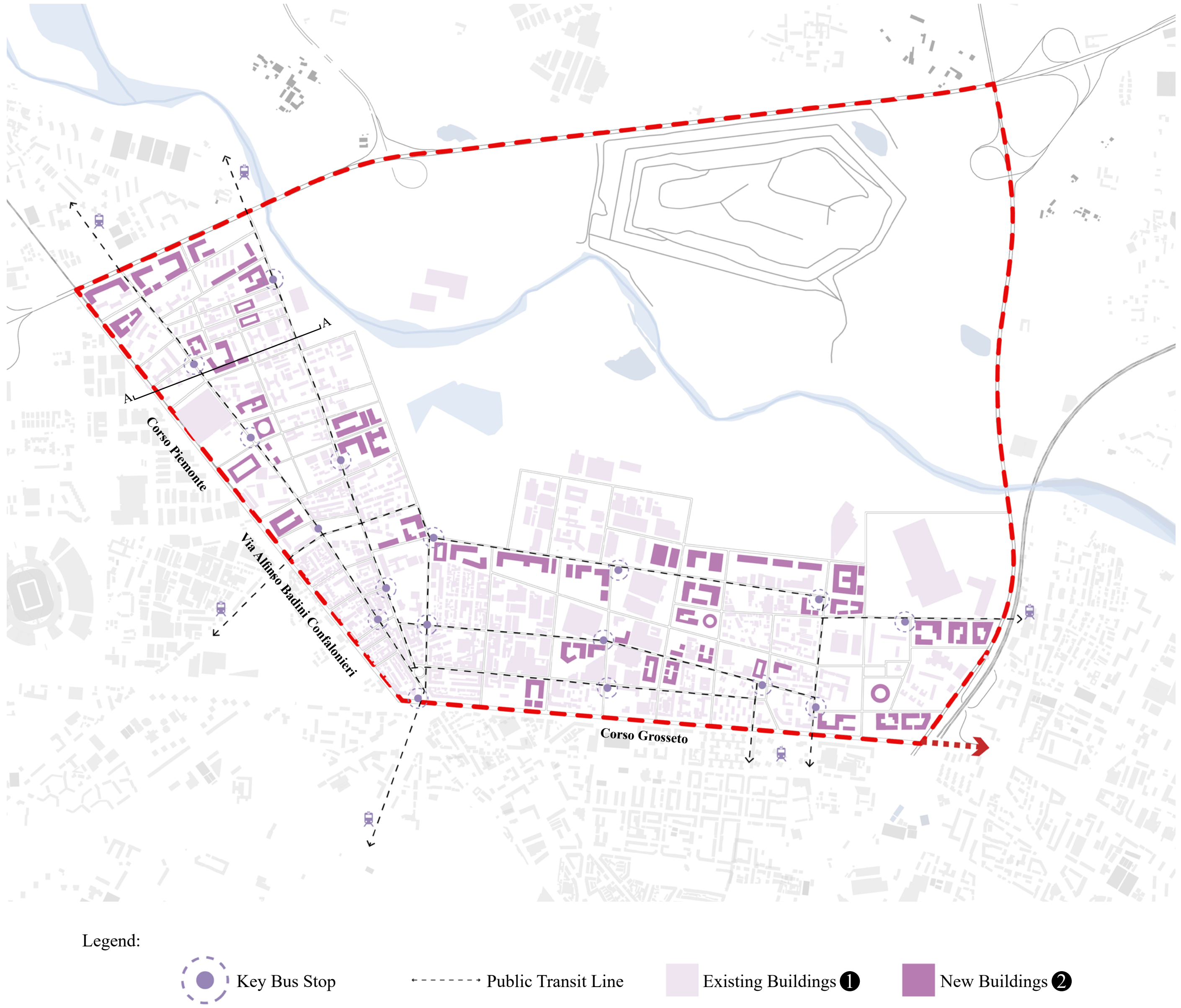


Figure 58 (a)Redeveloped Morphology of Basse di Stura with Transit and Building Structure
Source: Created by the author.

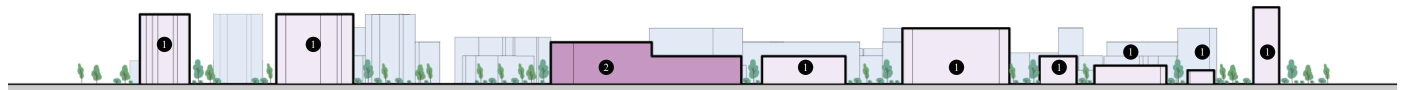


Figure 58 (b) A-A Section
Source: Created by the author.

The previous analysis of the energy potential in the Basse di Stura area highlighted its abundant solar and geothermal resources(The World Bank & Solargis, 2025). Accordingly, this study focuses on several key renewable energy technologies in the community's system planning: centralized photovoltaic power generation integrated with landscape design, solar-powered parking lots, solar rooftop installations, and geothermal heating systems.

As indicated in the previously established architectural design guidelines, the newly planned residential buildings in this area are relatively tall, making their rooftops less susceptible to shading from surrounding existing structures. This allows solar photovoltaic systems to be integrated directly into the architectural design during the construction phase. In addition, all existing commercial buildings are primarily large-scale warehouse-type structures with flat roofs, which provide ample and unobstructed space for cost-effective and efficient installation of rooftop solar panels.

During the first phase of demolition of industrial buildings, the parking lots adjacent to these buildings, which were poorly laid out, were also cleared. Therefore, in this design phase, the study comprehensively considered the parking needs within the community and the functional positioning of each functional area, and planned a large number of solar parking lots in the prosumer area. This measure not only effectively responded to the parking needs of residents and visitors but also made full use of solar energy resources to achieve the dual integration of energy supply and infrastructure functions.

In terms of the utilisation of geothermal energy, considering that old residential buildings generally have the problems of high energy consumption and poor insulation performance, this plan gives priority to the layout of geothermal equipment in residential areas and ensures that it is evenly distributed to maximise the comfort of the indoor environment for residents. In addition, during the urban design stage, the geothermal system has been allocated the same amount of space as the solar photovoltaic system to provide greater flexibility and freedom for later system installation and technical implementation. Thanks to the rational layout of the community's overall spatial structure in the early stages, the public spaces within the community are relatively spacious and possess good flexibility for future development and adjustments. Therefore, even if there is some uncertainty regarding the placement of certain geothermal points in this phase, optimisation and adjustments can be made in subsequent design stages based on specific circumstances.

And finally, the planning of the centralised solar power generation area. The Producer area offers a large amount of open space that designers can utilise flexibly. However, as this area has been designated as a 'development zone' in the overall positioning of the community's future development mentioned earlier, when arranging centralised solar power generation facilities at this stage, it is necessary to consider not only whether their location and scale can maximise the supply of electricity to the community, but also their guiding role in future urban development, so that they can serve as a bridge for subsequent development and design and lay a solid foundation for future construction.

In the analysis of the Basse di Stura area, it can be observed that the region not only features rivers and natural vegetation but also includes farmland and contaminated abandoned industrial/mining sites. These contaminated sites are located close to residential areas, and if not properly planned, they may hinder future community development(Pantaloni Giulio Gabriele, 2020; Politecnico di Torino – Dipartimento di Architettura e Design, 2025; Regione Piemonte et al., 1999). Therefore, in this planning proposal, the author has designated the entire area as a concentrated photovoltaic power plant to effectively address the issue of reusing contaminated sites and provide a clear direction for subsequent design.

Furthermore, whether in the Sustainable Development Goals or in the previous case study of the BedZED community, the importance of 'local production and local supply' in food and energy systems is evident. This approach not only provides convenience for residents but also helps the community to save energy and reduce emissions.Based on this, the design retains the farmland within the producer area and transforms it into a solar farm, which ensures a large-scale supply of clean energy while maintaining the agricultural characteristics of the land, and thus realizes multiple functions and enhances

Figure 59 (a)Renewable Energy-Oriented Functional Division: Producers, Consumers, and Prosumers in the Community
Source: Created by the author.

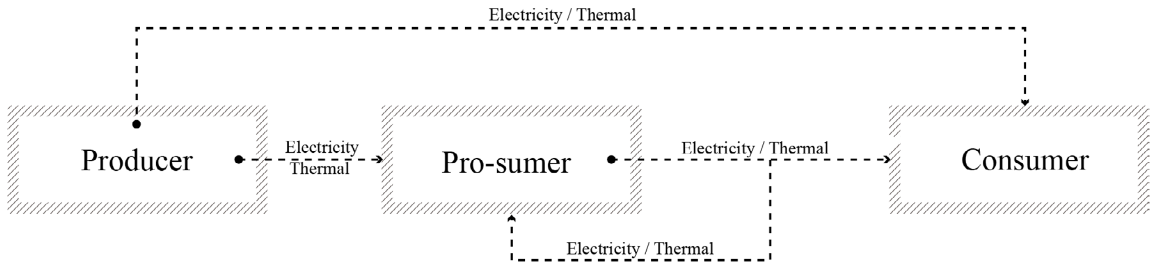


Figure (b) Energy Flow and Functional Relationship Between Producers, Consumers, and Prosumers
Source: Created by the author.

Note:Producers, Consumers, and Prosumers are the three most crucial and inextricably linked roles within renewable energy communities. Producers serve as the primary generators within the community, bearing the main responsibility for energy production. Prosumers typically refer to buildings equipped with renewable energy systems, capable of both generating energy and consuming a portion of it. Typically, when the energy generated suffices for their own consumption, surplus energy is fed into the community's energy network; should their self-generated energy prove insufficient, they draw upon a portion of the energy produced by the Producer. Consumers, constrained by their own circumstances and unable to install renewable energy systems, can only consume energy and thus constitute the primary energy consumers within the community.

its comprehensive contribution to. Through the above planning strategies, the original characteristics of some of the land have been preserved, the interference of polluted sites on subsequent development has been reduced, and a clear basic framework has been provided for the community's future landscape design, building layout, and functional zoning. Further planning based on this will help ensure the continuity and integrity of the community's future development. The Figure 60 shows the types and spatial distribution of renewable energy facilities within the community.

The final stage of this design focuses on the construction of a cycling system for the entire community. In previous designs, the community's road network, road structure, landscape system, building forms, and renewable energy systems have been systematically and comprehensively planned, with the benefits and importance of active travel emphasised in several sections.However, encouraging active mobility is not solely dependent on attracting people out of their homes through landscape systems, public buildings, or vibrant ground-floor commercial spaces, nor is it simply a matter of constructing a bicycle lane to effectively promote cycling behaviour among residents(Horton et al., 2024; Litman, 2003). The United Nations Human Settlements Programme (UN-Habitat) has placed 'urban rights' at the core of its New Urban Agenda, emphasising fair, safe, and sustainable mobility(Habitat III Secretariat, 2017). In my view, 'safe cycling in cities' can also be considered part of 'urban rights.' Achieving this goal hinges on building a safe, convenient and coherent cycling transport system that enables residents to truly enjoy their own urban space and mobility rights.

Safe cycling networks in cities and communities not only help improve the safety of transportation systems, but also enhance the overall comfort of public spaces and improve the travel experience for cyclists. More importantly, creating a safer and more friendly cycling environment for cyclists helps citizens 'reclaim' the public space that belongs to them from cars, allowing spacious and pleasant streets to return to everyday life. As pointed out by (UN-Habitat, 2025), cycling is not only closely related to the construction of healthy public spaces but also inextricably linked to the creation of vibrant communities. When it becomes safer, more convenient, and more comfortable to cycle, people will be more inclined to choose cycling as their daily mode of transport, which in turn will effectively reduce dependence on private cars and alleviate urban congestion. While creating a quiet and pleasant street environment, this initiative will also further stimulate social interaction and retail vitality within the street space. These positive changes, as envisioned in the previous discussion on landscape systems and ground-floor commercial space design, will create a virtuous cycle through the interconnected and mutually reinforcing interaction of every level of the space, ultimately fostering a more livable and vibrant living atmosphere for the entire community(Graells-Garrido et al., 2021; W. E. Marshall & Garrick, 2010; Pucher & Buehler, 2010).

So, how can we design a truly safe and effective cycling network? The Dutch *CROW Cycling Traffic Design Manual* proposes five basic design principles: cohesion, directness, safety, comfort, and attractiveness(CROW, 2016). Among these, 'cohesion' emphasises that cycle lanes should form a complete, interconnected network to reduce traffic obstacles and improve accessibility within the community, while 'directness' requires that cycling routes should be efficient and convenient. If the routes are too winding or long, it will be difficult to encourage citizens to choose cycling as their primary mode of transport.

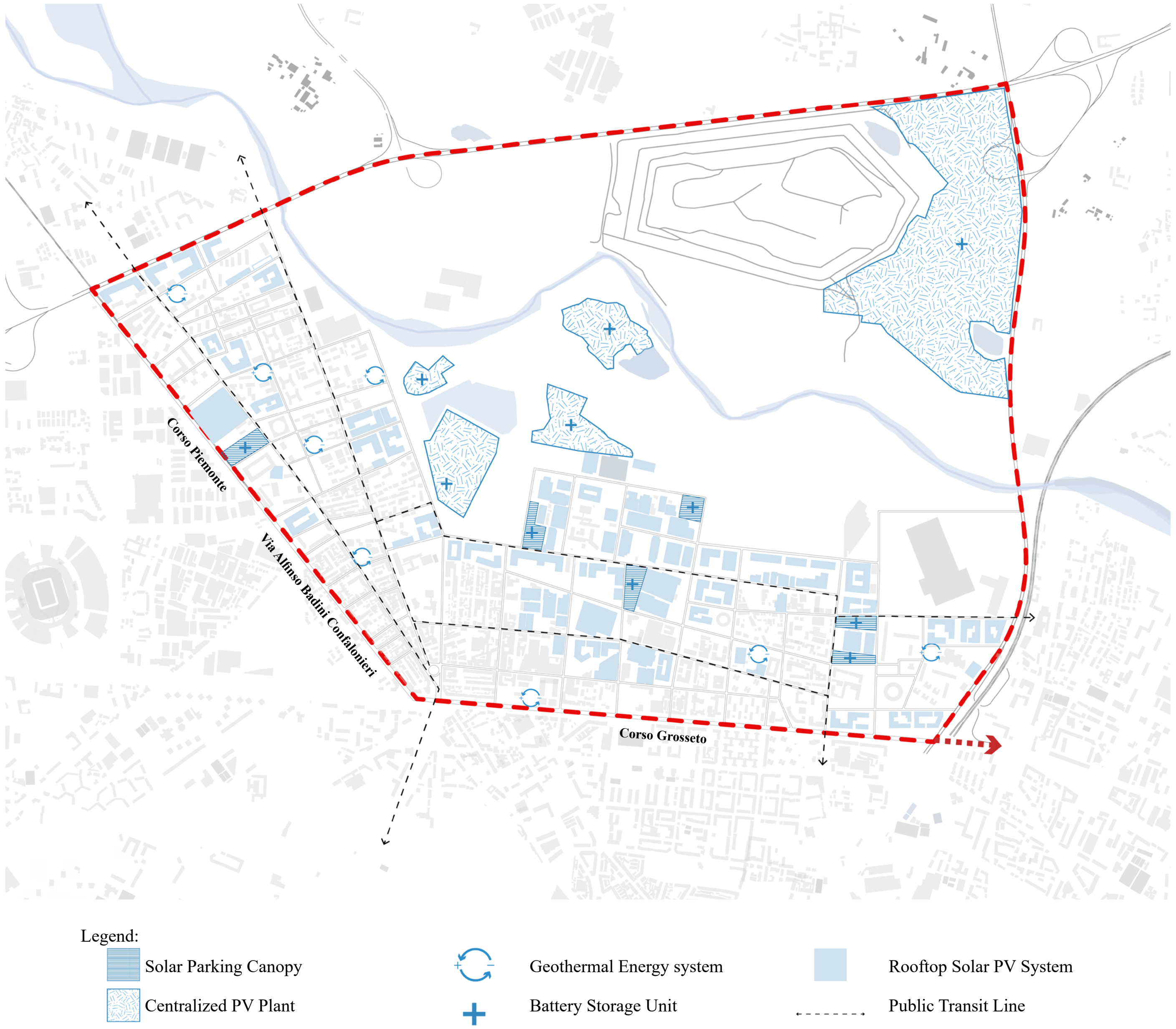


Figure 60(a) Spatial Distribution of Renewable Energy Systems in the Basse di Stura Community
Source: Created by the author.

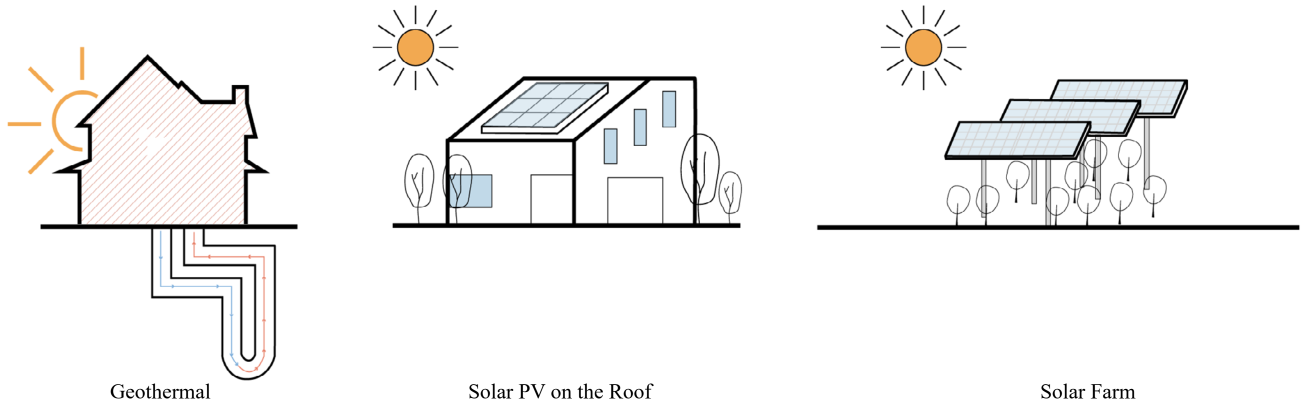


Figure 60(b) Conceptual Diagram Renewable Energy Technologies
Source: Created by the author.

Note:The above analysis diagram serves solely to illustrate the types of renewable energy technologies selected within the community. Detailed implementation requires further design refinement based on specific buildings and sites.

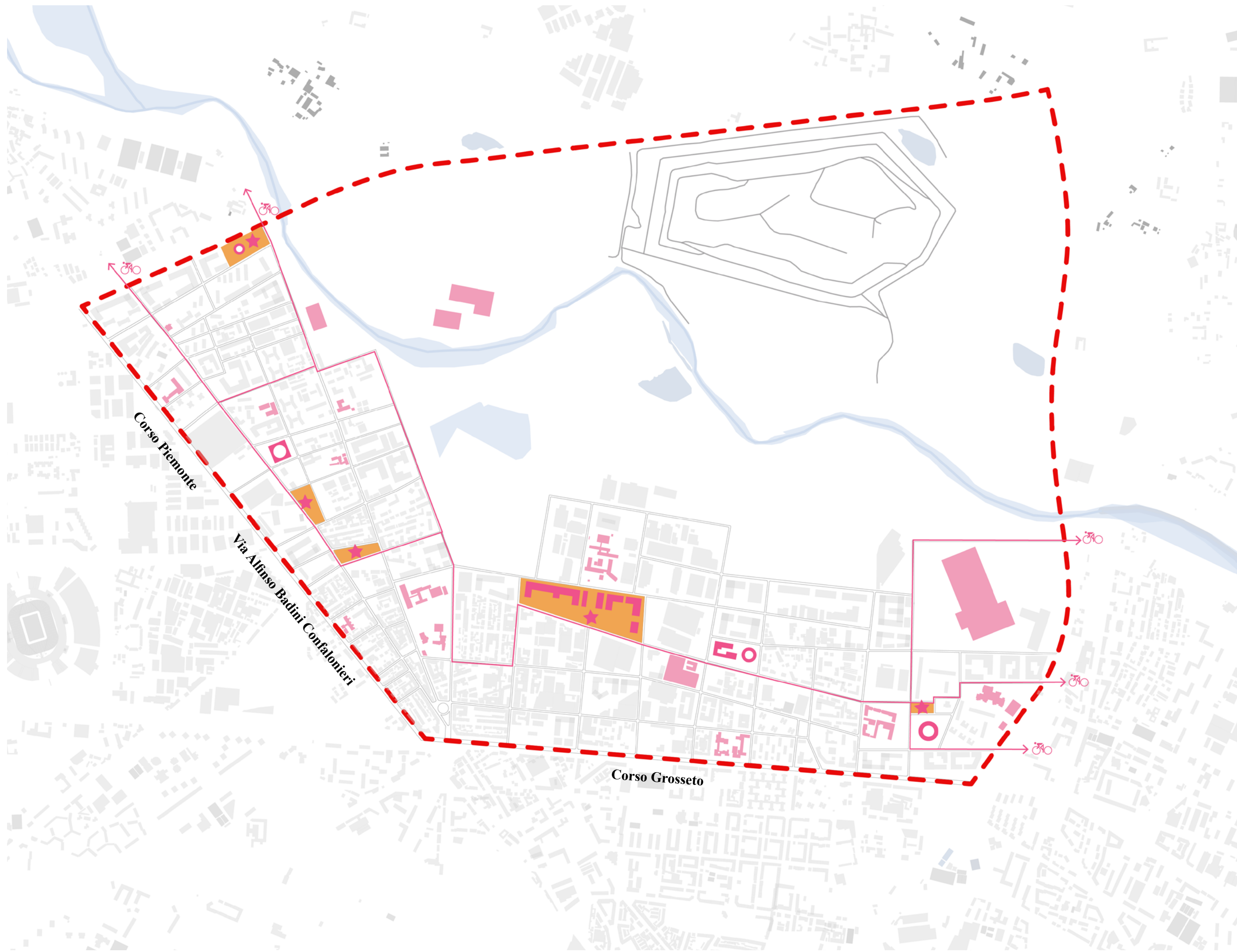
For instance, building-integrated solar systems need not be confined to rooftops; they may also be designed to integrate with the building envelope.As the ancient capital of China during the six dynasties, Nanjing is a city with a strong

It is considered in this study that safety is the most fundamental and critical aspect. Only through well-planned separation of bicycles from motor vehicles and pedestrians can riding safety be ensured. Without a safe environment, even the most scenic or efficient routes will be avoided. Comfort and attractiveness are also essential for expanding the cycling population and encouraging daily use. Integrating cycling paths with the landscape system and avoiding unnecessary slopes allows even those with limited physical ability to cycle comfortably. Meanwhile, a pleasant and visually appealing cycling environment helps embed cycling into daily life—not only as a practical mode of transportation but also as an enjoyable and meaningful leisure activity(Banister, 2008; Gobster & Westphal, 2004; Litman, 2003; Pucher & Buehler, 2010).

Accordingly, in designing the cycling network for the BdsREC, all roads within the site were systematically upgraded to include safe and spacious bike lanes, thereby achieving coherence, safety, and accessibility in the overall cycling infrastructure. As this aspect was already addressed in the earlier road network design, it will not be repeated here. Building on this foundation, and to further encourage residents to adopt cycling as a primary mode of transport, a main cycling network has been developed, as shown in the Fugure 61. This network is aligned with the community's major public transportation routes, ensuring the directness and efficiency of travel. Additionally, the design carefully integrates key public spaces, landscape nodes, the central landscape axis, green corridors, and major community buildings—creating a cycling experience that is not only functional but also visually engaging and emotionally pleasant. This system will not only provide residents with an attractive and pleasant cycling experience, but also improve the accessibility of public spaces and buildings by bicycle, thereby further activating the frequency of use of these public spaces, enhancing social interaction among residents, and promoting the positive development of community life(Mehta, 2009).

In this phase, this study gradually presents the overall design concept and steps. Through a systematic analysis of the importance, design logic, and reasons behind each link, it gradually constructs the overall blueprint of the BdsREC at the planning and design level. The study focuses on multiple dimensions, including the road system, landscape structure, building forms, renewable energy systems, and cycling networks, clearly presenting the design outcomes at various levels. Ultimately, all elements are integrated and overlaid to form a comprehensive master plan for the community and a vision for its future development.

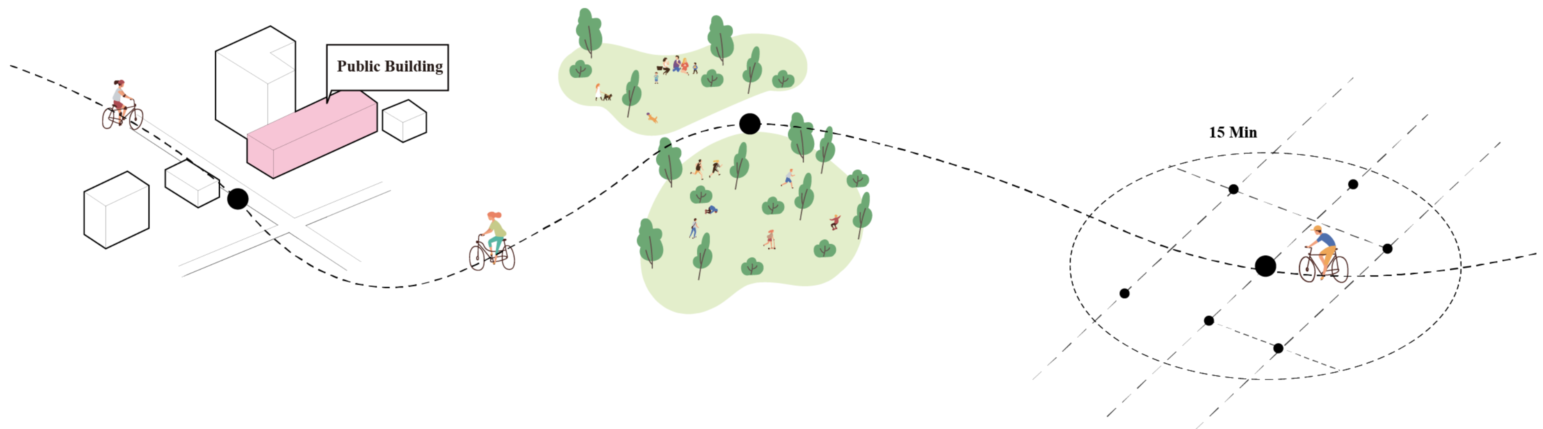
This master plan not only paints a beautiful picture of the future development of the community for residents, but also provides clear guidance for subsequent detailed design and planning work. It helps to truly return urban space to residents, creating a comfortable, energy-sufficient, sustainable community powered by renewable energy. The final master plan for the community is shown in Figure 62.To better demonstrate the post-design community effect and the harmonious coexistence of new and existing buildings, residential structures, public buildings, and RESs, this study selected Zones A and B to showcase their final outcomes, as depicted in Figures 63 and 64.



Legend:

Cycling Route | Existing Public Building | New Public Building | Key Public Space

Figure 61(a) Public Infrastructure and Cycling Network in the Basse di Stura Community
Source: Created by the author.



Note:The cycling network within the community weaves along key landscape axes, connecting and activating public buildings as well as green public spaces throughout the neighborhood.

Additionally, it ensures seamless connectivity with the rest of the community, facilitating the formation of a 15-minute living circle.

Figure 61(b) Key Functions of Cycling Network in the Basse di Stura Community
Source: Created by the author.

Figure 62 Master Plan of BdsREC
Source: Created by the author.

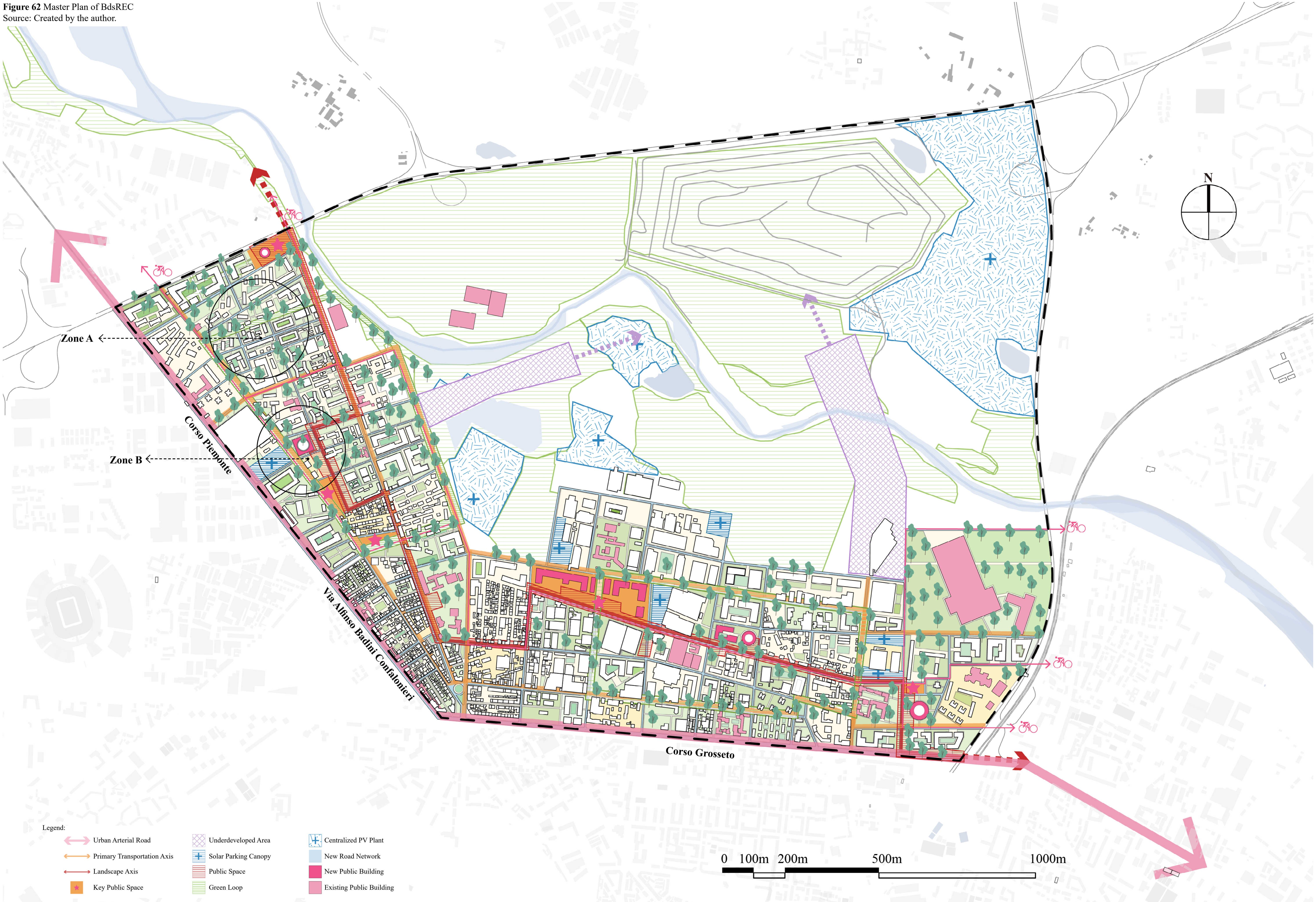


Figure 63 Axonometric View of Zone A
Source: Created by the author.

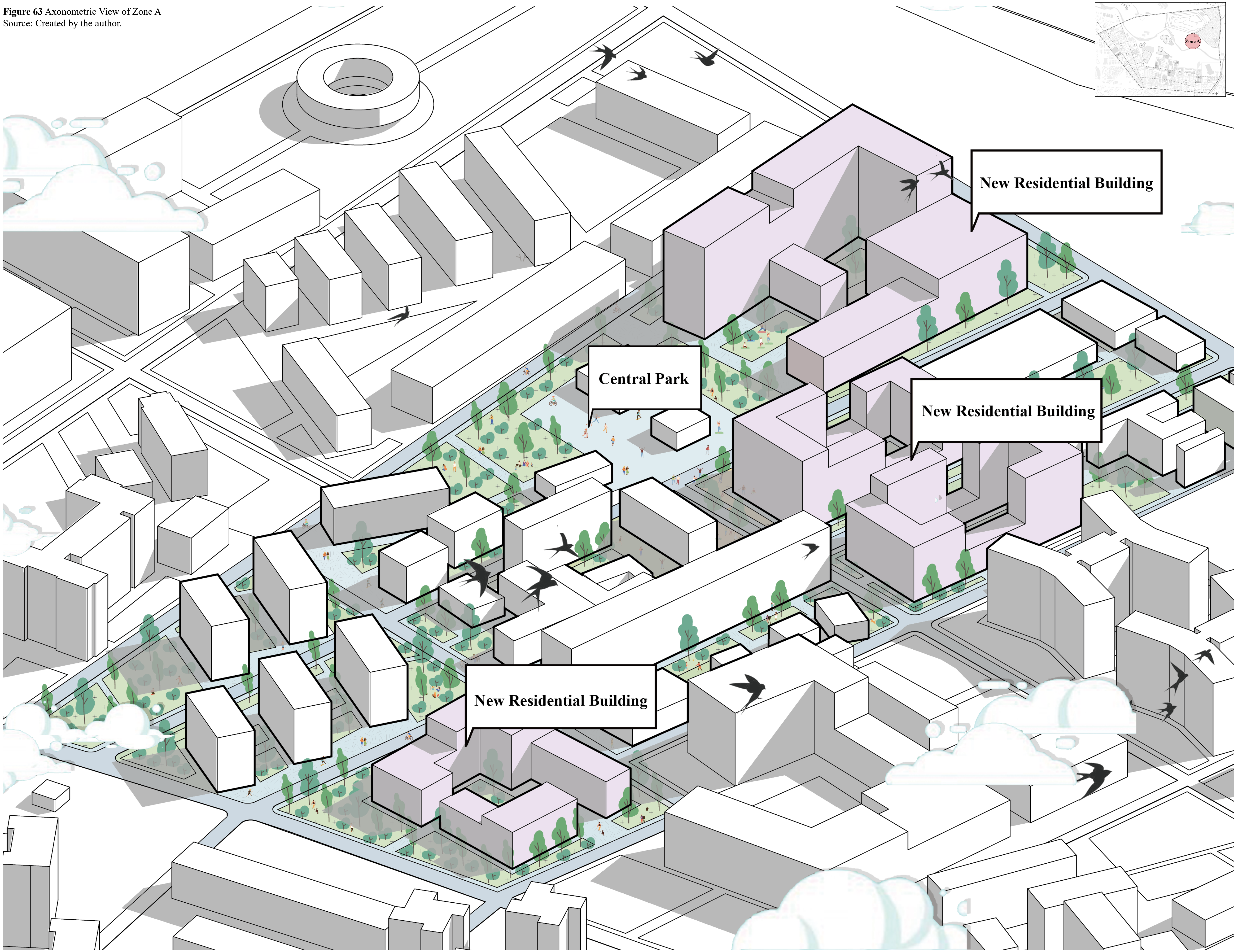
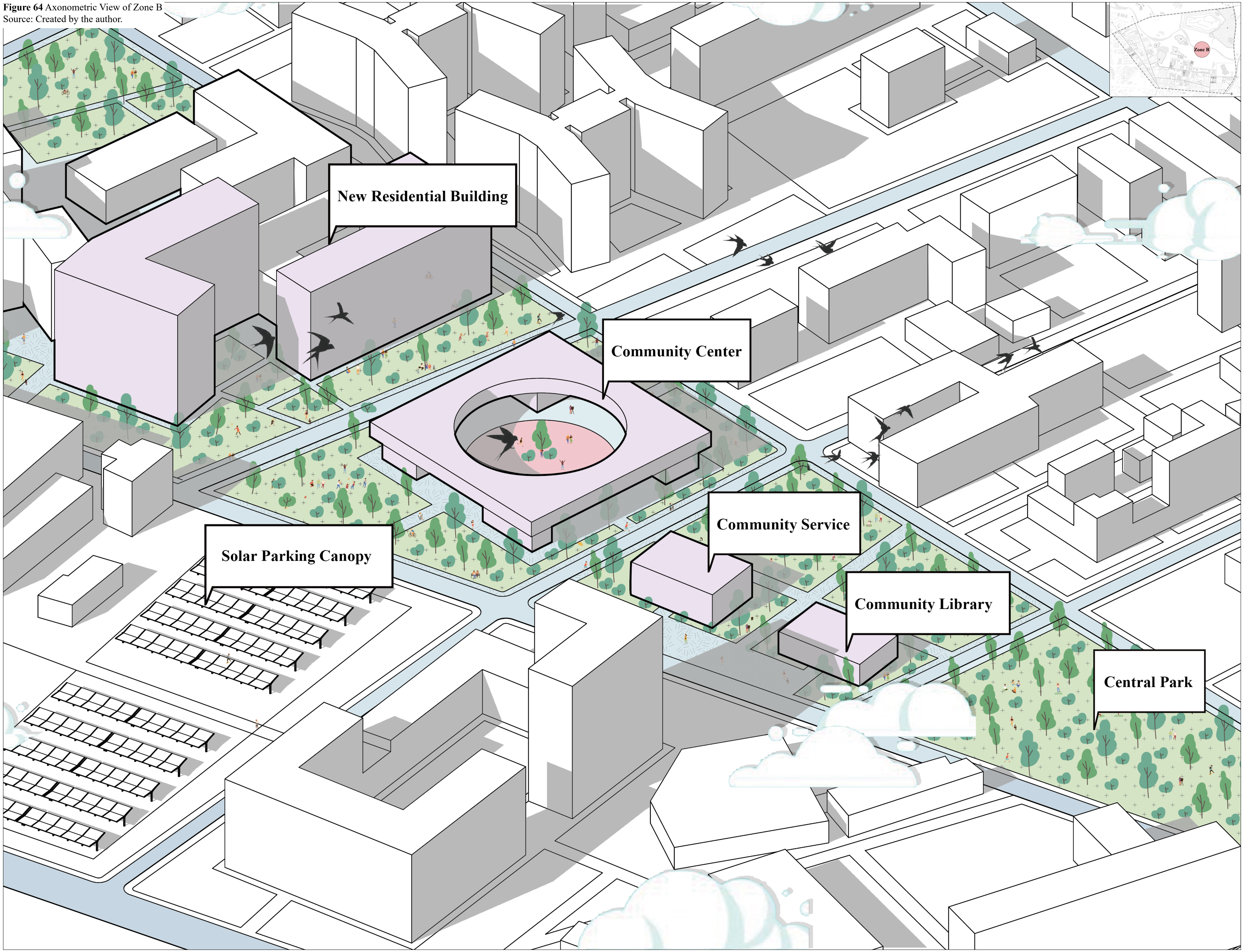


Figure 64 Axonometric View of Zone B
Source: Created by the author.



6.Evaluating the Renewable Energy Community Design: *Reflections and Outcomes*

After completing the urban design plan for the REC in the Basse di Stura area, it is necessary to conduct a preliminary feasibility assessment. As outlined in the previous chapter on the steps and elements of urban design for this community, this project covers multi-dimensional spatial design content such as road optimisation and urban space optimisation. However, the ultimate effectiveness of these elements is often not directly quantifiable, making it difficult to make a clear judgment on feasibility(White, 2015). In contrast, as one of the core elements of a REC, the potential energy output of RECs can be estimated through preliminary calculations, providing clear quantitative results that directly reflect the feasibility of the design scheme in terms of renewable energy utilisation.

In the process of conducting the current situation analysis and urban design for the Basse di Stura area, this study has carried out an in-depth exploration of the use of renewable energy in the region, ultimately determining an energy system layout with solar energy as the primary source and geothermal energy as a supplementary source. However, the amount of energy that the geothermal system can supply to the community depends not only on the planned location and area of the geothermal fields in the urban design, but also on several other factors, including the type of borehole configuration adopted, the capacity of the selected heat pumps, and the community's actual thermal energy demand (Brown et al., 2024; European Geothermal Energy Council, 2008). As these key parameters have not yet been defined at the urban design stage, it is difficult to reasonably estimate the geothermal system's energy supply at this point. Therefore, in the feasibility analysis of the BdsREC's renewable energy system, the calculation scope is limited to the solar energy system, and its quantified results are used as the basis for a preliminary feasibility assessment of the overall design proposal.

Given that this study is still at the urban design stage, it is neither feasible nor necessary to conduct an hourly energy consumption simulation for all buildings in the community. To estimate the annual electricity generation of the community's solar photovoltaic system at the community scale, this study adopts the calculation formula (1) provided in the Italian technical standard UNI/TS 11300-4(UNI, 2016). This formula has been widely applied in calculating the contribution of renewable energy in building energy performance assessments and is here used to estimate the annual electricity generation Epv of the community's PV system:

$$E_{pv} = \frac{H_y \cdot W_{pv} \cdot f_{pv}}{I_{ref}} = \left[\frac{\mathrm{kWh_{el}}}{\mathrm{a}}\right] \qquad (1)$$

Where:

H_y: total annual solar radiation (per square meter) on the surface of the panels [kWh/m²per year]

W_{pv}: total effective area of mountable panels [m²]

f_{pv}: the system efficiency factor which takes into account the global efficiency of the photovoltaic system considering the losses due to the presence of inverters and the real temperature of the photovoltaic cells

I_{ref}: reference solar irradiance equal to 1kWm²

Since the solar photovoltaic system in this community includes three different types—rooftop, parking lot, and solar farm—and the parameters used in formula (1) to calculate the final output value of the solar photovoltaic system depend on the local geographical location, climate conditions, available installation area, and the technical characteristics of the selected photovoltaic system, it is necessary to determine the value of each parameter separately before obtaining the final result.Before determining the parameter values, it is necessary to first select a photovoltaic module model as a reference for subsequent preliminary calculations. After comparing and analysing multiple photovoltaic modules widely produced and applied across Europe, the Hanwha Q CELLS Q.PEAK DUO 400W monocrystalline silicon module[23], which is widely used in residential and commercial projects in Italy, was selected as the reference model for subsequent calculations..

[23] Hanwha Q CELLS Q.PEAK DUO 400 W monocrystalline PV module, half-cell design (132 cells), module efficiency ~20.4%, dimensions 1879 × 1045 × 32 mm, weight 22 kg, power temperature coefficient −0.34%/K

a) Annual in-plane solar irradiation H_y

The annual incident solar irradiation H_y refers to the total amount of solar energy received on the plane of the photovoltaic (PV) modules over the course of one year, under given tilt and azimuth conditions(UNI, 2016). This parameter depends solely on the climatic conditions of the geographic location and on the tilt and azimuth angles of the PV modules, and is independent of the installation type. Therefore, to simplify the quantitative assessment of solar resources at the urban design stage in this study, it is assumed that the mounting tilt and azimuth of PV modules are identical for rooftop PV systems, PV carports, and solar farms. Under this assumption, the H_y values are the same for all three installation types.

Based on the above simulation principle, the PVGIS tool (European Commission, Joint Research Centre) was used to perform a preliminary simulation for PV modules in the Basse di Stura community of Turin, Italy, in order to obtain annual incident irradiation data under the specified tilt and azimuth conditions. The corresponding simulation results are shown in the Figure 63.

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	90.9	107.9	14.8
February	97.2	118.0	15.8
March	127.1	158.9	16.3
April	128.3	165.1	16.8
May	134.8	177.3	12.7
June	138.0	185.5	10.2
July	151.0	205.7	8.6
August	144.7	196.0	7.5
September	123.6	162.7	7.9
October	98.0	123.4	12.3
November	77.6	94.7	16.2
December	82.0	97.5	12.3

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Figure 63 Monthly PV electricity production and in-plane solar irradiation in the Basse di Stura community, Turin
Source: PVGIS © European Union, 2001–2025. Report generated on 29 July 2025 using PVGIS-SARAH3 database, crystalline.

Based on the simulation results, the average monthly incident solar irradiation H_i for the Basse di Stura community in Turin can be obtained under the specified tilt and azimuth conditions. By summing the H_i values for all twelve months, the annual incident solar irradiation H_y can be derived, as expressed in equation (2):

$$H_y = \sum_{i=1}^{12} H_i \quad (2)$$

b) Available PV installation area W_{pv}

Given that the calculations at this stage are preliminary estimates and do not yet involve detailed design and precise computation, the assessment of the installable area for PV installations in the community was nevertheless divided into three categories according to the differences in installation types, in order to ensure the rationality of the quantitative results:

$$W_{PV} = \{W_{pv1}, W_{pv2}, W_{pv3}\}$$

Where:

W_{pv1}: PV panel area of rooftop

W_{pv2}: PV panel area of solar carports

W_{pv3}: PV panel area of solar farms

The calculation methods for these areas are as follows:

1) Rooftop PV system

In estimating the available area for rooftop PV panels, this study draws on the research findings of Georgia Kakoulaki, Nigel Taylor, and others regarding rooftop PV potential in the European Union. Following the work of (Bódis et al., 2019), their study assumes that approximately half of all rooftops are suitable for PV installation. Based on this, by considering factors such as the spacing between photovoltaic modules, excluding roof areas with unfavourable orientations, obstructions from other buildings, and roof maintenance access routes, the study ultimately concluded that the area of photovoltaic panels that can be installed on each building accounts for approximately 26% of the total roof area(Kakoulaki et al., 2024). Accordingly, this study adopts equation (3) to calculate the rooftop PV panel area W_{pv1} for the BdsREC:

$$W_{PV1} = S_{roof} \cdot 26\% \quad (3)$$

Where:

S_{roof}: the total roof area available for PV panel installation[m²]

2) Solar parking carport

In calculating the area of PV panels that can be installed on solar carports, this study likewise adopts the method of applying a utilization factor for a preliminary estimation of PV installations in this category. (Julieta et al., 2022) conducted a comprehensive analysis and comparison of multiple real-world cases, ultimately selecting a relatively realistic and conservative proportional factor of 35% for estimating the PV-installable area of parking lots. On this basis, the method used in this study to calculate the PV panel area of solar carports (W_{pv2}) is expressed in equation (4):

$$W_{PV2} = S_{parking} \cdot 35\% \quad (4)$$

Where:

$S_{parking}$: the total parking lot area available for PV panel installation[m²]

3) Solar farm

The deployment of PV systems can take various forms, which are mainly classified into three categories. Among them, the first two—rooftop systems and infrastructure-integrated PV—have been addressed earlier as rooftop PV panels and PV carports, respectively. The solar farms calculated in this subsection fall under the third category, namely ground-mounted systems(Chatzipanagi et al., 2023).

The energy yield of ground-mounted PV systems varies depending on factors such as module technology, material selection, and installation layout design. Recent assessments of ground-mounted PV systems indicate that their global average energy yield is approximately 0.87 MWh/ha (Bolinger & Bolinger, 2022). In the case of agrivoltaic systems, the latest guidelines from Fraunhofer ISE suggest a potential installed capacity of around 0.25 MW/ha, while Next2Sun reports that its grassland-deployed agrivoltaic systems can reach 0.4 MW/ha. Overall, across various operational agrivoltaic projects, the achievable installed capacity typically ranges from 0.2 to 0.9 MW/ha, depending on the specific technology pathway and design approach adopted (Chatzipanagi et al., 2023; Ise, 2022). To ensure the reference value and reliability of the subsequent calculations, this study adopts the value reported by (Chatzipanagi et al., 2023), assuming a PV panel installation density for solar farms of Dinst=0.6MW/ha. Accordingly, the calculation method for the available PV panel area of solar farms (W_{pv3}) is given in equation (5):

$$W_{pv3} = \frac{D_{inst} \cdot S_{farm}}{P_{mod}} \cdot A_{mod} \quad (5)$$

Where:

D_{inst}: installation density of PV panels in the solar farm, set here at 0.6MW/ha

S_{farm}: total area of the solar farm[ha]

P_{mo}: rated power of a single PV module [kW]; the rated power of a single Hanwha Q CELLS Q.PEAK DUO 400W monocrystalline module is 0.415 kW

A_{mod}: surface area of a single PV module [m²]; the surface area of a single Hanwha Q CELLS Q.PEAK DUO 400W monocrystalline module is 1.96 m²

c) Performance ratio f_{pv}

As mentioned at the beginning of this chapter, the Italian technical standard UNI/TS 11300-4 defines the system efficiency factor fpv as a coefficient that accounts for the overall efficiency of the PV system, the performance of the inverter, and potential efficiency losses of the modules under actual operating temperatures, and is used to calculate the effective power generation capacity of the PV system (UNI, 2016). Referring to the coefficient value table provided in UNI/TS 11300-4 (see Figure 64), it can be observed that the f_{pv} values vary depending on the ventilation conditions of the PV modules: when modules operate under poor ventilation conditions (e.g., building-integrated PV modules installed flush with the roof), f_{pv} is 0.70; when modules are in moderately ventilated conditions, f_{pv} is 0.75; and under well-ventilated conditions or when forced ventilation measures are applied, the coefficient can be increased to 0.80.

Valori del fattore di efficienza f_{pv}

Grado di ventilazione dei moduli fotovoltaici	f_{pv} [-]
Moduli non ventilati	0,70
Moduli moderatamente ventilati	0,75
Moduli molto ventilati o con ventilazione forzata	0,80

Figure 64 Values of the system efficiency factor f_{pv}
Source: (UNI, 2016).

Within the scope of this research, the three types of PV systems can be classified into two categories according to their ventilation conditions. As the planned solar rooftops in the community are all flat roofs, their ventilation conditions can be considered moderate; therefore, the system efficiency factor f_{pv1} for rooftop systems is set at 0.75. In contrast, both solar carports and solar farms are located in open environments with good natural ventilation, so their system efficiency factor f_{pv2} is set at 0.8(UNI, 2016).

In summary, after determining the calculation methods and values for each parameter, the total annual electricity generation of the community's solar PV system can be calculated as follows:

$$E_{total} = E_{pv1} + E_{pv2} + E_{pv3} = H_y \cdot \frac{(W_{pv1} \cdot f_{pv1} + W_{pv2} \cdot f_{pv2} + W_{pv3} \cdot f_{pv2})}{I_{ref}} \qquad (5)$$

By substituting the above parameters into equation (5), the total annual electricity generation of the community's PV system is calculated to be E_{total}=210.34GWh/year. To provide a more intuitive evaluation of this quantitative result, a preliminary estimation of the building energy consumption in BdsREC was conducted. According to the *Energy Use in Buildings – EU Buildings Factsheet* published by the European Commission, the average annual specific energy consumption of residential buildings in the EU is approximately 180 kWh/m²(European Commission, 2016). Based on the total building floor area calculated in this study, the total average annual energy consumption of BdsREC is estimated at approximately 415.16 GWh/year.

Based on current estimates, even without further systematic optimisation of the solar photovoltaic system within the community and without incorporating geothermal energy, the planned photovoltaic system in this community will be able to cover approximately half of the annual energy consumption. This indicates that, with more in-depth system design and the development and utilisation of geothermal energy, BdsREC has the potential to achieve a higher degree of energy self-sufficiency. In addition, in the early stages of urban design, both the urban spatial layout and the planning of RESs have been designed with a high degree of flexibility and room for adjustment. This not only enables the community to effectively support its operations through RESs in the present, maximising energy self-sufficiency and flexible development, but also ensures that it can comfortably upgrade and adjust its systems in response to future technological advances and technical iterations, thereby

maintaining long-term sustainability.

In conclusion, through quantitative calculations and comparative analysis in this chapter, it can be clearly determined that the urban design plan proposed in this study is feasible in terms of renewable energy utilisation and community sustainability.

7.Conclusion

This study is situated against the background of global efforts to address climate change, mitigate the energy crisis, and promote the transition towards renewable energy and low-carbon urban development. With the acceleration of urbanisation, cities have become a key area for addressing climate and energy challenges. Due to dependence on fossil fuels, energy and climate issues have evolved into global concerns. The primary approach to addressing these challenges is to shift energy use towards clean, sustainable, and low-carbon RESs(Ahmed et al., 2024; European Commission, 2020; International Energy Agency, 2021; Sancino et al., 2022; United Nations, 2019).

To achieve the 2050 carbon neutrality target, the European Union introduced the concept of RECs(European Union, 2018). As this study progressed, this study has identified the potential to re-examine RECs from an urban design perspective and integrating their design principles into the urban design phase. This approach aims not only to create efficient and sustainable RECs but also to achieve broader goals of urban sustainability. RECs can drive the green transition of energy systems in urban regeneration areas and serve as an important means of addressing multiple urban challenges. Urban design, in turn, serves as the spatial vehicle for realising energy functions, forming the essential foundation for establishing mature and efficient RECs while ensuring their long-term operation and development.

As the research progressed, Basse di Stura area, has emerged as a unique and representative opportunity for exploring urban design approaches to RECs. Using this area as a case study, the research systematically presents the full process—from design concepts and methodology to final outcomes—and followed by a quantitative analysis and feasibility assessment of the proposed scenario. The ultimate goal is to establish a strategic framework through this comprehensive design and evaluation process, that integrates the planning and design of RESs into the urban design stage, thereby providing a reference for future related practice.

Based on the overall research results, the following findings can be summarised:

Finding 1: Although research on urban design and RECs has reached a relatively mature stage, studies that truly integrate the two is still in the early stages of development. Such integration has not yet attracted widespread attention in the academic community and still lacks a systematic and in-depth research results to support its development.

Finding 2: Case studies indicate that even when renewable energy technologies are relatively mature, achieving energy self-sufficiency and long-term sustainability in a community still requires allocating sufficient and flexible space for RESs during the early planning and design stage. This ensures that the strategies can be adjusted according to different conditions and challenges during implementation.

Finding 3: Although case studies emphasise the importance of preliminary planning and design, it can still be observed in actual planning and subsequent quantitative calculations that the development of renewable energy technologies has not yet been effectively integrated into the preliminary planning stage of urban design. Taking the planning of geothermal resources as an example, it is difficult to reasonably estimate their potential capacity in the early stages, and it is also difficult to accurately judge the suitability of their spatial layout.

7.1 Relevance of Findings

As demonstrated by the research findings summarised in the previous section, the intersection field between RECs and urban design remains in the early stages of development, with significant gaps in both academic research and practical application. These gaps mean that even in the face of strategic goals for low-carbon urban transformation or the urgent demands of sustainable urban regeneration, urban designers still struggle to seamlessly integrate the planning and design of RESs into the urban design process. The most fundamental reason lies in the significant disconnect between the development of renewable energy technologies and the practice of urban design.

From the functionalism advocated in the *Athens Charter*, to Aldo Rossi's in-depth studies on urban form, and to the contemporary explorations driven by sustainable development and carbon neutrality goals, the evolution of urban design has undergone generations of refinement and is now approaching maturity.(Mehaffy & Low, 2018; Oktay Derya, 2015). Similarly, studies such as (Beckman, 2013) and (European Geothermal Energy Council, 2008) indicate that renewable energy utilisation technologies have also reached a relatively mature stage. However, in order to fully realise the potential of renewable energy and ensure its sustainable development, it is essential to provide suitable spatial locations and supportive conditions at the planning level to maximum the utilisation of natural resources, while preserving sufficient flexibility and freedom for future development.

In practice, technological progress and application are often passively adapted to existing conditions and constrained by land availability, environmental factors, and infrastructure limitations. These constraints not only reduce the efficiency of renewable energy utilisation but also the effectiveness of its technological applications. Moreover, the capacity assessment of RESs typically requires the designs to reach a more advanced stage before accurate figures becomes availiable. This means that in the early stage, there is a lack of preliminary estimation tools that can support strategic planning and feasibility assessments(Kammen & Sunter, 2016; Schmid et al., 2025).

Due to the absence of research integrating renewable energy technologies with urban design, this issue has persisted for a long time, making it difficult to effectively evaluate the feasibility of RES layouts and strategies during the urban design stage. As a result, technological development, urban design, and RES planning form mutually constraining and influencing cycle, where shortcomings in any one of these aspects can weaken the overall effectiveness of the practical outcomes and hinder the achievement of sustainable development goals.

In this context, new measures are urgently needed to break this vicious cycle, promote positive interactions that can drive the further development of renewable energy technologies, while expanding urban design concepts and methods to create new strategic frameworks. This will more effectively contribute to achieving carbon neutrality targets and addressing the diverse urban challenges in today's societal context.

By analysing the intrinsic connections among the three research findings outlined above, and combining them with the overall outcomes of this study, it is also possible to answer the three core questions raised in the analysis of the research objectives in the *Introductio*n section.

Q1: What is a renewable energy community, and why is urban design essential to its development?

From an urban design perspective, a REC refers to an area in which renewable energy technologies are organically integrated with elements such as urban space and buildings, thereby achieving energy self-sufficiency, low carbon emissions, and a balance between economic benefits and environmental sustainability(Caramizaru, n.d.; Robinson, 2022). Since the efficient use of RESs depends on their installation sites and locations—which are fundamentally components of urban space—urban design can be employed in the early stages to analyse, plan, and strategically allocate these systems. This approach maximises energy utilisation efficiency and lays a solid foundation for their long-term sustainable development(Paatero & Lund, 2007; Passey et al., 2011; Ramirez Camargo & Stoeglehner, 2018).

Q2: How can renewable energy system design be incorporated into the urban design process to facilitate the creation of renewable energy communities?

From the design concepts and implementation steps proposed in the conceptual design phase, it can be seen that, during the urban design stage, a comprehensive analysis of the renewable energy resources available at the proposed site should first be conducted. The aim is to identify which types of renewable energy can be adopted in the area. Based on this, the corresponding measures can then be defined. Subsequently, preliminary planning and layout of the selected RESs should be carried out, with appropriate choices made regarding equipment types and installation locations. On this basis, the layout of RESs should be integrated into the overall urban spatial planning. Their spatial scope and configuration need to be optimised to maximise the use of local renewable energy resources. At the same time, the structure and function of the urban space should not be compromised. Ideally, these systems should also be organically integrated into urban landscape design, allowing them to become an integral part of the urban space that combines functionality and aesthetic value. In this way, the design can not only meet the construction requirements of RECs, but also align with and promote the sustainable development of urban space, while reserving sufficient and flexible adaptive capacity for the long-term sustainable operation of both the region and its RESs

Q3: How to evaluate the feasibility of the conceptual design?

In this study, although the design proposals involved updates and modifications to elements such as urban space and road networks, these aspects are difficult to quantify and therefore cannot be directly integrated into the feasibility assessment(White, 2015). Therefore, the research focused on the core component of the RECs—the renewable energy systems—and conducted a preliminary evaluation of their annual energy output. To enable readers to more directly and conveniently understand the quantitative data represented by the design results, to clearly grasp the conclusions of the feasibility assessment, and to provide a reference value for subsequent feasibility analyses, this stage also introduced an estimation of the community's overall energy consumption. By comparing the potential energy output of the designed RESs with the estimated total energy consumption of the whole community's buildings, it was possible to make an initial assessment of the overall feasibility of the proposed scenario at an early stage.

7.2 Limitations

In the *Introduction* section of this study, the overall framework of the research methodology has been briefly summarised and analysed, with the following sequence: literature review → identification of research problems and study area → site analysis → case study analysis → proposal development → feasibility assessment. While this methodological framework is clear in structure and rigorous in logic, certain limitations exposed during its practical application. This chapter will examine these limitations in depth from three perspectives: data collection and sampling, quantitative assessment and urban design.

7.2.1 Data Collection and Sampling

In the literature review stage, this study aimed to gain a comprehensive understanding of the current state and development trends in this cross-disciplinary field. The focus was on integrating renewable energy community design into urban design. For this purpose, the Scopus database was used as the primary source for literature retrieval and analysis. To ensure that the search results were highly relevant to both RECs and urban design, the keywords used in the search were strictly defined. However, due to the relatively narrow scope of the selected keywords and reliance on a single database, some relevant studies may not have been identified, which may have, to some extent, limited the comprehensiveness of the assessment of the overall current state and future trends in this filed.

In the subsequent research stage, in order to provide both theoretical and practical support for the proposed design concepts and methods, two representative and classic cases were selected for analysis. Although these cases hold a certain degree of reference value in this field, the limited number of cases means that, even after detailed comparison and analysis, the design methods and strategies derived from them may still be somewhat biases. Additionally, the selection of Basse di Stura as the study area was intended to demonstrate the complete design process and to offer direction and reference for future research. However, conducting the design work based on a single study area, even after feasibility assessment, may still lead to a degree of selection bias, thereby affecting the generalisability of the research findings to some extent.

7.2.2 Quantitative Assessment

In the quantitative analysis and feasibility assessment of the final design results, a unified configuration scheme was applied to all solar photovoltaic systems in order to simplify the calculation process. Although validated reference values were selected for estimating photovoltaic module areas according to different system types, differences in installation location, orientation, and environmental conditions mean that the actual achievable power output of each type of photovoltaic system would differ. Given that the system is inherently a comprehensive and highly complex system, an overly simplified quantification approach may result in significant deviations from real-world conditions, thereby affecting the reliability of the final assessment conclusions. Furthermore, since it was not possible to estimate the initial power generation capacity of geothermal energy(an important component of the RESs in this study's REC),so the absence of such data may also have a significant impact on the feasibility evaluation of the proposed scenario.

When estimating building energy consumption, the large scale of the study area and the diversity of building types—together with the large number of old residential buildings even after urban design interventions—present significant challenges. These old buildings, due to their age, lack detailed structural and performance data. Moreover, since this research remains at the urban design stage, the complete dataset required for precise simulation and calculation was not yet available, making it impossible to accurately assess building energy consumption. To simplify the calculation process, this study adopted the EU's annual average residential building energy consumption statistics, without distinguishing between different building types or using Italy-specific average consumption data. Therefore, the estimated annual average energy consumption for the entire community may differ from actual conditions.

7.2.3 Urban Design

In the urban design process for this community, due to the incomplete and imprecise nature of the available data for the area, the design outcomes produced from the existing information may differ from the actual circumstances.

Moreover, given the current relatively limited reference materials and case studies on integrating renewable energy systems during the urban design phase, coupled with insufficient data and theoretical supports, the design concepts, procedures, and outcomes proposed in this article are primarily formed based on the author's understanding of relevant research. The renewable energy systems presented are still preliminary proposals, intended to illustrate their general distribution and configuration rather than provide an exact representation of the entire system. Consequently, there may be certain differences between these proposals and their practical application in real-world contexts.Nevertheless, this design approach and its outcomes may serve as a reference for scholars involved in urban design today.

7.3 Contribution of the Thesis

Starting with an analysis of the current state of research, this study sequentially carried out case selection, case analysis, urban design, and finally feasibility assessment, thereby systematically examining and exploring the field of RECs from the perspective of urban design.

At the academic level, this study reveals the current state of research in this field, as well as its shortcomings and gaps. Through a comprehensive research process, this study analyses and summarises the significance of research in this field, along with the potential connections and mutual influences between renewable energy technologies and urban design these two fields that may appear to be independent but can, in fact, foster each other's development. Consequently, whether viewed from the perspective of urban design or the development of renewable energy technology, this study expands the existing theoretical framework, proposes a new interdisciplinary research paradigm, and provides new perspectives on addressing the common problems and challenges faced by RESs in both theoretical research and practical application (such as the inability to achieve optimal performance under existing urban spatial conditions, or the lack of sufficient space reserved for their future sustainable development). At the same time, this study provides urban designers with new conceptual approaches and theoretical methods to help achieve goals and meet demands related to urban decarbonisation in real-world projects

Based on this, through the comprehensive analyses of case studies and the systematic presentation and in-depth examination of the design concepts and steps in the conceptual design phase, this study offers referenceable design ideas and methodological guidance on how to incorporate renewable energy system design into the urban design stage—namely, how to conduct the urban design of RECs. Although the methods and approaches presented here are not yet fully mature, they can still serve as a valuable research pathway and comparative references for other scholars conducting related studies.

7.4 Practical Recommendations and Suggestions for Future Research

The preceding sections have provided a detailed analysis and discussion of the three core issues identified in this study and their interrelationships. Through this analysis, it becomes clear that even two research fields that appear to be relatively mature can constrain each other when their developmental trajectories become misaligned. On the surface, these may seem like three separate issues; however, in essence, they can be all traced back to a single core problem—the disconnect between the development of renewable energy technologies and urban design theory and practice. This viewpoint has been emphasised repeatedly in the earlier discussion. The question that now arises is: how can this problem be effectively addressed?

In fact, the issue revealed during the conceptual design stage of urban design can also be solved through urban design itself. By using urban design as a starting point, it is possible to break this vicious cycle and explore new solution pathways and directions.

At the academic level, it is important to involve more scholars in conducting diverse exploratory and simulation studies under different geographical, climatic, and urban conditions. What is especially important is strengthening research on urban design methods and strategies that integrate renewable energy technologies. Through a large number of research and simulation can not only deepen the academic community's understanding and knowledge of this field, but also gradually consolidate its theoretical framework and disciplinary foundation. At the same time, researchers in the field of renewable energy technologies should actively engage in interdisciplinary collaboration with urban design scholars to jointly develop more rational, comprehensive, precise, and efficient methods for planning and designing RESs, as well as tools for subsequent energy output assessment and building energy consumption estimation. In doing so, the in-depth research and ongoing development of the interdisciplinary field that combines RECs development with urban design will be further advanced.

As discussed in the previous sections, this study has certain limitations in its research process. To address these issues, future research in this field could expand the number of analysed cases and include a broader range of urban areas that differ in geographical characteristics and background conditions. By widening the scope of comparative analysis and enriching the dataset, researchers can reduce the risk of selection bias and thereby enhance both the reliability and the generalisability of the research outcomes.

At the policy level, the preliminary analysis and discussion in this study indicate that, whether approached from the perspective of urban design or from a technological standpoint, the development of RECs is closely linked to current carbon neutrality targets and policy frameworks (such as the Clean Energy Package) (Ahmed et al., 2024; Lowitzsch et al., 2020). However, since the signing of the Paris Agreement, the absence of binding policies and enforcement mechanisms has meant that, while many countries have demonstrated ambitious commitments, there remains a significant gap in the implementation of concrete measures. As of 2024, only 72 out of the 197 carbon-neutrality countries had developed relatively comprehensive policy frameworks. Overall, under the current trends, the progress of achieving global carbon neutrality targets is facing significant delays (Tørstad et al., 2025; Zhang et al., 2025).

The achievement of political goals cannot be realised solely through the efforts of the academic community; policy methods and institutional capacity are the key pillars for realising these ambitious goals (IPCC, 2022). Therefore, government authorities should formulate and implement relevant policies and measures to promote the development in this field. At the same time, scholars engaged in research and exploration should actively collaborate with government agencies to jointly develop policy solutions that can support and facilitate the translation of theoretical research into practical application. For example, the planning of RESs could be integrated into the statutory urban design stage, or energy performance indicators could be introduced into urban regeneration and development guidelines. Such measures would not only help to advance interdisciplinary research and development combining RECs with urban design, but would also, to some extent, contribute to the low-carbon transition of cities, thereby further promoting the achievement of carbon neutrality and sustainable development goals.

Moreover, as research in this field is still in its early stages, both the establishment of a comprehensive theoretical framework and the formulation of a systematic policy framework face certain challenges. In view of this, governments could take the lead in establishing pilot projects, such as REC demonstration zones, enabling scholars to conduct comprehensive research on the urban design and development of such communities—from the early stages of social organisation and political institutional frameworks to contemporary urban design perspectives (Lowitzsch et al., 2020). With the support and promotion of the government, the experiences gained from these pilot projects could be summarised and promoted, thereby helping to accelerate the development in this field and convert research results into practical applications.

In conclusion, while this study has certain limitations in some aspects, it successfully identified key gaps within the relevant academic field and provided valuable insights and reference materials for future research in related fields through the design concepts and methods presented. The issues and

shortcomings identified during the research process, together with the academicand policy insights derived from them, also hold significant reference value. It is anticipated that future scholars will increasingly engage in exploring the design and development of RECs from an urban design perspective, thereby fostering deeper interdisciplinary collaboration and institutional innovation, and ultimately advancing the long-term goals of urban low-carbon transition and energy system transformation.

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To enhance the clarity of the academic writing, the author made limited use of Deepl(translation) and Grammarly for language editing process. Their role was limited to language support, while the whole research design, analysis, structure and conclusions were carried out independently by the author.