

Review

# Economic Impact Assessment for Positive Energy Districts: A Literature Review

Marco Volpatti <sup>1,2</sup>, Andreas Tuerk <sup>3</sup>, Camilla Neumann <sup>3</sup>, Ilaria Marotta <sup>4</sup>, Maria Beatrice Andreucci <sup>5</sup>, Matthias Haase <sup>6</sup>, Francesco Guarino <sup>7</sup>, Rosaria Volpe <sup>8</sup> and Adriano Bisello <sup>1,\*</sup>

- <sup>1</sup> Institute for Renewable Energy, Eurac Research, Viale Druso 1, 39100 Bolzano, Italy
  - <sup>2</sup> Interuniversity Department of Regional and Urban Studies and Planning, Polytechnic of Turin, Viale Mattioli 39, 10125 Torino, Italy
  - <sup>3</sup> Johanneum Research, Waagner-Biro Straße 100, 8010 Graz, Austria
  - <sup>4</sup> Institute for Advanced Energy Technologies (CNR-ITAE), National Research Council (CNR) of Italy, 98126 Messina, Italy
  - <sup>5</sup> Department of Planning, Design, Technology of Architecture, Faculty of Architecture, Sapienza University of Rome, 00185 Roma, Italy
  - <sup>6</sup> Institute for Facility Management Grüental, 8820 Wädenswil, Switzerland
  - <sup>7</sup> Department of Engineering, University of Palermo, Viale delle Scienze, Building 9, 90121 Palermo, Italy
  - <sup>8</sup> Department of Electrical, Electronics and Computer Engineering, University of Catania, Viale Andrea Doria 6, 95125 Catania, Italy
- \* Correspondence: [adriano.bisello@eurac.edu](mailto:adriano.bisello@eurac.edu)

## Abstract

To address the global challenge of sustainable energy transition in cities, there is a growing demand for innovative solutions to provide flexible, low-carbon, and socio-economically profitable energy systems. In this context, there is a need for holistic evaluation frameworks for the prioritization and economic optimization of interventions. This paper provides a literature review on sustainable planning and economic impact assessment of innovative urban areas, such as Positive Energy Districts (PEDs), to analyze research trends in terms of evaluation methods, impacts, system boundaries, and identify conceptual and methodological gaps. A dedicated search was conducted in the Scopus database using several query strings to conduct a systematic review. At the end, 57 documents were collected and categorized by analysis approach, indicators, project interventions, and other factors. The review shows that the Cost–Benefit Analysis (CBA) is the most frequently adopted method, while Life Cycle Costing and Multi-Criteria Analysis result in a more limited application. Only in a few cases is the reduction in GHG emissions and disposal costs a part of the economic model. Furthermore, cost assessments usually do not consider the integration of the district into the wider energy network, such as the interaction with energy markets. From a more holistic perspective, additional costs and benefits should be included in the analysis and monetized, such as the co-impact on the social and environmental dimensions (e.g., social well-being, thermal comfort improvement, and biodiversity preservation) and other operational benefits (e.g., increase in property value, revenues from Demand Response, and Peer-To-Peer schemes) and disposal costs, considering specific discount rates. By adopting this multi-criteria thinking, future research should also deepen the synergies between urban sectors by focusing more attention on mobility, urban waste and green management, and the integration of district heating networks. According to this vision, investments in PEDs can generate a better social return and favour the development of shared interdisciplinary solutions.



Academic Editor: Dimitris Damigos

Received: 21 June 2025

Revised: 24 September 2025

Accepted: 29 September 2025

Published: 10 October 2025

**Citation:** Volpatti, M.; Tuerk, A.; Neumann, C.; Marotta, I.; Andreucci, M.B.; Haase, M.; Guarino, F.; Volpe, R.; Bisello, A. Economic Impact Assessment for Positive Energy Districts: A Literature Review. *Energies* **2025**, *18*, 5341. <https://doi.org/10.3390/en18205341>

**Copyright:** © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Keywords:** Positive Energy Districts (PEDs); economic impact assessment; urban energy transition; multi-criteria analysis; cost–benefit analysis

---

## 1. Introduction

As consistently emphasized by the Intergovernmental Panel on Climate Change (IPCC) [1–3], climate change represents a growing threat to human and natural systems, with cities at the forefront of its impacts. Rising temperatures, extreme weather events, and increased climate variability are already affecting urban areas, compromising the quality of life of their inhabitants and exacerbating social vulnerabilities. The 1.5 °C threshold set by the Paris Agreement [4] is not only a global environmental imperative but also a critical boundary for maintaining the habitability and resilience of urban ecosystems. Without rapid and coordinated mitigation efforts, urban populations will face intensified risks related to heat stress, water scarcity, energy insecurity, and damage to infrastructure [3]. Scientific evidence highlights that tackling climate change is deeply intertwined with achieving the Sustainable Development Goals (SDGs) [5,6]. In particular, SDG 11 states that “making cities inclusive, safe, resilient, and sustainable” requires rethinking how urban environments are designed, powered, and governed. This calls for systemic strategies that promote decarbonization, enhance adaptive capacity, and improve the well-being of communities, especially in the face of growing environmental and socio-economic pressures. In this framework, the building sector is still a key contributor to global greenhouse gas (GHG) emissions, with 9.7 GtCO<sub>2</sub>eq reached in 2019 (31% of total emissions) [2]. Similarly, it represents around one-third of energy-related emissions in the European Union (EU), and since 2002, it has been seriously tackled through the release of the Energy Performance of Buildings Directive (EPBD). From that year onwards, several policies and initiatives have been issued, addressing the need to decarbonize the building stock by 2050 and increase the penetration of renewable energy sources (RESs) [7,8] in the building stock. To address the challenge of sustainable energy transition in cities, there is a growing demand for innovative solutions aimed at providing flexible, low-carbon, and socio-economically profitable energy systems [9,10]. In this context, the concept of Positive Energy District (PED) emerged from the scientific community to institutional organizations and related documents. As a cornerstone in this debate, the Strategic Energy Technology (SET) Plan is often mentioned, as it ambitiously set the target to 100 Positive Energy Districts in the EU by 2025 [11] (unfortunately, this was not fully achieved). Following this wave, the International Energy Agency (IEA)—Energy in Buildings and Communities (EBC) Annex 83 working group, ‘Positive Energy Districts’ [12], was established in 2019 with the aim of advancing research on the topic, operationalizing and demonstrating the PED concept, and fostering connections among researchers and academics worldwide.

In this regard, the promotion of PEDs, defined as innovative urban areas, not only provides an annual surplus of clean energy but also delivers economic, social, and environmental sustainability [13], and should be regarded as a further step toward the achievement of the SDGs. Undoubtedly, in order to make urban areas resilient and prepared for energy crises, there is a need for energy crises, it is essential to enhance energy efficiency and adopt flexible strategies for the intelligent management of energy flows. But, to achieve long-term sustainability, robust assessment frameworks that take into account different aspects of sustainability and shape the design of PED in a holistic perspective are needed [12,14,15]. So far, technocratic approaches have long ignored social needs by focusing more attention on the development of energy-efficient and economically profitable buildings and systems. However, based on the policies of the United Nations and the EU, in recent

decades, researchers have shown a growing interest in the concept of sociotechnical transition, deepening social issues to avoid the perpetuation of inequalities in order to build urban models of sustainable development, but further efforts are required [16–18]. In this regard, with a view to unlocking local economic potential and facilitating the diffusion of PEDs, it is important to define economic approaches for prioritizing project interventions and optimizing economic resources while also ensuring broader societal welfare gains. In addition, according to a broader vision, links with the social and environmental dimensions of sustainability should be taken into account, as well as synergies between urban sectors, in the case of multi-sectoral investments. Furthermore, the multi-sectoral and multi-dimensional approach should be based on tailor-made business models (i.e., considering the interaction with the electricity grid and flexibility markets as well as the circular economy potential) and an innovative financing scheme [12].

### 1.1. Aim of the Study

This study presents a systematic literature review (SLR) on the topic of sustainable planning and economic evaluation of innovative urban areas, intending to identify transferable insights applicable to the Positive Energy District (PED) concept. The review aims to examine how economic sustainability is addressed in the built environment, with a focus on low-carbon solutions and innovative energy systems.

The SLR was conducted using the Scopus and ScienceDirect databases, covering the period from 1975 to 2024, and following a structured query design. The review process was divided into three analytical fields:

- General field, filtering the broad literature on economic evaluation in energy contexts;
  - Territorial scale, focusing on the urban, district, and neighbourhood levels;
- Economic evaluation methods, analyzing specific assessment approaches such as CBA, LCA, LCC, and sensitivity analysis. The objectives of this study are threefold: (i) to identify research trends, including evaluation methods, impact categories, Key Performance Indicators (KPIs), and spatial boundaries; (ii) to highlight conceptual and methodological gaps; and (iii) to propose future research directions toward the integrated and sustainable development of PEDs.

The paper is structured as follows: Section 2 details the methodology adopted for the SLR. Section 3 presents the results on methodological approaches to economic sustainability. Section 4 focuses on the quantification of impacts through KPIs. Section 5 discusses research gaps and future outlooks for the economic framework of PEDs. Conclusions are presented in Section 6.

### 1.2. The Evolution of Urban Energy Systems: Toward the PED Paradigm

The evolution of urban energy systems has been shaped by multiple technological, policy, and societal shifts over the last century. From centralized fossil-fuel-based infrastructures to decentralized, smart, and low-carbon networks, cities have progressively become key laboratories for sustainable energy innovation. Understanding this developmental trajectory is crucial to contextualize the emergence of Positive Energy Districts (PEDs) as a new frontier in urban sustainability [12,14,15]. Historically, urban energy planning was driven by supply-side logic, large-scale grids, and centralized governance. This began to change during the 1970s oil crisis [5], which triggered concerns over energy security and economic resilience. Subsequent decades saw the liberalization of energy markets, the rise in cogeneration and district heating systems, and the progressive integration of renewable energy sources (RESs). At the same time, urban planning frameworks started to incorporate environmental criteria, culminating in landmark policy instruments such as the Kyoto Protocol (1997) and the Energy Performance of Buildings Directive (EPBD, 2002) [11].

The 2000s marked a turning point, with the digitalization of grids, the development of energy communities, and the proliferation of low-carbon technologies. The concept of smart cities gained traction, promoting data-driven management of urban infrastructures, while the EU Green Deal and Mission for Climate-Neutral and Smart Cities explicitly called for new spatial models capable of producing more energy than they consume, leading to the formalization of PEDs under the Horizon 2020 and Horizon Europe frameworks [14].

### 1.3. Definitions of Energy-Efficient Buildings and Positive Energy Districts (PEDs)

Energy-Efficient Buildings definitions:

- IEA EEBP (1997)—Buildings are defined as energy-efficient when they “use less energy for heating, cooling, lighting, and appliances, while maintaining or improving comfort, health, and functionality.”
- EPBD 2002/91/CE—The Energy Performance of Buildings Directive defines energy performance as the “calculated or measured amount of energy needed to meet the energy demand associated with typical use of the building.”
- EPBD 2010/31/EU—Introduces Nearly-Zero Energy Buildings (nZEBs): “Buildings with very high energy performance. . . with nearly zero or very low energy demand covered to a significant extent by energy from renewable sources.”
- EPBD 2018/844/EU—Expands the definition to include “smart operation, user awareness, and integration with wider energy systems.”
- IPCC AR6 (2022)—Extends efficiency to a life cycle perspective: “Buildings that minimize life cycle energy use and emissions while maximizing comfort, affordability, and resilience.”

Positive Energy Districts (PEDs)

- SET-Plan Action 3.2 (2018)—Defines PEDs as “urban areas capable of producing at least as much renewable energy as they consume annually, integrating energy-efficiency measures, renewable sources, smart systems, and active user engagement.”
- IEA EBC Annex 83 (2020–2025)—States that the “basic principle of PEDs is to create an area within the city boundaries capable of generating more energy than consumed and agile/flexible enough to respond to market variation.” It specifies three key requirements: local energy efficiency, cascading of energy flows, and low-carbon generation, enhanced by smart control and flexibility.
- JPI Urban Europe (2020)—Defines PEDs as “inclusive, flexible urban districts aiming for an annual positive energy balance through integrated design, optimization of energy flows, user involvement, and synergies with broader urban and mobility systems.”
- White Paper JPI/UrbanEurope (2020)—Adds that PEDs “manage surplus renewable energy annually, integrate building systems, users, mobility, ICT, and stakeholder governance.”

Key Characteristics of PEDs

From these definitions, core components of PEDs emerge clearly:

- Annual net energy surplus: A PED must generate as much or more renewable energy than it consumes in a year.
- System flexibility: Integration of storage, Demand Response, and smart controls to adjust to market and grid conditions.
- Local cascading of energy: Utilization of surplus energy at district scale, e.g., district heating reuse and local storage.
- Technological integration: Buildings, generation, storage, and ICT systems must operate cohesively.

- Socio-technical dimension: Active user engagement, participatory governance, and stakeholder inclusivity.
- Multi-sectoral linkages: Connection to mobility, waste, ICT, and public services to embody wider sustainability goals.
- Urban boundary: Districts can be delineated physically or virtually, depending on configuration and business model.

These characteristics establish the conceptual baseline for assessing economic frameworks in PEDs, such as Cost–Benefit Analysis, Life Cycle Costing, and Multi-Criteria Analysis. The subsequent review (Sections 3–5) analyzes whether and how existing studies reflect this integrated PED paradigm in their economic evaluations.

## 2. Materials and Methods

### 2.1. Database Selection and Rationale

To ensure the methodological rigour of the systematic literature review, two leading academic databases were selected: Scopus and ScienceDirect, both maintained by Elsevier. These platforms were chosen due to their complementary characteristics. Scopus offers broad multidisciplinary indexing, covering publications from a wide range of publishers—including Springer Nature, Wiley, IEEE, and Taylor & Francis—which makes it highly suitable for mapping large-scale research trends. In contrast, ScienceDirect focuses on providing full-text access to high-quality, peer-reviewed journals and books within the Elsevier ecosystem, thus allowing for in-depth analysis of selected contributions. The combination of these two sources guarantees both breadth and depth, essential for addressing a complex and interdisciplinary topic such as the economic evaluation of Positive Energy Districts (PEDs).

### 2.2. Query Strategy and Fields of Analysis

The search strategy was designed around three thematic analytical fields aimed at structuring the review process in a systematic and replicable manner:

1. General Field—Targeted literature broadly dealing with economic evaluation in energy contexts, restricted to peer-reviewed sources (articles, books, and book chapters).
2. Territorial Scale—Focused on the spatial level of analysis, distinguishing between urban, district, and neighbourhood scales, all of which are relevant for PED planning and implementation.
3. Economic Evaluation Methods—Identified the specific tools and models used to conduct economic assessments, such as Cost–Benefit Analysis (CBA), Life Cycle Costing (LCC), Multi-Criteria Analysis (MCA), and others.

Table 1 provides a concise yet comprehensive overview of these three fields, outlining their definitions, objectives within the review process, and the keyword strategies adopted to extract relevant data from the literature databases. This framework guarantees a transparent and replicable review process, enabling the identification of methodological trends, spatial dynamics, and research gaps in the economic evaluation of PEDs.

To operationalize the framework mentioned above, a dedicated research study was conducted using the Scopus and ScienceDirect databases, which are widely acknowledged as two of the most comprehensive sources for peer-reviewed academic literature. The search strategy was devised around three analytical fields—general scope, territorial scale, and economic evaluation methods—as previously outlined. Each field was associated with a set of structured query strings, allowing for a systematic and replicable filtering process. The objective of the present study was to retrieve publications that not only address economic valuation in energy-related contexts but also provide spatial and methodologi-

cal granularity relevant to the Positive Energy District (PED) framework. The literature search covered the full temporal span of available indexed publications, from 1975 to 2024, ensuring a diachronic perspective on the evolution of economic assessment approaches. The queries incorporated Boolean operators and targeted fields (e.g., title, abstract, and keywords) to enhance precision and minimize irrelevant records. The search results were subsequently categorized by field, with duplicates removed to calculate the number of unique records retrieved. As illustrated in Table 2, the comprehensive set of query strings utilized for each field is outlined, along with the number of documents retrieved from each database and the resulting number of unique items post-harmonization. This detailed breakdown demonstrates the scale and specificity of the systematic review process and underpins the subsequent phases of analysis presented in the paper.

The literature search was conducted across the full available temporal range, from 1975 to 2024. This wide period was intentionally chosen to trace the conceptual and methodological evolution of economic evaluation practices in the energy and urban planning domains. Methods such as Cost–Benefit Analysis (CBA), Life Cycle Costing (LCC), and Multi-Criteria Analysis (MCA) have undergone substantial transformation in recent decades—particularly in response to environmental externalities, climate targets, and policy innovation. Moreover, including earlier literature allows the review to capture foundational theoretical contributions, many of which remain relevant or have been adapted to current frameworks. While the search included the full historical spectrum, analytical priority was given to recent publications, particularly those produced from the early 2000s onward, when key European and international policy frameworks (e.g., the Energy Performance of Buildings Directive—EPBD) began to shape integrated approaches to energy, economics, and sustainability.

**Table 1.** Field of analysis.

Field of Analysis	Description	Purpose in the Review	Keywords/Filters
1. General Field	Filters the broad literature on economic assessment in energy contexts, including peer-reviewed articles, books, and chapters.	To establish a foundational corpus of literature relevant to economic valuation in the energy domain.	“economic evaluation”, “economic assessment”, “energy”; publication type: articles, books, chapters
2. Territorial Scale	Focuses on studies conducted at specific spatial levels: urban, district, and neighbourhood.	To identify how economic assessments vary across different spatial contexts relevant to Positive Energy Districts (PEDs).	“urban”, “district”, “neighbourhood” (in title, abstract, keywords)
3. Economic Evaluation Methods	Investigates the specific methodologies used in the selected literature for economic assessment.	To analyze which tools are applied most frequently and evaluate their strengths, limitations, and applicability.	“Cost–Benefit Analysis”, “Life Cycle Costing”, “Multi-Criteria Analysis”, “Sensitivity Analysis”, etc.

**Table 2.** Query strings in Scopus and Science Direct databases.

	Query	N° Doc. Science Direct	N° Doc. Scopus	N° Unique Items
Field 1	(ALL ((economicAND evaluation) OR ALL (economic AND valuation) OR ALL (economic AND assessment) AND ALL (energy)) AND PUBYEAR > 1974 AND PUBYEAR < 2024	371,786	1,002,688	1,002,688
	(TITLE-ABS-KEY (economic AND evaluation) OR TITLE-ABS-KEY (economic AND valuation) OR TITLE-ABS-KEY (economic AND assessment) AND TITLE-ABS-KEY (energy)) AND PUBYEAR > 1974 AND PUBYEAR < 2024	3009	58,115	58,115

Table 2. Cont.

	Query	N° Doc. Science Direct	N° Doc. Scopus	N° Unique Items
Field 2	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND (Urban)) AND PUBYEAR > 1974 AND PUBYEAR < 2024	153	350	350
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND (District)) AND PUBYEAR > 1974 AND PUBYEAR < 2024	94	320	320
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND (Neighbourhood)) AND PUBYEAR > 1974 AND PUBYEAR < 2024	31	23	31
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Life cycle Assessment (LCA)") AND PUBYEAR > 1974 AND PUBYEAR < 2024	22	29	29
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Sensitivity Analysis") AND PUBYEAR > 1974 AND PUBYEAR < 2024	25	32	40
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Cost Benefit Analysis") AND PUBYEAR > 1974 AND PUBYEAR < 2024	22	29	29
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Environmental Impact Assessment") AND PUBYEAR > 1974 AND PUBYEAR < 2024	11	14	14
Field 3	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Monte Carlo Method") AND PUBYEAR > 1974 AND PUBYEAR < 2024	5	2	7
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Discounted Cash Flow") AND PUBYEAR > 1974 AND PUBYEAR < 2024	6	6	6
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Life Cycle Cost" OR "LCC") AND PUBYEAR > 1974 AND PUBYEAR < 2024	19	24	24
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Multicriteria" OR "MCDA" OR "MCA" OR "Multi-Criteria" OR "Multiple Criteria Decision Analysis") AND PUBYEAR > 1974 AND PUBYEAR < 2024	12	21	21
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Social Return on Investment" OR "SROI") AND PUBYEAR > 1974 AND PUBYEAR < 2024	1	1	1
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Preference Evaluation" OR "Econometrics") AND PUBYEAR > 1974 AND PUBYEAR < 2024	11	2	11
	TITLE-ABS-KEY (("economic evaluation" OR "economic valuation" OR "economic assessment") AND ("energy") AND ("Urban" OR "District" OR "Neighbourhood")) AND ("Quantitative Analysis") AND PUBYEAR > 1974 AND PUBYEAR < 2024	35	6	39

Table 2 presents the full set of query strings and the corresponding number of documents retrieved for each field and method, providing transparency and reproducibility to

the review process. The significant volume of publications retrieved in the last two decades, especially from 2008 to 2024, demonstrates the growing relevance of integrated economic evaluation in sustainable urban development and confirms the urgency of consolidating this dispersed knowledge through a systematic review.

### 2.3. Interpretation of Query Results and Literature Trends

The data presented in Table 2 illustrate important trends in the current academic landscape.

General Field retrieved over 1,000,000 documents on Scopus and more than 370,000 on ScienceDirect, confirming the broad and increasing scholarly interest in economic valuation methods in the energy domain.

Refining the query to “Title, Abstract, Keywords” still indicates significant growth, albeit at reduced levels: ScienceDirect accounts for 3009 documents overall, with 590 in 2024; Scopus reaches 58,115 total and 7355 in that year.

Regarding the territorial scale, the research revealed a significant academic preference for urban-level analysis (350 results on Scopus), followed by district-level studies (320 results), while neighbourhood-scale research remains limited (31 results). This confirms the relevance—but also the underrepresentation—of the district scale, which is central to the PED framework. Both datasets show a strong academic preference for broader spatial scopes. Documents mentioning “urban” (T-A-K-U) total 153 in ScienceDirect and 350 in Scopus. “District” (T-A-K-D) appears 94 times in ScienceDirect and 320 times in Scopus, whereas “neighborhood” (T-A-K-N) appears rarely, only 31 and 23 instances, respectively. This suggests that research is more focused on urban and district scales, with considerably less attention paid to neighbourhood-level inquiries.

The methodological analysis shows that traditional approaches such as CBA, LCC, and MCA dominate the literature, while more holistic or socially sensitive tools like SROI (social return on investment) and WTP (willingness to pay) are sparsely adopted. This suggests a methodological gap in the inclusion of intangible and long-term co-benefits in current economic evaluations.

In sum, the data clearly illustrate two key observations:

1. The wider coverage of Scopus relative to ScienceDirect results in much higher publication counts.
2. Over the past two decades, interest in urban and district-scale research has grown significantly, overshadowing the comparatively limited attention on neighbourhood analysis.

### 2.4. Temporal and Geographic Distribution of Publications

The literature search spans from 1975 to 2024, a range deliberately selected to trace the conceptual evolution of economic assessment methods over time. This long-term perspective allows for the identification of shifts in evaluation logic, particularly after the early 2000s, when key European directives (e.g., the Energy Performance of Buildings Directive, EPBD) began to influence energy policy and urban planning paradigms. While older studies were included to recognize foundational theoretical contributions, greater analytical focus was placed on the literature published from 2008 onward, corresponding with an exponential growth in academic production and policy-driven interest in sustainable energy systems.

Table 3 illustrates the annual distribution of documents across databases and spatial scales, demonstrating that academic output on the topic has increased significantly, especially between 2008 and 2024.

Table 3. Data obtained from Scopus and Science Direct databases.

Year	Publications Science Direct					Publication Scopus				
	ALL	T-A-K	T-A-K-U	T-A-K-D	T-A-K-N	ALL	T-A-K	T-A-K-U	T-A-K-D	T-A-K-N
1974	2	9	0	0	0	115	40	2	0	0
1975	442	3	0	0	0	189	65	2	1	0
1976	694	7	0	0	0	215	81	1	0	0
1977	703	7	0	0	0	280	108	2	0	0
1978	878	6	0	0	0	377	144	0	1	0
1979	1211	10	0	2	0	489	177	1	3	0
1980	1330	13	1	1	0	493	172	0	0	0
1981	1448	12	0	1	0	572	139	1	2	0
1982	1353	38	6	7	0	593	145	0	0	0
1983	1336	15	3	1	1	615	168	0	1	0
1984	1353	32	6	0	0	688	184	0	0	0
1985	1253	12	0	0	0	691	151	1	0	0
1986	1328	47	0	0	0	709	123	0	0	0
1987	1360	17	1	0	1	688	99	0	0	0
1988	1443	11	0	0	0	707	87	0	0	0
1989	1526	21	0	0	0	758	87	0	0	0
1990	1606	14	0	0	0	775	112	1	1	0
1991	1618	22	1	0	0	820	125	0	1	0
1992	1802	20	1	0	0	901	122	0	0	0
1993	1877	40	5	1	0	931	112	0	1	0
1994	1938	29	5	3	1	1076	150	0	0	0
1995	3024	37	0	0	0	1187	164	0	0	0
1996	2777	20	1	2	1	1665	177	2	2	0
1997	2738	23	1	1	0	1692	167	0	2	0
1998	2201	22	1	1	1	1796	179	0	0	0
1999	2104	71	1	1	0	1969	152	1	3	0
2000	2439	17	0	1	0	2292	231	0	2	0
2001	2279	17	0	0	0	2476	241	2	2	0
2002	2345	10	1	3	0	2764	265	0	2	0
2003	3154	15	0	0	0	3720	350	1	2	0
2004	3277	21	0	1	0	3876	376	0	3	0
2005	3523	30	1	0	0	5130	444	3	0	0
2006	3759	20	2	1	1	5724	500	2	3	0
2007	3921	22	2	1	0	6759	611	5	4	0
2008	4346	25	1	1	0	8150	694	1	3	0
2009	5024	22	1	1	1	11,271	872	6	7	0
2010	5517	17	3	2	0	13,850	1023	5	6	0
2011	6847	27	4	4	1	16,974	1281	6	5	0
2012	7976	35	4	2	1	20,649	1399	11	2	0
2013	9752	27	4	4	2	25,239	1672	13	17	3
2014	11,532	43	5	2	0	29,237	1996	10	12	3
2015	12,897	53	1	1	0	32,943	2107	6	8	2
2016	14,766	78	4	5	2	38,389	2468	12	16	0
2017	17,180	71	2	3	2	45,852	2955	14	22	2
2018	17,987	105	7	3	1	54,286	3294	23	19	0
2019	20,116	133	8	7	2	65,694	3721	24	18	2
2020	23,126	140	8	6	3	79,516	4214	31	24	1
2021	29,040	225	7	3	3	99,292	5061	25	23	1
2022	32,759	292	17	4	0	117,540	5507	40	34	3
2023	35,891	416	20	11	3	131,738	6048	42	29	5
2024	52,988	590	18	7	4	158,336	7355	54	39	1
TOT	371,786	3009	153	94	31	1,002,688	58,115	350	320	23
		Queries Field 1					Queries Field 2			

Number of publications identified in the ScienceDirect and Scopus databases from 1974 to 2024, broken down by year, query type, and research field (All fields (ALL), Title-Abstract-Keywords (T-A-K), T-A-K-U (Urban), T-A-K-D (District), and T-A-K-N (Neighbourhood)). The table highlights the temporal evolution of publications, the overlap between the two databases, and the distribution of contributions according to the territorial scale considered.

Moreover, the geographic distribution of documents (based on Scopus metadata) in Figure 1 shows that Italy emerges as a leading contributor, particularly for documents referencing both “urban” and “district” scales. The United Kingdom, Sweden, and Germany also show strong outputs, while Germany stands out with “neighbourhood”-scale research. Outside Europe, China and the United States are active in “urban” scale contributions. These trends suggest that the adoption of certain territorial terms may reflect national urban models, academic traditions, or institutional priorities—offering valuable grounds for future comparative research. It should be noted at the outset that the Science Direct database, although a relevant source of scientific literature, does not provide an explicit parameter regarding the nationality of authors or their affiliated institutions. For this reason, data from this source were not included in the proposed chart, which is instead based on the Scopus dataset, where such information is available and traceable. The analysis of data extracted from the Scopus dataset highlights how scientific production on this topic is distributed unevenly across countries, with Italy standing out as the primary contributor. In detail, Italy emerges as the leading nation, with a total of 35 documents containing the keyword “urban” and 34 documents including the term “district,” demonstrating a consolidated and cross-scalar interest in these topics. The United Kingdom follows, with a considerable number of publications using the term “district” (21 documents), while Sweden and Germany present 18 and 12 documents, respectively, with this keyword, confirming a preference for this territorial scale among Northern European countries. It is noteworthy that the keyword “neighborhood” appears less frequently and is associated with scientific output from Germany (14 documents overall), suggesting a focus on micro-scale territorial issues in the German context. Furthermore, non-European countries such as China and the United States are also prominently represented, particularly concerning the use of the keyword “urban,” with 25 and 20 documents, respectively, indicating a stronger focus on broader urban-scale challenges. The distribution of contributions suggests that the terminology adopted reflects not only different academic and cultural sensitivities but also the specific characteristics of national urban and territorial contexts. This heterogeneity is of particular interest for further investigating the methodologies and approaches employed in different geographical areas. Therefore, the chart offers a valuable tool for understanding the geography of research on these topics and for encouraging additional comparative studies.

### *2.5. Prevalence of Evaluation Methods and Disciplinary Distribution*

A deeper analysis of the retrieved documents reveals key insights regarding the economic evaluation methods most commonly adopted in the literature. As illustrated in Figure 2, Cost–Benefit Analysis (CBA) emerges as the most widely applied method, referenced in 29 documents. CBA is frequently complemented by Sensitivity Analysis, which appears in 40 documents, indicating a methodological pairing commonly used to assess the robustness of economic assumptions.

Although the selected publications span from 1975 to 2024, it is noteworthy that the most intensive period of production began only in 2018, reflecting a relatively recent consolidation of the research interest in the economic assessment of sustainable urban energy systems. This trend aligns with broader shifts in policy and research priorities in the context of climate neutrality, the European Green Deal, and PED initiatives.

To better understand the thematic orientation of the literature, Figure 3 classifies the selected documents according to the research domains in which the evaluation methods are applied. The most frequently represented fields are environmental sciences, energy, and engineering. These areas are consistent with the interdisciplinary nature of PEDs, which lie at the intersection of technological innovation, environmental policy, and socio-economic

planning. Additionally, it is important to note that a substantial portion of the literature retrieved from Scopus overlaps with that obtained from ScienceDirect, as expected given that both platforms are managed by Elsevier. However, Scopus covers a broader array of journals, including those published by non-Elsevier academic outlets, which ensures wider inclusion. To further refine the dataset, a targeted search was conducted on Scopus using a focused set of keywords: “economic analysis”, “economic assessment”, “economic evaluation”, “economic valuation”, and “economic environmental”. This search yielded 71 articles. A subsequent filter limited the results to those falling under disciplinary categories most relevant to the economic and sustainability dimensions of PEDs—specifically, environmental sciences and energy—resulting in a final selection of 57 core documents forming the analytical base for the next sections of the review.

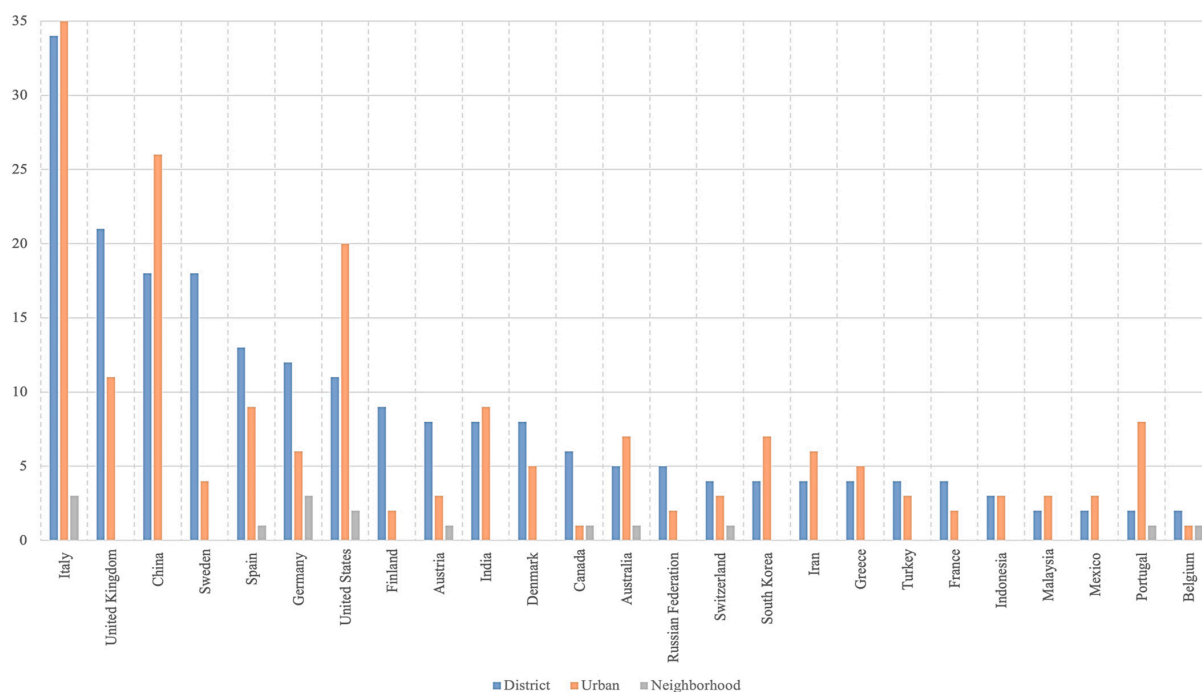


Figure 1. Country of production for the keywords “urban, district, neighbourhoood”.

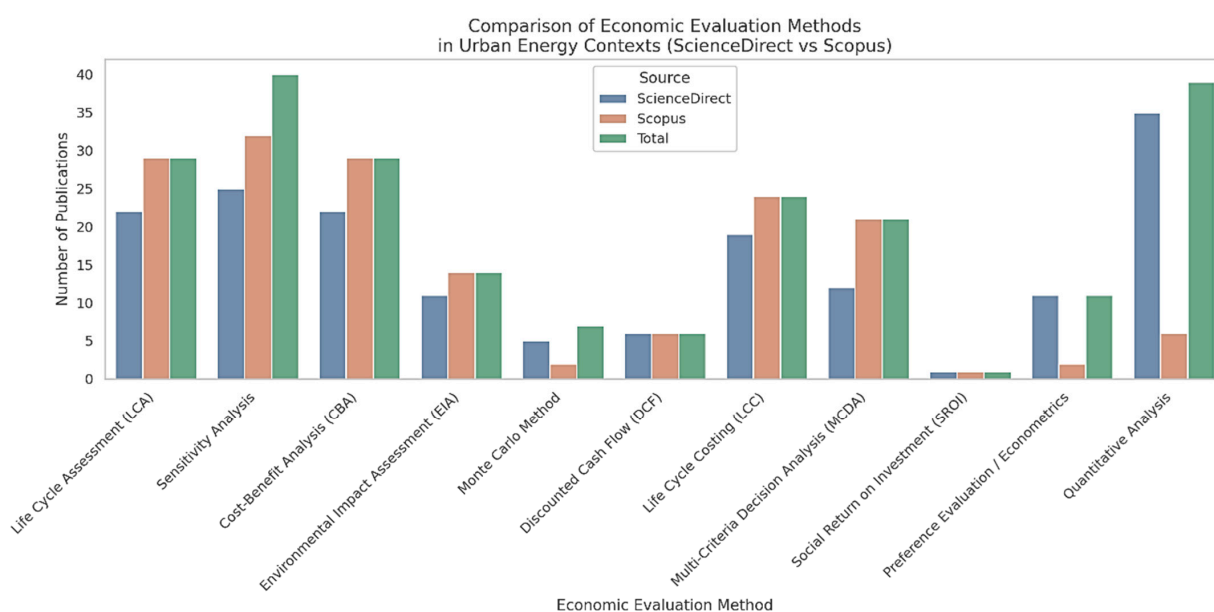
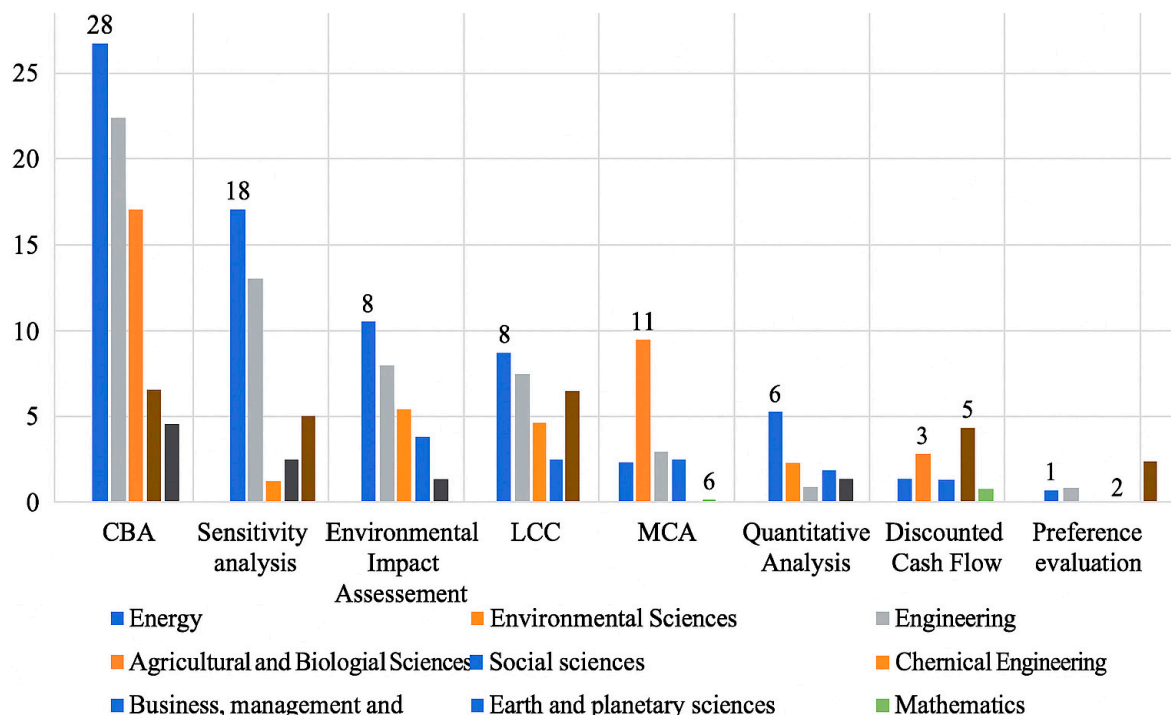


Figure 2. Number of documents related to evaluation approaches.



**Figure 3.** Research sources areas related to the evaluation approaches.

Figure 3 serves not only to illustrate the distribution of the selected literature across disciplinary domains, but also to reinforce the inherently cross-sectoral nature of the economic evaluation of Positive Energy Districts (PEDs). The concentration of publications within environmental sciences, energy, and engineering reflects a tendency to approach PEDs primarily from technological and environmental standpoints, often emphasizing performance optimization, energy efficiency, and carbon mitigation. However, the relative underrepresentation of social sciences and economics suggests that broader socio-economic impacts and distributional aspects remain secondary in the current literature landscape. This imbalance may hinder the development of comprehensive assessment frameworks capable of capturing the multidimensional benefits PEDs can deliver—such as social inclusion, behavioural change, and long-term well-being.

Furthermore, the thematic focus highlighted in Figure 3 indicates an opportunity for greater integration between disciplines that are still often treated in silos. Future research could benefit from methodological cross-pollination, for example, by combining economic models with urban sociology, participatory planning, or behavioural economics. The selected domains also reveal the types of stakeholders most involved in PED-related research, namely, engineers, environmental scientists, and energy system analysts—underscoring the importance of broadening interdisciplinary collaborations to include planners, economists, and policy experts. In this light, Figure 3 is not merely descriptive, but also diagnostic, helping to identify gaps and potential directions for a more balanced and inclusive research agenda on PED economic assessment.

### 3. Methodological Trends and Review Findings

This section is twofold in nature, serving to both describe the economic methods that have been identified in the extant literature and to highlight the main findings of the review and the evolution of methodological approaches. The analysis demonstrates a progression from classical tools, such as Cost–Benefit Analysis (CBA) and methods based on life cycle approaches, towards more integrated and multidisciplinary frameworks. In recent decades, there has been an increasing adoption of Multi-Criteria Analysis (MCA), spatial

decision support systems, and socio-economic evaluation techniques (e.g., willingness to pay, hedonic pricing, and social return on investment) within the field of literature. This evolution is indicative of the necessity to address not only economic efficiency but also environmental, social, and spatial dimensions in the assessment of energy and urban interventions. The analytical structure of this chapter builds on three core points, which served as the basis for the study: firstly, the consolidation of economic evaluation methods; secondly, the integration of environmental and social parameters in emerging methods; and thirdly, the identification of methodological gaps in the literature.

A review of the shortlisted studies revealed the prevalence of recurrent economic methods (or methods incorporating economic parameters) in supporting the PED design, development, and assessment phases. The following widely utilized methods are employed:

- **Cost/Benefit Analysis (CBA).** This method is mainly used to support energy interventions involving different technologies [19,20] or using different energy sources [21,22] to facilitate a more efficient allocation of resources, by demonstrating the convenience (social benefit) of a particular intervention compared to other possible ones. Also, it is used to estimate the social benefit coming from the use of alternative energy carriers [23,24].
- **Life Cycle Costing Analysis (LCC).** This method helps to evaluate the economic performance of a system, building, or energy infrastructure (e.g., a geothermal heating system [25]), looking at the overall cost over its entire lifetime from the installation until the disposal.
- **Life Cycle Assessment (LCA).** This methodology is based on assessing the environmental impacts associated with all the stages of the life cycle of energy sources. For example, those associated with energy recovery from a Municipal Solid Waste (MSW) system [26] or to estimate the optimal solutions coming to an environmental advancement for the central solar heating plants coupled with seasonal energy storage (CSHPSS) [27,28].
- **Techno-/Thermo-Economic Assessment.** This method focuses on estimating the costs of energy, or energy efficiency interventions [26,29–35].
- **Multi-Criteria Analysis (MCA).** This method takes into account different categories. Usually, the categories encompass social, environmental, and economic attributes. Attributes widely vary, including qualitative, quantitative, and economic values such as the CO<sub>2</sub> emissions, the Levelized Cost of Energy (LCOE), land price, and the well-being of the population [36]. Multi-criteria analysis can also be associated with the GIS (geographic information system) to cope with spatial information and attributes [19].

The analysis reported in Table 4 shows the application of economic methods at different territorial scales.

**Table 4.** Comparison of evaluation method used at different scale.

Economic Evaluation Method	Building	District	Urban
Cost–Benefit Analysis (CBA)	[Lower Degree]	[19–24]	[19–24,37–40]
Life Cycle Costing Analysis (LCC)	[25]		
Life Cycle Assessment (LCA)	[26–28]		
Techno-/Thermo-Economic Assessment		[26,29–35]	[26,29–35]

Table 4. Cont.

Economic Evaluation Method	Building	District	Urban
Multi-Criteria Analysis (MCA)			[19,36]
Contingent Valuation (CV)			[10,22]
Willingness to Pay (WTP)			[10,22]
Cost of Illness (COI)			[41–43]

Table 3 illustrates that the most often used CBA method has been mostly applied to the district and urban perspective, and only to a lower degree to the building level. The district and urban area level often concerns studies related to the heating system. To support the analysis at the district or urban level, in some studies, the use of GIS software is adopted [37–39]. In particular, it is used for refining and enriching a building inventory to increase the use of renewable energy.

Systems and infrastructures investigated through the previously mentioned methods from an economic perspective are as follows:

- Heating system and district heating (DH) system. Interventions on the heating system, especially in northern countries (such as Canada, Denmark, and Netherlands) [20,23,30,35], are a key point to reduce the energy demand in wintertime, as well as cooling systems for the southern countries [27,30,40]. Various configurations and generations of the DH system [20,21,27,44,45] are also considered, especially those associated with renewable energy such as geothermal energy [21,27,29,31,46]. Combinations of different renewable energy sources, such as a geothermal DH network with solar energy [47], could be suggested as a way to decrease the CO<sub>2</sub> emissions in the space air-conditioning sector.
- Distribution generation system. Another focus to reduce the energy demand and to decarbonize the heating sector is focusing on the distribution of the heating system [27], especially when there is a distributed multi-energy system (DMES) [35].
- Electricity generation. In order to reduce the environmental impact related to the building sector, it is necessary to intervene with respect to electricity. Major reduction in this area occurs by using renewable energy such as solar energy [19,32,48] or by using wind energy [24,49].
- Conversion of waste to energy. Nowadays, there is an increase in annual waste generation due to urbanization, industrialization, and population growth. Poor waste management can increase the environmental impact, but wise management can convert the waste to energy (WTE) [26,50].
- Nature-based solutions. The urban areas are often suffering from heavy pollution because of the concentration of anthropogenic activities. In order to have a better outdoor quality air (OQA), it is possible to intervene in the built environment by applying nature-based solutions. The nature-based solution most used in the building sector is based on the integration of green roofs, according to various configurations [51,52], but green façades [35] are gaining consensus.

Another subset of selected studies focuses on the reduction in GHG emissions, as the building sector is recognized as a large contributor to global CO<sub>2</sub> emissions and related climate change [20,22,49,50,52–55], but also considers how, at the local level, reducing the pollutants may help in increasing human health, particularly in the urban areas [23,24].

From the analysis, it emerges that the interventions are considered at different territorial scales. Recurrent levels are the district and urban ones, particularly for studies related

to the heating system. Instead, natural solutions interventions are mostly analyzed at the building scale.

Overall, several different energy sources emerge from the literature review and are considered. Table 5 presents a classification of applications based on the use of renewable energy by type of renewable source.

**Table 5.** Renewable energy sources by literature review.

Renewable Source	References
Solar Photovoltaic Panel	[19,32,48,56–58]
Geothermal	[21,27,29,31,43,59]
Solar + Geothermal	[44,45]
Wind	[24,46]
Biomass	[28,59]
Waste Water	[27,30,40]
Waste	[26,47,60,61]
Bio Oil	-
Water Desalination	[45]

To the shortlisted papers, using a snowball method based on citations, other research works were identified and reported by authors as addressing Net Zero Energy Buildings (NZEBS) [41] and districts (NZEDs) [40,42] as well as Plus Energy Buildings (PEBs) or districts (PEDs) [43].

Also in this case, methodologies for calculating the cost efficiency of energy efficiency measures in buildings, in general, are introduced [36]. Moreover, potential economic KPIs as well as overall methods to support urban decision-making are considered [41]. Many papers focus on the residential sector, especially on multi-family buildings. Differences among the papers emerge in terms of e.g., by the local climate and the type of buildings (newly built vs. renovations), and the urban density. The majority of papers report on local or national case studies in which a building is subject to energy efficiency improvements. The activities described in the aforementioned documents primarily concern local trading, encompassing energy, energy flexibility, and load management, as well as energy efficiency measures and the selection or combination of technologies. Additionally, spatial planning is a significant aspect.

The methods outlined in the extant literature predominantly aspire to the “cost-optimal,” “cost-efficient,” or “cost-effective” realization of disparate objectives, such as the attainment of a particular target energy efficiency level [35]. The majority of these papers employ “classical” dynamic investment analysis methods [36,41,42,62,63], with some consideration given to life cycle and global costs [22]. Certain methodologies utilize Cost–Benefit Analysis, which involves the comparison of investment costs to the subsequent overall savings [53]. Alternatively, other approaches derive net savings for customers and society [22,63]. Synnefa et al. [64] explore the potential for cost reductions in acquisition, supply, and installation, attributable to mass customization.

One particular instance is the EU methodology on cost-optimal levels of minimum energy performance requirements, as it is delineated in an official and binding regulation (Regulation (EU) No. 244/2012 [41]). This framework introduces a methodology for defining reference buildings at the national level. As this method serves as a basis for the national economic assessment of energy performance solutions in the EU, it plays an essential role and is partly referred to in the literature [65]. The aforementioned framework encompasses a time span of 30 years for residential and public buildings and 20 years for commercial and other non-residential buildings. Financial analyses, in contrast to macroeconomic analyses, incorporate the elements of taxes, value-added (VAT) charges, and subsidies. Financial analyses are distinct from macroeconomic analyses in that they

consider these elements, while macroeconomic analyses do not. Conversely, the latter approach incorporates the financial implications of greenhouse gas (GHG) emissions. It is hereby proposed that a sensitivity analysis be conducted on cost input data, including energy prices and discount rates.

The majority of extant approaches prioritize the business economics of decision-making for technology choices on an individual case basis, such as at the building level. A number of approaches adopt a more comprehensive perspective by comparing different business models. A Multi-Criteria Decision Analysis (MCDA) application called Macbeth is presented in [36] in combination with classic economic analysis methods. This combination allows for an integrated sustainability evaluation that takes qualitative and quantitative aspects, as well as environmental, social, and economic aspects, into consideration.

Multi-criteria spatial decision support tools that address energy retrofit interventions at the district level are emerging to facilitate the discussion of alternative scenarios among stakeholders and to manage participatory planning processes [36].

Macroeconomic perspectives are employed to calculate employment impacts or to investigate the net savings to society [63,66]. A significant number of the aforementioned methodologies exhibit congruence with assessments that are more oriented towards technology and energy systems, including energy system modelling/simulations [53]. Furthermore, there is a discernible presence of links pertaining to environmental aspects, particularly those associated with emissions [62,64].

A novel approach to the economic assessment of energy interventions at the district level is proposed, which involves the estimation of implicit value reflected in the real estate market. In this regard, the hedonic price method is frequently implemented as a multiple regression model. The objective of this approach is to ascertain the marginal contribution of specific variables in the price function. In this approach, the economic valuation considers the market capitalization of a given characteristic of energy sustainability. Such characteristics may include the presence of photovoltaic (PV) panels on the rooftop, the class of energy performance certificate, and energy bill expenditure. These characteristics are considered independent of implementation cost or expected savings over the lifetime of the investment. A number of recent studies have employed a combination of the hedonic price method, as it pertains to energy issues, and spatial models. This integration facilitates the consideration of spatial dependence, spillover effects, and bias in variable contribution specifications [66].

In lieu of revealed preference, monetizing implicit preferences is achieved through the implementation of stated preference techniques. This results in the determination of consumers' willingness to pay for specific characteristics or levels of service, as evidenced by the energy retrofit of buildings [67] and the acceptance of renewable energy sources (RESs) by the local community [68,69]. A plethora of alternative valuation methodologies have been developed for the purpose of assessing the economic viability of building energy retrofit initiatives. These methodologies can be categorized into two distinct groups: single-criterion approaches and multi-criteria/multi-objective approaches. The former involves the calculation of life cycle costs and Net Present Value, while the latter encompasses a more comprehensive evaluation of multiple criteria and objectives.

To estimate the creation of new green jobs, some authors [69,70] apply the Janssen and Staniaszek method [69]. From the literature data and from the knowledge of the wages of each new worker, the avoided unemployment subsidy is calculated.

A quite different approach to interventions, expressed by a monetary ratio between investment costs and societal gains, is the social return on investment (SROI), wherever societal gains are evaluated as a priority, rather than focusing solely on reductions in energy use. By following this approach, it is also possible to pass from the concept of relatively

homogenous, individual users and the significance of user groups at various scales, which is much more interesting in the case of analysis at the district level and may leverage behavioural and social levers.

Overall, from the literature review, it emerges that economic assessment methods are widely used to support the analysis of different energy efficiency interventions. The main aim of the energy renovation is to reduce the environmental impact induced by the building sector. The air-conditioning system (space heating and cooling) is mainly responsible for emissions of substances (i.e., CO<sub>2</sub> emissions and pollutants) into the air, water, and soil. Within the literature review studies, several measures aimed at decreasing the energy needs for space heating decrease the GHG emissions and improve energy efficiency and thermal comfort. These include the following:

- System technology replacement.
- Use of local renewable energy.
- Interventions on the architecture of the building and insulation of the building envelope.

The economic evaluation approaches are different in scope and perspective, designed to help specific stakeholders make decisions. The most frequently adopted economic method in the analyzed papers is Cost–Benefit Analysis (CBA). This evaluation is usually conducted *ex ante* to forecast costs and benefits and determine whether a project should be implemented or if it is preferable to alternative solutions. CBA is mainly conducted at the district and urban levels, and to a lesser extent at the building level. The outcome should lead to modifying a design option or deciding not to implement the project and maintain the status quo.

A CBA can also be conducted *ex post facto*, or retrospectively, to evaluate the intervention. In this case, the selected project design is assessed to determine its benefit to society. The analysis revealed that only 45% of the reviewed case studies used a discount rate or discount cash flow. All relevant costs and benefits arising over time should be calculated using a common temporal basis (as is usually performed presently). This is achieved through time value of money calculations, which convert future expected streams of costs and benefits into present values using a discount rate. Table 6 summarizes different methods that apply a discount rate.

**Table 6.** Economic methods using a discount rate in the calculation.

Economic Method	Uses Discount Rate	References
Cost–Benefit Analysis (CBA)	Yes (52% of cases)	[20,22–24]
Cost of Illness (COI)	No	[23,24]
Willingness to Pay (WTP)	No	[67,69]
Life Cycle Costing (LCC)	Yes (debated)	[25,65]
Life Cycle Assessment (LCA)	Yes (60% of cases)	[20,50,66]
Techno-/Thermo-Economic Assessment	Yes (37% of cases)	[26,27,29,30,40]
Multi-Criteria Analysis (MCA)	Rare or unclear	[36]

Recurrent discount rate values range between 3% and 7%. In detail, for economic assessment, 52% of studies adopting the CBA method use a discount rate, 60% of those using LCA, and just 37% of studies deal with techno-/thermo-economic analysis. Instead, for Cost of Illness (COI) and willingness to pay (WTP), related papers do not apply the discount rate. Also, the intangible cost used to estimate WTP from the people to invest in the energy area is not directly in the area of intervention, but it was used in benefit transfer [23,24]. Life Cycle Costing Assessments are increasingly discussed among experts but are hardly applied. Regarding greenhouse gases, just 11 papers of all 37 documents consider this topic. Most of the papers generally mention how relevant it is to reduce the

CO<sub>2</sub> emissions and the advantages coming from the reductions, but just four of the papers include the reduction of CO<sub>2</sub> as part of the economic evaluation [20,22,50,67].

As mentioned, the evidence assessment was conducted using the Scopus database and selected keywords, considering the topic of economic evaluation method as the common feature. To check for possible correlation and cross-fertilization among papers, research with the Mendeley system was carried out. The research indicated that most of the articles do not refer to each other, so there is no explicit knowledge of similar research, although the similarity of intent is depicted by the keywords.

Overall, the review reveals that economic assessment methods have been mainly applied at the building, district, and urban levels, with the district scale receiving the greatest attention, especially in relation to heating systems. While classical approaches such as CBA remain the most frequently used, recent years have witnessed a diversification of methods, including socio-economic evaluations and multi-criteria frameworks. Nevertheless, applications explicitly integrating greenhouse gas reductions, health impacts, and broader socio-economic benefits remain limited. This indicates a research gap and suggests that future studies should further combine economic, environmental, and social perspectives to support comprehensive and multi-scale decision-making in Positive Energy Districts.

#### 4. Key Performance Indicators

This section illustrates the results of the literature review on the quantification of economic impacts and benefits and discusses the Key Performance Indicators used within the reviewed case studies.

Table 7 reports the main KPIs encountered in analyzed papers, distinguished by different economic or economic-related methods: Techno/Term Economy, Cost Benefit Analysis (CBA), Cost of Illness (COI), Multi-Criteria Analysis (MCA), Life Cycle Assessment (LCA), and Life Cycle Costing Assessment (LCCA/LCC).

**Table 7.** KPIs encountered in analyzed papers, distinguished by economic methods.

ECONOMIC METHOD	KPI	SOURCES
TECHNO/TERM ECONOMY	- LCOE (Levelized Cost of Energy)	[1,2]
	- EEP (Electrical Power Produced)	
	- Energy Efficiency	[3,4]
	- Exergy Efficiency	
	- Energy Loss Rate (Ren)	
	- Exergy Loss Rate (Rex)	
	- Endogenous Avoidable Exergy Destruction	[5]
	- Exogenous Avoidable Exergy Destruction	
	- Endogenous Unavoidable Exergy Destruction	
	- Exogenous Unavoidable Exergy Destruction	
- LCOH (Levelized Cost of Heat)	[6]	
- HEP (Heat Power Produced)		
- Annual Losses Heating	[7]	
- Cost of Heat Distribution		

Table 7. Cont.

ECONOMIC METHOD	KPI	SOURCES
CBA (COST-BENEFIT ANALYSIS)	- NPV (Net Present Value)	[7–13]
	- CAPEX	
	- OPEX	
	- IRR (Internal Rate of Return)	
	- PBP (Payback Period)	
	- CAPEX	[2,14,15]
	- OPEX	
	- Energy Consumption	
	- Emissions (CO <sub>2</sub> and Other Pollutants)	
	- NPV (Net Present Value)	[16]
- Energy Consumption		
- Emissions (CO <sub>2</sub> and Other Pollutants)		
- NPV (Net Present Value)	[15]	
- PBP (Payback Period)		
- NPV (Net Present Value)	[17]	
- Installation Cost		
- Energy Consumption		
- PBP (Payback Period)		
- Cost of Revenue Different Performance System	[18]	
- CO <sub>2</sub> Emissions		
	[19]	
- CAPEX	[6]	
- OPEX		
- Salvage Value		
- NPV (Net Present Value)	[20]	
- CAPEX		
- OPEX		
- IRR (Internal Rate Return)		
- WTP (Willingness to Pay)		
- PBP (Payback Period)		
- CAPEX	[21,22]	
- OPEX		
- Energy Consumption		
- Emissions (CO <sub>2</sub> and Other Pollutants)		
- IRR (Internal Rate of Return)		
- PBP (Payback Period)		
COI (COST OF ILLNESS)	- Direct Cost	[23]
	- Indirect Cost	
	- Direct Cost	[24]
- Indirect Cost		
- Intangible Cost (WTP   VOLLY)		

Table 7. Cont.

ECONOMIC METHOD	KPI	SOURCES
MCA (MULTI-CRITERIA ANALYSIS)	- CO <sub>2</sub> emissions	[25]
	- Population	
	- Land Prize	
MCA (MULTI-CRITERIA ANALYSIS)	- LCE (Levelized Cost of Energy)	[26]
	- EEP (Electrical Power Produced)	
	- Transportation Analysis	
MCA (MULTI-CRITERIA ANALYSIS)	- Land Prize	[27]
	- CO <sub>2</sub> Emissions	
	- GIS and Light and Raging (LiDAR) to Estimate the Rooftop PV Electricity	
LCA (LIFE CYCLE ASSESSMENT)	- Cost and Revenue Regard Different PV	[8,17,28,29]
	- Power Output Energy Produced	
	- LCOE (Levelized Cost of Energy)	
LCA (LIFE CYCLE ASSESSMENT)	- NPV (Net Present Value)	[32]
	- Bioenergy Costs	
	- Commodity Prices	
LCCA (LIFE CYCLE COSTING ASSESSMENT)	- Bioenergy Production	[2]
	- Initial and Operating Cost CO <sub>2</sub> Emissions	
	- Present Worth Factor (PWF) Depending on the Inflation Rate and Interest Rate	

Conversely, macro-economic approaches prioritize social Key Performance Indicators (KPIs), such as employment factors or impacts. These include metrics like the number of jobs created per EUR 1 million invested and jobs generated over a 40-year period. Additionally, these approaches consider the net savings to society, including the value of externalities, such as the sum of lifetime energy cost savings and the value of externalities minus the lifetime investment [46,52]. Furthermore, impacts on fuel poverty [63] are considered.

Economic Key Performance Indicators (KPIs) frequently exhibit a high degree of correlation with KPIs from technical domains. These technical domains include, but are not limited to, thermal comfort, energy labelling, energy savings, primary energy demand, grid impact, and deferred grid investment. Economic KPIs also exhibit a high degree of correlation with environmental metrics, such as carbon costs. Furthermore, economic Key Performance Indicators (KPIs) may encompass awareness regarding the economic advantages of diminished energy consumption or take into account grants (i.e., the proportion of investment that is financed by grants) [34].

#### 4.1. Differences Among KPIs

The KPIs identified in the reviewed literature can be broadly distinguished into three main categories. First, financial indicators (e.g., Net Present Value, Internal Rate of Return, Payback Period, CAPEX, and OPEX) primarily serve private investors by measuring the profitability and cost-effectiveness of energy interventions. Second, technical-economic indicators (e.g., Levelized Cost of Energy, Levelized Cost of Heat, exergy efficiency, energy loss rates) provide a bridge between energy system performance and economic feasibility, and are especially useful for technology assessment and system comparison. Third, macro- and socio-economic indicators (e.g., Cost of Illness, willingness to pay, employment factors, avoided externalities, social return on investment) evaluate broader societal impacts and

capture benefits not directly reflected in market prices. This categorization highlights that while the same intervention may be assessed with multiple KPIs, each set of indicators responds to different stakeholder needs and decision-making contexts.

#### *4.2. Applicability of KPIs to PEDs*

In the context of Positive Energy Districts (PEDs), the applicability of evaluation metrics depends on the perspective and scale of analysis. Financial indicators are particularly relevant for evaluating single-building retrofits or local investments within the district, providing a clear signal to owners and investors. Technical-economic indicators are essential at the district scale, where the interaction of multiple technologies (e.g., heating networks, renewable generation, and storage) requires a systemic comparison of costs and efficiency. Finally, macro- and socio-economic indicators are more suitable for policymakers and urban planners, as they capture distributional effects, health co-benefits, employment impacts, and environmental externalities. This multi-level applicability shows that PED assessment requires a combination of KPI types to fully capture the private, public, and societal value of interventions.

#### *4.3. Findings KPIs to PEDs*

To summarize, the existing literature demonstrates that a wide variety of Key Performance Indicators (KPIs) have been utilized to quantify the economic and socio-environmental impacts of energy interventions. The diversity of the projects under consideration reflects the multiple dimensions of PED assessment, ranging from project-level profitability to systemic efficiency and societal benefits. Financial indicators predominate in the decision-making process regarding private investment, while technical, economic, and macro-socio-economic indicators facilitate a more comprehensive evaluation of energy transitions at the district scale. The findings emphasize the necessity of adopting a balanced set of KPIs to capture the full range of outcomes associated with Positive Energy Districts. This conclusion provides the foundation for the subsequent section, which focuses on the operationalisation of such indicators as decision-support tools in practice.

## **5. Discussion and Research Gaps**

In the undertaken literature research, most economic assessments are performed in terms of a techno-economic assessment using Cost–Benefit Analysis (CBA), with a focus on cost efficiency. Longer time spans greater than 25 years are often considered; however, end-of-life phases such as disposal are only partly regarded. Life Cycle Costing (LCC) assessments that would include the disposal of a building or system are not yet widely applied. Furthermore, cost assessments seldom account for the value or cost of integrating Positive Energy Districts (PEDs) into broader energy systems, such as through interactions with energy markets or demand-side flexibility. Some methods have started to adopt broader and more holistic approaches. The European Commission’s “Economic Appraisal Vademecum 2021–2027” [70] outlines appropriate methods for assessing investment programmes across different sectors. In particular, Multi-Criteria Analysis (MCA) is recommended for urban development initiatives involving multisector investments—such as energy efficiency, renewable energy sources (RESs), and sustainable mobility—which are key to PED design. MCA allows identification of cross-sectoral synergies, supports integrated planning, and improves understanding of overall project benefits. For buildings, the Vademecum recommends cost-effectiveness assessments with externalities; for larger projects, it highlights the importance of evaluating added impacts on the operation and value of buildings, such as longer lifespan, lower maintenance, better comfort, and enhanced property value. Nevertheless, several methodological shortcomings remain. A

lack of discounting in costs and benefits persists across much of the literature, contrary to recommendations in [71–73]. Sensitivity analysis is infrequently applied [30]. Important co-benefits such as biodiversity or well-being are described in theory but not included in quantitative models due to difficulties in valuation [23]. This creates a gap between the actual societal benefits and the economic framing used for PEDs. As [33] notes, collective and public gains should complement the typical private-oriented focus in project appraisals. Research such as [55] overlooks CO<sub>2</sub> and greenhouse gas emissions in the evaluation model; others, such as [71,74], emphasize the ethical and uncertainty dimensions of valuing CO<sub>2</sub>. Furthermore, economic assessments typically focus on cost avoidance rather than monetizing the full spectrum of social and environmental benefits [75]. Willingness to pay (WTP) approaches can be an alternative but are underutilized.

### 5.1. Tools and Data for Enhanced Economic Modelling

Section 5.1 identifies three strategic avenues that could be used to enhance the economic modelling of Positive Energy Districts (PEDs). Firstly, it is possible that the integration of carbon pricing mechanisms, such as shadow pricing or marginal abatement cost, could improve the internalization of environmental externalities in economic assessments. Secondly, it is important to note that willingness to pay (WTP) approaches are not being used to their full potential and often rely on transferred values from external contexts. This highlights the need for localized data and survey-based evidence. Thirdly, the adoption of geographic information systems (GISs) could offer valuable support for spatial cost analysis, demand visualization, and more effective communication of PED-related benefits. It is hoped that these tools, when used together, will contribute to more robust, context-sensitive, and policy-relevant economic evaluations.

1. CO<sub>2</sub> Pricing Integration: Future models should integrate carbon pricing scenarios (e.g., shadow pricing and marginal abatement cost).
2. Willingness to Pay (WTP): WTP is often based on transferred values from other cases. More local data and surveys are needed.
3. GIS for Economic Modelling: GIS supports spatial cost mapping, demand visualization, and better communication of PED benefits.

### 5.2. Methodological Gaps Across Scales

Table 8 clearly outlines the key methodological gaps in the application of economic assessment methods across different spatial scales. These gaps are in line with the paper's objective to evaluate the economic impact of Positive Energy Districts (PEDs). Cost–Benefit Analysis (CBA) is frequently applied at the district level (primarily *ex ante*) yet often overlooks social co-benefits and applies partial discounting. Life Cycle Costing (LCC) is still in its early stages of development, with limited use on the building scale and virtually no application at urban levels. Additionally, the disposal phase is rarely considered. Multi-Criteria Analysis (MCA) has significant potential at the city scale, but it is not being used enough in PED planning. Techno-economic assessments are mainly focused on operational costs and do not take a comprehensive approach to long-term impacts. Finally, methods such as willingness to pay (WTP) and Contingent Valuation (CV) are rarely employed and often rely on non-local data, limiting their contextual validity.

**Table 8.** Key methodological gaps in the application of economic assessment methods across different spatial scales.

Method	Building Scale	District Scale	City/Urban Scale	Identified Gaps
Cost–Benefit Analysis (CBA)	Rare	Frequent (ex ante)	Limited	Partial discount; missing social co-benefits
Life Cycle Cost (LCC)	Emerging	Rare	Not applied	Disposal phase rarely included
Multi-Criteria Analysis (MCA)	Limited	Moderate	High potential	Underused in PED planning
Techno-Economic Assessment	Frequent	Moderate	Rare	Focused only on operational costs
WTP/CV Methods	Building	Rare	Rare	Often based on non-local data

### 5.3. Case-Based Evidence of Gaps

Section 5.3 provides case-based insights that expose critical limitations in current economic evaluation frameworks for Positive Energy Districts (PEDs). Study [71] emphasizes the uncertainty surrounding marginal CO<sub>2</sub> cost assumptions, raising concerns about the robustness and reliability of long-term economic trade-offs. This highlights the sensitivity of climate-related cost estimations to methodological variations, which may undermine policy guidance. In parallel, study [52] conducts a Cost–Benefit Analysis (CBA) within an energy-efficiency context yet omits CO<sub>2</sub> valuation, resulting in an incomplete representation of environmental impacts and potential underestimation of net social benefits. These cases collectively demonstrate the insufficient consideration of externalities, particularly those associated with decarbonization. They reinforce the need for integrative, multi-dimensional appraisal frameworks capable of incorporating intangible, intertemporal, and spatially diffuse benefits. Addressing these gaps is essential to align economic assessments with sustainability goals and to support evidence-based decision-making for PED development.

## 6. Concluding Remarks

To address global sustainability goals, urban energy transitions require complex, cross-sectoral solutions that integrate energy systems, buildings, digital platforms, and infrastructure. However, tensions persist between innovation and funding limitations. Economic assessments must be used both *ex ante* (to guide investment choices) and *ex post* (to assess performance and outcomes).

Most PED economic evaluations rely on fragmented techniques: building-scale analyses do not capture district-level interactions, and many fail to articulate societal or long-term gains. Future research must bridge this gap by embedding PED assessments within a broader public value perspective.

### 6.1. Extending the Public Value Lens

Public value refers to net benefits created for society beyond private economic returns. This can be operationalized by the following:

1. Extending CBA to include co-benefits such as health improvements or reduced inequality.
2. SROI (social return on investment) to measure indirect community impacts.
3. Equity-weighted appraisals, giving voice to vulnerable groups and marginalized populations.

### 6.2. Sectoral Synergies: Energy, Mobility, Digital

Synergies between energy, transport, and digital infrastructure are underexplored in many PED evaluations. Horizon Europe projects such as ATELIER, MAKING-CITY, and oPEN Lab highlight the following:

1. Vehicle-to-grid integration;
2. Smart mobility combined with energy optimization;
3. Shared data platforms for operational insights.

### 6.3. Synthesis PED Economic Evaluation Outlook

1. Current Methods: CBA, LCC, MCA, Techno-economic, and WTP;
2. Main Limitations: Lack of discounting, externality integration, and spatial sensitivity;
3. Future Directions: GIS integration, public value frameworks, and dynamic modelling;
4. Recommendations: Multi-scale evaluations, local WTP data, ESG alignment, and SDG mapping.

This synthesis offers a roadmap for more robust and holistic economic evaluations of PEDs. It emphasizes the need to go beyond purely financial indicators by embedding multidimensional values—including environmental resilience, equity, and quality of life—into planning tools and policy frameworks. The figure serves not only as a conceptual summary but also as a guiding matrix for both researchers and practitioners seeking to operationalize economic sustainability in urban energy transitions.

By applying a multi-criteria, public-value-oriented approach, PEDs can maximize their contribution not only to energy and climate goals, but also to social well-being, inclusion, and spatial justice.

**Author Contributions:** Conceptualization, A.B. and M.V.; methodology, A.B. and A.T.; software, M.V.; validation, C.N., A.B., A.T., F.G., R.V., M.B.A. and M.H.; formal analysis, I.M., M.V. and A.B.; investigation, I.M. and M.V.; resources, A.B., A.T., F.G., C.N. and R.V.; data curation, I.M. and M.V.; writing—original draft preparation, A.B. and M.V.; writing—review and editing, I.M. and M.V.; visualization, I.M. and M.V.; supervision, A.B., A.T., F.G., R.V., M.B.A. and M.H.; project administration, A.B. and A.T.; funding acquisition, A.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was partially funded by the European Union’s Horizon 2020 program under the Prolight Project (grant agreement no. 101079902) and the ARV Project (grant agreement no. 101036723).

**Data Availability Statement:** The data presented in this study are openly available in: IPCC Sixth Assessment Report at (<https://www.ipcc.ch/report/ar6/wg2/>, accessed on 20 September 2025); Renewable energy at ([https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable\\_energy\\_statistics#Share\\_of\\_renewable\\_energy\\_almost\\_doubled\\_between\\_2004\\_and\\_2018](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_almost_doubled_between_2004_and_2018), accessed on 20 September 2025). SCOPUS (<https://www.scopus.com/>, accessed on 20 September 2025).

**Acknowledgments:** This work was developed within the context of the International Energy Agency (IEA) Energy in Buildings and Construction (EBC) Annex 83 working group on Positive Energy Districts.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Intergovernmental Panel on Climate Change. *Climate Change 2014: Mitigation of Climate Change*; Cambridge University Press: Cambridge, UK, 2014. [CrossRef]
2. IPCC. *Climate Change 2022—Mitigation of Climate Change—Working Group III*; Cambridge University Press: Cambridge, UK, 2022; p. 1454.

3. IPCC. *Climate Change 2022: Impacts, Adaptation and Vulnerability Working Group II Contribution to the IPCC Sixth Assessment Report Citations to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2022. [CrossRef]
4. United Nations Climate Change. COP 21 Paris Agreement. 2015. Available online: <https://unfccc.int/process-and-meetings/the-paris-agreement> (accessed on 20 September 2025).
5. Roy, J.; Tscharket, P.; Waisman, H.; Abdul Halim, S.; Antwi-Agyei, P.; Dasgupta, P.; Hayward, B.; Kanninen, M.; Liverman, D.; Okereke, C.; et al. *Sustainable Development, Poverty Eradication and Reducing Inequalities*; Cambridge University Press: Cambridge, UK, 2018; pp. 445–538.
6. United Nations. *The Sustainable Development Goals Report*; Stylus Publishing, LLC.: Sterling, VA, USA, 2020.
7. European Commission. European Commission, Green Deal. Available online: [https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal\\_it](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_it) (accessed on 28 February 2021).
8. European Commission. *Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 Amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency*; European Union: Brussels, Belgium, 2018.
9. IEA. *World Energy Outlook 2019-GlobalABC Regional Roadmap for Buildings and Construction in Asia 2020–2050*; OECD: Paris, France, 2019. [CrossRef]
10. IEA E UN. *2019 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector*; The UN Environment Programme: Nairobi, Kenya, 2019.
11. European Union. SET-Plan Working Group, SET-Plan Action No 3.2 Implementation Plan-Europe to Become a Global Role Model in Integrated, Innovative Solutions for the Planning, Deployment, and Replication of Positive Energy Districts. 2018. Available online: [https://jpi-urbaneurope.eu/wp-content/uploads/2021/10/setplan\\_smartcities\\_implementationplan-2.pdf](https://jpi-urbaneurope.eu/wp-content/uploads/2021/10/setplan_smartcities_implementationplan-2.pdf) (accessed on 4 July 2025).
12. Hedman, Å.; Rehman, H.U.; Gabaldón, A.; Bisello, A.; Albert-Seifried, V.; Zhang, X.; Guarino, F.; Grynning, S.; Eicker, U.; Neumann, H.-M.; et al. IEA EBC Annex83 Positive Energy Districts. *Buildings* **2021**, *11*, 130. [CrossRef]
13. JPI Urban Europe. Positive Energy Districts (PED). Available online: <https://jpi-urbaneurope.eu/ped/> (accessed on 21 March 2021).
14. Marotta, I.; Guarino, F.; Longo, S.; Cellura, M. Environmental sustainability approaches and positive energy districts: A literature review. *Sustainability* **2021**, *13*, 13063. [CrossRef]
15. Tuerk, A.; Frieden, D.; Neumann, C.; Latanis, K.; Tsitsanis, A.; Kousouris, S.; Llorente, J.; Heimonen, I.; Reda, F.; Ala-Juusela, M.; et al. Integrating plus energy buildings and districts with the eu energy community framework: Regulatory opportunities, barriers and technological solutions. *Buildings* **2021**, *11*, 468. [CrossRef]
16. Hearn, A.X.; Sohre, A.; Burger, P. Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. *Energy Res. Soc. Sci.* **2021**, *78*, 102127. [CrossRef]
17. Jenkins, K.; Sovacool, B.K.; McCauley, D. Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change. *Energy Policy* **2018**, *117*, 66–74. [CrossRef]
18. Müller, B.; Liu, J.; Cai, J.; Schiappacasse, P.; Neumann, H.-M.; Yang, B. *Towards Socially Integrative Cities: Perspectives on Urban Sustainability in Europe and China*; MDPI-Multidisciplinary Digital Publishing Institute: Basel, Switzerland, 2021; Volume 6.
19. Kouhestani, F.M.; Byrne, J.; Johnson, D.; Spencer, L.; Hazendonk, P.; Brown, B. Evaluating solar energy technical and economic potential on rooftops in an urban setting: The city of Lethbridge, Canada. *Int. J. Energy Environ. Eng.* **2019**, *10*, 13–32. [CrossRef]
20. Delwati, M.; Ammar, A.; Geyer, P. Economic evaluation and simulation for the Hasselt case study: Thermochemical district network technology vs. Alternative technologies for heating. *Energies* **2019**, *12*, 1260. [CrossRef]
21. Pirouti, M.; Bagdanavicius, A.; Ekanayake, J.; Wu, J.; Jenkins, N. Energy consumption and economic analyses of a district heating network. *Energy* **2013**, *57*, 149–159. [CrossRef]
22. Chester, M.V.; Nahlik, M.J.; Fraser, A.M.; Kimball, M.A.; Garikapati, V.M. Integrating life-cycle environmental and economic assessment with transportation and land use planning. *Environ. Sci. Technol.* **2013**, *47*, 12020–12028. [CrossRef] [PubMed]
23. Mena-Carrasco, M.; Oliva, E.; Saide, P.; Spak, S.N.; de la Maza, C.; Osses, M.; Tolvett, S.; Campbell, J.E.; Tsao, T.E.C.C.; Molina, L.T. Estimating the health benefits from natural gas use in transport and heating in Santiago, Chile. *Sci. Total Environ.* **2012**, *429*, 257–265. [CrossRef] [PubMed]
24. Macías, P.; Islas, J. Damage costs produced by electric power plants. An externality valuation in the Mexico City Metropolitan Area. *Sci. Total Environ.* **2010**, *408*, 4511–4523. [CrossRef] [PubMed]
25. Bisello, A.; Antoniucci, V.; Marella, G. Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market. *Energy Build.* **2020**, *208*, 109670. [CrossRef]
26. Zia, U.U.R.; Rashid, T.; Ali, M.; Awan, W.N. Techno-economic assessment of energy generation through municipal solid waste: A case study for small/medium size districts in Pakistan. *Waste Dispos. Sustain. Energy* **2020**, *2*, 337–350. [CrossRef]

27. Dahash, A.; Ochs, F.; Tosatto, A. Techno-economic and exergy analysis of tank and pit thermal energy storage for renewables district heating systems. *Renew. Energy* **2021**, *180*, 1358–1379. [CrossRef]
28. Eriksson, G.; Kjellström, B. Assessment of combined heat and power (CHP) integrated with wood-based ethanol production. *Appl. Energy* **2010**, *87*, 3632–3641. [CrossRef]
29. Keçebaş, A. Performance and thermo-economic assessments of geothermal district heating system: A case study in Afyon, Turkey. *Renew. Energy* **2011**, *36*, 77–83. [CrossRef]
30. Chen, Y.; Xu, J.; Zhao, D.; Wang, J.; Lund, P.D. Exergo-economic assessment and sensitivity analysis of a solar-driven combined cooling, heating and power system with organic Rankine cycle and absorption heat pump. *Energy* **2021**, *230*, 120717. [CrossRef]
31. Tan, M.; Keçebaş, A. Thermodynamic and economic evaluations of a geothermal district heating system using advanced exergy-based methods. *Energy Convers. Manag.* **2014**, *77*, 504–513. [CrossRef]
32. Bandara, A.; Hemapala, K.T.M.U.; Herath, A. Optimal Sizing and Economic Evaluation of a Photovoltaic Integrated Energy System-A Case Study for a Semi-Urban Area in Sri Lanka. In Proceedings of the 2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, India, 1–3 December 2020; Institute of Electrical and Electronics Engineers Inc.: New York, NY, USA, 2020. [CrossRef]
33. Bisello, A. Assessing Multiple Benefits of Housing Regeneration and Smart City Development: The European Project SINFONIA. *Sustainability* **2020**, *12*, 8038. [CrossRef]
34. Karner, K.; Theissing, M.; Kienberger, T. Modeling of energy efficiency increase of urban areas through synergies with industries. *Energy* **2017**, *136*, 201–209. [CrossRef]
35. Zuberi, M.J.S.; Narula, K.; Klinke, S.; Chambers, J.; Streicher, K.N.; Patel, M.K. Potential and costs of decentralized heat pumps and thermal networks in Swiss residential areas. *Int. J. Energy Res.* **2021**, *45*, 15245–15264. [CrossRef]
36. Becchio, C.; Bottero, M.C.; Corgnati, S.P.; Dell’Anna, F. Decision making for sustainable urban energy planning: An integrated evaluation framework of alternative solutions for a NZED (Net Zero-Energy District) in Turin. *Land Use Policy* **2018**, *78*, 803–817. [CrossRef]
37. Angelakoglou, K.; Nikolopoulos, N.; Giourka, P.; Svensson, I.-L.; Tsarchopoulos, P.; Tryferidis, A.; Tzouvaras, D. A Methodological Framework for the Selection of Key Performance Indicators to Assess Smart City Solutions. *Smart Cities* **2019**, *2*, 269–306. [CrossRef]
38. Coutinho-Rodrigues, J.; Simão, A.; Antunes, C.H. A GIS-based multicriteria spatial decision support system for planning urban infrastructures. *Decis. Support Syst.* **2011**, *51*, 720–726. [CrossRef]
39. Bottero, M.; Mondini, G.; Oppio, A. Decision Support Systems for Evaluating Urban Regeneration. *Procedia-Soc. Behav. Sci.* **2016**, *223*, 923–928. [CrossRef]
40. Bottero, M.; Assumma, V.; Caprioli, C.; Dell’oVo, M. Decision making in urban development: The application of a hybrid evaluation method for a critical area in the city of Turin (Italy). *Sustain. Cities Soc.* **2021**, *72*, 103028. [CrossRef]
41. Cruz, C.O.; Silva, C.M.; Dias, P.V.; Teotónio, I. Economic impact of changing thermal regulation—An application to the city of Lisbon. *Energy Build.* **2017**, *149*, 354–367. [CrossRef]
42. European Parliament. II of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements (Text with EEA relevance). *Eur. J. Oper. Res.* **2012**. Available online: [http://data.europa.eu/eli/reg\\_del/2012/244/oj](http://data.europa.eu/eli/reg_del/2012/244/oj) (accessed on 22 May 2025).
43. Isaac, S.; Shubin, S.; Rabinowitz, G. Cost-Optimal Net Zero Energy Communities. *Sustainability* **2020**, *12*, 2432. [CrossRef]
44. Liu, W.H.; Hashim, H.; Lim, J.S.; Ho, C.S.; Klemeš, J.J.; Zamhuri, M.I.; Ho, W.S. Techno-economic assessment of different cooling systems for office buildings in tropical large city considering on-site biogas utilization. *J. Clean. Prod.* **2018**, *184*, 774–787. [CrossRef]
45. Flores, J.C.; Lacarrière, B.; Chiu, J.; Martin, V. Assessing the techno-economic impact of low-temperature subnets in conventional district heating networks. *Energy Procedia* **2017**, *116*, 260–272. [CrossRef]
46. Vespucci, M.T.; Zigrino, S.; Bazzocchi, F.; Gelmini, A. A software tool for the optimal planning and the economic evaluation of residential cogeneration districts. In Proceedings of the 2011 8th International Conference on the European Energy Market (EEM), Zagreb, Croatia, 25–27 May 2011; pp. 376–381.
47. Keçebaş, A.; Alkan, M.A.; Yabanova, I.; Yumurtaci, M. Energetic and economic evaluations of geothermal district heating systems by using ANN. *Energy Policy* **2013**, *56*, 558–567. [CrossRef]
48. Rosasco, P.; Perini, K.; Magliocco, A.; Cattaneo, E. Experimental project of a green facade: Monitoring and economic evaluation. *Geoinf. Ambient. Mineraria* **2018**, *155*, 53–64.
49. Calise, F.; Dentice d’Accadia, M.; Macaluso, A.; Vanoli, L.; Piacentino, A. A novel solar-geothermal trigeneration system integrating water desalination: Design, dynamic simulation and economic assessment. *Energy* **2016**, *115*, 1533–1547. [CrossRef]
50. Mostafaeipour, A.; Rezaei, M.; Jahangiri, M.; Qolipour, M. Feasibility analysis of a new tree-shaped wind turbine for urban application: A case study. *Energy Environ.* **2020**, *31*, 1230–1256. [CrossRef]

51. Leme, M.M.V.; Rocha, M.H.; Lora, E.E.S.; Venturini, O.J.; Lopes, B.M.; Ferreira, C.H. Techno-economic analysis and environmental impact assessment of energy recovery from Municipal Solid Waste (MSW) in Brazil. *Resour. Conserv. Recycl.* **2014**, *87*, 8–20. [[CrossRef](#)]
52. Teotónio, I.; Silva, C.M.; Cruz, C.O. Eco-solutions for urban environments regeneration: The economic value of green roofs. *J. Clean. Prod.* **2018**, *199*, 121–135. [[CrossRef](#)]
53. Clark, C.; Adriaens, P.; Talbot, F.B. Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. *Environ. Sci. Technol.* **2008**, *42*, 2155–2161. [[CrossRef](#)] [[PubMed](#)]
54. Peng, L.L.H.; Jim, C.Y. Economic evaluation of green-roof environmental benefits in the context of climate change: The case of Hong Kong. *Urban For. Urban Green.* **2015**, *14*, 554–561. [[CrossRef](#)]
55. Lamagna, M.; Nastasi, B.; Groppi, D.; Rozain, C.; Manfren, M.; Astiaso Garcia, D. Techno-economic assessment of reversible Solid Oxide Cell integration to renewable energy systems at building and district scale. *Energy Convers. Manag.* **2021**, *235*, 113993. [[CrossRef](#)]
56. European Commission. Climate Positive Circular Communities. 2021. Available online: <https://cordis.europa.eu/project/id/101036723> (accessed on 22 September 2025).
57. McCord, M.; Haran, M.; Davis, P.; McCord, J. Energy performance certificates and house prices: A quantile regression approach. *J. Eur. Real Estate Res.* **2020**, *13*, 409–434. [[CrossRef](#)]
58. Welsch, B.; Göllner-Völker, L.; Schulte, D.O.; Bär, K.; Sass, I.; Schebek, L. Environmental and economic assessment of borehole thermal energy storage in district heating systems. *Appl. Energy* **2018**, *216*, 73–90. [[CrossRef](#)]
59. Mosannenzadeh, F.; Bisello, A.; Diamantini, C.; Stellin, G.; Vettorato, D. A case-based learning methodology to predict barriers to implementation of smart and sustainable urban energy projects. *Cities* **2017**, *60*, 28–36. [[CrossRef](#)]
60. Dastrup, S.R.; Zivin, J.G.; Costa, D.L.; Kahn, M.E. Understanding the Solar Home price premium: Electricity generation and “Green” social status. *Eur. Econ. Rev.* **2012**, *56*, 961–973. [[CrossRef](#)]
61. ZEBRA. D5.1 Nearly Zero-Energy Building (nZEB) technology solutions, cost assessment and performance. 2016. Available online: <https://www.bpie.eu/publication/strategies-for-a-nearly-zero-energy-building-nzeb-market-transition-in-the-eu/> (accessed on 20 September 2025).
62. Derkenbaeva, E.; Vega, S.H.; Hofstede, G.J.; van Leeuwen, E. Positive energy districts: Mainstreaming energy transition in urban areas. *Renew. Sustain. Energy Rev.* **2022**, *153*, 111782. [[CrossRef](#)]
63. Rehman, H.U.; Reda, F.; Paiho, S.; Hasan, A. Towards positive energy communities at high latitudes. *Energy Convers. Manag.* **2019**, *196*, 175–195. [[CrossRef](#)]
64. Synnefa, A.; Laskari, M.; Gupta, R.; Pisello, A.L.; Santamouris, M. Development of Net Zero Energy Settlements Using Advanced Energy Technologies. *Procedia Eng.* **2017**, *180*, 1388–1401. [[CrossRef](#)]
65. Akande, A.; Cabral, P.; Gomes, P.; Casteleyn, S. The Lisbon Ranking for Smart Sustainable Cities in Europe. *Sustain. Cities Soc.* **2019**, *44*, 475–487. [[CrossRef](#)]
66. D’Alpaos, C.; Bragolusi, P. Buildings energy retrofit valuation approaches: State of the art and future perspectives. *Valori Valutazioni* **2018**, *20*, 79–94.
67. Bottero, M.; D’Alpaos, C.; Dell’Anna, F. Boosting investments in buildings energy retrofit: The role of incentives. In *Smart Innovation, Systems and Technologies*; Springer Science and Business Media Deutschland GmbH: Heidelberg, Germany, 2019; pp. 593–600. [[CrossRef](#)]
68. Janssen, R.; Staniaszek, D. How Many Jobs? A survey of the employment effects of investment in Energy Efficiency of Buildings. In *The Energy Efficiency Industrial Forum*; Union of International Associations: Brussels, Belgium, 2012.
69. Good, N.; Ceseña, E.A.M.; Heltorp, C.; Mancarella, P. A transactive energy modelling and assessment framework for demand response business cases in smart distributed multi-energy systems. *Energy* **2019**, *184*, 165–179. [[CrossRef](#)]
70. European Commission. Economic Appraisal Vademecum 2021–2027—General Principles and Sector Applications. Available online: [https://ec.europa.eu/regional\\_policy/en/information/publications/guides/2021/economic-appraisal-vademecum-2021-2027-general-principles-and-sector-applications](https://ec.europa.eu/regional_policy/en/information/publications/guides/2021/economic-appraisal-vademecum-2021-2027-general-principles-and-sector-applications) (accessed on 20 September 2025).
71. Lumley, N.P.; Ramey, D.F.; Prieto, A.L.; Braun, R.J.; Cath, T.Y.; Porter, J.M. Techno-economic analysis of wastewater sludge gasification: A decentralized urban perspective. *Bioresour. Technol.* **2014**, *161*, 385–394. [[CrossRef](#)] [[PubMed](#)]
72. Gulli, F. Social choice, uncertainty about external costs and trade-off between intergenerational environmental impacts: The emblematic case of gas-based energy supply decentralization. *Ecol. Econ.* **2006**, *57*, 282–305. [[CrossRef](#)]
73. Blöchle, M.; Zucker, G.; Xypolytou, E.; Leber, T.; Prügler, W.; Rührlinger, T. Optimizing neighborhood consumption of renewables through clustering and H<sub>2</sub> storage: An economic assessment of an Austrian community. In *Proceedings of the 12th International Conference on the European Energy Market (EEM)*, Lisbon, Portugal, 19–22 May 2015; IEEE Computer Society: Los Alamitos, CA, USA, 2015.

74. Tulus, V.; Abokersh, M.H.; Cabeza, L.F.; Vallès, M.; Jiménez, L.; Boer, D. Economic and environmental potential for solar assisted central heating plants in the EU residential sector: Contribution to the 2030 climate and energy EU agenda. *Appl. Energy* **2019**, *236*, 318–339. [[CrossRef](#)]
75. European Bank Authority. *Handbook on Valuation for Purposes of Resolution*; European Bank Authority: Paris, France, 2019. Available online: <https://www.eba.europa.eu/sites/default/documents/files/documents/10180/2613666/9f0772ea-a052-49e5-86ce-64c157adff10/Valuation%20Handbook.pdf?retry=1> (accessed on 22 February 2024).

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.