

Review

# From ‘Zero’ to ‘Positive’ Energy Concepts and from Buildings to Districts—A Portfolio of 51 European Success Stories

Sesil Koutra 

Faculty of Architecture and Urban Planning, University of Mons, 88 Str. Havre, 7000 Mons, Belgium; sesil.koutra@umons.ac.be

**Abstract:** Since 2020, Europe has introduced strategies and key policies to promote common efforts on a roadmap toward energy efficiency and decarbonization. From ‘low’ to ‘passive’ and from ‘zero’ to ‘positive’, the concepts have fascinated the scientific community around the globe and promise the deployment of planning responses to the challenges of decarbonization faced by the European and local agendas. This work provides an overview of a comprehensive understanding of emerging concepts with a focus beyond the boundaries of an individual building. The booklet of 51 European projects, firstly introduced in Joint Programming Initiative documents, unveiled the prioritization of energy efficiency and the path for the enhancement of environmentally friendly communities. In this sense, this work presents an overview of the Net-Zero Energy Districts, and beyond, namely through the discussion of different aspects and dimensions. Based on published scientific literature, this work collects, organizes and discusses approaches of European cases, concluding with the knowledge base to support further developments and reinforce an established pathway for future implementations.

**Keywords:** case-study analysis; climate change; positive energy districts; zero-energy strategies



**Citation:** Koutra, S. From ‘Zero’ to ‘Positive’ Energy Concepts and from Buildings to Districts—A Portfolio of 51 European Success Stories. *Sustainability* **2022**, *14*, 15812. <https://doi.org/10.3390/su142315812>

Academic Editors: Mattia Federico Leone, Giulio Zuccaro, Ebru Gencer and Cristina Visconti

Received: 3 November 2022  
Accepted: 23 November 2022  
Published: 28 November 2022

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the author. 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/>).

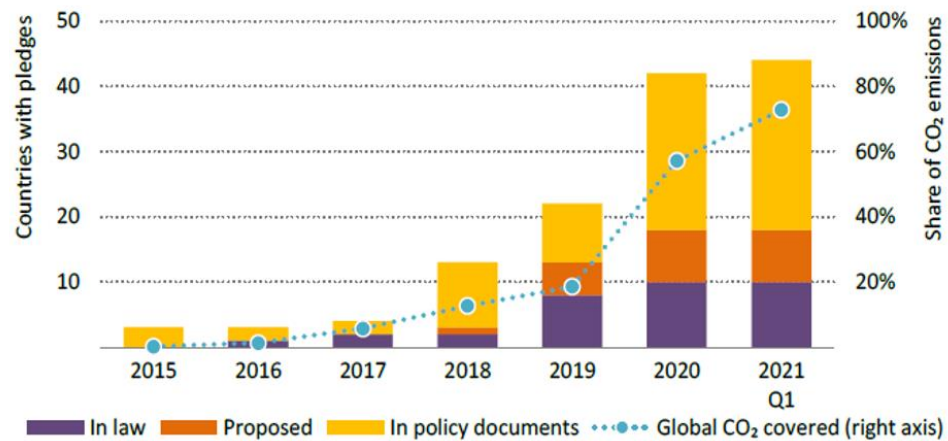
## 1. Introduction

The United Nations’ latest IPCC report (2021) argues that the scenario faced is that 11 years remain before triggering an irreversible climate disaster on Earth [1]. Increasing evidence reveals the gravity of climate mitigation at macro and micro levels [2], making a roadmap toward a clean energy transition a priority, and perhaps one of the greatest challenges of humankind. In his book, ‘*The 3rd Industrial Revolution*’, Rifkin underlines that “our houses must become a power plant using geothermic, solar, wind, even rubbish will be a major source of energy” [3]. Saheb et al. accentuate highly energy-efficient buildings as the cornerstones of decarbonization with meaningful impact [2]. Nevertheless, reducing global emissions calls for long-term transformations in production processes, daily mobility and adapted behaviors and strengthens the need for synergies among actors and citizens.

Nevertheless, achieving decarbonization in 30 years is a huge challenge requiring systemic and radical urban transformations. Climate-neutral cities have a mission to address climate adaptation and attenuation through resilient strategies, risk and vulnerability assessments and concrete actions. As innovation hubs, European cities are the global fore-runners able to tackle this challenge and accelerate this transition, along with the mission for carbon neutrality, to boost a twofold objective [4]:

- a. Setting the GHG reduction target by 2030 at 100%;
- b. Leading a systemic and comprehensive adaptation through the development of bottom-up and horizontal governance mechanisms.

In this pathway, there has been a rapid increase in initiatives and interest to make pledges to this transition by mid-century (Figure 1) [5]:



**Figure 1.** Total final consumption and demand by mitigation measures in zero-energy scales.

In reality, the dawn of this engagement finds its roots at the early beginning of the 1950s with the ECSC and the EURATOM Treaty (1957), intended to bring together knowledge- and infrastructure-sharing and promote the peaceful use of nuclear energy [6]. In this arena, several other relevant policies provided a legislative framework to enable MS to reach its targets. In this sense, important milestones in the path towards tackling climate change appeared in 2007—the “2020 Climate and Energy Package” [7]—and, later, in October 2014 with the definition of the “2030 Climate and Energy Framework” [8]. In 2018, in line with the EU’s commitment to global climate action under the Paris Agreement [9], the European Commission set out on the “2050 long-term strategy” for a climate-neutral EU, looking at all the key sectors and exploring pathways for this transition [10].

These main roadmaps and strategies have crystallized during the last decades in a set of regulatory packages that pave the way to reaching these ambitions. It is, however, commonly agreed that is necessary to scale up to district-level approaches, since they are one of the potentially most effective approaches to speed up the decarbonization process. This point is mentioned in different recommendations, such as CR-EU 2019/786 of 8 May 2019 on building renovation [11] or the update of the EPBD in 2018 which states that the Commission “shall review this Directive by 1 January 2026 at the latest” and “as part of that review, ( . . . ) examine in what manner Member States could apply integrated district or neighborhood approaches in Union building and energy efficiency policy ( . . . ) using overall renovation schemes applying to several buildings in a spatial context instead of a single building” [12]. In addition, the “Renovation Wave Strategy”, one of the energy-related actions of the European Green Deal and published by the European Commission in 2020 to double the annual energy renovation rate of buildings, remarked upon the necessity of developing district and community approaches and integrating renewable solutions for creating zero-energy districts, since “aggregating projects at this level may lead to zero-energy or even positive energy districts” (Table 1) [13].

**Table 1.** EU 1st Climate and energy package objectives and progress.

Field of Application	Objectives 2020	What Does It Mean?	Where Are We?
Renewable energies	20% of energy consumed from RES in final energy consumption	20% is the overall, EU-wide goal, but each Member State has different national targets	14.1% RES of gross final energy consumption in 2012
	10% in the transport sector	10% of the transport sector must come from RES sources such as biofuels	24.2% share of RES in gross electricity generation 5.1% share of RES in fuel consumption of transport
GHG emissions	20% reduction compared to 1990 levels	No more than 4501.1 MtCO <sub>2</sub> e in 2020	In 2012, the EU 28 emitted 4544.2 MtCO <sub>2</sub> e
Energy efficiency	Saving 20% of the EU’s primary energy consumption by 2020	No more than 1078 Mtoe of final energy consumption by 2020	1104.4 Mtoe of final energy consumption in 2012 (down from 1130.9 Mtoe in 2000)

### 1.1. Research Scope

In this paper, the authors contextualize the accelerating efforts to seek the operationalization of high-energy-performance districts and present a systematic analysis of selected projects of European portfolios. So far, the perception of PEDs has been predominately researched from a technological perspective. Nevertheless, in-depth comprehension of the concept requires a focus on the multifaceted analysis of organizational, legal, financial, urban and institutional issues as well as effective instruments and structures. In this work, the spectrum definitions for PEDs through the different levels and dimensions is leveraged over a portfolio of 51 projects. The literature gap is unveiled and the extant challenges are filtered to achieve significant contribution toward synthesizing and enriching the concepts along with practical examples and accomplishments.

### 1.2. Structure

After a brief historical analysis of the concept's origin, a comprehensive understanding of the 'zero' to the 'positive' energy ambition is introduced. A systematic review is followed underlining the importance of boundaries and the interest of the urban scale to enable the penetration of 2050 decarbonization strategies, emphasizing PEDs as pivotal means of contributing to a transition away from fossil fuel dependence and toward urban resilience. The remainder of the manuscript is organized as follows: Section 3 contributes to the embedded challenges and constraints of the pathway for the 'zero' to 'positive' roadmap. Section 4 proposes a booklet of 51 European projects as paramount to energy efficiency initiatives, while Section 5 synthesizes the main findings and challenges for further development. The work plan and the organization of the study are presented in Figure 2.

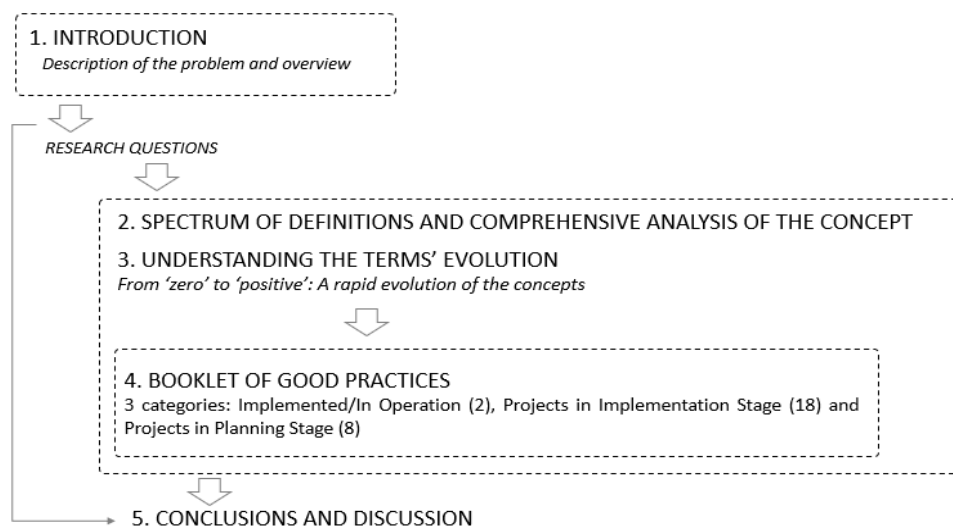


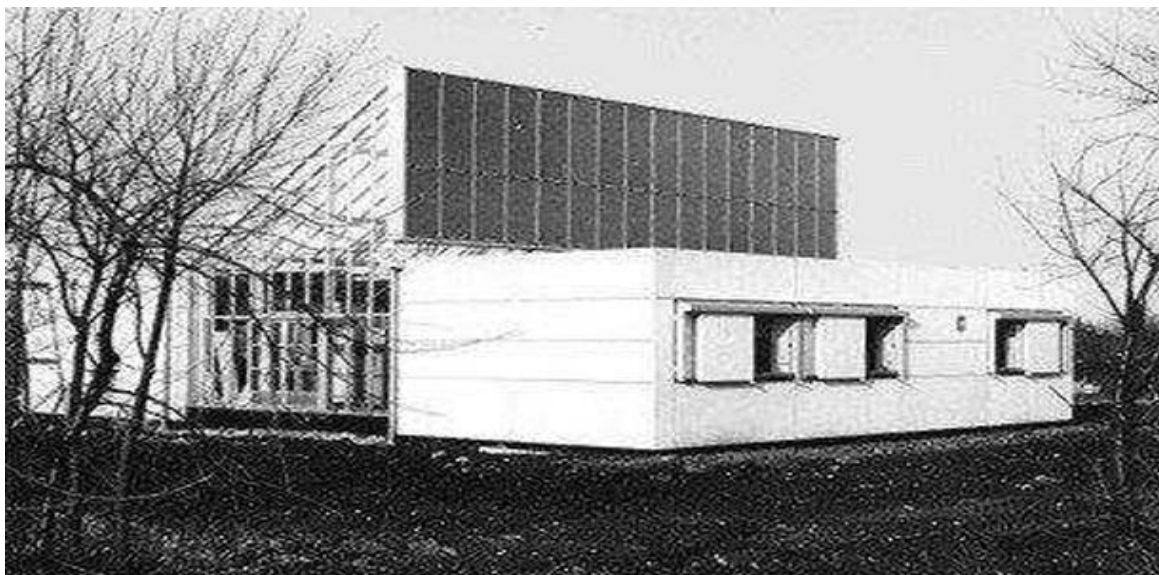
Figure 2. Work plan and organization.

## 2. Understanding the Concepts—A State-of-the-Art Analysis

Starting with a comprehensive analysis of the concepts is an important lever to identify the lessons learnt and the evolution of the diverse applications of energy autonomy. The existing literature and previous works propose an umbrella of definitions, sometimes contradictory; a prism of them is provided in this section.

### 2.1. Brief Historical Background

The origin of the 'zero-energy' concept is traced back to 1976, when Esbensen and Korsgaard studied the solar heating of an experimental residential building (Figure 3) [14] and dubbed it the 'Zero Energy House' [15].



**Figure 3.** The first experimental ‘zero-energy’ house (1976).

At the pathway towards building-scale zero-energy strategies, other prototypes are considered:

- the ‘Impact 2000 house’ built by the Boston Edition to demonstrate to the public state-of-the-art energy technologies and conservation techniques (including photovoltaic arrays, passive heating systems, air-to-air heat exchanger, etc.) [16];
- the prototype of ‘Carlisle house’, developed in 1980 for the US Department of Energy as the first building with an integrated PV system, included an exemplar residential roof and was known for its passive solar heating and cooling systems. Carlisle is the first residential building in US powered by a utility-interactive PV system with no fossil fuel needs and which exports surplus power [17];
- the pioneering realizations proposed by Rolf Disch based on a solar estate of ‘plus-energy houses’ in Freiburg (Germany) built towards a holistic testing ground for ecological constructions, with plus-energy dwellings (50 terraced houses) being one of the major components [18];
- the manifesto of Powerhouse at Brattorkaia (Norway), the world’s northernmost energy-positive building, setting new construction standards and producing more than twice as much electricity as it consumes daily with RES supplied to itself, neighboring buildings, etc., through a local microgrid. The building leverages a series of technologies and noticeably reduces the energy used for its operation [19].

Nevertheless, it was only in the early 2000s when the concept gained traction in both research and policymaking due to its demonstrated success [8].

## 2.2. Spectrum of Definitions

Whereas the understanding of the zero-energy idea sounds simple, a range of terminologies exists currently in the literature. The NZEB concept has been primarily linked to an evolution of bioclimatic architecture and passive housing [6] and has introduced an integrated and comprehensive approach to energy efficiency and on-site (or nearby) production [20]. Broadly, the idea was explained as an ‘autonomous’ building targeted to operate with the off-grid generation of all energy required, without referring to connections to the ‘grid’ [21].

A thorough analysis, proposed by Brozovsky et al., searching Scopus and Web of Science (updated in 2021) with the filters of ‘article title’, ‘abstract’ and ‘keywords’ unveils a plethora of relevant studies on the building level (more than 2000 documents) [22].

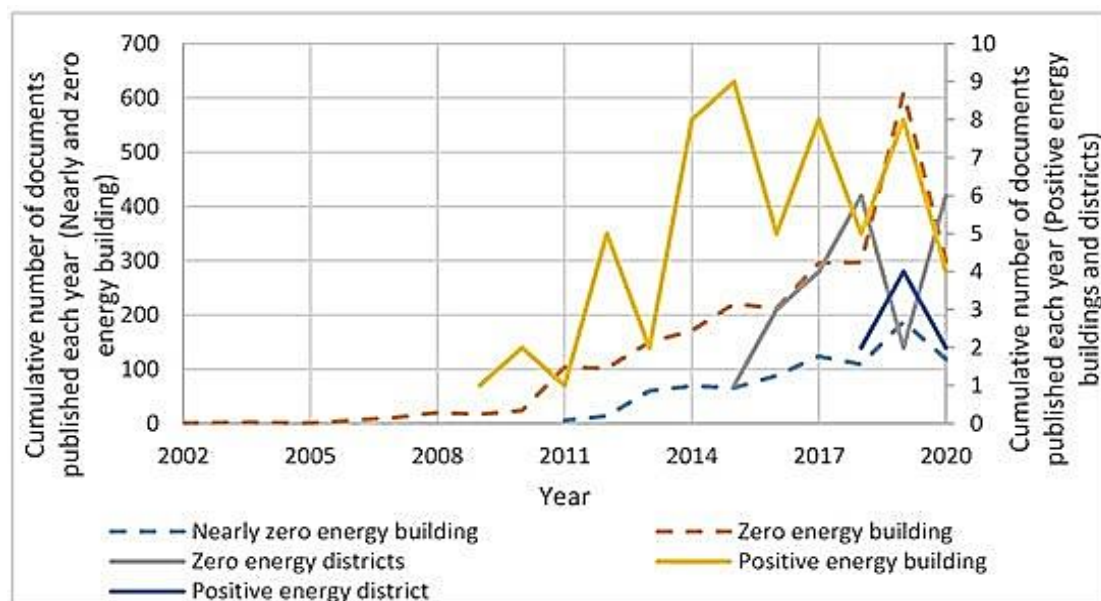
D’Agostino and Mazzarella launched an in-depth and similar analytical process provided in Table 2 [23].

**Table 2.** Overview of main terms in the literature around the zero-energy concept in buildings.

Reference(s)	Acronym	Description	Attributes
[24]	(net) ZEB	Net-Zero-Energy Building	A yearly energy-neutral building that delivers as much energy to the grid as it draws back.
[25]	ZE(emissions)B	Zero-Emissions Building	Carbon emissions balance.
	ZE(energy)B	Zero-Energy Building	Energy balance by a building in its day-to-day operation.
[26]	NZSiEB	Net-Zero-Source-Energy Building	A building produces at its location as much energy as it uses yearly.
	Net Zero Site Energy Building	Net-Zero-Site-Energy Building	
	NZEC	Net Zero Energy Cost (Building)	Energy cost annual-basis balance.
[27]	NZEB	Nearly Zero-Energy Building	A building with a national, cost-optimal energy use greater than zero.
[28]	Autonomous ZEB	Autonomous Zero-Energy Building	Standalone and energetically autonomous building.
	+ZEB	Energy-Plus Building	A building produces more energy from renewables than it imports annually.
[29]	PV-ZEB	Photovoltaic Zero-Energy Building	A building with a low energy demand and a PV system.
	Wind-ZEB	Wind Zero-Energy Building	A building with a low energy demand and an on-site wind turbine.
	PV-Solar thermal heat pump ZEB	Photovoltaic Solar thermal heat pump Zero-Energy Building	A building with heat and electricity demand and a PV system.
	Wind-Solar thermal heat pump ZEB	Wind Solar thermal heat pump Zero-Energy Building	A building with low heat and electricity demand.

### 2.3. Expansion of the Concept on Urban Scale

Even though the debate about the definitions of ‘district’ (and/or ‘neighborhood’) has not yet come to a consensus, the terms are accepted by their original significance and relation to a ‘community’ [30]. The transition beyond single buildings to include larger scopes increases the complexity of the different approaches and is found in several theories [31]. Figure 4 is an example of the rising scientific interest in this challenge [32].



**Figure 4.** Rising interest of the scientific community in the zero-energy concept on an urban scale.

Especially concerning the spatial dimension, there are terms, usually ambiguous, about when to call a ‘cluster of buildings’ or a ‘neighborhood’ or a ‘district’, a ‘block’, a ‘community’, etc., but also a vast terminology to express zero-energy patterns. Most used are: ‘nearly Zero Energy Neighborhood’ (NZEN), ‘Positive Energy Block’ (PEB), ‘Energy Positive Neighborhood’ (EPN), ‘Low Carbon District Heating’ (LCDH), ‘Zero Energy District’ (ZED), ‘Zero Carbon District/Neighborhood’ and ‘Net Zero Exergy District’ among others. To address this problem, Brozovksy et al. argue that the proportion of the literature using the term ‘neighborhood’ to express the boundaries outweigh those using ‘district’ or even ‘block’, while most of the more frequently used terminology is related to the energy or emission balance over a specific accounting period (usually within a year), and use of the term ‘low carbon’ is fairly vague [22].

A first approach towards the definition of zero-energy districts is found in the works of Carlisle et al. [33], stating that:

*[ . . . ]’a net-zero energy community has greatly reduced energy requirements through energy efficiency gains of vehicles; thermal and/or electrical energy within the community is met by RES’.*

In 2014, Marique et al. adapted this definition, considering the energy consumed in a district as the ‘sum of the demand of each dwelling and the mobility of its users’ [34]. Kennedy and Sgouridis [35] questioned the challenge, whereas Todorovic searched for the role of simulation tools in zero-energy urban planning [36].

Among the related topics, the research concludes:

- The majority of the publications focus on energy systems, energy sharing and GHG emissions (e.g., EU, 2010) in buildings, on-site supplies, etc. A large part addresses multi-energy systems and resource management (e.g., [13,14,37]), while an assessment of energy production is also commonly found (e.g., [38–40]) or even of the inclusion of storage systems, with some articles focusing on thermal (e.g., [41]) or on electrical storage.
- From another angle, the research project ZenN [42] proposes a definition whereby the global energy demand of a residential cluster meets the local energy production by resources on-site in renovating processes, considering the neighborhood as a sum of buildings. In this sense and by analogy, the Nearly Zero-Energy District is a part of a city with ‘nearly zero or very low amount of energy covered to a very significant extent by energy from renewable sources produced on-site or nearby’. Frequently, Mixed-Integer Linear Programming was used, as well as Model Predictive Control [43] or a non-linear model to simulate the distribution and connection to the public grid. Boccalatte et al. discussed the optimal arrangement of building-integrated PV to reach zero-energy layouts [44].
- Stakeholder engagement: utility of a ‘smart energy community’, ‘innovative public procurement’ [45] or ‘citizen empowerment’ [46], ‘Public–Private’ synergies [47] or even the visualization of key factors for improved participatory processes and governance mechanisms [48] are discussed.
- Urban morphology: historically, the correlations between density, energy consumption and mobility were thoroughly investigated; for instance, in the study of Newman and Kenworthy [49]. Amaral et al. reviewed urban parameters influencing the energy balance in NZEDs [50]. Guarino et al. studied solar energy optimization in the Mediterranean in line with a parametric analysis of geometrical and other relevant factors [51]. Wang et al. suggested an indicator system design exploring the relationship between the land-use data [52] and household CO<sub>2</sub> emissions in Beijing [53], while others (e.g., [54]) developed cartographical visualization to assess the influence of urban form and building typology on the energy performance and carbon emissions (cases in Macau and Chi). Other authors analyze assessment methods for energy use in urban forms, such as the creation of energy modeling systems of the embodied energy.

Refs. [55–57].

- Social aspects: Tironi performed research on a public experiment in the form of a laboratory in Santiago de Chile, where a district was temporarily transformed through a design process to monitor the air pollution and the microclimate [58]. Woods and Berker discussed the limitations and potential associated with the concept of ‘living labs’ in zero-energy patterns in a Norwegian case [59].

Lindholm et al. [60] provided a synthesis of zero-energy terms that addressed building- or urban-level applications and focus on energy efficiency, renewable resources, storage and trading (Table 3). As a comparative analysis, the Table below reveals the complexity within the concepts’ understanding of the relevant approaches; nonetheless, despite the differing angles of analysis, all the concepts agree on the balance and increase of RES share.

**Table 3.** Synthesis of zero-energy definitions (adapted by [60]).

Term	Definition	Energy Efficiency	Renewable Energy	Energy Storage	Energy Trading	(B: Building or D: Districts)	Reference
NZEB A building that ...	covers a large amount of its demand with the on-site or nearby RES generation.	✓	✓	×	×	B	[24]
	exports a particular amount of energy to the grid.	×	✓	×	✓	B	
A ZEB does not..	consume any type of energy.	×	×	×	×	B	
	release any type of emissions.	×	×	×	×	B	
A net-zero-source-energy building ...	generates all the energy it consumes based on primary consumption.	×	✓	N/A	×	B	[61]
A net-zero energy cost building ...	covers the cost of imported energy by exporting on-site RES generation.	×	✓	×	✓	B	
An autonomous zero-energy building..	generates all the amount of energy it consumes.	×	✓	×	✓	B	
A photovoltaic wind zero-energy building ...		✓	✓	×	×	B	
A photovoltaic and solar thermal and heat pump zero-energy building ...	requires a low energy demand covered by PV panels, solar thermal collectors and heat pumps.	×	✓	✓	×	B	[26]
Wind and solar thermal and heat pump zero-energy building ...		✓	✓	✓	×	B	
PEB	A building with negative annual energy consumption.	✓	✓	✓	✓	B	[62]
A net-zero-energy district ...	exports an amount of energy to the grid equal to what it imports from it.	×	✓	×	✓	D	[63]
An energy-positive district...	has energy demand lower than the supply from local RES.	×	✓	×	✓	D	[64]

To this end, Table 4 summarizes a set of methodological approaches and the advances in the literature review complementary to Table 3 and the previous analysis. Summarizing the existing studies, a lack of cross-sectoral and holistic views on the topic is observed,

revealing the complexity and challenges of the topic in a multidimensional context (urban, societal, legislative, etc.).

**Table 4.** Methods and tools found in the literature to support the study of the district scale (adapted from [50]).

Topic	Objectives	Methods	Scale <sup>1</sup>	Reference(s)
NZED	Definitions of district scale	A hierarchical and qualitative approach	D	[33]
	Extensive analysis from building to district level	Dynamic simulations	D	[65]
	Development of a methodological approach for evaluating NZED	Simplified energy demand calculation	D	[66]
	Strategic evaluation	Multicriteria decision analysis (PROMETHEE)	D	[67]
Sustainability assessment tools	Analysis of existing sustainability assessment tools	Benchmarking case study analysis	D	[68]
		Top-down and bottom-up approaches	U	[69]
			D	[70]
Solar potential	Development of residential solar blocks	Dynamic simulations (EnergyPlus)	U	[71]
	Typo-morphological analysis and solar potential	CityCIM	D	[72,73]
Urban microclimate	Urban morphology analysis for solar potential maximization	DIVA for Rhino	D	[74]
	Impact of urban microclimate on buildings' energy performance	Dynamic simulations	U	[75]
	Inclusion of Urban Heat Island effect on the performance of the building	Combination of GIS with simulation (TRNSYS)	U	[76]
Energy systems	Analysis of load matching and grid interaction in the role of NZEBs	Data and information analysis	B	[77]
	Evaluation of available energy sources for a district heating system	PROMETHEE	D	[78]
Urban energy modeling	Optimization of urban energy systems	Mixed integer linear program	D	[79]
	Impact of localization on energy consumption	Benchmarking analysis of energy consumption data	D	[80]
	Optimization of a district heating system	Linear programming	D	[70]
	Characterization of consumption patterns	Dynamic simulation coupled to a GIS platform	D	[81]
Computer tools	Development of a technical scenario for a 100% RES city	EnergyPLAN	U	[82]
	Solar access to support decision processes focusing on sustainable urban design	3D urban information system coupled with solar assessment	U	[83]
	Simulation of energy flows for sustainable urban planning	CitySim	U/D	[84]
	Urban layout optimization to maximize solar potential	Simulation/Optimization	U	[81]
	Urban energy simulation and modeling for energy use in districts	OpenStudio	B/D/U	[85,86]
	Evaluation of building energy consumption	Canopy Interface Model and simulation (CitySim)	B	[87]

<sup>1</sup> B: Building, D: District, U: Urban.

Synthesizing the main findings of the literature, a bibliometric analysis to figure out the correlations in line with the Scopus database is displayed using the keywords of 'positive' and 'energy' for the published works from 2000 onwards. In particular, for the building level, more than 3700 documents are detected (Figure 5) compared to 650 for the district scale (Figure 6), endorsing the research gap and the complexity. Nonetheless, the aggregation per country is similar; China, India and the United States aggregate more than 1000 citations, whereas in Europe, Italy, the UK, Finland and Sweden have a notable number of citations as well.

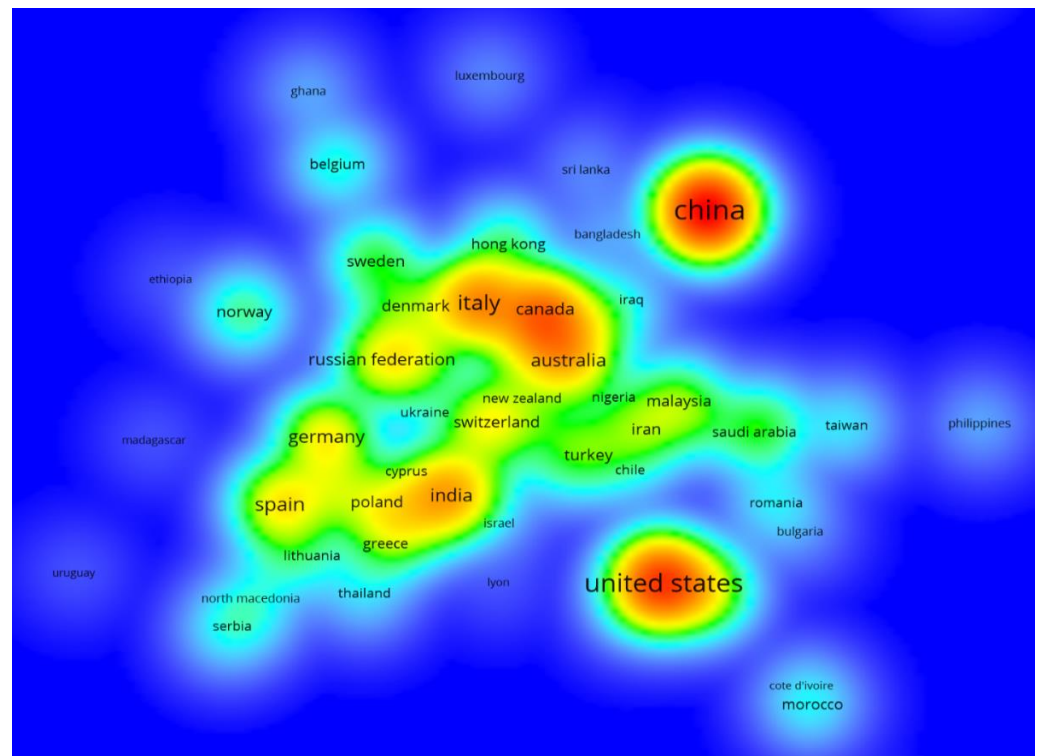


Figure 5. Correlation of 'positive', 'energy', 'building' (own elaboration from Scopus database).

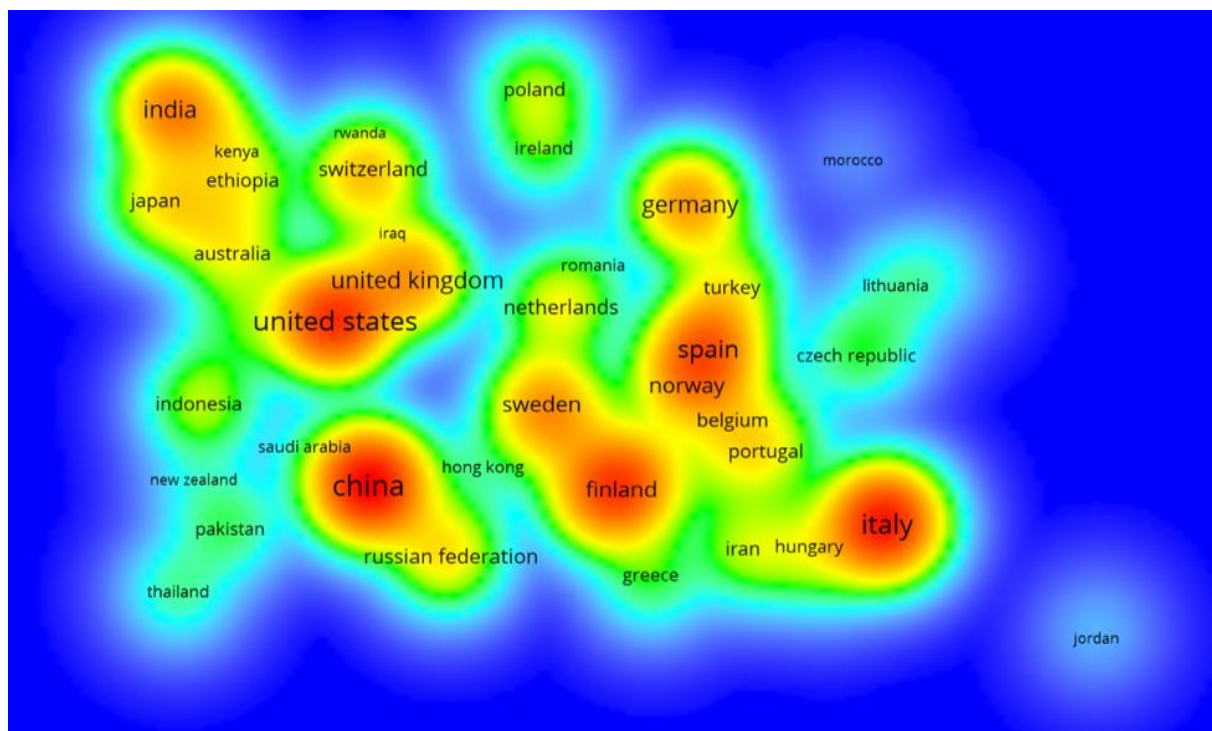


Figure 6. Correlation of 'positive', 'energy', 'districts' (own elaboration by Scopus database).

### 3. From 'Zero' to 'Positive': A Rapid Evolution of the Concepts

After the overview of the main concepts presented in the previous section, an introduction on PEDs' milestones is provided along with the key pillars to be considered for their implementation.

### 3.1. TWG 3.2: An Introductory Dimension towards PEDs

To take advantage of the benefits of zero-energy applications, the EU launched the strategy of ‘Plan Action 3.2: Smart Cities and Communities’ [88], being recognized as one of the major tools to deliver the ‘Energy Union Strategy’ and support the replication of 100 ‘Positive Energy Districts’ by 2025 [89]. In this challenging concept, the PEDs are defined as: ‘Energy-efficient and flexible urban areas or groups of connected buildings, which produce (net) zero GHG emissions and actively manage an annual local or regional surplus production of RES’ [90].

The TWG 3.2 developed an integrative approach for positive-energy planning including technological, spatial, regulatory, financial, legal, environmental, social and economic perspectives, summarized as:

- a pathway towards PED development in Europe and worldwide;
- the generation of a commitment to innovative research and implementation actions for process monitoring;
- a continuous PED management ensuring coordination of related activities.

The main functions of PEDs, as presented in the 3.2 Program (Figure 7), with the ambition of reaching the COP21 targets are [9]:

- Energy efficiency: achievement of an optimal reduction of energy consumption within the PED balancing the requirements of the different sectors;
- Energy flexibility functions: resilience and balance of the urban energy systems coupling the storage potential towards their autonomy;
- Energy production function (locally and regionally): optimal reduction of GHG emissions and economic viability.

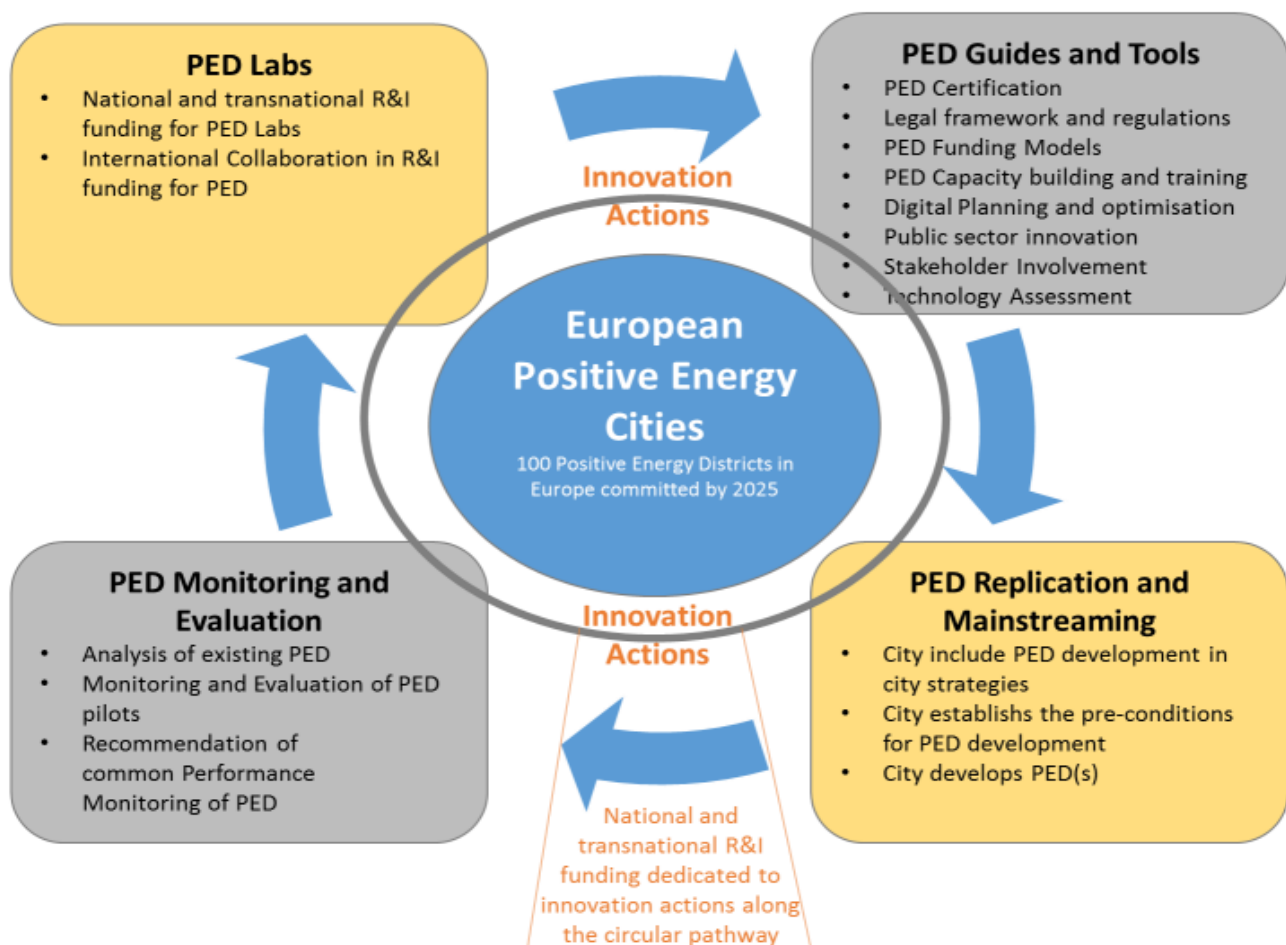
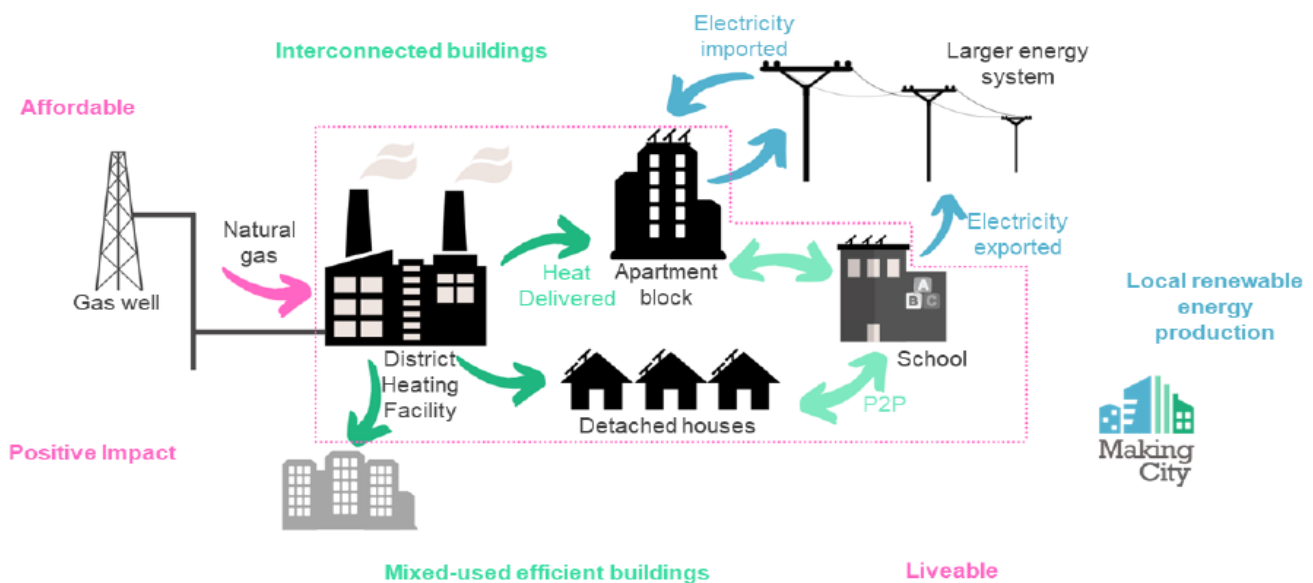


Figure 7. Pathways to Positive-Energy Districts in Europe (SET-Plan ACTION n°3.2 Implementation Plan).

Regulatory stimuli and public funding for research projects led to a considerable amount of dissemination as documented in the IEA report (Annex 83 on PED) [91]. Since 2018, the concept has been introduced to the debates acknowledging that the urban scale has a major role in this process, making it a strategic key for carbon neutrality by 2050 [92]. Hinterberger et al. [93], in their ‘White Paper on the Reference Framework for Positive Energy Districts and Neighborhoods’, defined the PED as a ‘group of connected buildings’; however, in Annex 83 the description is provided without any clear focus on the GHG emissions, merely: ‘A PED is an area within the city boundaries, capable of generating more energy than is used, flexible and adequate to respond to the energy market variations. Rather than simply achieving an annual net energy surplus, it supports in parallel a minimization of impacts on the connected centralized networks by offering alternative options for increasing onsite load-matching and self-use of energy and technologies. Nonetheless, reaching the PED ambitions requires prioritizing the energy efficiency, cascading the local energy flows and using the low-carbon flexibility to match the (annual) demand with the maximization of the local production, while in parallel minimizing the burdens and optimizing their usefulness at large’.

Figure 8 represents a briefing on the concept and the interchangeable components with possible connections of the district’s components to local energy production are also found in the literature [94]:



**Figure 8.** PED components and interchangeable connections.

Yet, there is no unified and commonly acknowledged PED definition; meanwhile, an adequate policy framework is required at regional and national levels to concretize the boundaries, specify the objectives and reinforce the commitments and synergies. For Europe, the ambition is noticeable [93]:

100 Positive Energy Districts in Europe are expected to be in concrete planning, construction, or operation, synergistically connected to the energy system in Europe, by 2025.

From the above definitions, it is acknowledged that the PEDs’ implementation requires in-depth comprehension of contextual conditions, policies and strategies for user adaptation [95]. Existing PED definitions address the fact that a PED is an added value to the users and enables high-quality living standards.

### 3.2. Issues and Related Concepts

As an emerging concept, PED is developed along with several criteria, constraints and levels of interpretation [64]:

- Primary energy indicators: conversion efficiency of the energy from primary sources to the delivered carriers to the end users to convert the building demand and later to evaluate its performance [20].
- PED (and PEB) categorization: a variety of different types and categories of PED/PEBs according to their (physical) boundaries.
- EV integration: one of the main objectives of this concept is to minimize the negative effects on the grid and reduce the need for energy transfer. Zhou et al. [96] analyze energy integration and its interaction between buildings and vehicles regarding different energy forms, advanced conversions, storage systems, etc.
- Energy integration as the driver for circular economy renewables and further efficiency: achieving PEDs requires an integrated approach toward energy systems planning, development and operations across all energy infrastructure. Buildings and urban energy systems work together to optimize temperature levels, time of use and storage opportunities to minimize total life cycle cost while also recording input from usage patterns, weather predictions and future utility costs.
- Citizen engagement, governance mechanisms and participation: incorporation of fact-based and proactive communication, transparent and inclusive frameworks for public participation in decision-making processes and efficient governance mechanisms.
- RES integration at regional/local levels: development of demonstration technologies, systems and solutions to match temperatures with locally available low-carbon sources and other techniques to enable buildings' operation with low supplies and on-site production in a cost-effective and sustainable process.

#### 4. A Booklet of Good Practices

The Strategic Energy Technology Plan of 2008 and the Joint Programming Initiative defined an outlook of PED projects (grouped into three categories: Implemented/In Operation (2), Projects in Implementation Stage (18) and Projects in Planning Stage (8)).

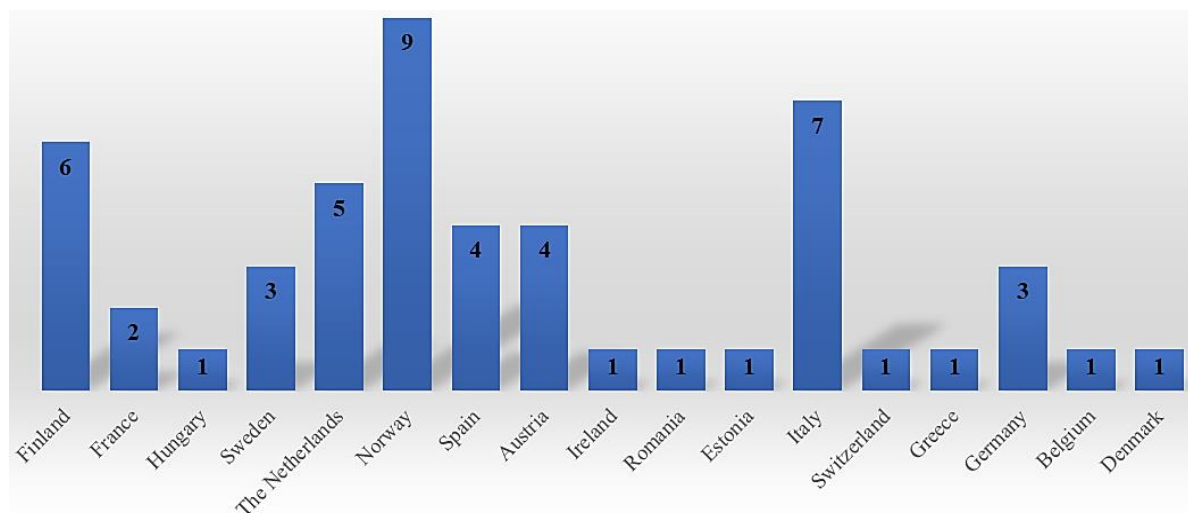
The first Positive Energy Block in operation in Europe was the 'Hikari' project ('light' in Japanese) and was completed in 2015, described by Roccamena et al. [92]. Located on the most emblematic site of the new Confluence District, it brings together commercial, residential and leisure functions in the southwest of the center of the French city of Lyon (Figure 9). Key development targets of this particular project include high environmental patterns, harnessing technology, walkability and QoL indices as well as the social, cultural and economic vibrancy designed to bioclimatic standards.



Figure 9. View of Hikari, first PED project in France (©Renaud Araud).

#### 4.1. Results

For this study, a portfolio of 51 European projects with zero or positive targets is discussed, analyzed and compared (Figure 10). A concentration of PED projects appears in Norway, Italy, Finland and the Netherlands.



**Figure 10.** Number of analyzed (European) projects within the zero- (or positive)-energy context per country.

On the other side, Table 5 unveils in more detail the overview of these projects in each country; the majority of them include at conception comprehensive urban strategies against climate change and toward mitigation beyond energy efficiency. Representative examples are provided in Table 6.

**Table 5.** List of representatives in the literature with PED ambitions (adapted from [97]).

City	Name of the Project	Overview	Reference(s)
Åland Island, Finland	Smart Energy Åland (pilot project)	Urban energy system based on RES.	[98]
Carquefou, France	Fleuriaye west	Increase in comfort level, QoL, carbon neutrality, and transposable economic model.	[99]
Alkmaar, The Netherlands	PoCiTYF	Citizen and community engagement strategies with open innovation and co-creation activities.	[100]
Amsterdam, The Netherlands	ATELIER	Demonstration project of RES, storage and digitalization strategies.	[101]
Bilbao, Spain		Energy analysis of the new neighborhood, including three pilots located in different areas.	
Oslo, Norway	Furuset project—ZEN Pilot Project	Pilot projects with renewal strategies including infrastructure renewal considering energy, waste, water, traffic, green landscaping and social issues.	
Bærum, Norway	Fornebu2, Bærum—ZEN Pilot Project	Innovation hubs to test new solutions for the construction, operation and use of carbon neutrality.	[102]
Bodø, Norway	NyBy—Ny Flyplass (New City—New Airport), Bodø4	New solutions for the construction, operation and use of carbon neutrality.	[102]
Elverum, Norway	Ydalir project	New neighborhood with high energy and emission ambitions.	
Graz, Austria	City District Development Graz-Reininghaus	Demonstration of the vision of energy self-sufficient, CO <sub>2</sub> -neutral city districts.	[103]
Groningen, The Netherlands	Making-City	Demonstration of the urban energy system transformation toward smart and low-carbon cities.	[104]
Oulu, Finland		Development of new integrated strategies to address the urban energy system transformation toward low-carbon cities.	
Limerick, Ireland	+CityxChange	Development of value-added solutions for replication in other EU cities as well as the exploitation of commercial markets.	[105]

**Table 5.** *Cont.*

City	Name of the Project	Overview	Reference(s)
Voru (Estonia)		Innovative solutions for decreasing CO <sub>2</sub> emissions and user adaptation.	
Măgurele, Romania	Laser Valley—Land of Lights	Accelerator for city development.	[106]
Stor-Elval Municipality (Norway)	Campus Evenstad (ZEN pilot project)	Pilot project within the Research Centre on Zero Emission Neighborhoods.	[107]
Trondheim (Norway)	ZEN pilot project	Development of campus for excellent research, education, dissemination and innovation.	
Bergen (Norway)	Zero Village (pilot project)	Development of a new neighborhood on the outskirts of Bergen. Autonomy and RES utilization.	
Espoo (Finland)	SPARCS	Virtual Positive Energy communities.	[108]
Parma (Italy)	Castelletto	Redevelopment of a part of the city into the first PED.	[109]
Paterna (Spain)	Barrio La Pinada	First eco-district in Spain to create social and environmental value and an attractive environment.	[110]
Rome (Italy)	Pietralata PED	Climate-, cultural-, socio-economic-specific approach for urban energy efficiency. Integrated innovative solutions for PEBs/districts.	[111]
Tampere (Finland)	Ilokkaanpuisto	New residential area in an urban environment.	[112]
Trento (Italy)	Santa Chiara Open Lab	Refurbished four public building complexes supplied with an innovative geosolar heating and cooling supply concept.	[113]
Vienna (Austria)	Zukunftsquartier (Future Quarter)	Decarbonization and development of sustainable, safe and affordable energy supply strategies.	[114]

**Table 6.** List of representative cases with energy efficiency objectives (but not PED concepts) (adapted from [97]).

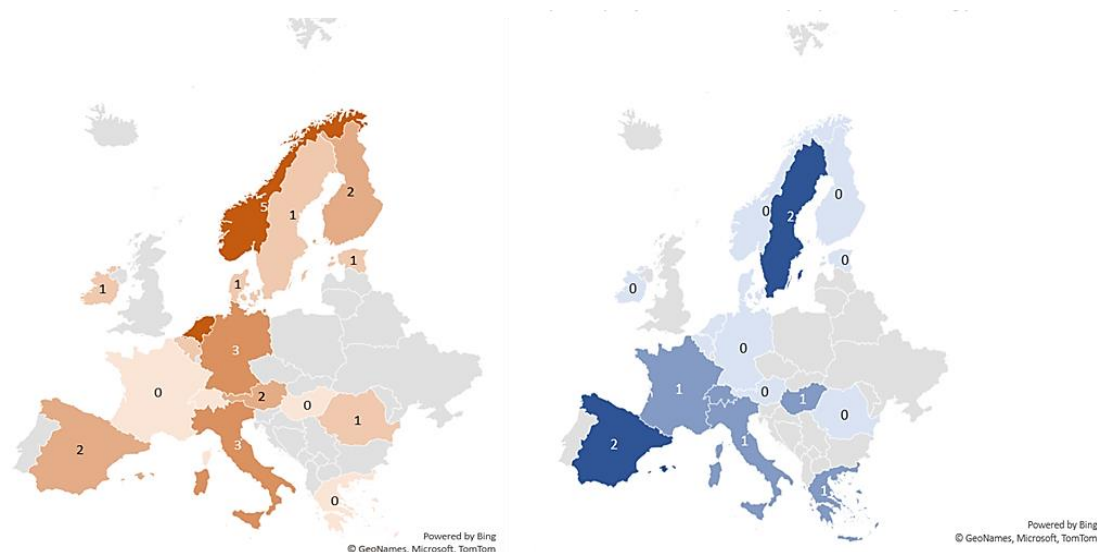
City	Name of the Project	Overview and Description of the Project	Reference(s)
Drammen (Norway)	Jacobs Borchs Gate	A mixture of electric, biomass and gas/oil.	
Mieres (Spain)	District heating Poze Barredo	Project for urban heat network in the municipality of Mieres.	[115]
Mostoles (Spain)	Mostoles Ecoenergias	Heating and DHW system with RES.	
Henningsdorf (Germany)	Heat Hub Henningsdorf	District heating with 100 % renewable and carbon neutrality by 2025.	
Odense (Denmark)	Coal phase out by 2025	Coal consumption Already reduced from ~900,000 t/y in 2010.	
Espoo (Finland)	Smart Otaniemi	Piloting area for a new type of smart energy.	[116]
Grenoble (France)	City-wide project	RES integration and innovative solutions for storage and carbon neutrality.	[117]
Gyor (Hungary)	Gyor Geothermal District Heating project	Enhancement of the geothermal energy to the heating system of the district.	[118]
Lund (Sweden)	Cityfied	Pioneering smart city projects based on a mix of demonstration, technology, renovation strategies and sound business models.	[119]
Milano (Italy)	Shared electric mobility in 10 Mobility Areas (Sharing Cities project)	In making smart cities a reality, a district has been identified for implementation.	[120]
Hammarby Sjöstad (Sweden)	Hammarby Sjöstad 2.0	Citizen-driven initiatives; the key is to develop sustainable solutions.	[121]
Vienna (Austria)	SCITHOS	Concept of guidelines and tools for solutions to make the transition towards socially responsible tourism.	[122]
Zurich (Switzerland)	Hunziker Areal	Minergie-P standards and heated with waste heat.	[123]
Bolzano (Italy)	Sinfonia	Ambitious investment plan for large-scale urban refurbishment.	[124]
Florence (Italy)	REPLICATE	The intervention of old existing individual heating systems with high-performance micro-DHS.	[125]
Graz (Austria)	My Smart City Graz	Implementation of smart technologies for a sustainable, livable and intelligent district.	[126]
Florina (Greece)	District Heating Municipal Company of Amindeo	Construction of two thermal power plants using biomass with a total installed capacity of 30 MWth (2 × 15 MW).	[127]
Helsinki (Finland)	mySMARTlife	Innovative technological solutions in connection with energy refurbishment of buildings.	[128]

**Table 6.** *Cont.*

City	Name of the Project	Overview and Description of the Project	Reference(s)
Hoogeveen (The Netherlands)	Hydrogen district Hoogeveen	Contribution to the energy transition with a techno-economic blueprint.	[129]
Kaiserslautern (Germany)	Pfaff Quartier	Climate-neutral district in the area of the former sewing machine factory Pfaff close to the city center. Living lab workshop and an electric vehicle and battery lab.	[130]
Malmö (Sweden)	Klimatkontrakt Hyllie	Aims to be the most climate-smart district in the region. Four questions are developed for this project: <ul style="list-style-type: none"> <li>• How do we gain a grip on the determinants for the energy transition in local communities?</li> <li>• How do we develop smart solutions in which energy transition, sustainable life-long housing and enhancing comfort converge?</li> <li>• How can individual and collective behavioral change be established in local communities?</li> <li>• How can we transfer local insights in the approach to energy transition to other communities?</li> </ul>	[131]
Arhem (The Netherlands)	Community-focused energy transition	Promotion of social cohesion and citizen involvement.	[132]
Brussels (Belgium)	Positive 4 North	Development of a climate-neutral city quarter with about 6500 apartments for 15,000 inhabitants.	[109]
Freiburg (Germany)	Dietenbach	Highly adaptable and replicable systemic approach towards urban transition into sustainability.	[133]
Lecce (Italy)	SmartEnCity		

**4.2. Analysis of Realized and Under-Construction Projects in a Zero- or Positive-Energy Context in Europe**

In line with the criterion of the implementation phase of the analyzed projects, the conducted analysis study reveals the level of complexity and the multifaceted dimensions of their context, including the societal and economic barriers complementing the technical ones. Figure 11 portrays the cartographical distribution of the analyzed projects in the European continent unveiling the pioneering role of the Netherlands and Norway (five projects, respectively, with PED concepts under construction) in the process, while Sweden and Spain seem to have obtained already the first lessons learnt with realized projects in their territories.



**Figure 11.** Number of (studied) European projects within a zero- (or positive)-energy context under construction (left) and realized (right).

Complementary to the previous statements, the analysis provides the prioritization of the projects' targets per country. As expected, the first concern for a plethora of countries is energy efficiency and the minimization of the environmental impacts due to climate change in order to reply to the 2030 and 2050 engagements (Figure 12). To respond to these objectives, countries prioritized the mutualization of different technologies and available on-site resources to maximize local production. The analysis emphasizes the prioritization of solar potential (solar panels and PVs) and heat pumps or geothermal exploitation. The organization of storage has rising interest for many cities as well towards autonomy. Notably, of lessening priority are the projects in economic or social contexts.

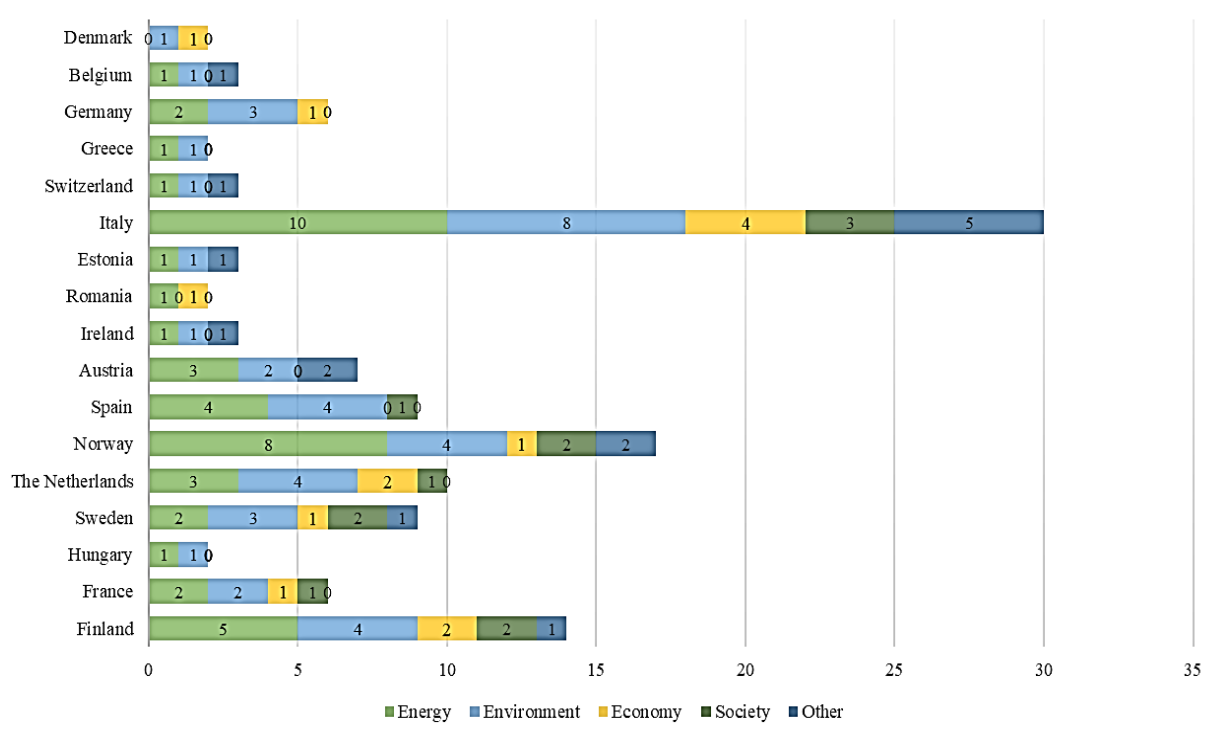


Figure 12. Number of projects per objective(s) in European studied cases.

## 5. Conclusions and Future Challenges

The deployment of the energy efficiency roadmap provides a framework for intensified efforts by all European Member States from 2020 onwards to develop strategies to deal with the inherent challenges of energy consumption associated with GHG emissions. Significant work has been explored around the globe on possible variations of the zero-energy idea at the building level on models for design calculations and outreach of case studies. Even though there is a lack of far-reaching definitions to characterize the concept, namely on an urban scale, it consists of a promising design for the mitigation of climate change for the coming decades toward a clean energy transition and an inclusive economy. Under the Europe 2020 strategy, the flagship initiatives supported resource-efficient and low-carbon communities, while the pathway is reinforced toward the 2030 and 2050 horizons for higher standards of living and minimized impacts with robust and resilient action plans.

This works provides an overview of comprehensive understandings of the concepts' evolution from 'zero' to 'positive' energy transitions, underlying the strong engagement on an urban scale and the need for intensive efforts to achieve climate change mitigation. To move beyond the boundaries of an individual building—applying the concepts of energy efficiency from an urban planning perspective—increases the complexities and the respective level of implementation difficulty; however, it also fosters an overall design to overcome the existing barriers for financial, societal or other reasons. In reply to this

challenge, the Program on PED (Action 3.2) supports the replication of 100 PEDs across Europe by 2025, reaching the goal set by the COP21 agenda.

The booklet of 51 European projects, under construction or realized, unveiled and confirmed the prioritization of the key policies of energy efficiency and the path toward the enhancement of environmentally friendly communities. The analysis also highlighted not only the importance of energy mutualization for the diverse technologies and RES exploitation, but also the compelling constraints of social acceptance and financial limitations.

An enhancement of the studies to unify the concepts and assess the feasibility of their implementation is a primary concern. When moving to the urban scale to analyze the district as a whole, additional design factors have a significant role in performance evaluation, and the literature has evidenced a lack of appropriate methodologies and tools that account for all these parameters, either for researchers or practitioners and stakeholders.

Hence, in this sense, this work presented a literature review on the NZED—and beyond—concepts, namely, through the discussion of different aspects to take into account when designing or studying. Based on published scientific literature, this work collected, organized and discussed approaches of European cases, while concluding with contributing to establishing a knowledge base to support further developments and reinforce the established pathway for future implementations.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The author would like to thank Prof Bouillard for his valuable guidance and help.

**Conflicts of Interest:** The author declares no conflict of interest.

## Nomenclature

Abbreviation	Definition
BEMS	Building Energy Management Systems
CE4E	Clean Energy for all Europeans
CIM	City Information Modeling
ECSC	European Coal and Steel Community
EURATOM	European Atomic Energy Community
EPBD	European Performance Building Directive
EPN	Energy-Positive Neighborhood
EVs	Electric Vehicles
EU	European Union
GIS	Geographical Information Modeling
GHG	Greenhouse Gas (emissions)
HEMS	Home Energy Management Systems
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JPI	Joint Programming Initiative
LCDH	Low-Carbon District Heating
NREL	National Renewable Energy Laboratory
nZEB	nearly Zero-Energy Building
NZEB	Net-Zero-Energy Building
NZEC	Net Zero-Energy Cost
NZED	Net-Zero-Energy District(s)

NZEN	Net-Zero-Energy Neighborhood
PEB	Positive-Energy Block
PED	Positive-Energy District(s)
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PV	Photovoltaic
QoL	Quality of Life
RES	Renewable Energy Sources
SET	Strategic Energy Technology
TRNSYS	Transient Systems Simulation Program
TWG	Temporary Working Group
ZEB	Zero-Energy Building
ZenN	Zero-Energy Neighborhood(s)

## References

- Intergovernmental Panel on Climate Change (IPCC). *IPCC Special Report on Carbon Dioxide Capture and Storage*; Cambridge University Press: Cambridge, UK, 2005.
- Saheb, Y.; Shnapp, S.; Paci, D. *From Nearly-Zero Energy Buildings to Net-Zero Energy Districts*; Publications Office of the European Union: Luxembourg, 2019.
- Rifkin, J. *The Third Industrial Revolution: How Later Power is Transforming Energy, the Economy and the World*, 1st ed.; Palgrave Macmillan: London, UK, 2013.
- European Commission. *Proposed Mission: 100 Climate-Neutral Cities by 2030-by and for the Citizens*; Report of the Mission Board for Climate-Neutral and Smart Cities; European Commission: Brussels, Belgium, 2020.
- International Energy Agency. Net Zero by 2050: A Roadmap for the Global Energy Sector. 2021. Available online: <https://iea.blob.core.windows.net/assets/4719e321-6d3d-41a2-bd6b-461ad2f850a8/NetZeroBy2050-ARoadmapfortheGlobalEnergySector.pdf> (accessed on 15 October 2022).
- European Commission. Treaty Establishing the European Atomic Energy Community (EURATOM). 1957. Available online: [https://www.cvce.eu/en/obj/treaty\\_establishing\\_the\\_european\\_atomic\\_energy\\_community\\_rome\\_25\\_march\\_1957-en-a3390764-3e75-421b-9c85-f52de5a14c2f.html](https://www.cvce.eu/en/obj/treaty_establishing_the_european_atomic_energy_community_rome_25_march_1957-en-a3390764-3e75-421b-9c85-f52de5a14c2f.html) (accessed on 15 October 2022).
- European Commission. 2020 Climate and Energy Package. 2020. Available online: [https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package\\_en](https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en) (accessed on 3 February 2022).
- European Commission. 2030 Climate and Energy Framework. 2020. Available online: [https://ec.europa.eu/clima/policies/strategies/2030\\_en](https://ec.europa.eu/clima/policies/strategies/2030_en) (accessed on 3 September 2021).
- European Commission. Paris Agreement. Paris. 2015. Available online: <https://eur-lex.europa.eu/content/paris-agreement/paris-agreement.html> (accessed on 2 November 2022).
- European Commission. 2050 Long-Term Strategy. 2020. Available online: [https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy\\_en](https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en) (accessed on 3 May 2022).
- European Commission. Commission Recommendation (EU) 2019/786 of 8 May 2019 on Building Renovation. 2019. Available online: <https://op.europa.eu/en/publication-detail/-/publication/4a4ce303-77a6-11e9-9f05-01aa75ed71a1/language-en> (accessed on 3 May 2022).
- 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. 2018. Available online: [https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L\\_.2018.156.01.0075.01.ENG](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.156.01.0075.01.ENG) (accessed on 3 May 2022).
- European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region*; European Commission: Brussels, Belgium, 2020.
- Esbensen, T.V.; Korsgaard, V. Dimensioning of the solar heating system in the zero energy house in Denmark. *Sol. Energy* **1977**, *19*, 195–199. [CrossRef]
- Andoura, S.; Vinois, J.-A.; Delors, J. From the European Energy Community to the Energy Union: A Policy Proposal for the Short and Long Term. 2020. Available online: <https://institutdelors.eu/wp-content/uploads/2020/08/energyunion-andouravinois-jdi-jan15.pdf> (accessed on 3 May 2022).
- Jurgen, R.K. Impact 2000: A place in the sun: Sponsored by Boston Edison as an energy-conservation experiment, this home in the suburbs was seen during its construction by public-television viewers across the United States. *IEEE Spectr.* **1985**, *5*, 64–68. [CrossRef]
- Solar Design Associates. Carlisle House. 1980. Available online: <http://solar-design.com/carlisle-house/> (accessed on 19 November 2022).
- Heinze, M.; Voss, K. Goal: Zero Energy Building, Exemplary experience based on the solar estate. Solarsiedlung Freiburg am Schlierberg, Germany. *J. Green Build.* **2009**, *4*, 93–100. [CrossRef]
- Entra. Powerhouse Brattorkaia—The World’s Northernmost Energy-Positive Building. 2019. Available online: <https://snohetta.com/projects/456-powerhouse-brattorkaia-the-worlds-northernmost-energy-positive-building> (accessed on 19 November 2022).

20. European Commission. Concentrated Action: Energy Performance of Buildings (EPBD). 2010. Available online: <http://www.epbd-ca.eu/> (accessed on 5 January 2015).
21. Directorate-General for Research and Innovation. *A Climate Resilient Europe: Prepare Europe for Climate Disruptions and Accelerate the Transformation to a Climate Resilient and Just Europe by 2030: Report of the Mission Board for Adaption to Climate Change, Including Societal Transformation*; European Commission: Brussels, Belgium, 2020.
22. Brozovsky, J.; Gustavsen, A.; Gaitani, N. Zero emission neighbourhoods and positive energy districts—A state-of-the-art review. *Sustain. Cities Soc.* **2021**, *72*, 103013. [[CrossRef](#)]
23. D’Agostino, D.; Mazzarella, L. What is a nearly zero energy building? Overview, implementation and comparison of definitions. *J. Build. Eng.* **2018**, *21*, 200–212. [[CrossRef](#)]
24. Panagiotidou, M.; Fuller, R.J. Progress in ZEBs: A review of definitions, policies and construction activity. *Energy Policy* **2013**, *62*, 196–206. [[CrossRef](#)]
25. Lund, H.; Arler, F.; Ostergaard, P.A.; Hvelplund, F.; Connolly, D.; Van Mathiesen, B.; Karnoe, P. Simulation versus optimisation: Theoretical positions in energy system modelling. *Energies* **2017**, *10*, 840. [[CrossRef](#)]
26. Torcellini, S.; Pless, M.; Deru, D.; Crawley, P. Zero Energy Buildings: A Critical Look at the Definition. In *ACEEE Summer Study Pacific Grove*; National Renewable Energy Lab.(NREL): Golden, CO, USA, 2006.
27. Sartori, I.; Lollini, R. Nearly-zero, Net zero and Plus Energy Buildings—How definitions and regulations affect the solutions. *REHVA J.* **2012**, *12*, 23–27.
28. Laustsen, J. *Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings*; International Energy Agency (IEA): Paris, France, 2008.
29. Zacà, I.; D’Agostino, D.; Congedo, P.M.; Baglivo, C. Data of cost-optimality and technical solutions for high energy performance buildings in warm climate. *Data Brief* **2015**, *4*, 222–225. [[CrossRef](#)]
30. Philips, R.; Pittman, R. *An Introduction to Community Development*; Taylor & Francis (Routledge): London, UK, 2009.
31. Yamagata, Y.; Maruyama, H. *Urban Resilience: A Transformative Approach*; Springer: Berlin, Germany, 2016.
32. Aghamolaei, R.; Shamsi, M.H.; Tahsildoost, M.; O’Donnell, J. Review of district-scale energy performance analysis: Outlooks towards holistic urban frameworks. *Sustain. Cities Soc.* **2018**, *41*, 252–264. [[CrossRef](#)]
33. Carlisle, N.; Geet, O.; Pless, S. *Definition of a “Zero Net Energy” Community*; National Renewable Energy Lab.(NREL): Golden, CO, USA, 2009.
34. Marique, A.F.; Penders, M.; Reiter, S. From Zero Energy Building to Zero Energy Neighbourhood. Urban form and mobility matter. In Proceedings of the PLEA 2013-29th Conference of Sustainable Architecture: A Renewable Future, Munich, Germany, 10–12 September 2013.
35. Kennedy, S.; Sgourids, S. Rigorous classification and carbon accounting principles for low and Zero Carbon Cities. *Energy Policy* **2011**, *39*, 5259–5268. [[CrossRef](#)]
36. Todorovic, M. BPS, energy efficiency and renewable energy sources for buildings greening and zero energy cities planning: Harmony and ethics of sustainability. *Energy Build.* **2012**, *48*, 180–189. [[CrossRef](#)]
37. Eurostat. Final Energy Consumption. 2020. Available online: [https://ec.europa.eu/eurostat/%0Adatabrowser/view/t2020\\_34/default/table?lang=en](https://ec.europa.eu/eurostat/%0Adatabrowser/view/t2020_34/default/table?lang=en) (accessed on 6 September 2021).
38. Becchio, C.; Corgnai, S.; Delmastro, C.; Fabi, V.; Lombardi, P. The role of nearly-zero energy buildings in the transition towards Post-Carbon Cities. *Sustain. Cities Soc.* **2016**, *27*, 324–337. [[CrossRef](#)]
39. Koutra, S.; Pagnoule, C.; Galatoulas, N.F.; Bagheri, A.; Waroux, T.; Becue, V.; Ioakimidis, C.S. The Zero Energy Idea in District. Application of a Methodological Approach in the Case Study of Epinlieu (Mons). *Sustainability* **2019**, *11*, 4814. [[CrossRef](#)]
40. Santamouris, M. Innovating to zero the building sector in Europe: Minimising the energy consumption, eradiation of the energy poverty and mitigating the local climate. *Sol. Energy* **2016**, *128*, 61–94. [[CrossRef](#)]
41. Sameti, M.; Haghghat, F. Optimization approaches in district heating and cooling thermal network. *Energy Build.* **2017**, *140*, 121–130. [[CrossRef](#)]
42. Sornes, K.; Sartori, I.; Fredriksen, E.; Martinsson, F.; Romero, A.; Rodriguez, F.; Schnewly, P. ZenN Nearly Zero Energy Neighborhoods. Final Report on Common Definition for nZEB Renovation. 2014. Available online: <https://www.zenn-fp7.eu> (accessed on 6 September 2021).
43. Marszal, A.J. Zero Energy Building: A review of definitions and calculation methodologies. *Energy Build.* **2011**, *43*, 971–979. [[CrossRef](#)]
44. Boccalatte, A.; Fossa, M.; Menezo, C. Best arrangement of BIPV surfaces for future NZEB districts while considering urban heat island effects and the reduction of reflected radiation from solar façades. *Renew. Energy* **2020**, *160*, 686–697. [[CrossRef](#)]
45. Hamdan, H.A.M.; De Boer, L. Innovative public procurement (IPP)—Implications and potential for zero-emission neighborhood (ZEN) projects? In Proceedings of the IOP Conference Series: Earth and Environmental Science, Trondheim, Norway, 6–7 November 2019.
46. Fatima, Z.; Pollmer, U.; Santala, S.S.; Kontu, K.; Ticklen, M. Citizens and positive energy districts: Are Espoo and Leipzig ready for PEDs? *Buildings* **2021**, *11*, 102. [[CrossRef](#)]
47. Ekambaram, A.; Kvellheim, A.K.; De Boer, L. Public private collaboration and the role of learning in developing zero-emission neighborhoods. In Proceedings of the ECKM 2020: 21st European Conference on Knowledge, Trondheim, Norway, 2–4 December 2020.

48. Wiberg, A.; Lovhang, S.; Mathisen, M.; Tschoerner, B.; Resch, E.; Erdt, M. Visualisation of KPIs in zero emission neighbourhoods for improved stakeholder participation using virtual reality. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Graz, Australia, 11–14 September 2019.
49. Newman, P.; Kenworthy, J. *Sustainability and Cities. Overcoming Automobile Dependence*; Island Press: Washington, DC, USA, 1999.
50. Amaral, A.; Rodrigues, E.; Gaspar, A.; Gomes, A. Review on performance aspects of nearly zero energy districts. *Sustain. Cities Soc.* **2018**, *13*, 406–420. [[CrossRef](#)]
51. Guarino, F.; Bisello, A.; Frieden, D.; Bastos, J.; Brunetti, A.; Cellura, M.; Ferraro, M. State of the art on sustainability assessment of Positive Energy Districts: Methodologies, Indicators and Future Perspectives. *Sustain. Energy Build.* **2021**, *263*, 479–492.
52. Wang, N.; Phelan, P.; Gonzalez, J.; Harris, C.; Henze, G.; Hutchinson, R.; Langevin, J.; Lazarus, M.; Nelson, B.; Pyke, C.; et al. Ten questions concerning future buildings beyond zero energy and carbon neutrality. *Build. Environ.* **2017**, *119*, 169–182. [[CrossRef](#)]
53. Qin, B.; Han, S.S. Planning parameters and household carbon emission: Evidence from high and low-carbon neighborhoods in Beijing. *Habitat Int.* **2013**, *37*, 52–60. [[CrossRef](#)]
54. Li, F.G.N. Actors behaving badly: Exploring the modelling of non-optimal behaviour in energy transitions. *Energy Strateg. Rev.* **2017**, *15*, 57–71. [[CrossRef](#)]
55. Davila, C.C.; Reinhart, C. Urban energy lifecycle: An analytical framework to evaluate the embodied energy use of urban developments. In Proceedings of the BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, 26–28 August 2013.
56. Reinhart, C.; Dogan, T.; Jakubiec, J.; Rakha, T.; Sang, A. UMI—An urban simulation environment for building energy use, daylighting and walkability. In Proceedings of the 13th Conference of International Building Performance Simulation Association, Chambéry, France, 26–28 August 2013.
57. Swan, L.; Ugursal, V. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1819–1835. [[CrossRef](#)]
58. Tironi, M. Prototyping public friction: Exploring the political effects of design testing in urban space. *Br. J. Sociol.* **2020**, *71*, 503–519. [[CrossRef](#)] [[PubMed](#)]
59. Woods, R.; Berker, T. Citizen participation in Steinkjer: Stories about the ‘old NRK building at Lo’. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Trondheim, Norway, 30 May–3 June 2020.
60. Lindholm, O.; Ur Rehman, H.; Reda, F. Positioning Positive Energy Districts in European Cities. *Buildings* **2021**, *11*, 19. [[CrossRef](#)]
61. Lund, H.; Marszal, A.; Heiselberg, P. Zero energy buildings and mismatch compensation factors. *Energy Build.* **2011**, *43*, 1646–1654. [[CrossRef](#)]
62. Kolokotsa, D.; Rovas, D.; Kosmatopoulos, E.; Kalaitzakis, K. A roadmap towards intelligent net zero- and positive-energy buildings. *Sol. Energy* **2011**, *85*, 3067–3084. [[CrossRef](#)]
63. Saheb, Y. Analyse Critique Des Quartiers Durables. Paris. 2008. Available online: [http://www.lafabriquedelacite.com/fabrique-de-la-cite/data.nsf/3E01ADB92B5CA20EC125759A00533EF0/\\$file/analyse\\_critique\\_vf.pdf](http://www.lafabriquedelacite.com/fabrique-de-la-cite/data.nsf/3E01ADB92B5CA20EC125759A00533EF0/$file/analyse_critique_vf.pdf) (accessed on 6 September 2021).
64. Ala-Juuela, M.; Crosbie, T.; Hukkalainen, M. Defining and operationalising the concept of energy positive neighbourhood. *Energy Convers. Manag.* **2016**, *125*, 133–140. [[CrossRef](#)]
65. Marique, A.F.; Reiter, S. A simplified framework to assess the feasibility of zero-energy at the neighbourhood/community scale. *Energy Build.* **2014**, *82*, 114–122. [[CrossRef](#)]
66. 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 in Turin. *Land Use Policy* **2018**, *78*, 803–817. [[CrossRef](#)]
67. Haapio, A.; Viitaniemi, P. Environmental Criteria and Indicators used in the Environmental Assessment of Buildings. In Proceedings of the CIB World Building Congress CIB2007-241, Cape Town, South Africa, 14–17 May 2007.
68. Ameen, R.; Mourshed, M.; Li, H. A critical review of environmental assessment tools for sustainable urban design. *Environ. Impact Assess. Rev.* **2017**, *55*, 110–125. [[CrossRef](#)]
69. Huang, Y.; Musy, M.; Hégron, G.; Chen, H.; Li, B. Towards urban design guidelines from urban morphology description and climate adaptability. In Proceedings of the PLEA 2008-25th Conference on Passive and Low Energy Architecture, Dublin, Ireland, 22–24 October 2008.
70. Vartholomaios, A. The Residential Solar Block envelope: A method for enabling the development of compact urban blocks with high passive solar potential. *Energy Build.* **2015**, *99*, 303–312. [[CrossRef](#)]
71. Sarralde, J.J.; Quinn, D.J.; Wiesmann, D.; Steemers, K. Solar energy and urban morphology: Scenarios for increasing the renewable energy potential of neighbourhoods in London. *Renew. Energy* **2015**, *73*, 10–17. [[CrossRef](#)]
72. Mohajeri, N.; Upadhyay, G.; Gudmundsson, A.; Assouline, D.; Kampf, J.; Scartezzini, J.L. Effects of urban compactness on solar energy potential. *Renew. Energy* **2016**, *93*, 469–482. [[CrossRef](#)]
73. Lobaccaro, G. A cross-country perspective on solar energy in urban planning: Lessons learned from international case studies. *Renew. Sustain. Energy Rev.* **2018**, *108*, 209–237. [[CrossRef](#)]
74. Gros, A.; Bozonnet, E.; Inard, C.; Musy, M. Simulation tools to assess microclimate and building energy—A case study on the design of a new district. *Energy Build.* **2016**, *114*, 112–122. [[CrossRef](#)]
75. Palme, M.; Inostroza, L.; Villacreses, G.; Lobato-Cordero, A.; Carrasco, C. From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect. *Energy Build.* **2017**, *145*, 107–120. [[CrossRef](#)]

76. Salom, J.; Marszal, A.J.; Widén, J.; Candanedo, J.; Lindberg, K.B. Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. *Appl. Energy* **2014**, *136*, 119–131. [[CrossRef](#)]
77. Ghafghazi, S.; Sowlati, T.; Sokhansanj, S.; Melin, S. A multicriteria approach to evaluate district heating system options. *Appl. Energy* **2010**, *87*, 1134–1140. [[CrossRef](#)]
78. Morvaj, B.; Evins, R.; Carmeliet, J. Optimising urban energy systems: Simultaneous system sizing, operation and district heating network layout. *Energy* **2016**, *116*, 619–636. [[CrossRef](#)]
79. Riera Pérez, G.; Rey, E. A multi-criteria approach to compare urban renewal scenarios for an existing neighborhood. Case study in Lausanne (Switzerland). *Build. Environ.* **2013**, *65*, 58–70. [[CrossRef](#)]
80. Fonseca, J.A.; Schlueter, A. Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. *Appl. Energy* **2015**, *142*, 247–265. [[CrossRef](#)]
81. Ostergaard, P.A.; Lund, H. A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating. *Appl. Energy* **2011**, *88*, 479–487. [[CrossRef](#)]
82. Teller, J.; Azar, S. Townscope II—A computer system to support solar access decision-making. *Sol. Energy* **2001**, *70*, 187–200. [[CrossRef](#)]
83. Robinson, D. *Computer Modelling for Sustainable Urban Design: Physical Principles, Methods and Applications*; Routledge: London, UK, 2011.
84. Polly, B.; Kutsher, C.; Macumber, D.; Schott, M.; Pless, S.; Livingood, B.; Geet, O. From Zero Energy Buildings to Zero Energy Districts. In Proceedings of the American Council for an Energy Efficient Economy-2016 Buildings Summer Study, Pacific Grove, CA, USA, 21–26 August 2016.
85. Dogan, T.; Reinhart, C. Automated conversion of architectural massing models into thermal ‘shoebox’ models. In Proceedings of the BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, 26–28 August 2013.
86. Mauree, D.; Coccolo, S.; Kaempf, J.; Scartezzini, J.-L. Multi-scale modelling to evaluate building energy consumption at the neighbourhood scale. *PLoS ONE* **2017**, *12*, e0183437. [[CrossRef](#)] [[PubMed](#)]
87. European Commission. Energy Union Package: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank: A Framework Strategy for a Resilient Energy Union 2015. Available online: [https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC\\_1&format=PDF](https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF) (accessed on 3 May 2022).
88. JPI. 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/2018/09/setplan\\_smartcities\\_implementationplan.pdf](https://jpi-urbaneurope.eu/wp-content/uploads/2018/09/setplan_smartcities_implementationplan.pdf) (accessed on 3 May 2022).
89. Gohari Krangas, S.; Steemers, K.; Konstantinou, T.; Soutullo, S.; Liu, M.; Giancola, E.; Prebreza, B.; Ashrafian, T.; Murauskaite, L.; Maas, N. Positive Energy Districts: Identifying challenges and interdependencies. *Sustainability* **2021**, *13*, 10551. [[CrossRef](#)]
90. Hedman, A.; Ur Rehman, H.; Gabaldon, A.; Bisello, A.; 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](#)]
91. European Commission. *Questions and Answers on the Renovation Wave*; European Commission: Brussels, Belgium, 2020.
92. Hinterberger, R.; Gollner, C.; Noll, M.; Meyer, S.; Schwarz, H.-G. White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods. 2020. Available online: <https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White-Paper-PED-Framework-Definition-2020323-final.pdf> (accessed on 3 May 2022).
93. Moreno, A.G.; Alpagut, B.; Inarra, P.H. Guidelines to Calculate the Annual Primary Energy Balance of a Positive Energy District. 2020. Available online: <https://makingcity.eu/wp-content/uploads/2021/01/MCGUIDE-6.pdf> (accessed on 3 May 2022).
94. Bossi, S.; Gollner, C.; Theierling, S. Towards 100 Positive Energy Districts in Europe: Preliminary data analysis of 61 European cases. *Energies* **2020**, *13*, 6083. [[CrossRef](#)]
95. Zhou, Y.; Cao, S.; Hensen, J.L.M.; Lund, P.D. Energy integration and interaction between buildings and vehicles: A state-of-the-art review. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109337. [[CrossRef](#)]
96. Roccamena, L.; El Mankibi, M.; Stathopoulos, N. Development and validation of the numerical model of an innovative PCM based thermal storage system. *J. Energy Storage* **2019**, *24*, 100740. [[CrossRef](#)]
97. Schalin, B. Smart Energy Aland. 2021. Available online: [https://fedarene.org/wp-content/uploads/2021/04/2021-04-29-Aland-Energy-Story\\_Flexens.pdf](https://fedarene.org/wp-content/uploads/2021/04/2021-04-29-Aland-Energy-Story_Flexens.pdf) (accessed on 3 May 2022).
98. Bardon, L. District of La Fleuriaye. 2018. Available online: <https://www.construction21.org/city/fr/district-of-la-fleuriaye.html> (accessed on 4 November 2021).
99. POCITYF. POCITYF Project (the Case of Alkmaar). 2021. Available online: <https://pocityf.eu/city/alkmaar/> (accessed on 4 November 2021).
100. ATELIER. ATELIER Project (Positive Energy Districts). 2021. Available online: <https://smartcity-atelier.eu/outcomes/> (accessed on 4 November 2021).
101. Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities, Boerum ZEN. 2021. Available online: <https://fmezen.no/about-us/> (accessed on 4 November 2021).
102. Joanneum Research. Smart City Project Graz District Management. 2016. Available online: [https://pocacito.eu/sites/default/files/StadtLabor\\_Graz.pdf](https://pocacito.eu/sites/default/files/StadtLabor_Graz.pdf) (accessed on 5 November 2021).

103. Making City. Project Making City. 2021. Available online: <https://makingcity.eu/> (accessed on 6 November 2021).
104. +CityChange. +CityChange. 2021. Available online: <https://cityxchange.eu/> (accessed on 6 November 2021).
105. Pascariu, G.; Zlota, C.; Gradinaru, M.; Ghintuiala, D.; Vladut, M.; Radu, A. Laser Valley Masterplan & Vision Project. 2016. Available online: <https://wolfhouseproductions.ro/project/auto-draft-3/> (accessed on 6 November 2021).
106. Baer, D.; Andresen, I. ZEN Pilot Projects: Mapping of the Pilot Projects within the Research Center on Zero-Emission Neighbourhoods in Smart Cities. 2018. Available online: <https://fmezen.no/wp-content/uploads/2019/01/ZEN-Report-no-10.pdf> (accessed on 6 November 2021).
107. SPARCS. Sustainable Energy Positive and Zero cARbon Communities. 2021. Available online: <https://www.sparcs.info/about> (accessed on 6 November 2021).
108. JPI. Europe towards Positive Energy Districts First Update February 2020: A Compilation of Projects towards Sustainable Urbanization and the Energy Transition. 2020. Available online: [https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020\\_2.pdf](https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf) (accessed on 6 November 2021).
109. Rodriguez, A. The Innovative Eco-District in Valencia, La Pinada, Turns More International This Week. 2017. Available online: <https://www.barriolapinada.es/en/the-innovative-eco-district-in-valencia-la-pinada-turns-more-international-this-week/> (accessed on 8 November 2021).
110. Rueda Castellanos, S.; Oregi, X. Positive Energy District (PED) selected projects assessment, study towards the development of further PEDs. *Environ. Clim. Technol.* **2021**, *25*, 281–294. [CrossRef]
111. Ziguart Global Institute of Technology. Smart city series: Tampere Aspires to be the Smartest of Them All. 2019. Available online: <https://www.e-zigurat.com/blog/en/smart-city-series-tampere-aspires-be-smartest/> (accessed on 8 November 2021).
112. European Commission. Open Lab-Leading the Transition to Positive Energy Neighbourhoods. 2021. Available online: <https://smart-cities-marketplace.ec.europa.eu/news-and-events/news/2021/open-lab-leading-transition-positive-energy-neighbourhoods> (accessed on 8 November 2021).
113. Schneider, S. Cities4PEDs, SBC2021. 2021. Available online: <https://res.technikum-wien.at/project/cities4peds/> (accessed on 8 November 2021).
114. EUROHEAT & POWER, 100% RE District-Drammen. Norway. 2019. Available online: <https://www.euroheat.org/knowledge-hub/case-studies/100-re-district-drammen-norway/> (accessed on 8 November 2021).
115. Maki, K. Smart Otaniemi—An Open Playground for Energy Innovation. 2019. Available online: <https://www.vttresearch.com/en/news-and-ideas/smart-otaniemi-open-playground-energy-innovation> (accessed on 8 November 2021).
116. Gomez, V. City-Wide Project Grenoble. 2014. Available online: [http://www.cityzen-smartcity.eu/wp-content/uploads/2019/12/city-zen\\_d4-7\\_grenoble-roadmap.pdf](http://www.cityzen-smartcity.eu/wp-content/uploads/2019/12/city-zen_d4-7_grenoble-roadmap.pdf) (accessed on 8 November 2021).
117. PANERGY. Gyor Project. 2018. Available online: <https://panergy.com/en/projects/gyor/> (accessed on 8 November 2021).
118. CITYFIED: Replicable and Innovative Future Efficient Districts and Cities, Demo Sites-Lund. 2019. Available online: <http://www.cityfied.eu/newsletter/newsletter-1---citywtch/demo-sites---lund.kl> (accessed on 8 November 2021).
119. Sharing Cities. Smart Booklet: Sustainable Energy Management System. Towards an Energy Positive District. 2020. Available online: [https://nws.euocities.eu/MediaShell/media/2020\\_Booklets\\_SEMS\\_Final2.pdf](https://nws.euocities.eu/MediaShell/media/2020_Booklets_SEMS_Final2.pdf) (accessed on 8 November 2021).
120. Jernberg, J.; Hedenskog, S.; Huang, C.C. Hammarby Sjostad: An Urban Development Case-Study of Hammarby Sjostad in Sweden, Stockholm. 2015. Available online: <https://energyinnovation.org/wp-content/uploads/2015/12/Hammarby-Sjostad.pdf> (accessed on 8 November 2021).
121. Breda University of Applied Sciences. SCITHOS Project: Smart City Hospitality. 2016. Available online: <https://www.buas.nl/en/research/domains/tourism/scithos> (accessed on 8 November 2021).
122. Blumer, Y.; L'Orange Seigo, S.; Probst, M.; Stauffacher, M.; Lobsiger, E. Forderung Nachhaltiger Lebensformen Au Dem Hunziker Areal—Synthesebericht. 2021. Available online: <https://ethz.ch/content/dam/ethz/special-interest/usys/tddlab/docs/research/mercator-hunziker-report.pdf> (accessed on 6 November 2021).
123. European Academy of Bolzano. Sinfonia Project: Low Carbon Cities for Better Living. Bolzano. 2018. Available online: <http://www.sinfonia-smartcities.eu/en/demo-city/bolzano> (accessed on 8 November 2021).
124. REPLICATE project. REPLICATE Project: Florence. 2016. Available online: <https://replicate-project.eu/cities/florence/> (accessed on 8 November 2021).
125. Graz City. My Smart City Graz. 2019. Available online: <https://www.wegraz.at/de/projekte-hauptordner/my-smart-city-graz.php> (accessed on 8 November 2021).
126. Municipality of Amindeo. Municipal District Heating Company of Amindeo (Greece). 2015. Available online: <http://detepa.gr/dhca/> (accessed on 8 November 2021).
127. Viitanen, M. My Smart Life Project: City of Helsinki Environment Sector. 2021. Available online: <https://www.mysmartlife.eu/cities/helsinki/> (accessed on 8 November 2021).
128. Hazenberg, W. *Indicative Social Cost-Benefit Analysis Hydrogen Heating*; European Commission: Brussels, Belgium, 2021.
129. WA: Wettbewerbe Aktuell, Redesign of PFAFF Quartier, Kaiserslautern, Germany. 2017. Available online: <https://www.wettbewerbe-aktuell.de/ergebnis/neugestaltung-pforte-pfaff-quartier-kaiserslautern-90741> (accessed on 8 November 2021).
130. City of Malmo. Klimatkontrakt for Hyllie. 2009. Available online: <http://www.hyllie.com/media/34746/klimatkontrakt.pdf> (accessed on 8 November 2021).
131. Kemp, R. The Dutch Energy Transition Approach. *Int. Econ. Econ. Policy* **2010**, *7*, 291–316. [CrossRef]

132. Cityforster. Dietenbach Freiburg. 2018. Available online: <https://archello.com/project/dietenbach-freiburg> (accessed on 8 November 2021).
133. Fundacion Tecnia Research & Innovation. Towards Smart Zero CO2 Cities across Europe. 2016. Available online: <https://cordis.europa.eu/project/id/691883> (accessed on 8 November 2021).