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Review

Implementation of Positive Energy Districts in European Cities: A Systematic Literature Review to Identify the Effective Integration of the Concept into the Existing Energy Systems

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Abstract: The positive energy district (PED) is a rather recent concept that aims to contribute to the main objectives of the Energy Union strategy. It is based on an integrated multi-sectoral approach in response to Europe's most complex challenges. But to what extent have its development and implementation been supported by research and innovation programs? And what is the state of the art of its implementation and effective penetration into the current energy systems of European cities, according to the evidence provided by the scientific literature? This study aims to investigate these issues, providing a critical overview of the PED situation by means of a systematic literature review based on the use of open-access bibliometric software supplemented with content analysis. The results show that less than half of the documents analyzed refer to actual case studies, 80% of which were funded as part of research projects. This seems to lead to the conclusion that although PEDs have been strongly encouraged by the scientific community and policy initiatives at the European level, their implementation in cities is still limited. Moreover, an uneven distribution among countries can be observed. To overcome the existing barriers to PED diffusion and implementation, it would be useful to provide more ad hoc funding and, above all, facilitate its accessibility also by municipalities not yet well integrated into European projects, initiatives, and networks.

Keywords: positive energy districts (PED); renewables energy production; energy flexibility; energy efficiency; literature review; Scopus data; VOSviewer; bibliometrics; content analysis

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1. Introduction

Positive energy district (PED) is a relatively recent concept that aims to contribute to the main objectives of the Energy Union strategy. PED integrates energy efficiency, renewable energy production, and energy flexibility in an integrated, multi-sectoral approach at the city level. This concept serves as a response to Europe's most complex urban challenges. This introduction outlines the policy and regulatory framework that supported the development of the PED concept and the related funding program contributing to PED deployment in Europe. Our ambition is to help disseminate the PED concept to the wider public, which will require an improvement in the awareness and commitment of current and future stakeholders [1].

In an ever-globalizing world, cities, which act as communication hubs, are responsible for over two-thirds of the world's energy consumption and serve as primary contributors to climate change. This necessitates efforts to mitigate the potentially severe consequences of this significant human challenge [2]. Indeed, cities represent the foremost source of global pollution, accounting for about 75 percent of global CO_2 emissions, with transportation and buildings standing out as major contributors. Despite this environmental challenge, cities also function as engines driving both national economic development and global progress, contributing to over 80 percent of the global gross domestic product (GDP).

The 2030 Agenda, New Urban Agenda, Addis Ababa Action Agenda on Financing for Development, and the Paris Agreement on Climate Change collectively outline **global transformative strategies** for sustainable development, particularly in urban contexts. On the European level, the "2020 Climate and Energy Package" and "2030 Climate & Energy Framework" serve as **transformative roadmaps** for addressing climate change. Aligned with the EU's commitment to global climate action, the European Commission has established the "2050 long-term strategy" for a climate-neutral EU, covering key sectors and transition pathways. Initiatives like the European Green Deal and the "Renovation Wave Strategy" introduced in 2020, emphasize the need for district and community approaches and the integration of renewable solutions to create zero-energy districts, acknowledging that **aggregating projects at this level** can lead to zero or even positive energy outcomes [3].

These transformative roadmaps have materialized in a series of **regulatory packages and policies**, establishing a legislative framework that empowers individual European Member States and, collectively, Europe as a whole, in achieving the outlined objectives [4].

Moreover, transformative roadmaps have influenced the creation of dedicated actions and **funding programs**. These programs aim to unleash the potential of cities, facilitating the realization of sustainable urban development goals. Additionally, they serve to fortify the financial aspects of sustainable urban development and empower cities to expedite financial actions in pursuit of the Sustainable Development Goals (SDGs).

In essence, **the regulatory and policies framework supporting the decarbonization of the building** stock is encapsulated in the "Clean Energy for All Europeans Package" (European Commission, 2019) [5] while "Fit for 55" **is the legislative package for delivering** the EU's 2030 climate target—urban scale included, along with the REPowerEU Plan, which introduces energy savings as the quickest and cheapest way to address the current energy crisis, reducing the bills and increasing the binding Energy Efficiency Target from 9% to 13%.

On the other side, the EU RD&I **funding programs**, based on the transformative roadmap elaborated by the European Union, are realized through the Horizon Europe Framework Programme. It elaborates on the goals of energy consumption reduction, climate neutrality, and zero energy at the urban scale managing energy flexibility at the local/regional and national levels. This is operationally pursued through the EU Mission "100 Climate-Neutral and Smart Cities" [6] and two main partnerships: the Clean Energy Transition (CET) [7] and the Driving Urban Transitions (DUT) [8].

Thus, thanks to the Horizon Europe program and specifically the DUT Partnership, the instances promoted by the Smart City concept [9]—integration of diverse systems and infrastructures, interaction among buildings, users, and prosumers, and the regional energy dimension, mobility, and ICT systems—are pursued through the PED concept, of which the ambition is to achieve a positive energy dimension for urban districts.

Indeed, in 2015, the European Council initiated the Energy Union, consolidating energy policy under a unified framework.

The Energy Union's strategy focuses on three goals across five dimensions: energy security, internal energy market, energy efficiency, decarbonization, and research and innovation. The Commission's response [10] included fifteen action points, with the fourteenth emphasizing the need for a forward-looking EU research and innovation (R&I) strategy in energy and climate. This led to a proposed R&I approach, including an upgraded Strategic Energy Technology Plan and a transport R&I agenda, implemented in 2015–2016 with clear priorities and objectives.

As part of the deliverables of the Energy Union Strategy, the European Commission adopted a Communication for an Integrated Strategic Energy Technology Plan in 2015. The Communication identified ten priority actions to accelerate the energy system transformation **through coordinated or joint investments** between European countries, private stakeholders (including research and industry), and the European Commission. The SET-Plan Action Number 3 (out of the ten priority actions), namely, "Create technologies and services for smart homes that provide smart solutions to energy consumers" was divided up into two Sub-Actions: 3.1 "Smart Solutions for Energy Consumers", and 3.2 "Smart Cities and Communities" which was finally rephrased in "Europe to become a global role model in **integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts**".

Thus, for the very first time, the positive energy districts (PED) concept was defined [11] (2018) and then encapsulated in the "Renovation Wave Strategy" (2020) and—via the Driving Urban Transition Partnership—in the Horizon Europe Framework Programme.

The new strategic target of SET Plan Sub-Action 3.2 was inspired by discussions in the European Innovation Partnership on Smart Cities and Communities, especially by the Initiative on Positive Energy Blocks and the "Zero Energy/Emission Districts" in order to address the ambitious climate targets of the COP21 agreement, and to align with the increasingly progressive goals foreseen by the Energy Efficiency Directives (EED), under which EU countries must set up an energy efficiency obligation scheme, and recently adopted new Energy Performance of Buildings Directive (EPBD).

The concept of a positive energy district is based on an integrated multisectoral approach capable of combining the integration of renewable energy production, energy flexibility, and energy efficiency within the urban dimension. This involves aggregating and integrating projects on buildings and users (consumers and prosumers) as well as mobility and ICT systems, at both the local and regional levels. Therefore, PED has been developed as a support structure capable of integrating the above targets into a holistic perspective, all suitable for coordinated or joint European investments.

Indeed, on the one hand, Horizon Europe, through its five missions, has launched **research and innovation funding programs** aimed at enhancing the effectiveness of the funding itself, pursuing clearly identified major objectives, and addressing some of the greatest challenges of our time—such as the Mission 100 Climate and Neutral Cities [6,12]. On the other hand, through Partnerships, it has promoted the establishment of initiatives where the European Union, national authorities, and/or the private sector **jointly commit to supporting** the development and implementation of a research and innovation program in response to Europe's most complex challenges. This aligns with the political priorities and related strategies adopted by the EU, specifically the two Partnerships, CET (Clean Energy Transition) and DUT (Driving Urban Transition).

It is within the latter (DUT) that, **through a co-financing action between the European Union and the Member States**, the transformation of the energy system is to be accelerated by developing and implementing 100 positive energy districts [9] contributing to the overall sustainability and clean energy goals by 2025 [13–15].

A synthesis of the above contents can be found in Figure 1, which can contribute to an in-depth understanding of how and why the PED was conceptualized and which funding programs have supported and will support its deployment in Europe. In order to ensure such dissemination, it is essential that not only current stakeholders but also the workers of the future are made aware of its importance, in line with the SDGs goals [16–22].

Nowadays, five years after its conceptualization, it is, therefore, necessary to evaluate the status of the implementation of the PED concept in order to evaluate the effectiveness of the instruments (strategies, roadmaps, regulatory packages and policies, and research and innovation strategies) implemented so far to facilitate its penetration into the current energy systems of European cities. This has been only partially addressed by the literature produced so far.

In particular, to the best of our knowledge, a combined review of the status concerning the emergence, establishment, and evolution of the PED concept and the financing tools supporting its development, mainstream, and replication has not been previously undertaken. This study aims to fill this research gap, providing a critical overview of the situation of PED implementation thanks to a scientific literature review complemented using open-access bibliometric software with the content analysis carried out by the authors.

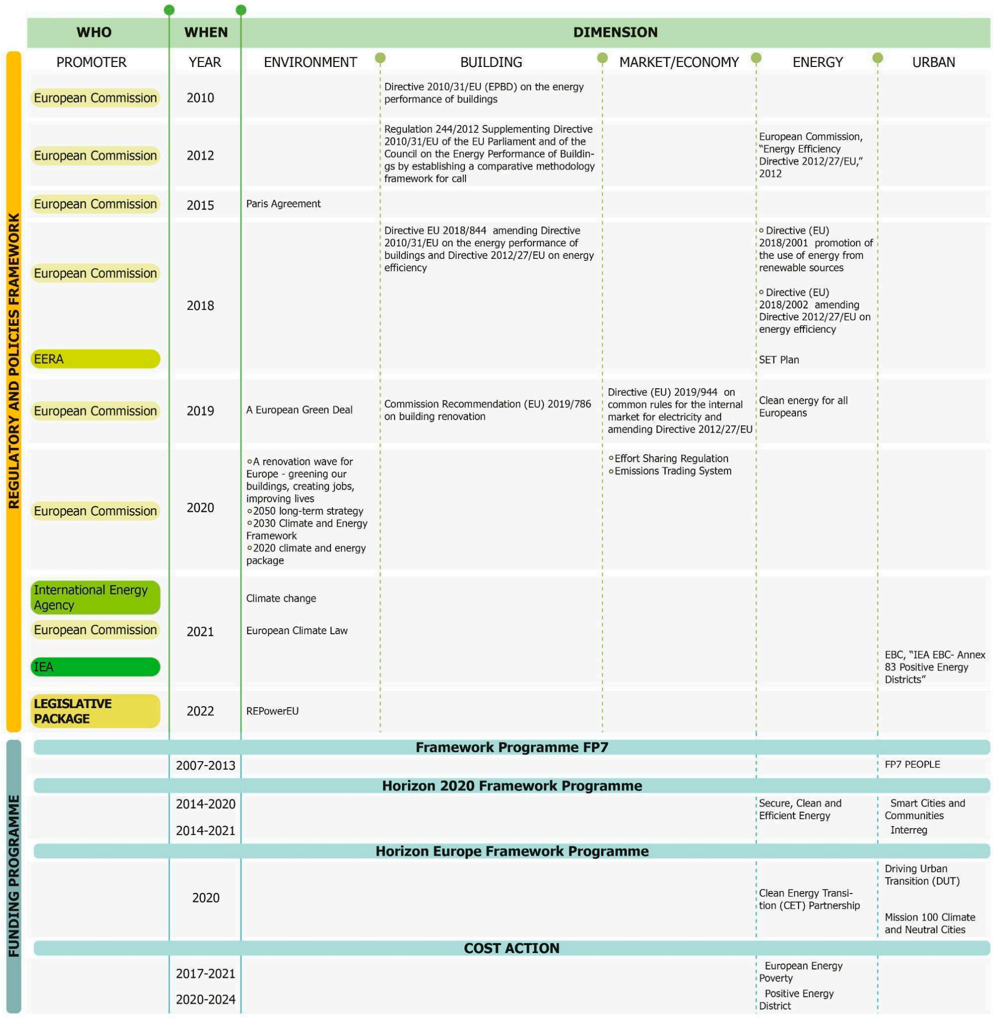

Figure 1. Synthesis of the main frameworks and programs underpinning the PED concept.

Our review paper highlights an original contribution to the current state of the research field by providing insights not only into the evolution of the PED concept [23–34], Urban District Energy Systems [35], or sustainability and KPIs [36], but establishing a link between the evolution of the PED concept and funding programs that support its creation. Three main research questions (RQs) are addressed in this study.

1. To what extent (**RQ1**) PED development and implementation has been supported by research and innovation programs? Referring to the status of its implementation and effective penetration into the current energy systems of European cities:
2. First, has the concept of PED been comprehensively defined in the current scientific literature? (**RQ2**) This opens the way to the following sub-questions:
   - 2.1 What concepts are most closely associated with a "positive energy district"? (RQ2.1)
   - 2.2 What are the strongest connections with other PEDs, and how have they changed over time? (RQ2.2)
   - 2.3 In which geographical contexts is most research being conducted in this area? (RQ2.3)
3. Second, in these studies, were the PED case studies clearly documented and supported by funding programs? (**RQ3**)

The literature review emphasized in the paper is the result of a meticulous analysis conducted on a list of articles finalized at the end of October 2023. Starting from this list, the authors first created a repository of the articles and then proceeded to collect, analyze, and visualize the data and indicators of interest, also thanks to the utilization of open-access bibliometric software, as indicated in the methodology section. In particular, in order to facilitate a critical evaluation of the data, the Scopus archive and the VOSviewer tool (version 1.6.20, released on 31 October 2023) were used to scrutinize and compare co-occurrence data across various publications. This made it possible to effectively undertake this review study, opening the way for subsequent research efforts that will employ more formal methodologies.

This paper is structured as follows: Section 2 describes the overall methodology related to the analysis of scientific literature; Section 3 presents the main results; and Section 4 presents a discussion of results, conclusions, and next steps of the research.

2. Materials and Methods

To answer the research questions, we opted for a broad holistic study of bibliographic sources according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). In addition to this, we further analyzed, mapped the data, and completed text mining through VOSviewer, which presents a user-friendly interface for building and visualizing bibliometric networks. In the following paragraphs, details on methodological steps adopted are presented.

2.1. Bibliometric Analysis of Scientific Literature

To carry out a bibliometric analysis of the scientific literature on PED, we opted for a scoping review according to the PRISMA-ScR [37] protocol, which provides a procedural reference for systematically mapping evidence on a specific topic, identifying key concepts and knowledge gaps. Following this protocol and considering the topic of PEDs, we decided to refer to Scopus and Web of Science, the two largest bibliographic databases globally [38] and recognized as the most reliable sources in the academic field [39,40].

To conduct the study, six methodological steps were followed (Figure 2a), and a screening process took place (Figure 2b).

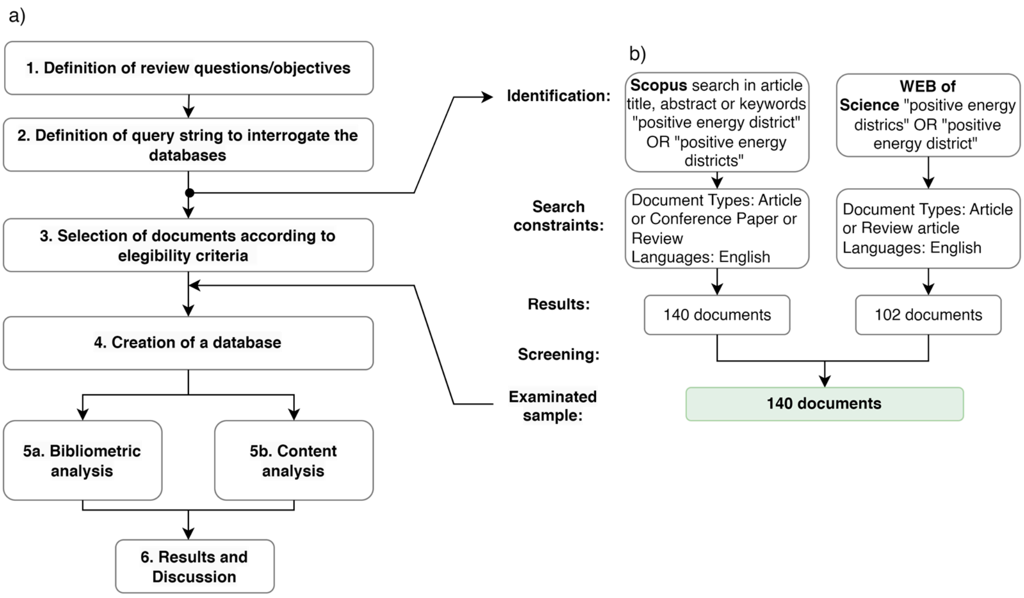

Figure 2. Methodological steps of the research (**a**) with a zoom on the article selection process (**b**).

In particular, the research work was based on the following operational steps:

1. *Definition of the questions/objectives of the review study*. This activity was essential to prepare the groundwork and effectively set up the subsequent steps of the work.
2. *Definition of query strings to interrogate the databases*. This step was performed on 27 October 2023 by using the search string "positive energy district(s)" in Scopus and Web of Science.
3. *Selection of documents according to predefined eligibility criteria.* In order to focus on articles that directly referred to the concept of PEDs, it was required that the search string be present at least in the title, abstract, or keywords. In addition, only scientific articles or conference papers, both in English, were considered eligible for this study. Article screening was performed automatically through the selection filters available in the bibliographic databases and, where necessary, manually. By eliminating duplicates, **140 articles** were selected for further analysis and constitute the core sample of this study. The screening process is represented in Figure 2b.
4. *Creation of a database*. Starting with the extraction in CSV format of metadata indexed by Scopus for each scientific publication, the selected articles were listed in an Excel file, where for each article the following attributes were associated: *Title;* DOI (digital object identifier); *year*; *journal*; *authors*; *authors' affiliation*; *keywords*; and *funding*. The last piece of information was functional in understanding the motivation that drove the article preparation (as declared within the main text and in the Funding and Acknowledgments sections). Moreover, based on the categories of article type defined by Scopus, articles were divided into "review", "article", or "conference paper".
5. *Analysis Bibliometric analysis (5.a).* By referring to the data extracted from Scopus and manually integrating the information derived from the articles retrieved exclusively from the Web of Science, an analysis of key bibliometric information was performed. This analysis was complemented by a further detailed analysis of the scientific literature using the VOSviewer tool, as described in detail in Section 2.2. *Content analysis (5.b).* The full text of the 140 sample articles was read carefully by the authors to investigate the presence and relevance of PED application in real case studies. Furthermore, for each paper falling under the category "articles and conference papers" (excluding reviews), each author indicated whether the article focuses mainly on methodological aspects or whether it specifically applies this research to real case studies (at district or city level, in one or more countries) in both the design and construction phase. This means that we have not included as case studies those articles that merely list case studies funded in different projects without providing the relevant information (e.g., different databases on PED projects). In the following phase, the articles were cross-checked among the authors. In the event of disagreement on the assignment of the type of article examined, a discussion was conducted between all authors until an agreement was reached.
6. *Results and Discussion*. Thanks to bibliometric and content analysis, it was possible to deduce a series of information in response to the research objectives. The results of the analysis and the related discussion are addressed in Sections 3 and 4 of this article.

2.2. Bibliometric Analysis of Scientific Literature Using VOSviewer

In this study, it was worth analyzing the data through bibliometrics, a branch of scientometrics, a sub-field of computer science focused on the statistical analysis of scientific literature such as books, articles, and publications. By mapping and visualizing data, bibliometrics allows us to measure and evaluate the performance of research [41].

Several programs can be utilized for data mapping, one of which is VOSviewer [42], developed by the Center for Science and Technology Studies (CWTS) at Leiden University in the Netherlands. The proposed scientific review relies on a bibliometric analysis process combined with the one elaborated with VOSviewer. The program allows for detailed examination of bibliometric maps in several different viewing modes, each describing a different aspect. VOSviewer was chosen to analyze the publications due to its user-friendly interface, its alignment with our preliminary research objectives, and its outstanding visualization capabilities, as well as its efficient import and export of data from various sources [36,43]. In particular, the analysis conducted with VOSviewer consisted of the following methodological steps:

1. *Data search and comparison*. This step was performed on 27 October 2023 by using the search string "positive energy district(s)" in Scopus and comparing the result with the previously selected articles.
2. *Export of the resulting file*.
3. *Bibliometric analysis*. VOSviewer provides the option to build co-occurrence networks of words extracted from the scientific literature, including journal types, researcher or organization names, country of publication, and author-chosen keywords, using text mining. The software can extract bibliographic networks from data files downloaded from various databases such as WoS, Scopus, Dimension, PubMed, and RIS. Keyword co-occurrence network analysis is among the most effective approaches for presenting scientific trends and the evolution of issues over time, creating concise and consistent maps [44]. The objective of co-occurrence analysis is to establish a framework for a bibliographic set by clustering terms extracted from the keywords [45].
4. *Results and discussion of the sub-questions*. Through the analysis, the software helped us to take a holistic approach to define, develop, model, and validate the current multi-layered PED concept. In particular, it was useful to answer sub-questions RQ2.1–RQ2.3 concerning, respectively, the concepts most closely associated with PEDs, the strongest connections with other concepts and their evolution over time, and the geographical contexts in which much of the research in this area is developed.

The data analysis and selection process are represented in Figure 3.

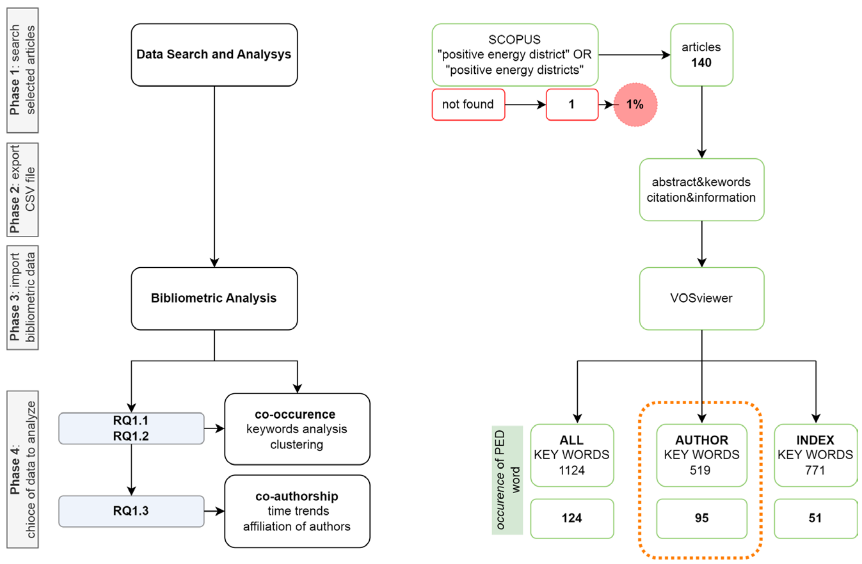

Figure 3. The VOSviewer-based data analysis and selection process.

3. Results

This section starts by presenting the results obtained with the bibliometric analysis based on Scopus and Web of Science and then discusses the results obtained with the VOSviewer tool.

3.1. Bibliometric Analysis Results

According to the article selection process described in Section 2.1, we found 140 documents in Scopus and 102 in Web of Science, which were found to be a subset of the Scopus sample.

Among the 140 selected articles (and conference papers), the position of the search string "positive energy district(s)" in the abstracts, titles, and keywords was analyzed.

In this way, it was possible to note that 82 articles had the string in the title, 120 in the abstract, and 100 in the keywords (Figure 4), with 65 of them falling under the three categories (abstract, title, and keywords).

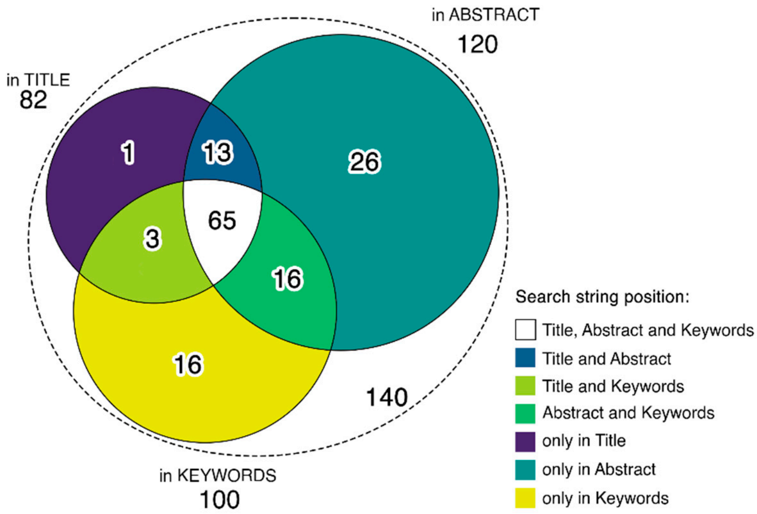

Figure 4. Subdivision of articles depending on the position of the search query.

Regarding the type of documents (Figure 5, inner circle), 11 were classified by Scopus as reviews (8%), 96 as articles (68%), and 33 as conference papers (24%).

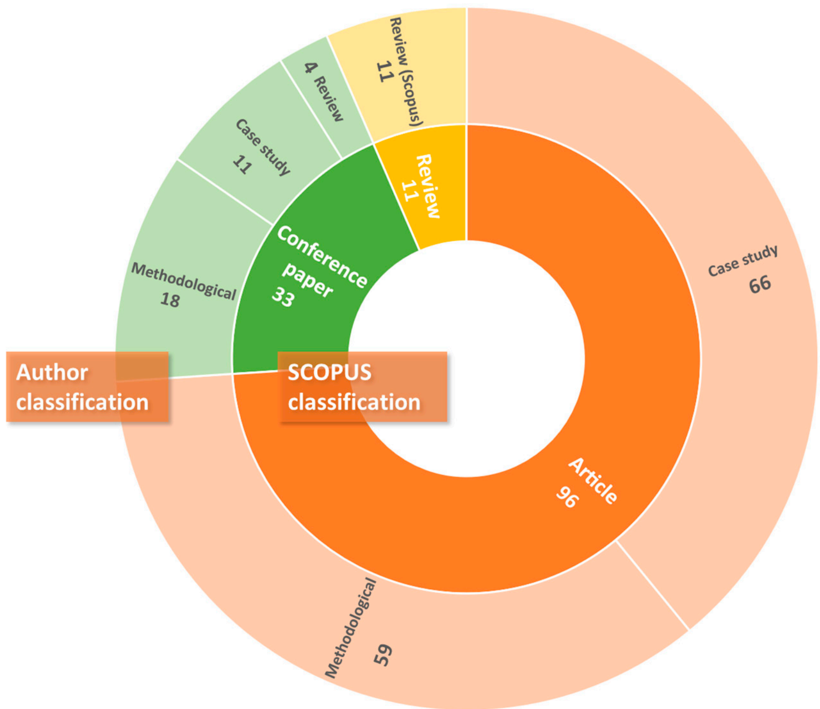

Figure 5. Document type classification. The inner circle represents the SCOPUS classification, while the outer circle represents the author's classification after content analysis.

Following the content analysis, the 33 conference papers were further subdivided: 4 were found to be reviews and 29 research articles.

Excluding the total of the reviews (11%), the 125 research articles (89.29%) resulting from the sum of the other two items turned out to be 59 methodological articles (42%) and 66 case studies (47%) (Figure 5, outer circle).

The distribution of the sample by year of publication (Figure 6) shows that, although no time limit was inserted, the first eligible article dates to 2017 and the majority (37.85%) of articles were published in 2022. It is noteworthy to compare the distribution of documents by the year of publication with an indication of key milestones in the regulatory and policy framework during the same years. Thus, a limited number of documents appeared between 2017 and 2020, while a significant growth in documents occurred when the PED concept was incorporated into the "Renovation Wave Strategy". This concept was further detailed in 2021 by IEA EBC Annex 83 and expanded upon in 2022 by REPower EU, thereby increasing the number of documents.

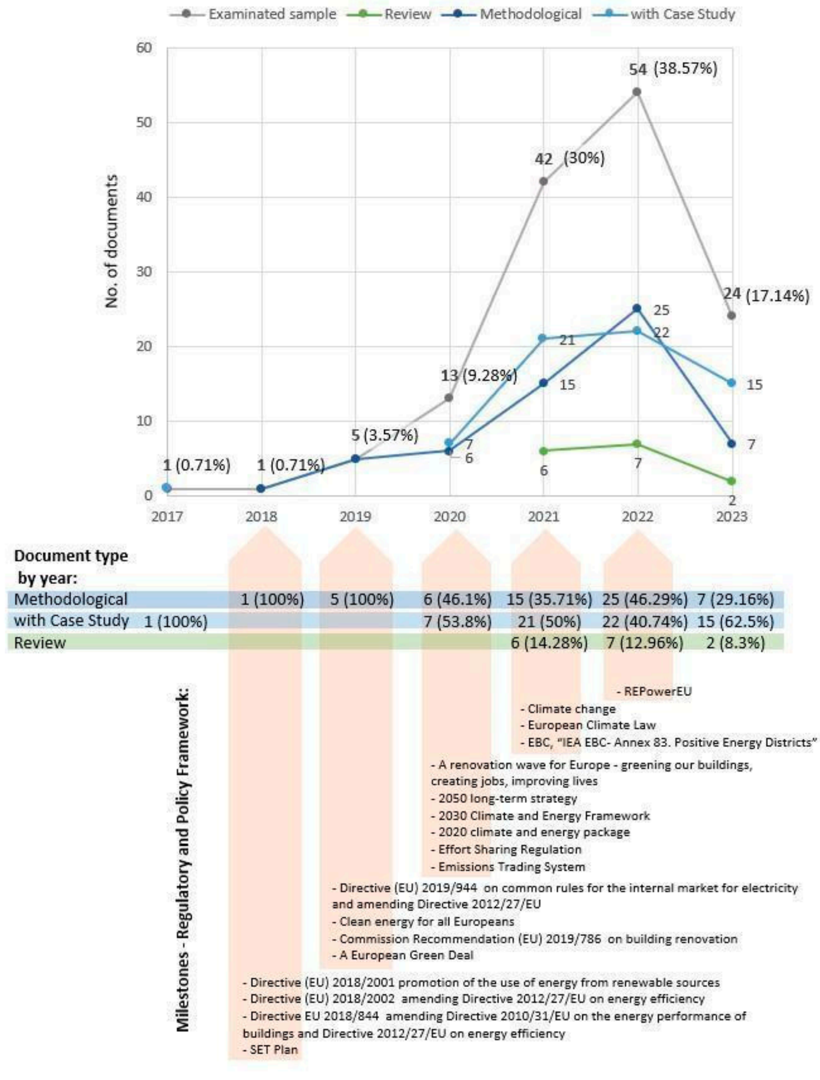

Figure 6. Distribution of documents by year of publication and type, with indication of key milestones in the regulatory and policy framework in the same years.

Documents describing methodological application to real case studies represent only 47% of the overall sample, i.e., 66 of the 140 documents analyzed. It is interesting to note that 80% of these case studies described in the papers were developed in the framework of European or nationally funded research projects. This is a very high percentage, which shows that the concept of PED is still very much confined to the experimental field and that implementation in real cases requires more ad hoc funding and, above all, greater dissemination and accessibility even by municipalities that are not yet well integrated into European projects, initiatives, and networks.

In particular, we found that European funding schemes finance a large share of the studies (50%, 33 papers); the most numerous are projects funded under Horizon 2020 (24), followed in smaller numbers by other funding sources (e.g., COST Actions, Interreg, etc.).

Funding from national sources covers 30% (20 articles in total) of the case studies implemented in the papers, the majority of which are Italian and Spanish (40%), followed by Danish and Canadian funding sources.

It is worth noting that four case studies were developed within the framework of the working group "Positive Energy Districts" of IEA Annex 83 (Energy in Buildings and Construction, EBC).

Finally, the graph in Figure 7 shows how the sponsor funds of the analyzed publications came almost exclusively from the European Union and, more specifically, from the Horizon programs.

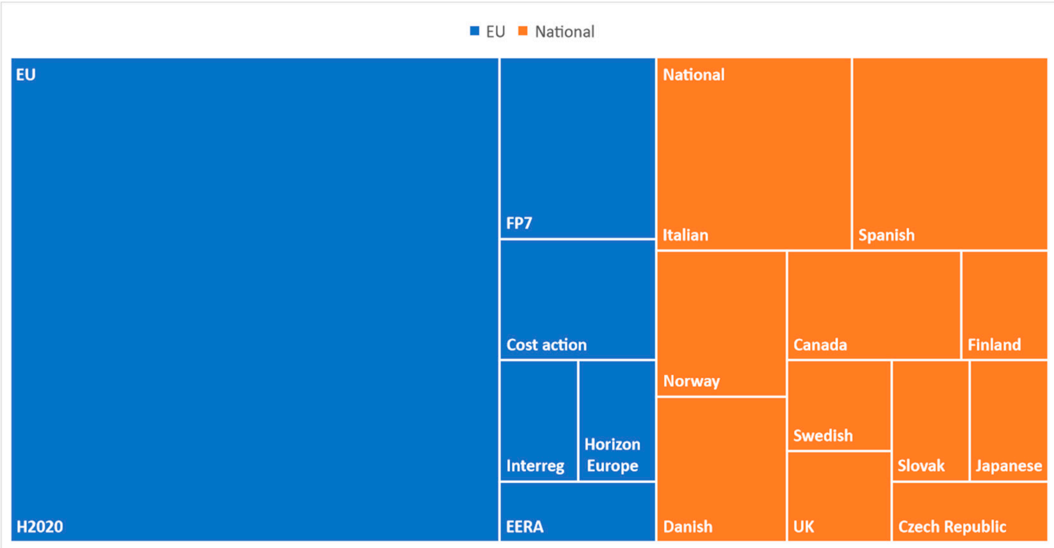

Figure 7. Subdivision of documents according to the funding sponsor.

3.2. VOSviewer Results

As already mentioned, the 140 articles analyzed (on 27 October 2023) came from the Scopus database, in which the repository contains a wide range of interdisciplinary publications [46] and allows registered users to export files in the required format.

The data were downloaded in CSV format (comma-separated values; CSV file stores tabular data in plain text, where each line of the file typically represents one data record), which is a suitable format to be processed by VOSviewer.

The first preliminary analysis processed by the software allowed us to verify the presence of the word "positive energy district (s)" in three categories: all text, authors' keywords, and abstract.

In our research, we deemed it more pertinent to concentrate co-occurrence analyses on bibliometric maps derived from authors' keywords. This category, in our opinion, more accurately reflects the topics stated in the publications [47].

Among the possible visualization modes made possible by the use of VOSviewer, we chose to present the results obtained from this bibliometric analysis in terms of network visualization (Figure 8) and overlay visualization (Figure 9). For both visualizations, each point is assigned a color indicating the density of items at that specific point.

In the authors' keywords, VOSviewer identified a total of 519 keywords, with 59 of them being associated with "positive energy district (s)". The results obtained (Table 1) show that among these keywords, the most frequent term is "positive energy districts" with a total link strength of 225 and 51 occurrences. It is closely followed by "positive energy district" with a total link strength of 176 and 32 occurrences. While the term "energy transition" is noteworthy, the keyword "smart cities" has a link strength of 47 and shows only 9 occurrences. Despite its lower frequency, its association with the selected literature is robust.

The software categorizes the keywords into 44 clusters, 5 of which specifically contain "positive energy district (s)" (Table A1, Appendix A). These clusters, distinguished by different colors, clarify the relationships between the various topics. The lines connecting the different items indicate the strength of the links (i.e., the number of publications in which two terms recur together), whereas thicker lines indicate a stronger link. Additionally, a strong link is observed when multiple clusters share the same color. Keywords are represented in nodes, and the size of the nodes corresponds to the frequency of occurrence of the keyword (Figure A1, Appendix A).

VOSviewer establishes the closeness of items by calculating the strength of association between them. This strength of association is defined as "a proportion of the total co-occurrences between items compared to the total expected co-occurrences between those items, assuming they are statistically independent" [48].

Examining the network visualization map (Figure 8), it becomes apparent that the predominant topics in the selected scientific literature are "positive energy district(s)", "ped", and "smart cities", followed by "energy efficiency". This implies that in the period from 2018 to 2023, researchers discussed and engaged extensively with these specific topics.

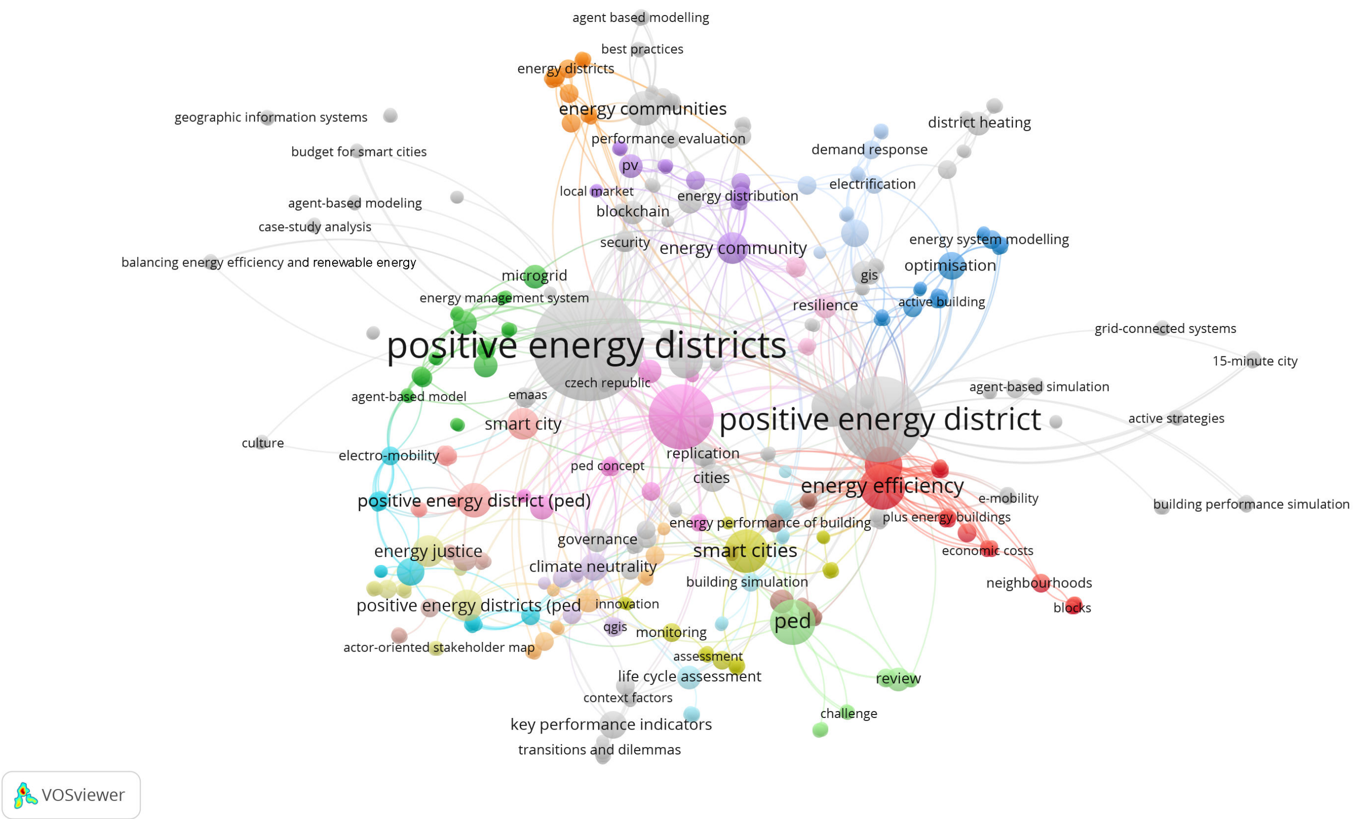

Figure 8. The network visualization map obtained with VOSviewer.

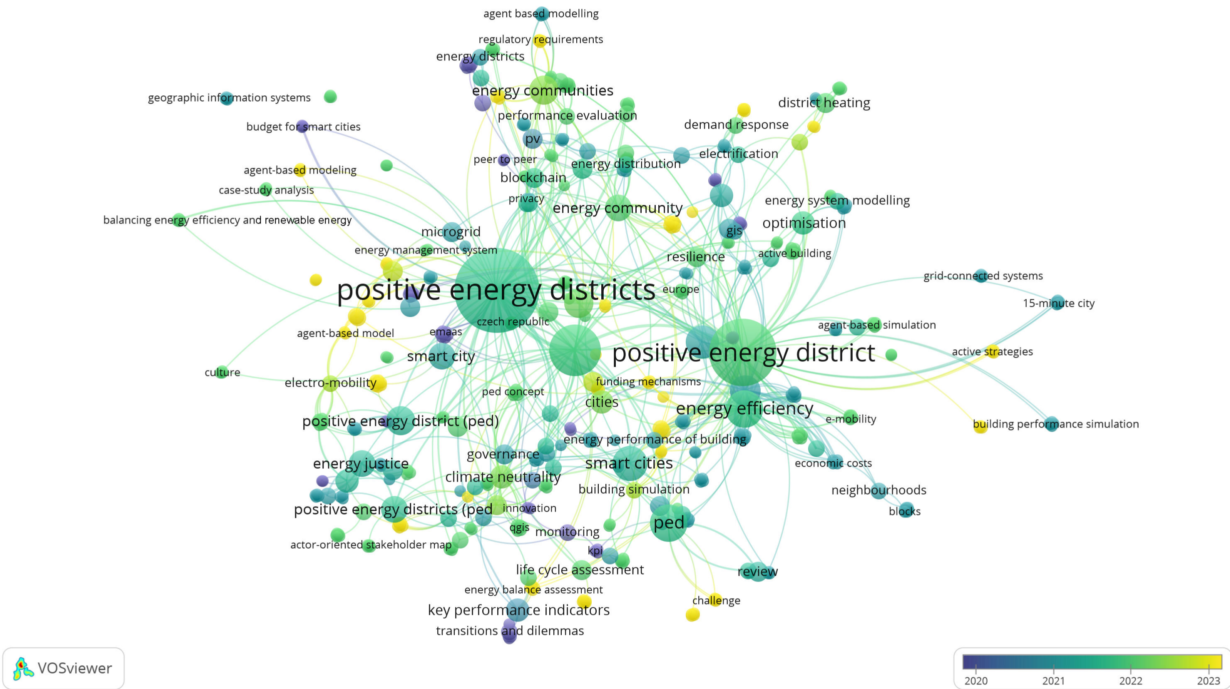

Figure 9. The overlay visualization map obtained with VOSviewer.

Table 1. The top 10 keywords with strong occurrences and links.

Key Words	Occurrence	Total Link Strenght
positive energy districts	51	225
positive energy district	32	175
energy transition	19	109
energy efficiency	10	63
ped	10	51
energy flexibility	7	47
smart cities	9	48
renewable energy	8	46
positive energy district (ped)	6	33
smart city	5	31

The analysis of keyword co-occurrence networks stands out as one of the most effective approaches to illustrate the evolution of scientific trends and issues over time. It is particularly interesting to isolate clusters in which "ped" demonstrates greater linking strength. For further insights into this phenomenon, refer to Figure A2 in Appendix A, which illustrates the keywords most frequently associated with "PED":

- "Energy efficiency";
- "Energy community";
- "Carbon neutrality";
- "Smart city";
- "Climate neutrality".

In the overlay visualization map (Figure 9), dynamic changes in trends within the research topic area are observed from one year to the next. The changing colors of the labels correspond to the years from 2020 to 2023. Notably, in the period between 2021 and 2022, PED emerged consistently in correlation with:"

- "Energy transition";

- "Energy efficiency";
- "Smart city".

On the other hand, some concepts are more rooted in the scientific literature, such as:

- "Transitions and dilemma";
- "Smart cities and communities";
- "Building energy transition";
- "Key performance indicator";
- "Budget for smart cities".

In contrast, we found more recent concepts, such as:

- "Climate neutral";
- "Nearly zero energy district";
- "Community";
- "Living lab";
- "Carbon footprint";
- "Consumer behavior".

These data show what the current trend/direction of association with PED research is and how it is changing compared to the early years of its emergence.

Bibliometrics enable us to understand and analyze not only topics but also authors, research countries, and language used, especially when focusing on co-authorship instead of co-occurrence. In Figure 10, using the overlay visualization map, we can deduce the countries that pioneered PED research: France, Slovenia, China, and the United States, followed by Norway, with India and South Africa among the next contributors. Conversely, through an examination of co-occurrence links, it is evident that Spain and Italy stand out as the most active nations in publishing and researching in this area.

Previous research has revealed the presence of the triad energy efficiency, energy flexibility, and renewable energy production in only two articles [49,50] (Figure A3, Appendix A). This finding is noteworthy for its low percentage, underlining that the PED concept remains rather fuzzy and not clearly defined.

VOSviewer's approach to interpreting co-occurrence maps therefore serves as an initial step in the analysis process rather than a unique method of interpretation. Co-occurrence maps provide a valuable starting point for recognizing meaningful relationships between elements, such as keywords. These visualizations were useful in this study to identify relevant themes and clusters within the dataset, thus providing a high-level overview of the interconnections between elements.

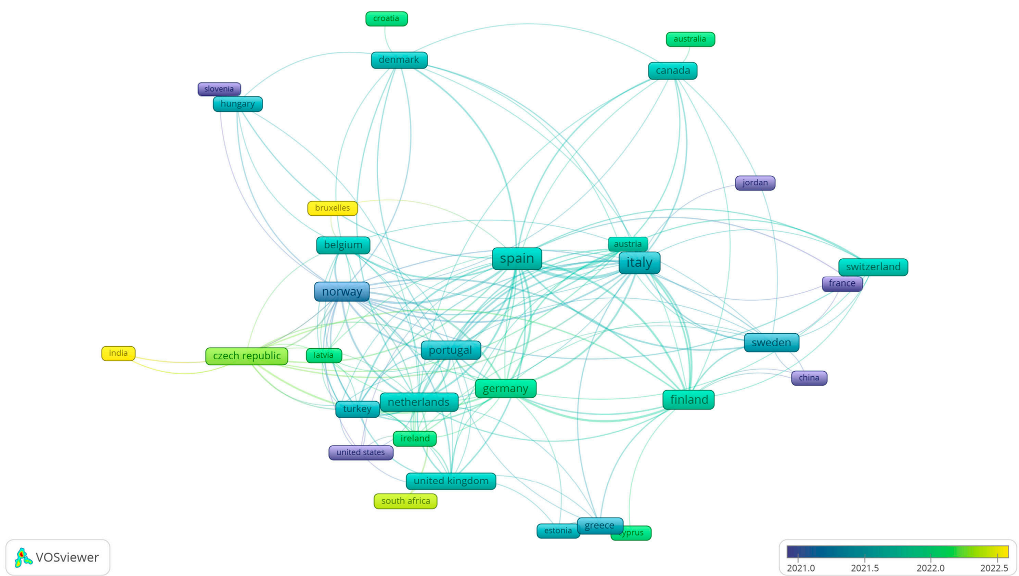

Figure 10. The overlay visualization map for countries obtained with VOSviewer.

4. Discussion and Conclusions

This paper addresses a scientific review analysis of PEDs with the aim of providing answers to specific questions pertaining to their definition, the concepts most associated with them, the most active geographic areas, the case studies developed to date, and the funding schemes most used to support them.

According to the results of the bibliometric analysis (Figure 6), the earliest eligible article [51], dating back to 2017, "presents an exploratory study on planning city refurbishment for the energy transition of Smart Cities". Notably, as highlighted in the introduction of this paper, it is only in 2020 that the "Renovation Wave Strategy" underscored the imperative for district and community approaches, along with the integration of renewable solutions to create zero-energy districts.

Furthermore, five papers, published in 2018 [52] and 2019 [53–56] highlighted—for the very first time—a potential ambition for a smart city: the goal of zero energy districts.

It is notable that the PED concept was defined in 2018, then only in 2020 has been encapsulated in the "Renovation Wave Strategy".

Moreover, among the seven articles that have been considered eligible for our scientific review, the paper "European Union funding Research Development and Innovation projects on Smart Cities: the state of the art in 2019" [57] focuses, for the first time, on how the European Union, member states and national and regional authorities should promote sustainable urban development and adapt policies and funding to the needs of cities.

Hence, the increasing number of papers related to PEDs (13 in 2020, 42 in 2021, and 54 in 2022) is likely associated with the evolution of regulatory and policy frameworks, legislative packages, and funding programs, as synthesized in Figure 6.

Another noteworthy finding from the bibliometric analysis is the emergence of review articles in 2021, three years after the initial conceptualization of PED. A similar trend is observed for methodological articles, and the combined number of review and methodological articles in 2021 is comparable to the number of articles presenting case studies, which unexpectedly doubles in 2022.

As depicted in Figure 6, the data underscores that, from 2020 to 2022, the majority of articles focus on the methodology of scientific reviews rather than on case studies of positive energy districts, which appear to be relatively scarce.

The analysis reveals that only a few of the examined articles pertain to tested instances of urban solutions in which experimentation has been supported by research, development, and innovation programs, such as H2020 Lighthouse.

Consequently, this finding leads the authors to state that, at present, the PED concept has not undergone significant improvement since its first definition was highlighted in the SET Plan Sub-Action 3.2 or the JPI Urban Europe White Paper. Furthermore, there is no positive energy district, either implemented, under construction, or planned. This paves the way for interesting research developments that should focus on the identification and analysis of existing barriers to the dissemination and implementation of PED and, consequently, on the tools and initiatives to be implemented to facilitate its implementation not only by "leading" municipalities but also by "lagging" ones in climate action [58].

This finding is reinforced by the results of the VOSViewer analysis, which notably identified that among the 66 articles related to case studies, only 2 include the combination of elements that characterize PED (energy efficiency, energy flexibility, and renewable energy production). Surprisingly, both references point to Sustainable Plus Energy Neighbourhood (SPEN) and not to a positive energy district case study (Figure A3, Appendix A).

The apparent contradiction in the current reconstruction of the state-of-the-art is now conspicuous: the intention to secure funding for mainstream adoption and replication of a model through research, development, and innovation, the outlines and consistency of which have yet to be defined. This stands in stark contrast to the approach taken with the smart city concept, where funding programs have supported experimentation with a clearly and effectively defined framework. This was highlighted, for instance, in the article by Clerici et al. (2019) [57] who focused on research projects funded under the EU funding program Horizon 2020.

Coming back to the research questions, the results of our study helped to shed light on the following aspects:

RQ1 concerned the need to investigate the level of support for the development and implementation of PED by research and innovation programs, based on information available from the scientific literature. As shown by Figure 1, the regulatory packages and policies in place have established a legislative framework that empowers European Member States to pursue an ambitious energy transition. The transformative roadmap of the Energy Union and SET Plan has influenced funding programs, introducing the concept of positive energy districts. This aims to develop an integrated multisectoral approach capable of combining renewable energy production, energy flexibility, and energy efficiency within the urban dimension. Indeed, Horizon Europe has promoted the establishment of initiatives wherein the European Union, national authorities, and/or the private sector jointly commit to supporting the development and implementation of a research and innovation program related to PED.

RQ2 was concerned with an in-depth examination of the current scientific literature to see whether the concept of PEDs was comprehensively described. The results of this study show that this is not the case, as the research topic areas found so far (Figure 8) are many and diverse. In response to RQ2.1, it is also difficult to identify the core concepts most closely associated with "positive energy district" (as shown in Tables 1 and A1—in Appendix A). Moreover (RQ2.2), the connections with other PEDs have changed significantly over time (Figure 9), and the geographical contexts in which the research was conducted (RQ2.3) are the major European countries (Figure 10).

RQ3 concerned case studies on PEDs and their possible documentation and support by funding programs. In this regard, it should be noted that the PED case studies (RQ3) encompass 76 cities, categorized into 26 small cities, 34 medium-sized cities, and 16 large cities, with 10 of them being selected from the EU Mission 100 Climate and Neutral Cities.

The unexpected results provided by the analyzed data pertain to the fact that, upon initiating this study, we were confident that it would have been possible to refine the basic characterization of PED (energy efficiency, energy flexibility, and energy renewables production) with a minimum set of KPIs. Surprisingly, we discovered that only a limited number of papers, which require a deeper investigation, provide this type of data. Consequently, we decided to limit the present paper to obtaining a cognitive framework.

The cognitive framework on positive energy districts in Europe resulting from this study and presented in this paper paves the way for further research that will adopt more formal methodologies to analyze the effective consistency of 76 case studies aspiring to become PEDs. Thus, further results on funding sources, the distribution of case studies, the types of funding and stakeholders involved, and the characterization of PEDs will be presented in a follow-up article matching the PED concept with "long-term climate goals towards climate neutrality" [12].

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Appendix A

Table A1. Clusters of positive energy district(s) obtained with VOSviewer.

Cluster 10		
key words	occurence	total link strenght
access network	1	9
building rehabilitaton	1	4
enabling solution for ped	1	4
fog computing	1	9
high order neutral unit	1	9
in reference to the process	1	4
living lab	1	9
polynominal neuron	1	9
positive energy district (ped)	6	33
prosumager	1	9
smart city	1	4
stability	1	9
tactile internet	1	9
ped booklet	1	2
set-pla	1	2
Cluster 13		
key words	occurence	total link strenght
actor-oriented stakeholder	1	9
capability approach	1	6
carbon democracy	1	5
energy justice	5	27
energy transition	1	9
just transition	19	109
local energy communities	1	4
multi-scalar governance	1	5
national energy and climate plan	1	5
ped as process	1	4
ped development phases	1	4
ped toolbox	1	4
positive energy districts	51	225
solar pv rollout	1	5
wellbeing	1	6
Cluster 22		
key words	occurence	total link strenght
context factor	1	7
energy balance assessment	1	7
key performance indicator	4	18
ped-positive energy district	1	4
ped assessment	1	7
ped definition	1	7
smart cities & communities solution	1	4
smart cities and communities	3	22
sustainable districts	2	11
transition and dilemma	2	7

Table A1. *Cont.*

zeed-zero energy efficiency	1	4
Cluster 30		
key words	occurence	total link strenght
country comparison	1	1
definition framework	1	2
green campus	1	2
modelling energy system	1	3
ped challenges	1	2
photovoltaics	1	2
positive energy districts	51	225
renewable energy technologies	1	2
spatial dimension	1	3
Cluster 31		
key words	occurence	total link strenght
active strategies	1	4
case study	1	4
energy demand reduction	1	4
inter-organizational collaboration	1	2
passive strategies	1	4
positive energy district	32	176
project stakeholder management	1	2

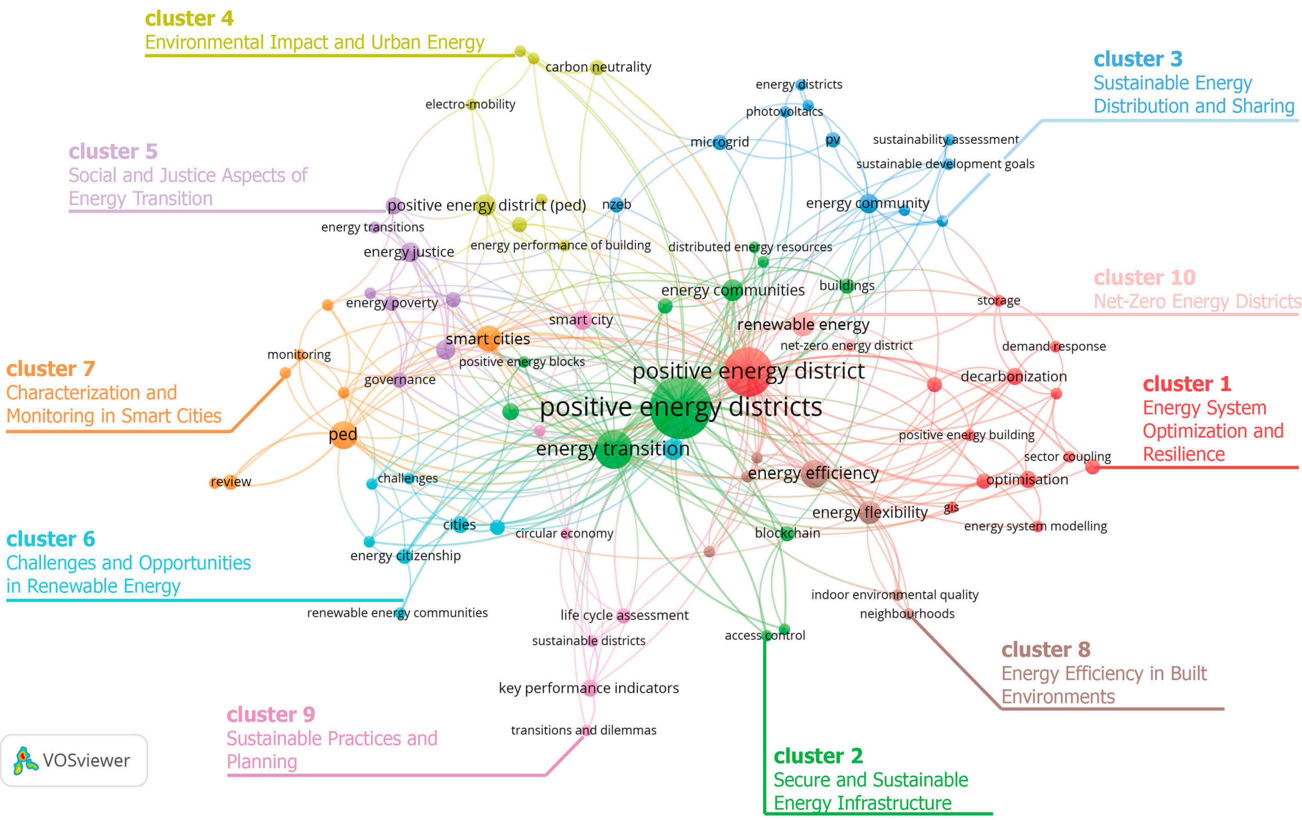
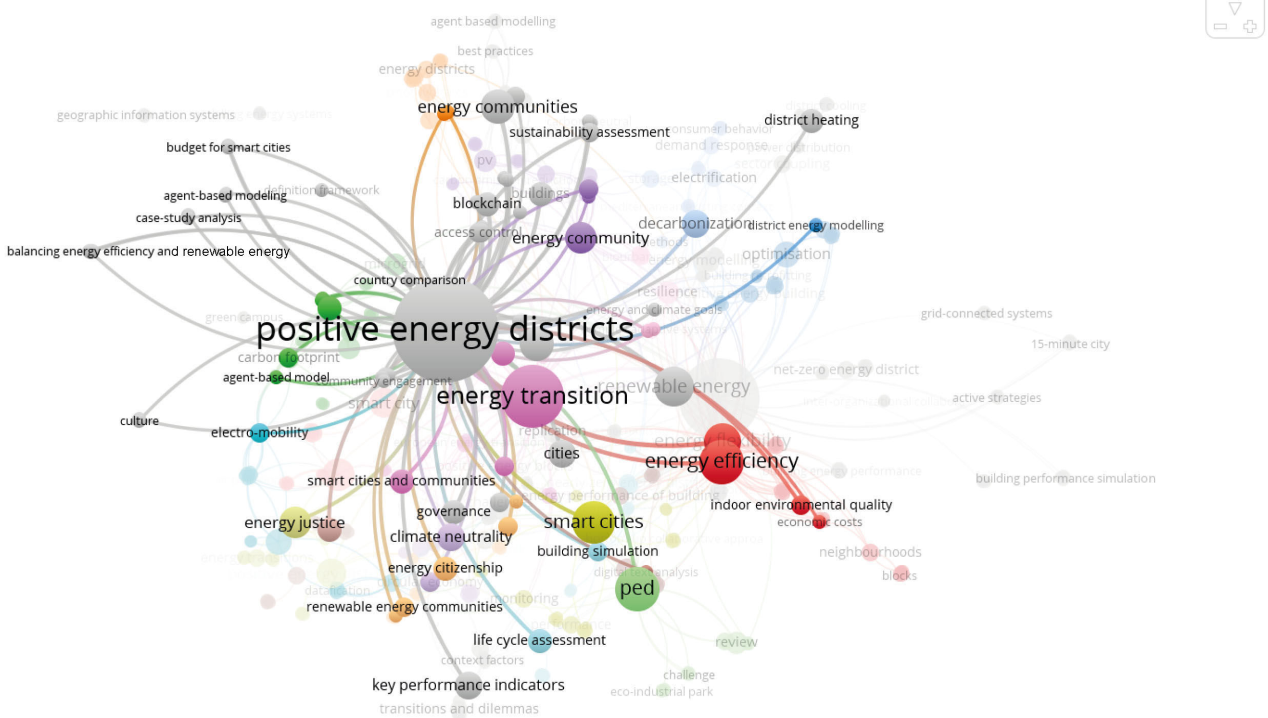


Figure A1. Co-occurrence analysis of keywords with frequency ≥ 2. Different colors indicate the clusters. After the word analysis, we gave titles to each cluster with the help of ChatGPT (version 3.5).

Cluster 33



Cluster 34

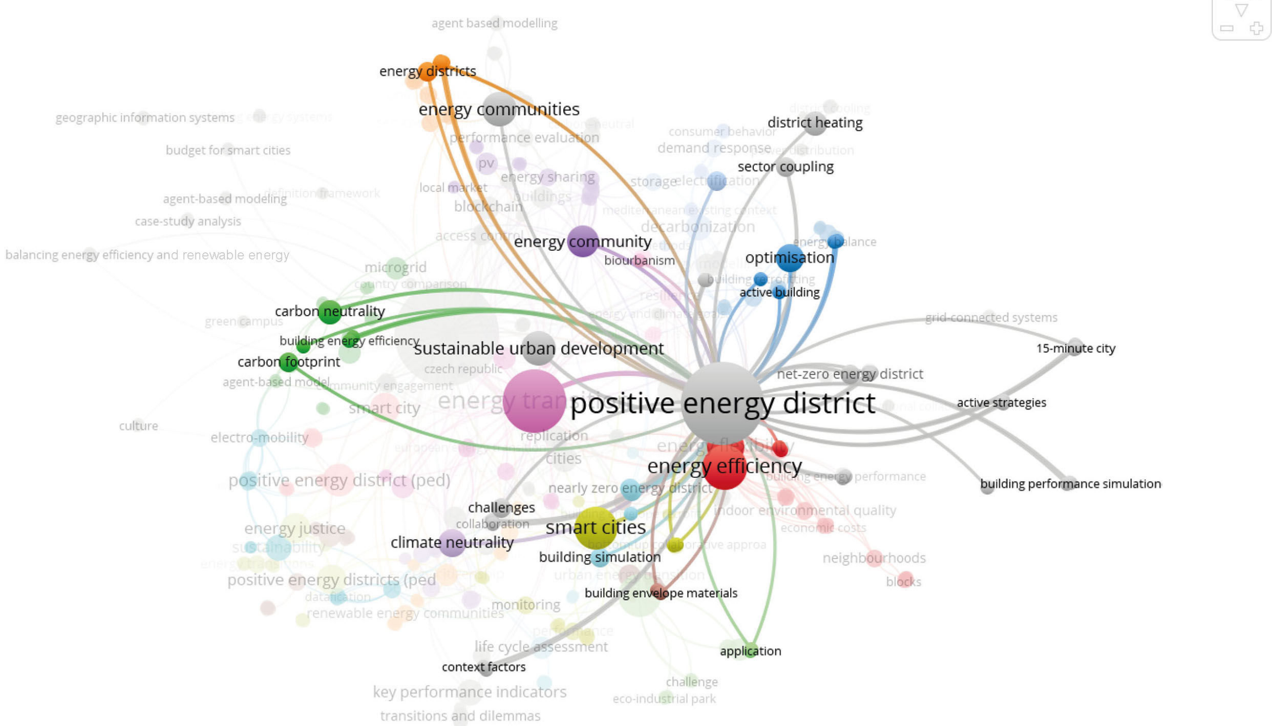


Figure A2. Cluster 33–34: most relevant associations with PED

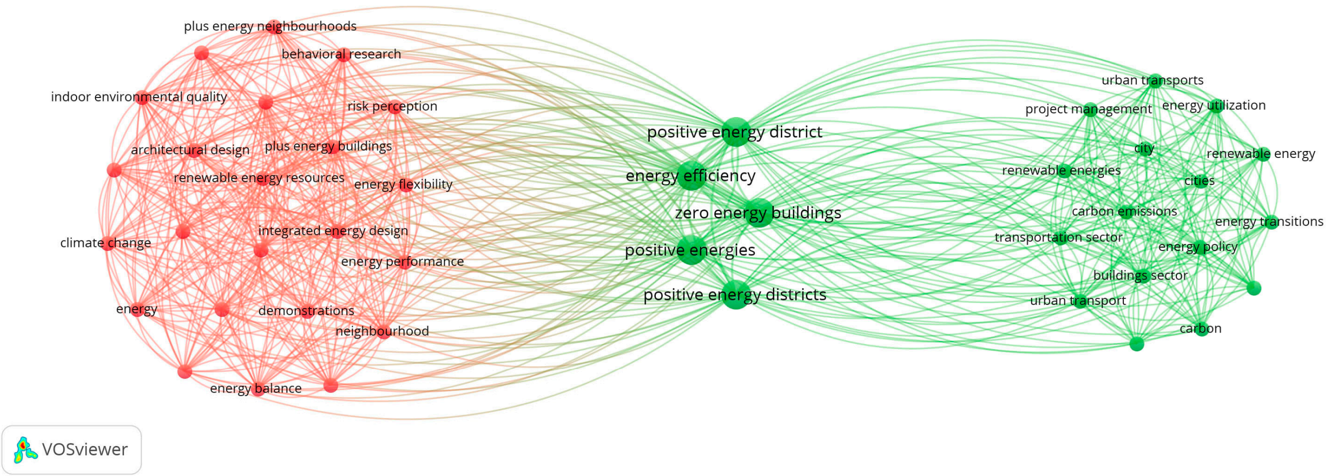


Figure A3. The clustering of the two articles [49,50] contains three words for creating an integrated multisectoral concept of PED.

Appendix B

List of 140 documents analyzed (as of 27 October 2023)

1. 'Decarbonizing Europe' A critical review on positive energy districts approaches; https://doi.org/10.1016/j.scs.2022.104356
2. A Blockchain-based Platform for Positive Energy Districts; https://ieeexplore.ieee.org/document/9854792
3. A Comprehensive PED-Database for Mapping and Comparing Positive Energy Districts Experiences at European Level; https://www.mdpi.com/2071-1050/14/1/427
4. A Critical Framework to Develop Human-Centric Positive Energy Districts: Towards Justice, Inclusion, and Well-Being; https://www.frontiersin.org/articles/10.3389/frsc.2021.691236/full#T1
5. A critical perspective on positive energy districts in climatically favoured regions: An open-source modelling approach disclosing implications and possibilities; https://www.mdpi.com/1996-1073/14/16/4864
6. A GIS-based multicriteria assessment for identification of positive energy districts boundary in cities; https://www.mdpi.com/1996-1073/14/22/7517
7. A Preliminary Analysis of the Characterizations of Positive Energy Districts; https://link.springer.com/chapter/10.1007/978-981-16-6269-0_34
8. A Quantitative Positive Energy District Definition with Contextual Targets; https://www.mdpi.com/2075-5309/13/5/1210
9. A Systematic Approach Towards Mapping Stakeholders in Different Phases of PED Development—Extending the PED Toolbox; https://www.researchgate.net/publication/358524138_A_systematic_approach_towards_mapping_stakeholders_in_different_phases_of_PED_development_-_Extending_the_PED_toolbox
10. Agent-Based Modelling of Urban District Energy System Decarbonisation—A Systematic Literature Review; https://www.mdpi.com/1996-1073/15/2/554
11. Analysis and Evaluation of the Feasibility of Positive Energy Districts in Selected Urban Typologies in Vienna Using a Bottom-Up District Energy Modelling Approach; https://www.mdpi.com/1996-1073/14/15/4449
12. Approaches to Social Innovation in Positive Energy Districts (PEDs)—A Comparison of Norwegian Projects; https://www.mdpi.com/2071-1050/13/13/7362
13. Assessing multiple benefits of housing regeneration and smart city development: The European project SINFONIA; https://www.mdpi.com/2071-1050/12/19/8038
14. Assessing the performance of Positive Energy Districts: The need for innovative methods; https://iopscience.iop.org/article/10.1088/1755-1315/1085/1/012014

15. Characterizing positive energy district (Ped) through a preliminary review of 60 existing projects in europe; https://www.mdpi.com/2075-5309/11/8/318
16. Citizens and Positive Energy Districts: Are Espoo and Leipzig Ready for PEDs? https://doi.org/10.3390/buildings11030102
17. Combining Sufficiency, Efficiency and Flexibility to Achieve Positive Energy Districts Targets; https://doi.org/10.3390/en14154697
18. Creating Comparability among European Neighbourhoods to Enable the Transition of District Energy Infrastructures towards Positive Energy Districts; https://doi.org/10.3390/en15134720
19. Decentralized data management privacy-aware framework for positive energy districts; https://doi.org/10.3390/en14217018
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21. Design, Modelling and Performance Evaluation of a Positive Energy District in a Danish Island; https://doi.org/10.5334/fce.146
22. Digital Twin for Accelerating Sustainability in Positive Energy District: A Review of Simulation Tools and Applications; https://www.frontiersin.org/articles/10.3389/frsc.2021.663269/full
23. Economic, social, and environmental aspects of Positive Energy Districts—A review; https://wires.onlinelibrary.wiley.com/doi/10.1002/wene.452
24. E-Mobility in Positive Energy Districts; https://doi.org/10.3390/buildings12030264
25. Energy Citizenship in Positive Energy Districts—Towards a Transdisciplinary Approach to Impact Assessment; https://doi.org/10.3390/buildings12020186
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43. Local Production and Storage in Positive Energy Districts: The Energy Sharing Perspective; https://doi.org/10.3389/frsc.2021.690927
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100. Living Lab Long-Term Sustainability in Hybrid Access Positive Energy Districts -A Prosumager Smart Fog Computing Perspective; https://ieeexplore.ieee.org/document/10137645
101. Methodology for estimating the decarbonization potential at the neighborhood level in an urban area: Application to La Carrasca in Valencia city-Spain; https://www.sciencedirect.com/science/article/abs/pii/S095965262302245X
102. Methodology for Quantifying the Energy Saving Potentials Combining Building Retrofitting, Solar Thermal Energy and Geothermal Resources; https://doi.org/10.3390/en13225970
103. Microgrid Oriented modeling of space heating system based on neural networks; https://doi.org/10.1016/j.jobe.2021.103150
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