buildings

MDPI

Article

IEA EBC Annex83 Positive Energy Districts

Åsa Hedman [1,*], Hassam Ur Rehman [1], Andrea Gabaldón [2], Adriano Bisello [3], Vicky Albert-Seifried [4], Xingxing Zhang [5], Francesco Guarino [6], Steinar Grynning [7], Ursula Eicker [8], Hans-Martin Neumann [9], Pekka Tuominen [1] and Francesco Reda [1]

1 VTT Technical Research Centre of Finland, Tekniikantie 21, 02150 Espoo, Finland; hassam.rehman@vtt.fi (H.U.R.); pekka.tuominen@vtt.fi (P.T.); francesco.reda@vtt.fi (F.R.)
2 Fundación CARTIF Centro Technologico, Energy Division, Parque Tecnológico de Boecillo, No: 205, 47151 Boecillo, Spain; andgab@cartif.es
3 Eurac Research, Institute for Renewable Energy, Viale Druso 1, 39100 Bolzano, Italy; adriano.bisello@eurac.edu
4 Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, 79110 Freiburg, Germany; vicky.bo.ki.albert-seifried@ise.fraunhofer.de
5 Energy and Community Building, Dalarna University, 79188 Falun, Sweden; xza@du.se
6 Department of Engineering, University of Palermo, Viale delle Scienze, Building 9, 90128 Palermo, Italy; francesco.guarino@unipa.it
7 Department of Geography, Planning, Environment, Concordia Unviersity, 1455 De Maisonneuve Blvd. W., Montreal, QC H3G 1M8, Canada; steinar.grynning@usintef.no
8 SINTEF, Strindvegen 4, 7034 Trondheim, Norway; ursula.eicker@concordia.ca
9 Austrian Institute of Technology—AIT, Giefinggasse 4, 1210 Vienna, Austria; hans-martin.neumann@ait.at
* Correspondence: asa.hedman@vtt.fi; Tel.: +358-40-570-3798

check for updates

Citation: Hedman, Å.; Rehman, H.U.; Gabaldón, A.; Bisello, A.; Albert-Seifried, V.; Zhang, X.; Guarino, F.; Grynning, S.; Eicker, U.; Neumann, H.-M.; et al. IEA EBC Annex83 Positive Energy Districts. *Buildings* **2021**, *11*, 130. https://doi.org/10.3390/buildings11030130

Academic Editors: Matheos Santamouris, Ambrose Dodoo, Ravi Srinivasan and Paulo Santos

Received: 31 December 2020
Accepted: 16 March 2021
Published: 20 March 2021

Abstract: At a global level, the need for energy efficiency and an increased share of renewable energy sources is evident, as is the crucial role of cities due to the rapid urbanization rate. As a consequence of this, the research work related to Positive Energy Districts (PED) has accelerated in recent years. A common shared definition, as well as technological approaches or methodological issues related to PEDs are still unclear in this development and a global scientific discussion is needed. The International Energy Agency's Energy in Buildings and Communities Programme (IEA EBC) Annex 83 is the main platform for this international scientific debate and research. This paper describes the challenges of PEDs and the issues that are open for discussions and how the Annex 83 is planned and organized to facilitate this and to actively steer the development of PEDs major leaps forward. The main topics of discussion in the PED context are the role and importance of definitions of PEDs, virtual and geographical boundaries in PEDs, the role of different stakeholders, evaluation approaches, and the learnings of realized PED projects.

Keywords: PED; stakeholder engagement; urban energy transition; bi-directional grid

1. Introduction

The increase in the energy consumption, the intensification of global warming and policies to reduce the need of fossil fuels have created interest in renewable energy sources (RES). The 2015 Paris Agreement has put more emphasis on international efforts to reduce carbon dioxide (CO_2) emissions [1]. According to the International energy agency (IEA), the use of RES has increased significantly in recent decades. For instance, photovoltaic (PV) energy generation increased from 91 GWh in 1990 to 554,382 GWh in 2018 and wind energy has increased from 3880 GWh in 1990 to 1,273,409 GWh in 2018 [2]. According to IEA, around 26% of the global energy was provided through RES in 2018 [2]. With plans to increase the share of the RES by 32% in the European Union (EU) by 2030 [3] and to further reduce CO_2 emissions by 80% by 2050 [4], it is expected that the share of RES will increase on a yearly basis. However, the challenge still remains on the variability of the RES generation, which could result in putting pressure on the grid and ultimately, in compromising the stability of the grid. Thus, power grids and energy systems have to be designed in a way that can regard such issues and challenges.

1.1. Impact of Buildings and Districts on Greenhouse Gas Emissions

An important sector that contributes significantly towards climate change and global warming is the building sector. Buildings account for 30–40% of global final energy consumption [5] and nearly 40% of the global CO_2 emissions. In the last decade, policies such as the Directive on Energy Performance of Buildings (EPBD) have been introduced to address the issue, aiming to decarbonize the building stock by 2050 and to reach nearly zero energy buildings (NZEBs) [6]. In 2009 ambitious energy and climate targets were set for 2020 (20% greenhouse gas emission reduction, 20% increase in efficiency and 20% increase renewable energy). After ten years, the EU in general is on track to achieve these targets, showing that GDP can be increased while reducing carbon emissions. In fact, by 2017 the EU's greenhouse gas (GHG) emissions decreased by 21.7% compared to the 1990 GHG emission levels [7]. In Canada, the residential sector is responsible for 16.6% of the energy consumption and 12.9% of GHG emissions [8]. Between 1990 and 2016, the residential sectors emissions have been reduced by 30.2 Mt CO_2 (27% of total) [8] through enhancing building codes, applying minimum energy performance standards for appliances, improving energy monitoring systems and home retrofits. Under the Paris Agreement, Canada committed to reducing its GHG emissions up to 30% below the 2005 level by 2030 [8]. Moreover, Canada announced a plan to set Canada on a net-zero emissions pathway by 2050. Canada's 2030 GHG emissions target is 511 Mt CO_2 eq, given a 2015 level of 815 Mt CO_2 eq [8]. Between nine principal sectors, buildings are committed to a 47 Mt CO_2 eq reduction [8]. The key priorities are increasing clean electricity, developing and implementing greener buildings and communities, and developing and implementing nature-based climate solutions.

The 2015 Paris Agreement has put more emphasis on international efforts to reduce CO_2 emissions, where urban areas with a 70% share of global emissions have a key role. Accordingly, the United Nations (UN) Sustainable Development Goals include as goal 11 "sustainable cities and communities" with the aim of supporting the transition towards low-carbon cities, in a general framework which also points towards, e.g., climate action, affordability, and clean energy. In 2015, when the Paris agreement was signed, the EU planned to move further ahead and reduce greenhouse gas emissions by 40% by 2030. In order to tackle this challenge and to lead the global energy transition, the EU Commission proposed in 2016 a set of new and ambitious rules known as the Clean energy package for all Europeans [5]. Therefore, to reach the emission reduction goals it is important to focus both at the energy systems level and at the buildings or district level.

1.2. Near and Net Zero Energy Building/District Concepts

Different NZEB, net zero energy or even zero energy building (ZEB) concepts have been developed and implemented in the building sector all over the world. According to the ZEB definition, "the building can be considered as ZEB after showing through actual measurements that the energy delivered to the building is less than or equal to the onsite renewable exported energy" [9]. Similarly, according to Article 2 of the Energy Performance of Building Directive (EPBD), the Nearly Zero Energy Building (NZEB) concept states that "'nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby'" [10]. A similar concept exists in the United States of America (USA) that is called net ZEB [11] it states that annually a building uses less or equal energy generated from the renewable energy on a primary energy basis. Similarly, concepts exists in other places [12] such as net zero energy (NZE) housing in Canada [13], zero emission building in Australia [14] and in Korea [15], etc. However, ZEBs or Nearly Zero Energy Building (NZEBs) mostly relate to individual building scales and do not consider the interaction with other energy consumers and producers. Nevertheless, ZEBs and NZEBs have recently received high academic and political interest around the world, as shown in Figure 1 [10,16–20]. Figure 1, x-axis shows the publication year, and the y-axis shows the cumulative number of documents published each year at the global level, for the keyword. The search is carried out using the keywords such as "nearly zero energy building", "zero energy building", "zero energy districts", "positive energy buildings" and "positive energy districts". The search is carried out from 1990 onwards until 2020 on Scopus [21]. It can be observed that interest and research are increasing each year for the ZEBs and NZEBs at the global level. Furthermore, since 2018, the positive energy district (PED) concept has come into the scene globally.

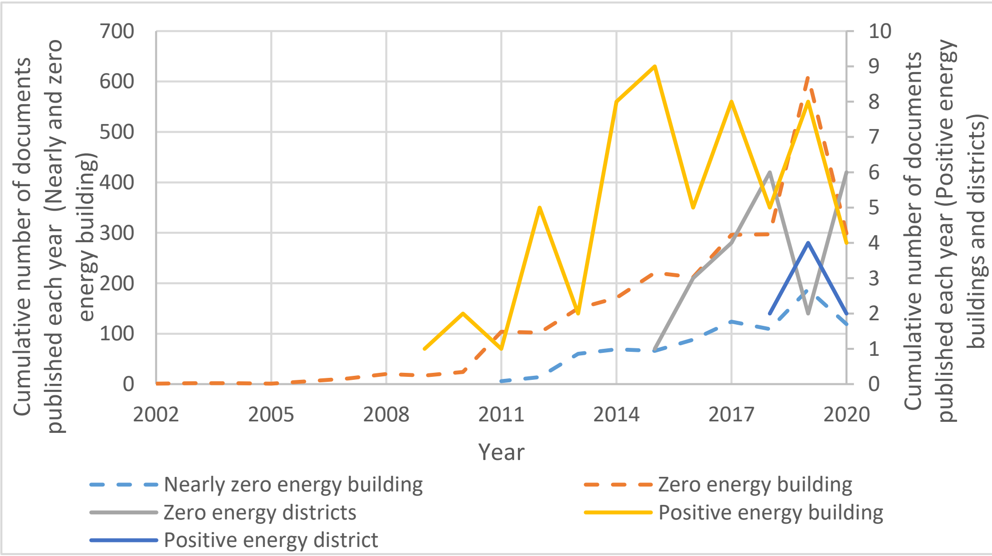

Figure 1. Cumulative number of documents published each year on the "Nearly Zero Energy Building", "Zero Energy Building", "Zero Energy Districts", "Positive Energy Buildings" and "Positive Energy Districts" according to Scopus at the global level [21].

1.3. Reasons for Positive Energy District (PED) Solutions Instead of Building Level and ZEB Soultions

ZEB or NZEB buildings do not only consume, but also produce energy onsite. The energy grids have to be designed in a way that allows consuming from the grid and injecting energy from RES to the grid, which can be applied to all types of grids: district heating and cooling networks (DHCN), natural gas grids, and/or power grids. Regarding power grids, bi-directional grids are needed to solve the issue of flexibility. If such issues are not considered, curtailment of the excess energy produced by buildings will be needed to avoid frequency and grid issues. For instance, in Germany [22] and in Belgium [23], the excess Photovoltaic (PV) generation has a power restriction on the export to the grid. When it comes to heat, buildings can be heated by DHCN, but it does not always allow export and production of heat by buildings (only if substations allow prosumers). In cases where this is technically possible, the financial compensation for exported heat is low. In some countries, buildings are just heated by means of an on-site generation system that consumes from the natural gas grid. However, in the future it is expected that an RES transition would occur in DHCN with the introduction of electrical heating systems (e.g., heat pumps) and prosumers, as well as the injection of hydrogen in natural gas grids. Utilizing waste heat streams from buildings and selling the waste heat to the DHCN is expected to grow [24,25]. Another aspect raised in the building sector is the inclusion of electro mobility within buildings and districts, such as a charging station for an electric-vehicle (EV). However, although the transport and mobility sector contributes 27% of the emissions in Europe, the NZEB/ZEB concepts [26] and EPB certificates (such as the ISO52000) usually omit the

EV load in the calculation process. Nevertheless, the transport and mobility sector are becoming increasingly important factors in the energy supply of populated districts, since the share of EVs is increasing rapidly at the global level. In fact, it is expected that by 2030, EV usage will increase to 44 million cars globally [27]. Many cities around the world are thus already including electrification of mobility in their city plans [28]. These EVs would increase the demand and load on the grids and they can also be used as peak savings with batteries. Other aspects, such as building mass and energy storage, have to be included in future energy systems [29]. Energy storage can provide needed flexibility and resilience to buildings [30]. All the above-mentioned issues and challenges call for large changes and renovation of the grids and energy systems so that all the issues can be addressed in an integrated and holistic way. These changes are needed at the district level rather than at the building level. Moreover, the aspects on better coordination between sectors (energy, building, mobility, etc.) and better integration of technologies (e.g., RES, EVs and other NZEB technologies) are other reasons to move from the building to the district level [31].

Various studies on buildings, smart grids and intelligent buildings have been carried out [32–34]. The flexibility and use of new technologies such as RES and storage can be increased by focusing at the district level, rather than at the building level. The research and testing of solutions are already moving from the building level to the district level. This would not only provide technically feasible solutions but also economically viable ones [35]. For example, the district energy refurbishment approach, already tested in some EU projects, leans on a set of innovative system integration activities at the district level and is geared to make the targeted district model robustly scalable and replicable and to maximize the multiple benefits creation [36,37]. Moreover, this would solve the grid and building-related emissions issues at a larger level. However, although the building level research on such topics has become well-structured in the past few years, the district level or, in particular, the positive energy district (PED) field is quite new, and it is developing on academic, scientific and business levels with time [38] as also shown in Figure 1.

1.4. Positive Energy District (PED) Concepts, Aims and Connection with Zero Energy Concepts and International Energy Agency Energy in Building and Communiy (IEA EBC) Annexes

A PED can be generally described as a district within a city that generates more energy than it consumes on an annual basis [39]. The aim of PED is not only to generate surplus energy, but rather to minimize the impact on the centralized grid by promoting higher self-consumption and self-sufficiency. The PED should offer options to increase the onsite load matching by allowing the integration of long and short-term storage and smart controls for improving the energy flexibility. This district level concept and its impact on flexibility, RES and storage integration are still in early stages globally, as shown in Figure 1. Therefore, a holistic approach is needed to define, develop, model and validate the PED concept in order to consolidate the PEDs. Moreover, as shown in Figure 2, the past research focus has been mainly on the ZEBs, intelligent buildings, energy efficiency, NZEB, RES, etc., at the global level. Therefore, Annex 83 will provide the needed platform to discuss and create a framework of PEDs considering the different urban contexts of the globe. According to the solar district heating database [40], there are approximately 195 pilot cases of different capacities of solar-based district heating systems operating in Europe. However, there is currently no insight into how the PEDs and their use in the future districts and cities would be able to provide the consumer-centric, bi-directional grids and districts that are emission-free and flexible. The PEDs can utilize the benefits of the building thermal mass, different typologies of energy storages, RES, electric mobility, demand side management, and flexibility options [30,41–43]. The district can also provide the advantage of shifting the demand, based on the functionality of the various buildings present in the district and this may assist in improving the energy flexibility at the building [44] and grid levels [45]. International Energy Agency Energy in Buildings and Communities (IEA EBC) Annex 83-Positive Energy Districts was developed to provide research contributions towards these fields, based on the outcomes of other IEA Annexes such as Annex 51 [46], Annex 60 [47], Annex 64 [48], Annex 67 [34], and Annex 73 [49].

Figure 2. The keywords used globally in the literature according to Scopus [21].

The PED concept introduces an opportunity to develop a framework that introduces energy positivity on a district level, with clear guidelines for grid interaction, energy storage and renewable integration for both buildings and Electric Vehicles (EVs). The main principle of a PED is to create a district within the city that is capable of producing higher energy than it consumes, it is flexible to respond to the energy market situation and in addition to this, it contributes by improving the quality of life and wellbeing of the residents.

The PED conceptual framework will be in line with the nearly or net zero energy building/district concept. The detailed conceptual framework will be planned and designed in this Annex 83. The framework has to be designed in such a way that it can accommodate and consider the local challenges, urban context and regulations, etc. This will provide a basis to analyze various PEDs in different geographical locations. Annex 83 will focus and support the research and development of the PED concept, principles, and frameworks, while keeping the global perspective.

1.5. Challenges, Opportunites, and Global Perspectives towards PEDs

The PED includes all types of buildings present in the district environment and are connected with the energy grid. PED is a growing concept within the research community at the global level in order to create carbon neutral cities for the future. This Annex is one of the first initiatives that aims to coordinate such research on PEDs at the global level. The PED concept may have its limitations depending on the location, local regulations, technology and urban contexts. For example, Denmark's regulations force buildings to be connected to the green district heating network (which will be imports for the PED), leading to higher investments to achieve a positive balance. At the same time, Denmark allows the creation of district heating cooperatives, allowing them to lower the prices of the user [50]. The prosumer regulations are also different within the European Union (EU). While Spain's self-consumption regulation makes the balance on a monthly basis, Latvia does so on a yearly basis and both of them do not reimburse users if the exported energy exceeds their electricity consumption. The Netherlands make the balance yearly, reimbursing prosumers for their exports at the end of the year [51]. Spain and Latvia limit the installed capacity per each user (except if they form a cooperative) while the

Netherlands enable the concepts of aggregators, virtual power plants or peer-to-peer energy exchange. Looking to global contexts, China has very large regions, and not all of them are connected by means of an electric grid [52], which can mean that it is harder in some contexts to apply PEDs. A potential solution to this may be micro-grids with self-sufficient districts (also known as energy islands in some of the literature). The focus of Annex 83 is on the development of the PED concept and its application at the global level, therefore this Annex involves researchers and experts from around the world (i.e., from Europe, USA, Canada, China, Australia, Japan, United Kingdom, South Korea, Turkey etc.) to include the global perspective and challenges as discussed above.

In order to reach the PED, the district first requires higher energy-efficient buildings, secondly the use of carbon free energy renewable energy sources to meet the remaining demand and thirdly cascading local energy flows by making use of any surpluses. Better and smarter controls are needed to match the demand and supply locally and also to minimize the liability on the grid and maximize the effectiveness of PED on the grid. Moreover, since the objective is also to go beyond the fulfillment of a mere mathematical positive energy balance, a wide spectrum of initiatives and parallel objectives are included in the definition of PEDs including social concerns, inclusiveness, solutions to energy poverty, spatial and civic planning of the person building in addition to district wide considerations on the transportation networks and design optimization.

The intrinsic multi-dimensional nature of the design of PEDs requires the contemporary involvement on different levels: mathematical and energy modeling, social, environmental, economic performance assessment, interaction with stakeholders, diffusion of know-how in the territory investigated and creation of PEDs are able to spark the diffusion of these concepts on large scales.

The transition towards carbon neutral districts require multisector and multidimensional solutions. It embraces a synchronized and parallel development of instrumental technologies, public perceptions of building energy technologies, new economic paradigms, assessment approaches, and tailored business models. In this case cities can provide and act as a living lab to facilitate and incubate new technologies and solutions. This is needed in order to co-design all-inclusive packages of citizen's centric carbon-free energy solutions. A common platform is needed to facilitate such collaborations and Annex 83 will focus on providing it with the ultimate aim to generate opportunities for creating such interdisciplinary solutions. Table 1 shows some of the practical application of PEDs or zero energy concepts available.

Table 1. Positive and Zero Energy Concept application across the world including ZEBs and NZEBs.

City	Project	Level of Application	Technologies [2]	Status [1]	Website, (Accessed Date)
Aland	Flexens	island	PV, W, CHP, BE, GB, WP, ES	O	flexens.com/the-demo/, (11 November 2020)
Carquefou	Quartier la fleuriaye	district	PH, EM, CE, PV	O	www.quartierlafleuriaye.fr/, (11 November 2020)
Groningen	MAKING-CITY	district	PV, BIPV, PVT, DHN, BE, WH, GB + HP	I	makingcity.eu/, (11 November 2020)
Oulu	MAKING-CITY	district	GB + HP, PV, DHN, STES	I	makingcity.eu/, (11 November 2020)
Limerick	+CITYXCHANGE	district	CE, HP, ST, EM	I	cityxchange.eu/, (11 November 2020)
	+CITYXCHANGE	district		I	cityxchange.eu/, (11 November 2020)
Amsterdam	ATELIER	district	PV, MG, GB + HP, DHN, BE, EM	I	smartcity-atelier.eu/, (11 November 2020)
Bilbao	ATELIER	district	GDN, PV, HP, EM	I	smartcity-atelier.eu/, (11 November 2020)
Alkmaar	PoCiTYF	district	ST, GE, HP, DHN, PV, EM, CE	I	pocityf.eu/, (11 November 2020)

Table 1. *Cont.*

City	Project	Level of Application	Technologies [2]	Status [1]	Website, (Accessed Date)
Évora	PoCiTYF	district	PV, BIPV, EM	I	pocityf.eu/, (11 November 2020)
Eespo	SPARCS	district	PV. GB, DHN, EM, VPP, STES	I	www.sparcs.info, (11 November 2020)
Leipzig	SPARCS	district	PV, VPP, DHN, ES, STES	I	www.sparcs.info, (11 November 2020)
Santa Coloma Gramenet	SYN.IKIA	district	DHN, PV	I	synikia.eu, (11 November 2020)
Loopkantsestraat (Area wonen)	SYN.IKIA	district	SH, GB + HP, PV	I	synikia.eu, (11 November 2020)
Gneis	SYN.IKIA	district	No info yet	I	synikia.eu, (11 November 2020)
Ammerud	SYN.IKIA	district	DHN, PH, High efficient PV, EM	I	synikia.eu, (11 November 2020)
Aarhus	RESPOND	district	PV, DHN, SH,	I	project-respond.eu/, (11 November 2020)
Aaran	RESPOND	district	PV, HP, ST,	I	project-respond.eu/, (11 November 2020)
Turku Graz	RESPONSE	city	GE, DHN, HP, WH, PV	I	
Brunnshög (Lund)	-	district	ST, HP, DHN, WH, PV	I	futurebylund.se/, (11 November 2020)
Aarhus	READY	city	Low DHN, WH, CE, PV, BIPV, VPP, Sea-HP, EM, BE	P	www.smartcity-ready.eu/about-aarhus/, (11 November 2020)
Okotoks, Alberta	DLSC	district	ST, PH, STES	O	https://www.dlsc.ca/how.htm, (10 January 2021)
Arvada, Colorado	Zero Energy Districts Accelerator	district	PH, REB, PV, GB, HP	I	https://zeroenergy.org/project-profiles/districts-communities/, (10 January 2021)

[1] O = In Operation, P = In planning stage, I = In implementation stage, [2] ST = Solar thermal, PV = photovoltaic panels, PVT = photovoltaic-thermal hybrid panels, W = wind turbine, MW = Micro-wind turbine, DHN = District heating network, GDN = Geothermal district network, SH = Social Housing, PH = Passive House, NZEB = Nearly zero energy building, REB = Retrofitted efficient buildings, BE = Bioenergy, WP = Wave power, GB = Geothermal boreholes, ES = Electric storage, EM = e-mobility (cars/bykes), WH = Waste Heat, MG = Micro grid, HP = Heat pumps, CHP = Cogeneration heat-power unit, CE = Circular economy perspective, STES = Seasonal thermal energy storage.

1.6. Aim and Scope of This Article

The aim of this article is to show the benefits and importance of scientific global level cooperation on the topic of PEDs. This article lays down and presents all the activities planned under each task and the objective of each tasks/subtasks under the proposed Annex 83 platform at the global level. This article provides an introduction to readers about the activities that are planned and in progress in IEA EBC Annex 83. It presents and provides for the Annex 83 project plan. Moreover, it introduces the current global interest of researchers in PEDs. This Annex will be conducted at the global level, in order to include a global perspective to the PEDs, as the topic is novel and requires a global collaboration.

The activities and tasks have recently started in Annex 83 from November 2020 and will continue up until the end of 2024. Under the planned Annex, all the outcomes, findings, new tools, and results will be presented and disseminated on various platforms and in scientific journals, reports, and books. As Annex 83 will progress for the next four years, all the challenges, such as climactic, geographical, regulatory framework, boundary conditions, stakeholders, technological approaches, as well as findings, will be disseminated. A flexible working definition of PED, case studies, development of methodologies, and tools will also be provided and discussed under the Annex.

2. IEA ECB Annex83 Positive Energy Districts: Objectives of the Annex

The International Energy Agency (IEA) has established an Implementing Agreement on Energy in Buildings and Communities (EBC). The function of the EBC program is to undertake research and provide an international focus for buildings and districts energy efficiency. Tasks are undertaken through a series of "Annexes", so called because they are legally established as annexes to the EBC Implementing Agreement. (https://www.iea-ebc.org/ebc/about, accessed date: 20 November 2020).

The largest benefits arising from participation in EBC are those gained by national programmes, such as leverage of R&D resources, technology transfer, training and capacity-building. Countries lacking knowledge can benefit from the experiences of those with more expertise, thereby avoiding duplicated research efforts (https://www.iea-ebc.org/ebc/about, accessed date: 20 November 2020).

The IEA EBC Research strategy states as an objective the following: "the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications". Annex 83, Positive Energy District answers directly this objective (https://www.iea-ebc.org/strategy, accessed date: 20 November 2020).

The international cooperation between research institutions from different parts of the world brings many opportunities. Sharing of experiences between different climate regions, cultures and economic systems enables researchers to develop globally sustainable solutions that are implementable around the world. The overall knowhow and understanding, not only on PEDs, but on society and city development, is increased by an active inclusion of a wide range of stakeholders.

2.1. Objectives

The aim of Annex 83 is to develop an in-depth framework for the devising of PEDs including analyzing the technologies, planning tools and the planning and decision-making processes related to positive energy districts. Experience and data to be used in the Annex will be gained from demonstration cases.

Annex 83 aims to enhance the cooperation of PED development at an international level through collaboration within the initiatives of the IEA. The main objectives of Annex 83 are:

- Objective 1: Map the relevant city, industry, research, and governmental (local, regional, national) stakeholders and their needs and roles to inform the work for Objectives 2, 3, 4, and 5. The main purpose of this is to ensure the involvement of the main stakeholders in the development of relevant definitions and recommendations.
- Objective 2: Create a shared in-depth framework of the definition of PED by means of a multi-stakeholder governance model. So far, international activities have developed generalized definitions that leave many questions open.
- Objective 3: Develop the needed information and guidance for implementing the necessary technical solutions (on the building, district, and infrastructure levels) that can be replicated and gradually scaled up to the city level, giving an emphasis to the interaction of flexible assets at the district level and also economic and social issues such as acceptability.
- Objective 4: Explore novel technical and service opportunities related to monitoring solutions, big data, data management, smart control, and digitalization technologies as enablers of PEDs.
- Objective 5: Develop the needed information and guidance for the planning and implementation of PEDs, including both technical planning and urban planning. This includes economic, social, and environmental impact assessments for various alternative development paths.

2.2. Organisation and Methodology of Annex 83

From various projects (as shown in Table 1) it is found that firstly, for each project, there is a certain definition of the concept, framework, and key performance indicators which are defined and laid down based on the local conditions and regulations, etc. Secondly, the technical framework, technology such as buildings, renewable energy sources, storage technology and simulation models are defined. Thirdly, the socio-economic and social impact assessment criteria are defined. Fourthly, the real physical PED demo is planned, implemented, operated, and measured. Lastly, the outcomes and learnings are communicated for future learnings. A similar method and approach is used to design the Annex 83 project plan and is communicated in this paper.

The Annex 83 is divided into four subtasks: Subtask A: definitions and context; Subtask B: methods, tools and technologies for realizing positive energy districts; Subtask C: organizing principles and impact assessment; and Subtask D: demos, implementation, and dissemination.

Each subtask has a subtask leader (or co-leaders) and a vice-subtask leader. The subtask leaders meet regularly to ensure a good coordination and communication between the tasks. This is imperative since many of the activities and results are dependent on the other tasks.

3. Activities, Subtasks, and Expected Results in the Annex 83

The Annex 83 execution phase started in December 2020. This chapter describes the expected results in the four-year project. The expected results are divided into the four subtasks but highlight the need for interaction between the subtasks. Annex 83 integrates work done in other projects and initiatives (see Table 1) through workshops, questionnaires, discussions, and joint publications among the experts who are working on the different projects. On the European level, the main PED-related activities are within the SCC1 projects under the framework Horizon2020. EERA Smart Cities is an active European platform for the collaboration among researchers within the topic of PEDs. The Annex work helps to share lessons and sets a stage for scientific discussion, bringing forward the lessons from projects and initiatives on a global level.

The annex aims to achieve a shared and internationally viable PED definition through a synthesis effort between the previous experiences, to develop new and integrated modeling approaches of PEDs through different techniques and resolutions, develop methodological advances to the sustainability assessment of PEDs, and test in real district environments the knowledge developed.

The interdependencies of the four subtasks are shown in Figure 3.

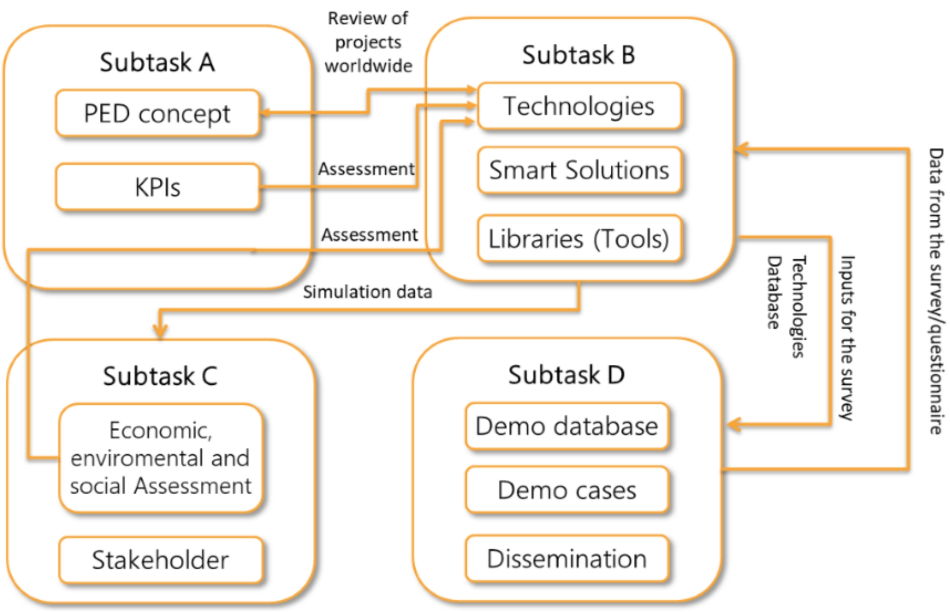

Figure 3. Subtask dependencies.

3.1. Subtask A: Activities and Planned Methodology

This activity will start by identifying the main aspects in the definition context, including system boundaries, different localities, timeframes, energy carriers, etc. The PED scope will be then defined to narrow down the focus in this Annex, so that it is practical while including the crucial elements. Furthermore, a literature review will be conducted to map the existing studies, projects, and initiatives at the international level. This task will be conducted in collaboration with other subtasks to align the scopes and foci within Annex 83.

Subtask A will examine the evolvement of the PED concepts and outline the crucial topics in the development of PEDs such as the spatial and temporal scales to be considered, essential technologies and system components, and regulations and implementation barriers. Visualization of PEDs in the form of infographics will be developed to enhance understanding of the PED concept. In addition, the stakeholders usually involved in the development of PEDs will be identified and categorized. These stakeholders can be urban planners, decision makers, energy system operators and planners, investors, construction companies, housing cooperatives, inhabitants, NGO's, etc. The stakeholders are a fragmented group with varying interests and levels of knowledge about energy and sustainability topics. A framework will be defined for different objectives of PED from different aspects of energy, economics, environment, and social context. Both the stakeholders and the objectives will be input into the Subtask C activities. Meanwhile, the KPI framework for PED will be finally developed in order to compare the performance of the different PED archetypes and PED solutions (developed by Subtask B) and define assessment models (Subtask C).

Based on case studies, common characteristics will be identified and summarized in a "Reference" PED or PED archetype. The "Reference" PED will be used for simulation and demonstration in other subtasks throughout the Annex. Moreover, this activity also plans to establish a common process flow for PED development, using the "Reference PED" as a case study to guide the development of PED projects.

3.2. Subtask B: Activities and Planned Methodology

The objective of Subtask B is to review which methods, tools, and technologies are necessary for realizing PEDs. The work is divided into three sub activities: B1, aimed at mapping the technical solutions (energy systems, infrastructures, etc.); B2, investigating how flexibility can help to balance the energy flows; and B3, identifying data and tools for modelling PEDs. The latter will model from two to three case studies to demonstrate different control strategies at the district level.

From the case studies identified in subtask D, an inventory of the current PED technologies applied in PEDs will also be analyzed in sub-activity B1. Through this exercise, the needed data for modelling and the best experiences of the different technologies will be identified. From the revision and analysis of the different technologies applied, the technologies can be classified into different topics/areas (heating, cooling, electricity, storage) and scopes (building, district, city). In each topic/area the technologies can be compared and evaluated (using KPIs from subtask A and assessment evaluation from subtask C) in terms of costs (LCoE, etc.) and regulatory, environmental, energy efficiency, and social acceptance indicators, among others.

The focus of sub-activity B2 is to investigate how flexibility management can help to balance energy flows within and beyond the PED boundaries. To do so, different decision-making processes (algorithms) and control strategies will be reviewed. The results from the previous task (B1) and demo cases (Subtask D) will highlight and reveal the practical challenges regarding the implementation of smart solutions at different levels, and also future research and development needs in PEDs.

This activity will conduct a literature review on decision-making process (solutions for decision makers, architects, citizens, energy experts, etc.) such as algorithms for planning a PED.

A literature review on control strategies and algorithms will be conducted from the information obtained in Subtask B1 and Subtask D. Research on data analysis techniques and control strategy techniques (more advanced control systems, forecasting, load shifting, peak saving, demand management, virtual power plants) is needed and will be conducted. Other issues, such as demand response, flexibility, and data management (block chain) which are useful for managing a PED will be considered. The result will be a comprehensive inventory of the different control solutions (depending on the technology) that can be applied at the building, district, and city levels. The different control strategies will be assessed to identify the barriers/enablers of the different smart solutions.

The focus of sub-activity B3 is to investigate and identify the data and tools for modelling a PED (from demand to the energy balance calculation) that can be used for designing and operating a PED. Activity B3 will mainly focus on data libraries and how these libraries can be used to model a PED. The idea is to generate a framework on how to standardize libraries for urban/district data models (such as City GML) and how to structure it.

To validate these urban scale models and to use data from subtask D case studies, the libraries from B3 will be used for modelling district scale case studies. To do so, existing tools and city platforms such as INSEL or City Energy Analyst, will be used. This will help to analyze how to extract attributes from data libraries, to parametrize urban scale models, and to apply different control strategies and assess them.

The result of sub-activity B1 will be a guideline of the best technologies applied in PEDs in different urban scenarios. As an output, sub-activity B2 provides ideas for the PED planning phase by city planners, citizens, etc. Furthermore, a prototype implementation of interface algorithms for decision-making solutions for PED will be developed. Finally, a report on urban scale modelling of PED districts (control-focused) and how flexibility management can help to balance energy flows within and beyond the PED boundaries will be carried out in sub-activity B3. Moreover, as an output, open-source libraries will be created.

3.3. Subtask C: Activities and Planned Methodology

The objective of Subtask C is to investigate potential sustainable pathways towards PED implementation. It aims at investigating both the impact assessment perspective as well as the organizational aspects within PEDs: the idea is to investigate through a harmonized and parallel approach the three different dimensions of sustainability (economic, environmental, social) of PEDs while ensuring that all three directions are developed through cultural contaminations and connections among them in a holistic and integrated way.

The activities are organized within a common framework that develops on three different levels, following the approach towards the sustainability of PEDs. The structure is vertically integrated.

The three major sub-activities are respectively:

- Economic Assessment (Activity C1);
- Environmental Assessment (Activity C2);
- Humanities and Social Impact Assessment (Activity C3).

The sub-activity C1 will investigate the potential of economic impact assessment methods for PED development and investigation. Key Performance Indicators (KPIs) will be used and tested for PEDs and market strategies and initiative potential will be assessed. Particular interest will be paid to renewable energy self-consumption models that are based on sharing and trading (and financing) approaches.

The development of the activity will also encompass the listing of the most relevant stakeholders to mobilize through the use of organizational models as well as the main barriers and drivers to the implementation of PEDs from an economic perspective.

The sub-activity C2 focuses on the environmental impacts of PED, taking into consideration the different stages of the life cycle of PEDs (e.g., construction, operation, end-of-life). To do so, various factors will be considered, both related to abiotic elements, as well as biotic. The sub-activity will face the challenging task of framing impacts within adequate time limits and scales by identifying relevant boundaries, such as environmental impacts, which widely vary, from climate change to local air quality or biodiversity. More likely, PEDs are going to deliver a combination of environmental benefits hardly able to be isolated. On the other hand, to realize a PED, regardless of whether they are done by new buildings or the rehabilitation of an existing brownfield, new technologies are going to be installed and natural resources consumed. Therefore, unwanted impacts on the ecosystem may arise and resources consumed. Adequate KPIs and assessment tools are going to be selected and applied to cope with this, and also the life cycle environmental perspective has to be taken in consideration in order to identify potential trade-offs and avoid burden shifts across impact categories or life-cycle stages.

The sub-activity C2 will investigate positive and negative impacts arising from the implementation and diffusion of PEDs, their social acceptance and social inclusiveness. It will also address organizational models and stakeholder engagement in PED development. Once again, social impacts are expected to be found at different levels, from the single householder (e.g., enhanced well-being due to improved indoor comfort) to the local community (social cohesion, social capital) or on a larger population. The peculiarity of the PED's energy system, calling for advanced and innovative solutions, energy sharing and synergies among prosumers, but also implying some behavioral changes due to new technologies, is an interesting and so far unexplored research field for social scientists. Social impacts may be much more relevant as in previous smart energy transition projects and needs specific KPIs. This includes both positive as well as unwanted negative impacts, as, for example, gentrification because of an enhanced attractiveness of the district.

The main outcome of this subtask is to perform the synthesis of the lessons learned and methodological developments by integrating the outcomes of previous ones into innovative and interdisciplinary KPIs—connected to the three spheres of sustainability—and develop sustainability inspired early design tools. Such tools may be based on life cycle sustainability assessments or consider multiple benefits to provide evidence of the contribution of PEDs toward the achievement of selected sustainable development goals.

A PED early design tool for sustainability assessment will be offered to support the decision-making process of policy makers and stakeholders, and also try to leverage investments (e.g., by exploiting the impact investing approach). Substantial collaboration will be carried out with other subtasks and case studies.

3.4. Subtask D: Activities and Planned Methodology

Subtask D spans all the objectives by testing and demonstrating their operationalization in demonstration cases, reaching objective 5 to develop the needed information and guidance for the planning and implementation of PEDs, including both technical planning and urban planning. This includes economic, social, and environmental impact assessment for various alternative development paths.

Firstly, the subtask will start the work with the scoping phase, with the aim to create a framework for data collection from demo cases. References to other initiatives (e.g., SCIS, JPI UE Booklet, and other references from outside EU) will be considered in order to take inspiration for creating the data collection framework collaborative process and to fix the main aspects to be built upon.

The data collection framework will be further elaborated into a template, which will be structured to collect relevant information from demo cases. This activity has a twofold purpose: identifying relevant demo cases and creating a knowledge mass for the whole Annex.

A demo case call will be launched periodically (every 6 months) for the Annex partners and supporters to identify demonstration activities at building blocks, districts, and city levels relevant to the Annex. These can be related also to non-PED demonstrations as long as they show a concrete value for the Annex activities. This is needed to gather detailed information on the best practices, KPIs, stakeholder assessment data, technological data, and key learnings from practical sites.

Secondly, the main outcomes of subtasks A, B, and C will be elaborated into a collection of cross-domains best practices accessible for professionals, city planners, and municipal stakeholders. They will be consulted in the early stages of this activity to identify their burning needs and where they would need support for planning PEDs. This will give an input to create the PED value chain from design and construction to operation, verification, maintenance, renovation and end of life, etc. The guidelines will support the PED planning in different dimensions: urban, suburban, and rural. The integration of PED in the existing urban environment and its role in the city energy transition will also be addressed.

Lastly, a communication and dissemination plan is created with the purpose of outlining the communication, networking, and dissemination strategy, identifying relevant initiatives (associations of cities, professionals, research organizations, initiatives organized by institutions, etc.) for the Annex, describing how the Annex intend to keep up the communication and networking activities. In this regard, the Annex Subtask leaders and Operating Agents will nominate a set of ambassadors to be Annex representatives to the selected initiatives. They will be responsible for setting up collaborative interactions and cooperation events.

As discussed in Section 1, the Annex will seek continuous collaboration with other networks, projects and IEA tasks/Annexes. It is planned to periodically (every 12 months) launch initiatives and conference scouting calls for the Annex partners and supporters to map the relevant PED communication and dissemination opportunities. Under subtask D, the responsibility for all the latest information, updates, relevant content, and outcomes from all the subtasks will be communicated through the Annex website.

4. Discussion and Conclusions

PEDs are seen as an ensemble of buildings of different typologies and functions (residential, commercial, industrial, public-owned, etc.) that are interconnected and produce more energy than what is needed to cover the buildings' demand on an annual basis. Whether the energy demand of the infrastructure (water and waste management, transportation, street lighting etc.) should be included in the PED demands calculations, and the mapping of the boundaries is a topic for discussion. So far, only the building's energy demands have been considered.

Becoming a PED is seldom the overall goal of a district being planned. Elements to be considered (e.g., the type of Renewable Energy Source (RES), number of buildings, etc.) and characteristics to be investigated (how it is organized, what is the governance model, etc.) should be selected and adjusted according to the main objectives and aims identified for creating a PED (improving the circular economy, ensuring high quality of life, etc.) beyond the technical goal of optimizing the energy balance.

Depending on the selection and the definition, the calculated annual energy balance will change. However, currently, all Energy Performance of Building Directive (EPBD) and building standards such as ISO52000 are applied at the building level, not at the district level, making calculation of the annual energy balance more complex and subject to interpretations.

The elements considered within the boundaries will determine how the Positive Energy District (PED) is defined and which loads should be considered for the calculation. The majority of PEDs in Europe apply the dynamic-PED concept, with geographical boundaries (such as PEDs in the projects ATELIER and MAKING-CITY as mentioned in Table 1), which means that buildings are close to each other and dynamically exchange energy (consuming and producing) with the energy grids. However, it is true that, when no space is available within the district boundaries, it could be useful to apply detached geographical patches or virtual boundaries. The main concern when applying the latter is the ownership of the energy solutions and the business models of trading energy to the PED over the virtual boundaries and how to guarantee the energy origin.

An effort to solve these challenges was done in the Sustainable Energy Positive & Zero Carbon Communities (SPARCS) project (as mentioned in Table 1). To upgrade the interaction between energy producing, storing and consuming entities, a virtual positive energy community is created. It is understood as a "variety of energy related actions virtually connecting the multiple buildings across the district on various locations within and across the city”. The entities can exchange energy based on “advanced control functionalities and dedicated communication channels (Information and Communications Technology (ICT) model, block chain infrastructure and prediction of the demand)”.

Some European projects are treating the PED concept in a different way. For example, the MAKING-CITY project (as mentioned in Table 1) characterized their PEDs by local renewable energy systems (RES) that interact dynamically with the grids (thermal and electrical) and are located within the district boundaries, and aim to achieve an annual positive energy balance incorporating building-related consumption. To do so, retrofit measures to improve the energy efficiency of the buildings as well as including mature technologies such as photovoltaics (PV), photovoltaic-thermal hybrid collectors (PVT), building-integrated PV (BIPV), PV on water, waste digestion, geothermal heat pumps, district heating, and thermal energy storage (such as boreholes, seasonal storage tanks, etc.) are implemented. The concept will be tested in the two lighthouse cities (LH), Groningen and Oulu, and replicated then in six follower cities (FC), taking into account the city needs and priorities, on-site resource availability, MAKING-CITY PED (as mentioned in Table 1) solutions and their business models through a decision-making journey emphasizing citizen engagement. The ATELIER project (as mentioned in Table 1), on the other hand, has two LHs, one district in Amsterdam and another one in Bilbao, with a number of very ambitious building groups (retrofitted and new) of different typologies (tertiary, residential, etc.) that are connected by means of grids (thermal and/or electric ones). Amsterdam will participate and interact with the existing energy communities, as well as with the grid, and will use the local waste for the production of biogas. Bilbao will retrofit an industrial old district and connect its buildings with a geo-exchange loop. In a similar way as in MAKING-CITY (as mentioned in Table 1), it will include Renewable Energy Source (RES), retrofit building measures, electro-mobility and digitalization. Both follow the Smart Energy Transition (SET) plan short definition, but their approach to replicate the concept in FCs is made in a softer way, allowing each city to adapt the PED definition to their own urban context.

Furthermore, several European networks are actively working on the topic of positive energy districts. These include JPI Urban Europe, a network of European funding agencies actively promoting and funding projects on Positive Energy districts, the Urban Europe Research Alliance, a network of Research Organizations and Universities closely working with and informing JPI Urban Europe, the Joint Program Smart Cities of the European Energy Research Alliance (EERA JPSC), the group of the European Smart City Lighthouse Cities, and the COST (European Cooperation in Science and Technology) action on Positive Energy Districts. All of the European members of IEA Annex 83 are also involved in at least one other initiative. This creates huge potential for collaboration, and many synergies will be created by organizing joint meetings and conferences and by writing joint publications and policy guidelines.

As discussed above and in Table 1, most of the districts and projects are under construction that can represent PEDs. However, few of the districts are partially operational, as shown in Table 1. For instance, the drake landing solar community (DLSC) in Canada is able to meet around 96% of the space heating demand of the district via renewable (solar) energy and seasonal storage. The Flexens project in Åland is aggressively targeting to meet 100% of the demand using renewables and to become a fossil-free island. Under the Quartier la fleuriaye project in Carquefou, currently 6000 m^2 of the roof area of the buildings (almost 300 houses) in the district are populated with the solar photovoltaic panels, which cover almost 80% of the energy demand of the district. It is planned to increase the total covered area of 15,000 m^2 (almost 600 h) to provide excess energy to the district so that it can become a PED. Similarly, under the Zero Energy District Accelerator project in Arvada, Colorado, the buildings in the district are designed to be zero energy and as a result the building’s life cycle costs are lower than the traditional buildings. Therefore, the building owners are saving not only in terms of reduced emissions, but also in terms of electricity price inflation and tax incentives. The owners are open to invest in new technologies such as passive building design, solar panels and ground source heat pumps etc., to become better.

The challenges raised above in the introduction section indicates that the PEDs are complex and multi-disciplinary in nature. Moreover, it has various challenges depending on the climate, location, regulations, technologies, key performance indicators, and urban context etc., and this requires a scientific global discussion. Many learnings can be done by exchanging experiences from different projects, knowledge, and cases around the world.

In the future, climate adaptation will become more important, which will bring new challenges to the planning of the urban environment and PEDs. Energy poverty might also become a bigger challenge than today due to increased immigration levels caused, among other things, by climate change. The detailed definition, key performance indicators and framework of PEDs will be discussed, developed and published in the future work as the Annex 83 progresses up until 2024. Moreover, all the issues, challenges, methodologies, technological solutions, and roles of the stakeholders will be discussed and developed under the subtasks (mentioned above) which will carried out in Annex 83.

Annex 83 is the main platform for this scientific discussion in the coming years. Different urban contexts will be covered in the different subtasks within Annex 83 to create a global framework of the concept, as well as to identify the barriers and enablers of PEDs. This will be possible thanks to cooperation between the partners involved in the Annex, with expertise from different fields and from all over the world. Canada, with the involvement of Concordia University, will give a perspective on urban scale modelling. Japan, thanks to Tokyo University, will give an overview of the different decision-making methodologies and on flexibility management. Different expertise from Europe and around the world, with the involvement of key actors and coordinators of current PED projects, will contribute to translating theory into practice and to test on the ground the latest findings.

Author Contributions: Conceptualization, Å.H., H.U.R.; methodology, Å.H., H.U.R.; investigation, H.R, Å.H., A.G., A.B., V.A.-S., X.Z.; resources, Å.H., A.B., V.A.-S., X.Z., A.G.; writing—original draft preparation, Å.H., H.U.R.; writing—review and editing, H.U.R., Å.H., A.G., A.B., V.A.-S., X.Z., F.G., U.E., S.G., H.-M.N., F.R., P.T.; visualization, H.U.R.; supervision, Å.H., H.U.R.; project administration, Å.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The authors would like to thank the VTT Technical Research Center of Finland (Finland), Eurac Research (Italy), the technology research center of CARTIF, Fraunhofer Institute for Solar Energy Systems (Germany), Swedish Energy Agency (Sweden), University of Palermo (Italy) for providing the resources, technical, and administrative support.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. United Nations Framework Convention on Climate Change The Paris Agreement | UNFCCC. Available online: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed on 19 May 2020).
2. International Energy Agency (IEA) Renewables-Fuels & Technologies. Available online: https://www.iea.org/fuels-and-technologies/renewables (accessed on 6 October 2020).
3. European Commisssion 2030 Climate & Energy Framework | Climate Action. Available online: https://ec.europa.eu/clima/policies/strategies/2030_en (accessed on 4 November 2019).
4. European Commisssion 2050 Long-Term Strategy | Climate Action. Available online: https://ec.europa.eu/clima/policies/strategies/2050_en (accessed on 4 November 2019).
5. Lutsch, W. European Commission Clean energy for all Europeans. *Euroheat Power Engl. Ed.* **2019**, *14*, 3. [CrossRef]
6. The European Parliament and the Council of the European Union 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. *Off. J. Eur. Union* **2018**, *L 156/75*, 75–91.

7. European Union Europe 2020 Indicators-Climate Change and Energy. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php/Europe_2020_indicators_-_climate_change_and_energy (accessed on 23 July 2020).
8. Environment and Natural Resources Progress Towards Canada's Greenhouse Gas Emissions Reduction Target. Available online: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html#DSM (accessed on 25 January 2021).
9. D'Agostino, D.; Mazzarella, L. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. *J. Build. Eng.* **2019**, *21*, 200–212. [CrossRef]
10. European Commission Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy Performance of Buildings. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN (accessed on 30 May 2020).
11. Torcellini, P.; Grant, R.; Taylor, C.; Punjabi, S.; Diamond, R.; Colker, R.; Moy Aecom, G.; Kennett, E. *A Common Definition for Zero Energy Buildings*; U.S. Department of Energy: Washington, WA, USA, 2015.
12. Liu, Z.; Zhou, Q.; Tian, Z.; He, B.J.; Jin, G. A comprehensive analysis on definitions, development, and policies of nearly zero energy buildings in China. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109314. [CrossRef]
13. Natural Resources Canada Net Zero Energy (NZE) Housing. Available online: https://www.nrcan.gc.ca/energy/efficiency/data-research-and-insights-energy-efficiency/housing-innovation/net-zero-energy-nze-housing/5131 (accessed on 25 January 2021).
14. Chris, R.; Aleta, L.; Nicky, I. *Defining Zero Emission Buildings-Review and Recommendations: Final Report*; Institute for Sustainable Futures, UTS: Sydney, Australia, 2011.
15. Liu, Y.; Zhang, S.; Xu, W.D. Cho Study of zero energy building development in Korea. *Build. Sci.* **2016**, *32*, 171–177.
16. Jin, Y.; Wang, L.; Xiong, Y.; Cai, H.; Li, Y.H.; Zhang, W.J. Feasibility studies on net zero energy building for climate considering: A case of "all Green House" for Datong, Shanxi, China. *Energy Build.* **2014**, *85*, 155–164. [CrossRef]
17. Wang, L.; Gwilliam, J.; Jones, P. Case study of zero energy house design in UK. *Energy Build.* **2009**, *41*, 1215–1222. [CrossRef]
18. Wells, L.; Rismanchi, B.; Aye, L. A review of Net Zero Energy Buildings with reflections on the Australian context. *Energy Build.* **2018**, *158*, 616–628. [CrossRef]
19. Al-Saeed, Y.; Ahmed, A. Evaluating Design Strategies for Nearly Zero Energy Buildings in the Middle East and North Africa Regions. *Designs* **2018**, *2*, 35. [CrossRef]
20. U.S. Department of Energy (DOE) A Common Definition for Zero Energy Buildings | Build Up. Available online: http://www.buildup.eu/en/practices/publications/common-definition-zero-energy-buildings (accessed on 1 April 2020).
21. Elsevier B.V. Scopus. Available online: https://www.scopus.com/ (accessed on 12 October 2020).
22. Wirth, H. Recent Facts about Photovoltaics in Germany. Available online: https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in- (accessed on 12 October 2020).
23. Consortium, G.B. Study on "Residential Prosumers in the European Energy Union" JUST/2015/CONS/FW/C006/0127 Framework Contract EAHC/2013/CP/04. Available online: https://ec.europa.eu/commission/sites/beta-political/files/study-residential-prosumers-energy-union_en.pdf (accessed on 11 May 2020).
24. Buffa, S.; Cozzini, M.; D'Antoni, M.; Baratieri, M.; Fedrizzi, R. 5th generation district heating and cooling systems: A review of existing cases in Europe. *Renew. Sustain. Energy Rev.* **2019**, *104*, 504–522. [CrossRef]
25. Abugabbara, M.; Javed, S.; Bagge, H.; Johansson, D. Bibliographic analysis of the recent advancements in modeling and co-simulating the fifth-generation district heating and cooling systems. *Energy Build.* **2020**, *224*, 110260. [CrossRef]
26. European Environment Agency Greenhouse Gas Emissions from Transport in Europe. Available online: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12 (accessed on 6 April 2020).
27. International Energy Agency (IEA) Global EV Outlook 2019. Available online: https://www.iea.org/reports/global-ev-outlook-2019 (accessed on 7 February 2020).
28. City of Helsinki Kaupunkisuunnitteluviraston Esitteet | Helsingin Kaupunki. Available online: https://www.hel.fi/kaupunkiymparisto/fi/julkaisut-ja-aineistot/julkaisuarkisto/kaupunkisuunnitteluviraston-esitteet (accessed on 30 December 2020).
29. Marino, C.; Nucara, A.; Panzera, M.F.; Pietrafesa, M. Towards the nearly zero and the plus energy building: Primary energy balances and economic evaluations. *Therm. Sci. Eng. Prog.* **2019**, *13*, 100400. [CrossRef]
30. 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]
31. Becchio, C.; Bottero, M.C.; Corgnati, S.P.; Dell'Anna, F. Decision making for sustainable urban energy planning: An integrated evaluation framework of alternative solutions for a NZED (Net Zero-Energy District) in Turin. *Land Use Policy* **2018**, *78*, 803–817. [CrossRef]
32. Hamdy, M.; Hasan, A.; Siren, K. Applying a multi-objective optimization approach for Design of low-emission cost-effective dwellings. *Build. Environ.* **2011**, *46*, 109–123. [CrossRef]
33. Cao, S.; Hasan, A.; Sirén, K. On-site energy matching indices for buildings with energy conversion, storage and hybrid grid connections. *Energy Build.* **2013**, *64*, 423–438. [CrossRef]
34. Jensen, S.Ø.; Marszal-Pomianowska, A.; Lollini, R.; Pasut, W.; Knotzer, A.; Engelmann, P.; Stafford, A.; Reynders, G. IEA EBC Annex 67 Energy Flexible Buildings. *Energy Build.* **2017**, *155*, 25–34. [CrossRef]

35. Rehman, H. Ur Techno-Economic Performance of Community Sized Solar Heating Systems in Nordic Conditions. Available online: https://aaltodoc.aalto.fi/handle/123456789/34808 (accessed on 4 November 2019).
36. Bisello, A.; Vettorato, D. Multiple Benefits of Smart Urban Energy Transition. In *Urban Energy Transition*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 467–490.
37. Bisello, A. Assessing Multiple Benefits of Housing Regeneration and Smart City Development: The European Project SINFONIA. *Sustainability* **2020**, *12*, 8038. [CrossRef]
38. Shnapp, S.; Paci, D.; Bertoldi, P. *Enabling Positive Energy Districts Across Europe: Energy Efficiency Couples Renewable Energy*; Publication Office of the European Union: Luxembourg, 2020.
39. Lindholm, O.; Ur Rehman, F. Positioning Positive Energy Districts in European Cities. *Buildings* **2021**, *11*, 19. [CrossRef]
40. Solar District heating Plant Database–Solar District Heating. Available online: https://www.solar-district-heating.eu/en/plant-database/ (accessed on 12 October 2020).
41. Ur Rehman, H.; Reda, F.; Paiho, S.; Hasan, A. Towards positive energy communities at high latitudes. *Energy Convers. Manag.* **2019**, *196*, 175–195. [CrossRef]
42. Chen, Y.; Xu, P.; Chen, Z.; Wang, H.; Sha, H.; Ji, Y.; Zhang, Y.; Dou, Q.; Wang, S. Experimental investigation of demand response potential of buildings: Combined passive thermal mass and active storage. *Appl. Energy* **2020**, *280*, 115956. [CrossRef]
43. Majdalani, N.; Aelenei, D.; Lopes, R.A.; Silva, C.A.S. The potential of energy flexibility of space heating and cooling in Portugal. *Util. Policy* **2020**, *66*, 101086. [CrossRef]
44. Hu, M.; Xiao, F. Quantifying uncertainty in the aggregate energy flexibility of high-rise residential building clusters considering stochastic occupancy and occupant behavior. *Energy* **2020**, *194*, 116838. [CrossRef]
45. Amaral Lopes, R.; Grønborg Junker, R.; Martins, J.; Murta-Pina, J.; Reynders, G.; Madsen, H. Characterisation and use of energy flexibility in water pumping and storage systems. *Appl. Energy* **2020**, *277*, 115587. [CrossRef]
46. Jank, R. IEA EBC ANNEX 51 Energy Efficient Communities. Available online: https://iea-ebc.org/projects/project?AnnexID=51 (accessed on 23 October 2020).
47. Michael Wetter; Christoph van Treeck IEA EBC Annex 60 New Generation Computational Tools for Building & Community Energy Systems. Available online: http://www.iea-annex60.org/ (accessed on 23 October 2020).
48. Dietrich Schmidt IEA EBC ANNEX 64 LowEx Communities-Optimised Performance of Energy Supply Systems with Exergy Principles. Available online: https://iea-ebc.org/projects/project?AnnexID=64 (accessed on 23 October 2020).
49. Rüdiger Lohse; Alexander Zhivov IEA EBC || Annex 73 || Towards Net Zero Energy Public Communities || IEA EBC || Annex 73. Available online: https://annex73.iea-ebc.org/ (accessed on 23 October 2020).
50. Danish District Heating Association The Danish District Heating Model. Available online: https://www.danskfjernvarme.dk/sitetools/english/the-danish-model (accessed on 4 December 2020).
51. Inês, C.; Guilherme, P.L.; Esther, M.G.; Swantje, G.; Stephen, H.; Lars, H. Regulatory challenges and opportunities for collective renewable energy prosumers in the EU. *Energy Policy* **2020**, *138*, 111212. [CrossRef]
52. Peter Fairley China's Ambitious Plan to Build the World's Biggest Supergrid-IEEE Spectrum. Available online: https://spectrum.ieee.org/energy/the-smarter-grid/chinas-ambitious-plan-to-build-the-worlds-biggest-supergrid (accessed on 4 December 2020).