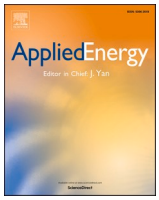
Applied Energy 322 (2022) 119477

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



Positive energy district stakeholder perceptions and measures for energy vulnerability mitigation

Adam X. Hearn

Sustainability Research Group, University of Basel, Basel, Switzerland
Department of Social Sciences /Departement Gesellschaftswissenschaften
Sustainability Research Group/Fachbereich Nachhaltigkeit, Petersgraben 52, CH-4051 Basel, Switzerland

HIGHLIGHTS

- Stakeholders see great potential in PEDs for energy poverty reduction.
- Energy poverty mitigation needs to be included in PEDs from the onset.
- PED replication can synergistically address both decarbonization and energy poverty mitigation.
- Increasing levels of energy poverty makes PEDs more financially viable as mitigation tools.
- More consideration needs to be given to the social dimension in decisions on new PED creation.

ARTICLE INFO

Keywords:
Smart cities and communities
Positive energy districts
PEDs
Energy justice
Energy vulnerability
Energy poverty
Fair transition
Governance
Inclusiveness

ABSTRACT

100 Positive Energy Districts (PEDs) are to be created in Europe by 2025, with a stated goal of urban decarbonization. These are highly energy efficient residential urban areas, powered entirely through renewables. PED creation is to be guided by principles of quality of life, sustainability, and inclusiveness (specifically focusing on affordability and energy poverty prevention). Although there is research into the decarbonization aspects of PEDs, there has been little focus on the guiding principles, and their potential to reduce energy vulnerability. Using energy vulnerability factors and an energy justice framework, this article examines how the topic of energy vulnerability mitigation is perceived by professional PED stakeholders. Stakeholders from multiple countries were interviewed in order to determine how and to what extent they approached the topic of inclusivity and energy vulnerability. The contribution of this paper to academic research is in helping to frame energy vulnerability in European smart city urban areas, focusing on the perceptions of key stakeholders. This contributes to research on the identification and evaluation of innovations such as PEDs which offer a potential

Acronyms: ATELIER, "AmsTErdam BiLbao cItizen drivEn smaRt cities" EU funded smart city project operating in 8 cities.; Banc D'Energia, non-profit social innovation project in Spain, whereby members are given energy advice and a portion of the savings are assigned to the energy vulnerable.; EERA, European Energy Research Alliance, comprising over 250 organisations working towards a climate-neutral Europe by 2050.; Energiewende, German term for the energy transition.; EuroPACE, Home renovation pilot project combining affordable financing with technical assistance.; IEA Annex 83, International Energy Agency group to enhance international cooperation on PED development.; JPI Urban Europe, Joint Programming Unit, European commission instrument to strengthen research and innovation in urban areas which also proposed PEDs.; MakingCity, Horizon2020 project to address and demonstrate PED concepts, enabling better replication of these. Operates in 8 cities.; MaxQDA, software tool for qualitative data analysis, used for interview analysis.; PAH, Platform for those affected by mortgages (Plataforma affectats per la hipoteca) Catalan grass roots movement to assist those evicted through non-payment of rent or mortgages.; PED, Positive Energy District, urban neighbourhood which produces an annual surplus of energy through the use of renewables.; PV, Photovoltaic panels.; REC, Renewable Energy Community, local energy associations often formed by residents which must also help to alleviate energy poverty (according to the EU renewable energy directive). Not fully implemented into national law in all EU member states.; RES, Renewable energy systems such as photovoltaics or wind turbines.; SET Plan 3.2, Strategic Energy Plan from the European Union in which PEDs are proposed.; Sharingcities, smart cities project operating in 89 European cities, addressing urban challenges such as energy use, low carbon transport and buildings, and harnessing data.; SILC, Survey on Income and Living Conditions, conducted yearly (since 2003) in the EU to provide comparable cross-sectional and longitudinal data on income, poverty, social exclusion and living conditions.; SPARCS, "Sustainable energy Positive & zero cARbon CommunitieS", Horizon2020 consortium operating in two lighthouse and five fellow cities.; TransPED, Co-funded by JPI Urban Europe, a 2-year project to develop a governance approach for PED stakeholders operating in 5 cities.; Triangulum, European Smart-district research and development Horizon2020 project coordinated by the Fraunhofer institute. Operated in 6 European cities..

https://doi.org/10.1016/j.apenergy.2022.119477
Received 5 April 2022; Received in revised form 27 May 2022; Accepted 15 June 2022
Available online 24 June 2022

model for an inclusive transition. Furthermore, this article offers a contribution for policymakers, informing PED replication policies with a focus on the synergistic aims of decarbonization and energy vulnerability mitigation.

1. Introduction

Prior to the COVID19 pandemic, at least 34 million Europeans were unable to afford sufficient access to energy [30], and there is evidence to indicate that although this number had been decreasing, post-pandemic it is growing [18;42,48,68]). This issue, referred to as energy poverty, receives growing policy prominence throughout Europe, particularly given recent fuel price rises[13]. Energy poverty is recognized as multidimensional[76], and multiple indicators are used when attempting to measure this phenomenon[21]. Energy vulnerability is understood as encompassing those that are currently energy poor including those that are at risk of becoming energy poor, but also recognizes the dynamic and temporal nature of energy poverty[14,65].

The main factors associated with energy vulnerability have been identified as access (not just to energy, but to the option of differing energy suppliers), affordability, flexibility (with many households tied in to specific suppliers), poor home energy efficiency, mismatched needs and a lack of recognition and support[88]). Different combinations of these factors may lead to households either having much higher energy bills compared to their income, or refraining from using energy that they cannot afford (known as hidden energy poverty, or the "heat or eat" dilemma) [3,5;8;47]. This is sometimes measured through low absolute expenditure, referring to those whose absolute energy expenditure is less than half of the national median[4]. There has been research suggesting energy poverty may increase in energy transitions (e.g., from coal to gas in Poland[56], or owing to increased energy costs in the *Energiewende* in Germany [93]. Recognizing methods of decarbonizing the economy whilst reducing energy poverty and inequality thus remain all the more important[49].

One key initiative which may meet both these goals is that of Positive Energy Districts (PEDs). PEDs are part of the planned decarbonization of European urban areas, combining high energy efficiency with the use of renewables[10;15]). The original stimulus to create 100 PEDs in Europe by 2025 is often positioned as a "first wave" which is to be replicated [1,79,94]and ramped up to create sustainable smart cities[35,86]. These districts are, for the main part, still in the early stages of development, and build on earlier concepts such as carbon–neutral districts and net-zero energy communities[41]. PEDs can either be new districts which are purpose-built, or older districts which are retrofitted to a high standard in order to meet the necessary PED energy targets, but the exact definition of a PED is still under discussion by groups such as the IEA Annex83 [95], and EERA[26].

Energy production, energy efficiency and energy flexibility are identified as the three mail pillars of PED creation [77], and these are meant to be guided by principles of sustainability, inclusiveness and quality of life [38]. The white paper framework for PEDs adds the words "*with special focus on affordability and prevention of energy poverty*" to inclusiveness, and a further guiding principle of "*Resilience and security of energy supply*" [55].

However, there are no clear definitions or explanations on the application of these principles currently. On a wider European level, EERA (European Energy Research Alliance) reports that the European Commission strongly urges the Strategic Energy and Technology (SET) Plan to increase its consideration of the social dimension and people-centred approaches, as there is a perception that these are neglected [26]. This issue is further problematized by socio-cultural-historical differences across European countries, which affect perceptions of energy poverty such as the application of different energy poverty indicators across Europe [47], as well as historical differences (e.g., in Eastern Europe [17]).

There is a significant body of research on energy poverty mitigation in urban areas, including at the district level [75,85], and focusing on novel aspects such as summer thermal comfort[9,89], but there is little research on how PED stakeholders perceive this, and how PEDs may contribute to its reduction. Furthermore, the study of socio-technical systems such as PEDs and energy justice at a district level is recognized as essential for the promotion and achievement of an inclusive energy transition [72]. Indeed, research has identified the need for further attention to be given to inclusion of those with limited income in the energy transition, with the identification and evaluation of potentially successful models such as PEDs [19].

Currently, published research on PEDs and energy poverty is limited, and includes research on the potential for PEDs to address energy poverty in Lisbon [39], PEDs and energy community initiatives in Spain [44], and how PEDs might advance urban energy justice [45,67]. Additionally, in the non-peer reviewed literature there is a Horizon2020 deliverable focussing on PEDs and energy poverty [60]. The above articles put forward suggestions on how PEDs might help alleviate energy poverty or vulnerability. However, there has been some research to suggest that smart home technologies and innovations such as one might encounter in PEDs, do little to reduce energy poverty and may even exacerbate inequalities [91]. This further highlights the need to address such issues throughout the initial processes of PED creation.

Research specifically into PED stakeholder perceptions, the focus of this paper, could shed further light on the usefulness of PEDs to tackle energy vulnerability, as well as on how PEDs might be replicated. For the purposes of this article, the term "stakeholders" refers to those involved in PED creation from a professional capacity, although naturally, prospective residents are also stakeholders. Furthermore, the very act of examining perceptions may also have an effect, inducing stakeholders to review and potentially change their perceptions, helping to reframe the mitigation of energy vulnerability as a concurrent goal to decarbonization.

Therefore, this article contributes to the emerging literature on PED and energy poverty by focusing on understanding how different PED stakeholders interpret and apply the main guiding principles (quality of life, inclusiveness, sustainability) and how this may have a potential to mitigate energy vulnerability, through an energy justice lens. This extends the academic debate on this topic, increasing an understanding of the connections between energy vulnerability and energy transitions [14,19]as well as providing a contribution for policymakers in PED practice, creation and development. Thus, the main research questions this paper focuses on are:

How is energy vulnerability perceived by stakeholders in different PED contexts?

Which measures are used (or planned) in order to mitigate energy vulnerability through the use of PEDs?

In order to answer these, a theoretical framework, combining energy vulnerability factors with energy justice tenets together with PED guiding principles and pillars, is presented prior to a section on the paper's methodology. This is followed by the results/discussion section in which interview data is presented and discussed in the context of existing research, followed by conclusions.

2. Theoretical background and framework

In the social sciences, energy research literature often examines energy poverty and vulnerability through an energy justice lens [11,43,45,49,63,67,69,81]. This includes the tenets of distributional, recognitional, procedural, intergenerational and global (or cosmopolitan) energy justice[45,46,63,69]. The reasoning for doing so here, is that it allows better understanding of the implications of PEDs when it

comes to reducing vulnerability, helping in the evaluation of where injustices may emerge, which groups might be affected, and what processes might be best applied to both reveal and reduce injustices[50]. A similar framework has been applied in energy ombudsmen research [84], and this paper seeks to extend this energy justice lens to energy vulnerability factors in the case of PEDs. For PEDs, energy justice issues incorporate the extraction of raw materials and creation of the means of energy production, the production, operation, supply and consumption of energy within the district as well as the import and export of energy outside of the district boundaries.

Main factors associated with vulnerability to energy poverty [88]are linked to energy justice tenets and both the guiding principles for PED development and PED creation pillars in the new framework below (Fig. 1), which provides the basis for the analysis of the PED stakeholder interviews.

The framework (Fig. 1) lists the main pillars of PED creation and PED guiding principles (either side of the figure) which can be linked to justice aspects most at risk for energy vulnerable people. In terms of **renewable energy production**, this can be associated with affordability given that operating costs for RES are significantly lower after installation ([15]), and savings may be passed on to residents, thus connecting to the PED principle of inclusiveness. **Inclusiveness** is linked to the affordability of housing, energy supply and energy retrofitting for residents in the PED. This also needs to be considered to avoid distributional injustices, which might occur if segments of the population are priced out of the district. Indeed, distributional energy justice in the context of energy vulnerability refers to the spatial dimensions [12]of the PED, i.e. looking at the geographic location of the PED and its effect on energy vulnerability both within and outside of its borders. When it comes to PEDs and energy vulnerability, this may include the distribution of energy suppliers, inclusive financing, subsidies or affordable housing for example[11]. Procedural justice is central to the ways in which residents are able to engage in a non-discriminatory and inclusive manner[43].

Recognitional energy justice refers to whether there are groups of citizens that are ignored or misrepresented[50], including gender disparities[33]. Furthermore, the use of renewables also has a positive impact on intergenerational justice compared to fossil fuels, and connects to the guiding principle of sustainability.

The PED pillar of **high energy efficiency** is also a major form of energy vulnerability mitigation, provided that it is combined with the PED principle of affordable housing, which also affects long-term social sustainability of the district. **Sustainability** connects to the requirement for heightened energy efficiency which in turn has a major potential in reducing energy costs for residents. Sustainability in this case is taken to refer to economic, environmental *and* social sustainability, an area which is often overlooked [92]. This can be connected to both intergenerational justice where the needs of future residents and their potential vulnerability to energy poverty needs to be considered. Furthermore, this also links to distributional justice, (related to the physical distribution of the means to produce, transport and store energy for the district), as well as global justice issues where the raw materials used in energy production may have a wider impact on energy poverty internationally. In terms of procedural justice, participation in policy and implementation processes connected to sustainability is deeply intertwined with procedural justice[69].

The third PED pillar of **energy flexibility** may be seen as connected to the need for some flexibility sand access to energy when it comes to those that are energy vulnerable, provided that different needs and practices are recognized, and connected to the PED principle of resilience and security of energy supply. **Resilience and security of energy supply** is connected to the energy vulnerability factors of flexibility and access. Examples of this are time specific pricing of energy which may affect certain segments of the population more than others [34]. Intergenerational justice in this context refers to ensuring that future generations are not made vulnerable owing to our actions in the present, and can be seen as closely associated with sustainable development[51]. This is particularly salient for PEDs, as in some research these have been positioned as polycentric business models for sustainability, which would help to ensure intergenerational justice[66].

In terms of vulnerability to energy poverty, **quality of life** is associated with the different energy needs and practices of residents, as access to energy is a prerequisite for the realization of a good or satisfactory life [6,7,22;45]. Identifying differing needs is essential in order to avoid recognitional injustices. These could involve misrecognition of groups (e.g., elderly or disabled), exclusion of groups as well as disrespect [12,63], the ease with which residents are able to change energy provider, how transparent and understandable billing is and the procedures and institutions available to residents (such as energy ombudsmen [84].

Procedural justice in terms of PEDs may refer to how decisions are taken related to the allocation of both benefits and burdens, processes of participation and inclusion in decision-making [45]. Procedural justice in the form of inclusive governance is seen as being of major importance, and transects all of the energy vulnerability factors.

This framework is used to both present and analyse the results from a series of interviews that were carried out (see Methods section for more details).

3. Methods and case

The study goal is to understand stakeholder perceptions of energy vulnerability, hence semi-structured interviews were chosen as the research method, as these enable the examination of commonalities, discrepancies and variations[64]and allow for the gathering of as yet unpublished information[80]directly from PED project stakeholders. Furthermore, semi-structured interviews enable researchers to understand topics in depths and allow for greater flexibility in responses than surveys, for example.

In order to reach data saturation[1] a total of 19 interviews were conducted online with 5 women and 15 men (1 interview was with 2 stakeholders, see Table 1), which also highlights the existing gender imbalance in energy transition pathways [33,59,78]. Interviewees were selected based on purposive sampling, focusing on PED stakeholders initially identified via the JPI PED booklet[38]as well as from international PED projects such as Triangulum, MakingCity, TransPED, ATELIER and SPARCS[2]. PED projects were sent an email requesting an interview with suitable stakeholders on the topic of energy vulnerability mitigation, just transitions and PEDs. Contacts were asked to suggest a more suitable person if they were not familiar with the topic, in order to ensure that the interviews were fruitful.

The interview schedule was developed based on the empirical literature and framework provided in the introduction. The semi-structured interviews focused on key probe themes of gentrification, community energy initiatives, inclusive financing, and energy advice, and were conducted in English (full semi-structured interview schedule included in Appendix 1.).

3.1. Interviewees

The 20 stakeholders were directly involved in managing the creation of PED, carbon–neutral or smart city districts, but many had multiple roles (e.g., political party spokesperson and planning councillor; private energy consultant working on PEDs and academic PED researcher). For

[1] [36] details how the number of semi-structured interviews necessary for reliable results is controversial, but that Guest, Bunce and Johnson [40] found that most data saturation occurs within 12 interviews.

[2] Triangulum: https://triangulum-project.eu/, MakingCity: https://makingcity.eu/, TransPED: https://*trans*-ped.eu/, ATELIER: https://smartcity-atelier.eu/ and SPARCS: https://www.sparcs.info/.

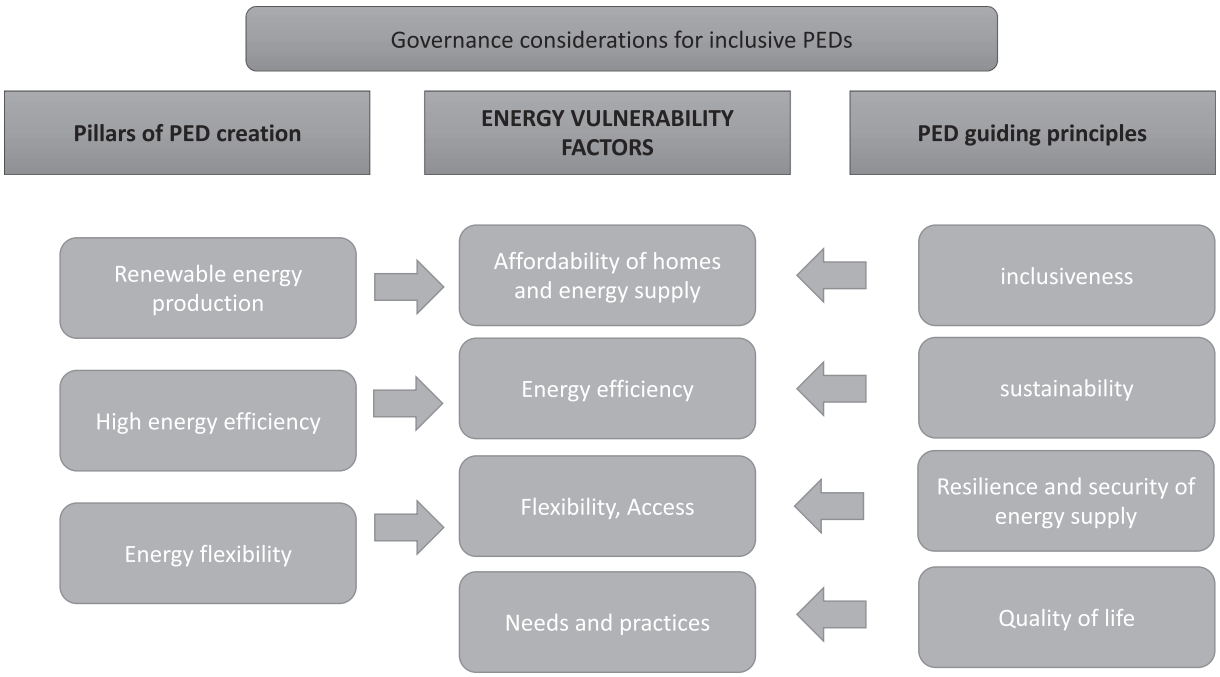


Fig. 1. Energy justice, PED Pillars, guiding principles and energy vulnerability, authors elaboration.

more information on the main PED projects the stakeholders are involved in, please refer to the table in Appendix 2. Participants were required to give informed consent and the average length of interviews was 42 min. All interviews were anonymized.

Interviews were transcribed in MaxQDA as this was readily available and practical for preparing, coding and exploring the transcriptions. Words and phrases were identified based on a series of codes which were created both deductively prior to the interviews, and inductively based on the raw data[74].

3.2. Analysis methodology

The findings were analysed through thematic content analysis[62]. For this, categories based on the PED guiding principles were created, which helped to provide a better understanding of potential injustices and effects on energy vulnerability.

Furthermore, to better understand and analyse the role that PEDs could have in mitigating energy vulnerability the analysis is structured by dividing member states according to levels of energy poverty, thus providing a clearer basis for comparison between similar member states. However, determining comparable levels of energy poverty is no easy task as there are multiple indicators which could be used in different ways to create different groupings (see table 2 for three examples). These are often divided into expenditure-based, or consensual-based indicators [61]. Ultimately, countries are grouped according to the European Survey on Income and Living Conditions (SILC) data from 2019 on self-reported inability to keep the home warm [96], into low (under 2%) medium (between 2 and 5%) and high (over 5%). SILC data is commonly used in Europe to determine energy poverty levels, as multiple indicators are collected and reported yearly in this European-wide survey, enabling some form of international comparison.

This metric was chosen over arrears on utility bills and low absolute energy expenditure (both of these metrics are also included in table 2) for several reasons. First, arrears on utility bills may not always be truly representative since utilities in some member states are included in total rental costs for tenants, reducing the possibility of entering into arrears in the first place. Conversely, some nations (particularly during the COVID19 pandemic[48]have implemented disconnection protection which may increase the potential for arrears. Second, although low absolute energy expenditure can be due to energy poverty, only older data was readily available (2015). It is also possible that in some cases, low absolute energy expenditure is due to highly energy efficient buildings rather than energy vulnerability. In Sweden for example, residential energy use has levelled off since the 1980s, largely due to energy efficiency policies such as the energy savings plan for existing buildings[58]which may help to account for the almost 25% low absolute energy expenditure reported. Finally, using a self-reported measure further validates the lived experience of energy deprivation that citizens perceive to be negatively affecting their quality of life[22]. However, it must be recognized that self-reported measures of energy poverty are by their very nature subjective, and thus only comparable as a measure of subjective deprivation. In order to then create groupings of countries, those where less than 2% of citizens reported being unable to keep their homes sufficiently warm in Winter were considered “Low energy poverty”, between 2% and 5% were considered “Medium levels of energy poverty” and over 5% were rated as “High energy poverty” (Table 2).

4. Results and discussion

4.1. Broader contexts

Common EU frameworks on PEDs and energy poverty are represented very differently in different member states which each have their own socio-technical, cultural, and historical backgrounds. This is partially because there are no common definitions of energy poverty within the EU (Jones et al., 2016) and levels of energy poverty differ widely between member state [11].

There were mixed responses on considering to what extent PEDs may mitigate energy poverty, but these broadly reflected national energy poverty levels. In countries with higher energy poverty levels where the issue may be better known and have specific policies designed to mitigate it, there seemed to be greater consideration for the issue within the context of PEDs. Most stakeholders seemed convinced that there was a **significant potential** for PEDs in this area.

“*We want to take the vision of using climate policy also as a way to regenerate communities. And it’s the main topic is to use the time of new climate actions that we are putting in place as a leveraged way to deliver a*

Table 1
Interviews conducted.

Interview number and gender (M/F)	Code-Name assigned	Project name, and stakeholders main PED location	Date of interview
1 M	G	TransPED, Smartcity,Graz, Austria	29.09
2 M	N	Natural-gas free neighbourhoods (multiple) Netherlands	30.09
3F	B	MakingCity Kadikoy Turkey (and multiple across EU)	4.10
4 M	L	TransPED, Brunnshög Lund, Sweden	11.10
5F	Br	Positive4North Belgium, Brussels	14.10
6 M and F	MM and MF	SharingCities, Milano, Italy	14.10
7 M	K	Smart Cities Kaiserslautern, Germany	15.10
8 M	Gr	MakingCity Groningen, Netherlands	22.10
9 M	O	MakingCity Oulu, Finland	25.10
10 M	E	Triangulum Eindhoven, Netherlands	17.11
11F	A	ATELIER Amsterdam, Netherlands	17.11
12F	ES	SPARCS Espoo, Finland	01.12
13 M	AA	ATELIER Amsterdam,Netherlands	24.11
14 M	Sp	SPARCs Portugal and 7 EU cities	30.11
15 M	ST	Triangulum Sabadell, Spain	01.12
16 M	AB	ATELIER Amsterdam, Netherlands and Bilbao, Spain	26.11
17F	TL	Triangulum Leipzig, Germany, and Eindhoven, Netherlands	08.12
18 M	KC	SPARCs Kladno, Czechia	10.12
19 M	Mu	SmarterTogether Munich, Germany	21.12

renovation of the city." (MF, Milan Pos. 15).

Multiple stakeholders highlighted the **increase** in energy poverty across Europe, both as a result of the COVID19 pandemic and the significant increases in **energy prices** in 2021, as increasing the likelihood of PEDs being successful mitigation tools:

"*I think that positive energy districts as a concept can indeed also help the prevention of energy poverty in this case.*" (A, Netherlands, Pos. 38).

"*The Price has to be right for the (PED to reduce) energy poverty*." (KC Czechia, Pos.18).

"I am fully convinced that the fossil fuel energy price will increase in the future, either due to the effects which we see at the moment or due to the CO2 price, which is on top, and therefore renewable energy will become if they are not already, they will become the cheapest way to provide energy. And therefore, under ***this*** *aspect, it will also help to reduce energy poverty."* (K, Germany Pos. 49).

This kind of statement highlights the scope for PEDs to be used to have an effect on energy vulnerability mitigation but that the way the PED is created is crucial and that this needs to be considered from the start. Otherwise, in the words of one of the Triangulum project coordinators:

"*At the end of the day, you are making the rich richer because they are the ones that really have access to these technologies because they can afford them.*" (TL, Germany Pos. 54).

This was shared by other stakeholders such as from the PED in Czechia, who highlighted the need for PEDs to function as part and parcel of the **financial make-up** of a city. Ultimately, the European SET Plan 3.2 [77]. for PEDs makes it clear that the bulk of the investment in PED growth is to come from the private sector, from real estate developers and housing companies who are profit-driven, and who may not consider energy vulnerability unless this is required of them.

In order to ensure that PEDs and other such smart city concepts do have a meaningful role in mitigating energy vulnerability as well as decarbonizing the energy system, there is a need to build social inclusion into the design:

"…in the end social inclusion will be the key to really produce a change within our cities" (TL, Germany, Pos. 59).

PEDs are **embedded within cities** and cannot be considered without examining the wider city context. However, there was still a perception that PEDs could be used as a way of stimulating both decarbonised and inclusive urban spaces:

"*The PED is a goal, but it's also leverage to achieve other goals.*" (Br, Belgium, Pos. 9).

Furthermore, PEDs interactions go further than just the cities they exist in, with frequent interactions between different PEDs (reported by numerous stakeholders, eg TL and AB). This allows stakeholders to note which policies are successful and replicate these in order to adapt to what works best, but more importantly to learn from failures and ensure these are not repeated:

"*What really helps is this idea of bringing all the projects together and sharing information as a group*" (TL, Germany, Pos.53).

One stakeholder (AB) noted that sharing was high, particularly between Netherlands, Sweden and Germany, but that some PED projects try to shield information that could cast them in an unfavourable light:

"*They share when it's necessary, when it's obligatory and when it's not necessary, they say nothing*" (AB, Netherlands, Pos. 17).

4.2. Inclusiveness; affordability of homes and energy supply

Affordability is a key topic when discussing energy vulnerability and PEDs. From table 3, it is clear that this is tackled in different ways according to levels of energy poverty. The perceptions of stakeholders from countries with lower levels of energy poverty seemed to indicate that although some low-cost housing was considered, the priority was technical aspects of the district in order to ensure that this becomes net positive in terms of energy. This will, out of necessity, come about through the combination of renewable energy which is locally produced (and thus likely to be more affordable) as well as highly energy efficient buildings which will lower energy demand (thus also reducing associated costs). Stakeholders from Finland (Oulu and Espoo) did not seem to perceive of energy vulnerability as a significant problem that needed addressing nationally, let alone at the PED level, partially due to the perception of very low levels of energy poverty, and partially because housing in the PED is already perceived to be low cost (but not social housing). Finnish stakeholders seemed to see energy poverty as connected to a very small rural demographic:

"*There may be some energy poverty. Say if you are 80 years old and live alone in a big house, then you may face energy poverty. But, it's very rare in Finland, and it's not an issue*" (O, Finland, Pos. 80–81).

For low energy vulnerability countries, in both Sweden and Finland affordable and low-cost housing was included, even if this was not social housing. However, in Austria, the PED in Graz is left entirely to market forces, partially owing to the wider city context and the existence of large quantities of social housing. This argument helps explain why other PEDs might not include social or affordable housing, as this is included in the wider city. Conversely, it can also be used to argue that PEDs **should** include social housing in order to be truly representative of the cities they are embedded within (e.g., Hunziker Areal, Zurich; [45].

In middle and high energy vulnerable countries, social housing was included in almost all PED projects (with the exception of Kladno and Amsterdam), partially because of national regulations on this.

Table 2
Countries included in this study, their approach to energy poverty and PED developments,

GROUP	Country	Definition of Energy Poverty	Current main policies to deal with energy poverty	Inability to keep home warm SILC, 2019	Arrears on utility bills SILC, 2019	Low absolute energy expenditure SILC 2015	Number of PED projects in PED booklet [38]
1	Finland	No	Social support policies, disconnection protection,	**1.8%**	7.8%	29.9%	4
1	Sweden	No	Social policies	**1.9%**	2.3%	24.3%	6
1	Austria	Yes[3]: low household income and high energy costs	Social support policies	**1.8%**	2.4%	15%	3
2	Netherlands	No	Social support policies and disconnection protection	**3%**	1.5%	4.4%	6
2	Belgium	No	Energy poverty policies, disconnection protection	**3.9%**	4.1%	14.6%	1
2	Germany	No	Social support policies	**2.5%**	2.2%	17.49%	4
2	Czechia	No	Social support policies	**2.8%**	1.8%	9.2%	0*
3	Italy	No (Within Milan, self-identifying as energy poor is considered sufficient	Targeted national strategies	**11.1%**	4.5%	13.6%	8
3	Spain	Yes: income related inability to keep the home warm, exacerbate by energy inefficient housing [4]	National strategy	**7.5%**	6.5%	14.6%	4

[3] https://www.e-control.at/documents/1785851/1811582/energiearmut_in_oesterreich_2016.pdf/54199124-f688-7aaa-3f46-8ab259d1d4c7?t = 1553792496267.

[4] https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf *The city of Kladno is listed as a fellow city in the H2020 SPARCS project with clear ambitions for PED creation and is thus included (https://www.Sparcs.info). Countries are clustered in groups of low less than 2%, medium 2–5%, and high > 5% energy poverty using the self-reported SILC data measure "Inability to keep the home warm in winter".

Although social housing is not included in the main Amsterdam PEDs, not only did a stakeholder (AB) indicate that the choice to omit this was not ideal, but there was a clear view that future PEDs should include housing associations. Indeed, including social housing in the creation of future smart cities and thus PEDs in the Netherlands is perceived as crucial[2]. In addition, new Dutch legislation has been introduced in order to reduce gentrification and speculation on the housing market:

"*For every new house that you buy or existing house you buy, you have to live in it for the next three years. So, you cannot rent it out. You also cannot speculate on it.*" (AB, Netherlands, Pos. 12).

Overall, however, it would appear that for countries with medium levels of energy poverty, the question of affordability and inclusion is left more to national level policies and quotas rather than tackled in any specific manner. Thus, **social housing is an integral planned aspect** of urban living (e.g., 20% social housing in Germany). Within stakeholders from countries with high levels of energy poverty, gentrification and social housing quotas seemed to be perceived as more important. The PED in Milan will also include specific measures to help reduce gentrification and ensure affordability, such as the "Affito condizionato".

"it's a kind of rent that has some specific conditions set by the administration. The owner of the development and the developer get a tax discount, if they keep the prices at a certain level and range." (MM, Italy, Pos. 60).

However, Milan stakeholders recognized that rapidly rising housing prices, together with a property boom in the city may mean that gentrification worsens despite the existing efforts to counter this.

In Spain, there is legislation requiring minimum social housing levels, but the Bilbao PED explicitly engages with both vulnerable low-income residents and high-income groups, which has not been done before, and may help with energy poverty mitigation and inclusion:

*"Some people say it's a little bit of a social experiment that you have at a relatively small area, two extremes of the spectrum because they have the low-end housing **and** the other end"* (AB, Pos. 11).

For Sabadell, Spain, the city location is such that prices tend to be much lower than in the rest of the metropolitan region (it is commuting distance from Barcelona), but there is also a significant amount of good quality social housing.

"*…they have already been built with standards of energy efficiency higher than the average.*" (ST, Spain, Pos. 17).

Affordability of energy supply, which is often used as an indicator of energy poverty, is perceived to be of much less importance when it comes to PEDs and energy vulnerability. Technical requirements of PEDs make it far more likely that renewable energy be produced locally, and the high energy efficiency of buildings in the district further reduces energy consumption requirements. However, in light of spiraling energy costs throughout Europe, there is certainly a potential for energy vulnerability even where energy consumption is low, and one way of reducing this may be through the creation of community energy initiatives.

When it comes to affordability, there have been calls from the International Union of Tenants for housing to not only become climate neutral but also **housing-cost neutral**, particularly through the use of funds in the aftermath of the COVID19 pandemic[23]. Such questions may require policymakers to examine the situation holistically and balance the costs of interventions against the potential benefits and savings that can be brought about by ensuring the district is as inclusive as possible (e.g., Groningen PED).

4.3. Sustainability; energy efficiency affordability and access to retrofitting programmes

The main focus of many PEDs is still on newly-built districts, which can be designed to be highly energy efficient. However, bearing in mind that most housing in the EU was built before thermal regulations ([27]), with only just over 5 new homes created per 1000 inhabitants in 2020 [82], there will be a need to retrofit existing housing stock. In terms of retrofitting, there are few pre-existing districts that are currently being converted into PEDs (see Table 3). However, in all of those that are being retrofitted there are measures to ensure that this is inclusive, with social housing targeted as prime candidates for retrofitting. This makes sense, in that in terms of governance, districts which are predominantly composed of social housing are likely to be easier to retrofit than districts with multiple mixed ownership.

In Ghent, the decision has been made to use loans and not subsidies as one of the primary means of financing energy efficiency measures [25]. The municipality found that subsidies were less accessible for the energy vulnerable, and that conversely, loans permitted greater participation from all income groups, thus increasing recognitional justice.

Table 3
Distributive justice issues- Affordability of homes, retrofitting, energy and use of community energy initiatives.

Energy poverty level	Country where PED located	Affordability of retrofitting*	Affordability of energy and use of Renewable Energy Communities (RECs)	Affordability of homes
Low energy poverty	Sweden	Not in scope of PED project	Use of residual waste-heat district heating, Electricity-use down to consumer choice.	Affordable housing (but not social housing)
	Finland	Not in scope of PED project	Energy costs included in municipally owned housing	Low cost (but not social housing)
	Austria	Not in scope of PED project	Not considered in PED project (market forces apply)	Not considered in PED project (Market forces apply)
Medium Energy poverty	Netherlands	Grants for retrofitting of privately owned homes in PED in Groningen	Energy sharing considered between Amsterdam PEDs as pilot project	Not in scope of Amsterdam PED- recognized as a shortcoming
	Germany	Subsidies for landlords (but tenant rent protection)	Use of local PV and green roofs, residual waste heat district heating	20% social housing included in PED
	Belgium	Social housing retrofitting paid using public funds	Use of PV and energy communities planned	Mainly social housing
	Czechia	Not in scope of PED project	Local PV, and residual waste heat district heating	Not considered in PED project (Market forces apply)
High Energy Poverty	Spain	Not in scope of PED project	Not considered in PED project (Market forces apply) but strong consumer lobbying	Social housing Included in design in Bilbao
	Italy	Tax credits/ loans/ Municipal funds	Plan to create multiple energy communities directed at reducing energy poverty	Social housing and "Affito Condizionato" designed to increase affordability

Not in scope for PEDs that are created in new districts where retrofitting is not required.

Two forms of loans are granted following home visits in which different improvements are suggested and the financial status of the residents is discussed (see Table 4). These could be proposed in PEDs in order to increase access to retrofitting and reduce energy vulnerability. In addition, pilot projects such as EuroPACE could be replicated throughout member states where property taxes are payable in order to make retrofitting more accessible.

The Brussels PED is exploring new forms of financing that are easier to access for those who are more vulnerable:

"This payment can be upfront. That's important to say. Not as standard, but if needed, it can be paid upfront. So, for people who don't have the money to invest. It can be solved in this way." (Br, Belgium Pos. 15).

In the Brussels PED, the issue of retrofitting costs is acknowledged as difficult to manage, particularly for rental properties where landlords may increase rents to pay for retrofitting by more than the monthly energy savings for tenants. This is a complex issue and hard to manage, particularly because energy consumption practices vary from home to home, level of retrofitting and quality of building stock also varies, and thus savings are not equal.

Amongst the PED projects in the medium energy poverty grouping, Groningen is also particularly worthy of mention in terms of retrofitting costs. The Groningen PED stakeholder explained that there are a small number of former social housing houses that were purchased by the residents and which require retrofitting beyond the financial means of the residents. In order to do so, rather than subsidies or loans, the stakeholder was able to quantify the costs of inaction versus the cost of providing a grant for the necessary work.

"*What are the benefits for the local society financially, but also what are the* ***increasing*** *costs for the municipality in doing nothing? Or you could also say what is the decrease in costs if you do quite a lot of things? So that also tells us actually that it is* ***not a waste of money*** *to invest in those houses*" (Gr, Netherlands, Pos. 23).

This confirms previous work in Nottingham, UK, where the co-benefits of conducting retrofitting (such as improving heating systems and replacing single glazed windows with double-glazed secure units) included a significant drop in burglary to domestic properties (42%) which was valued at nearly ¼ million yearly, 3.5 million GBP energy savings yearly, 700,000 GBP savings in national health costs yearly and a significant boost to the local economy with an estimated 1.36 GBP generated for every 1GBP spent (Jones et al., 2016; [53].

In the case of the natural-gas free districts stakeholder in the Netherlands, there was a clear overlap between smart energy natural gas-free districts and those in social housing brought about because:

"Most of the districts that applied for that (to become natural-gas free) contain a lot of energy poor households." (N., Netherlands, Pos. 72).

The reasoning behind this is that it is simpler for a municipality to work with a social housing association able to make decisions for multiple homes than to work with numerous individual home owners. Almost 1/3 homes in the Netherlands are some form of social housing [73], and targeting districts which are mainly social housing reduces potential vulnerability to energy poverty. In the Netherlands, those suffering from energy poverty are believed to mainly be in urban social housing ([28] which is precisely the target district for PED and natural gas-free smart districts (Urban, high density residential housing). However, the natural gas situation is quite unique in the Netherlands [32]and this theme recurred in Dutch stakeholder interviews. One stakeholder (N) recognised that vulnerable residents, in particular, will need protection when it comes to energy prices because natural gas has historically been the cheapest option.

Furthermore, the national "Superbonus" tax rebate scheme[37]in Italy offers a 110% tax deduction for energy efficiency retrofits but stakeholders noted that this is not easily accessible to the energy poor who may not have the time or skill to access such schemes.

As the PED programme continues and is replicated, more districts will be retrofitted, and determining fair and inclusive measures for retrofitting will certainly have an effect on distributional justice. Although the Groningen method may help to reduce energy vulnerability, perhaps the use of low or no-interest loans which are paid back through the savings made would be a better approach, in that this would ensure future funds for further work in the municipality, such as in Brussels or Ghent. However, it is clear that although there has been many beneficiaries from inclusive financing such as the Italian "Superbonus", this has also led to an increase in fraud[90]. Attaching finance for retrofitting to a property rather than a person, as in a pilot scheme in Olot Spain, through EuroPACE [31,60]. Further, ensuring that energy efficiency retrofits are of a high standard will reduce intergenerational injustices and make for robust districts that are "energy vulnerable proof".

4.4. Resilience and security of energy supply; flexibility and access

Access to different energy carriers and being able to change supplier easily were not topics that were perceived as highly significant to PED stakeholders, partially because these districts are meant to involve lower energy use (and hence lower costs) and partially because many of these districts are still in the planning phase and have few or no residents.

However, an area where there is lots of stakeholder interest is in the creation of energy communities. Although regulatory barriers prevent

Table 4
Different forms of inclusive financing for retrofitting that could be considered for PEDs.

Financial Measure	In use in PED	Examples of use	Effect on Vulnerable groups
Loans payable through the monthly financial saving on utility costs	Not currently	Ghent, Belgium	Enables those that own their own property to engage regardless of income levels. Does not address those in private rental, but can be used for social housing.
Loans payable only following the sale of a property/death of resident or major change of circumstances	Not currently	Ghent, Belgium	Funds eventually return to municipality enabling further benefits. Enables those that are in more precarious living conditions to participate without the need for any increase in costs.
Loans attached to the property and payable back through property taxes	Not currently	EuroPACE Programme (Based on US PACE programme), Olot, Spain	Enables tenants to engage more easily, makes retrofitting more attractive for landlords, as retrofitting is repaid through taxation of the property. Only currently applicable in countries where property tax is in use.
Full grants	yes	Groningen, Netherlands	Can help with specific targeted cases that are harder to reach with other methods. Reduces municipal costs long-term, but only actionable on a small scale as expensive
Tax rebates	yes	Munich, Germany	Subsidies are given to landlords but rent can only be increased by the proportion paid by the landlord, (and limited to 8% per year).
Tax rebate payable directly to retrofitting firm	yes	"Superbonus" 110% rebate, Italy	Can be paid directly to retrofitting firm, which can either use this for their own tax rebate, or sell this as a credit to a bank. Inclusive, but open to exploitation

these from being created in many countries, following European directives such as RED II (European Commission, 2018) it is clear that it is only a matter of time before national legislation is implemented in order to make these a possibility across the board. For the moment, most stakeholders said that the topic was being closely monitored with a view to implementing some form of energy community in the future. Furthermore, stakeholders in Amsterdam were examining the possibility of sharing energy between PEDs as a pilot project, which would potentially have an effect on reducing costs for residents.

The case of Milan is particularly salient as stakeholders believed that a series of energy communities could be created within the city specifically to reduce energy poverty and a pilot project had already started, highlighting potential recognitional justice benefits. Overall PEDs seem to be perceived as niches in which technical innovations such as community energy initiatives which may require regulatory changes, can be explored as solutions to both decarbonisation and energy poverty. It could even be argued that in conjunction, the current wave of PEDs form a strategic urban living lab in which socio-technical innovations can be tested prior to replication[16]. This will entail changes in procedural justice as new forms of energy producing and sharing are created.

4.5. Quality of life; recognizing differing needs and practices

As can be seen in Table 5, all PEDs incorporate some form of energy advice for residents. However, the extent of this advice, how it is given and to whom, vary considerably. Countries with low levels of energy poverty rely more on existing energy advice schemes, whereas those with medium levels of energy poverty seem to involve more proactive energy advice schemes. Particularly salient are the home visits offered in the PEDs in the Netherlands, and the creation of an augmented reality exhibition centre in Kaiserslautern which aims at extending energy advice beyond the local community and combining this with potential co-creation workshops in an exhibition centre. The stakeholder from Groningen PED indicated that offering energy advice is often not enough to reach those who are energy vulnerable, and that a concerted effort needs to be made to reach them:

"*We should proactively go to them and not only talk about the problems that they have, but also about how they should pay the bills and their finances, but also looking at their energy possibilities- to do this more proactively*." (Gr, Netherlands, Pos. 67).

In order to create truly inclusive PEDs citizen engagement is crucial. However, some stakeholders reported that difficulties associated with participation are complicated when it comes to the development of newly built PEDs because there are no residents to co-create with. Instead, residents from nearby districts are sometimes asked for input, but this has been further exacerbated by the COVID19 pandemic which

Table 5
Citizen Participation, recognitional and procedural justice in PEDs: engagement and energy advice.

Energy poverty level	Country where PED located	Citizen engagement/ co-creation	Energy Advice
Low energy poverty	Sweden	Minimal	Municipal advice team
	Finland	Multiple channels, Via media	App on phone
	Austria	Minimal	Energy advice scheme
Medium Energy poverty	Netherlands	**Co-creation** in Eindhoven,Minimal in Amsterdam, (with the exception of Schoonschip)	Energy coaches, home visits, telephone advice "Energy boxes" given out
	Germany	Minimal	Exhibition centre with augmented reality, workshops
	Belgium	Minimal	Regional agency gives advice, home visits
	Czechia	Minimal	Digital literacy programme
High Energy Poverty	Spain	PAH (Platform for those affected by mortgages[5], "Fight against Cerberus" group[57]	"Train the trainer programme" Mainly via citizen led groups
	Italy	**Civic participatory body** created	Use of social services to proactively reach those more vulnerable.

[5] PAH: https://afectadosporlahipoteca.com/.

has led to a move to online activities, with their own shortcomings (these automatically exclude those that are not online, and participation is dependent on stable internet connections).

Countries with higher levels of energy poverty show the greatest amount of proactive energy advice, with the city of Milan innovatively using social services to actively target those that are most vulnerable to energy poverty who would be unlikely to seek out advice for numerous reasons (e.g., lack of resources/stigma). The case of Milan is perhaps unsurprising as it has had a Smart City strategy for longer than many cities[92].

In terms of citizen engagement, many PEDs are new districts with no/few residents. However, prior to the COVID19 pandemic, in a Triangulum pilot project, residents in social housing in Eindhoven were invited to co-create retrofitting solutions through the use of 3D modelling. Stakeholders report that this was hugely successful, so much so that it continued after the initial pilot project had ended.

Countries with higher levels of energy poverty show high levels of citizen engagement, but in the case of Spain this can be at least partially attributed to burgeoning social movements such as PAH and Banc Denergia[3]. The former is a citizens' advocacy group that helps to fight for the rights of those that struggle to pay the rent or mortgage or are being evicted, providing free advice and support to those in need. The latter is a transformative solidarity energy association, which helps members to save money on their energy bills through personalized tips (such as changing supplier), and which uses a part of these savings to reduce energy injustices such as energy poverty. Similar groups such as the "Fight against Cerberus" group[57]demonstrate that identifying and defending the most vulnerable may occur from grass-root movements and as bottom-up actions as well as top-down governance. The stakeholder from Sabadell noted that a new council was set up in 2008 as a direct result of deliberative collaborative governance in local housing which was heavily influenced by campaigns from PAH[71].

In Milan a special civic participatory body is being created to increase citizen participation and ensure that the PED is as inclusive as possible. This is largely in response to minority and vulnerable groups not being easily identifiable from official databases. The body allows citizens to nominate themselves or others for membership according to categories of their own creation, in order to ensure that minorities, the elderly, those with mental/physical health conditions, and LGBTQ + are properly represented.

5. Conclusions

It is important to proceed cautiously with any claims that PEDs can alleviate energy vulnerability, as many PED projects are still in their infancy and it may be too soon to determine this, but it is very clear that **stakeholders see great potential in PEDs** for this.

PED guiding principles lack definitions, leaving them open to interpretation, and it is clear that many of the stakeholders interviewed saw these as side issues which were superseded by the importance of achieving the technological status of net-positive energy, despite clear interlinkages and added benefits that this could bring. What is very clear, is that if PEDs are not planned with inclusion in mind, making them inclusive a posteriori is problematic and difficult to manage.

For those in countries with lower levels of energy poverty, cost and the need to ensure that PEDs are profitable was crucial. PEDs are not districts created by municipalities alone, but involve multiple private partners which will only engage in PED creation if this is profitable. This may result in PEDs which are sustainable in terms of energy, but are not socially sustainable. In order to ensure that these are inclusive, it may be necessary to introduce added legislation that guarantees minimum levels of inclusion. The use of awards and tax-reductions for developers that exceed minimal levels of inclusion could also act as a further stimulus mechanism.

PED development often occurs within a niche in which special dispensation may be given in order to trial new forms of governance, but this is often limited to technical aspects.

If PEDs are to be a continuation of the existing modus operandi of profit-led capitalism, these may provide exclusive green living spaces for the wealthy but may not contribute to a sustainable and fair society. The long payback times associated with energy efficiency measures make for-profit models less likely to be inclusive and emphasize the case for greater public intervention to ensure inclusive PED replication.

In order to mitigate energy vulnerability, a number of measures are currently available for PEDs to make use of. Increasing the amount of affordable or social housing in the district will go some way to reduce energy vulnerability, and can be achieved through tax rebates such as the "Affito Condizionato" in Milan, which are given to developers as an incentive if housing is kept affordable. Simultaneously, retrofitting financing schemes such as the Superbonus in Italy could provide the impetus for the creation and replication of inclusive PEDs provided that they are regulated and monitored. Providing subsidies for landlords within PEDs may increase the uptake of retrofitting but combining this with tenant rent protection may be a way of ensuring that it does not simply result in the costs being passed on to tenants. The potential mitigating effect of RECs remains to be seen given that such energy communities are not fully functional everywhere in Europe, but their creation in Spain and Italy seems to encourage the notion that these can have some positive mitigatory effect on energy vulnerability. Other financial measures to enable greater citizen participation in PEDs such as the use of loans or full grants rather than partial subsidies may result in further uptake of retrofitting which would also reduce energy vulnerability. Furthermore, involving citizens in the co-creation of a PED such as through civic participatory bodies may increase knowledge related to differing needs and practices and further help to mitigate energy vulnerability.

For research in energy vulnerability, this article provides a contribution in emphasising the importance of including access to and affordability of retrofitting programmes, which are likely to become even more intertwined with future PEDs, that are created in existing districts. This article also offers a contribution for informing policy-making in PED replication with a focus on the synergistic aims of both decarbonization and energy poverty mitigation, as well as adding to the scientific debate on how the transition can affect energy justice. Targeted synergistic measures that simultaneously decarbonize whilst mitigating energy poverty, ensuring more effective resource management may enable significant savings whilst providing positive sustainable futures. It is hard to predict future patterns of energy poverty based on the current reversal in trends, but it is likely that if the increase in energy poverty continues, this will rise closer to the forefront of European energy policies in different countries, even in those that do not currently consider targeted mitigation policies.

In a number of the interviews, different stakeholders made it clear that there is a lot of interaction between projects and that cities are increasingly becoming able to access and share information in order to replicate the aspects that they consider most important. This may have an effect on perceptions of energy poverty and how policies are implemented in different PEDs as effective policies are discussed and potentially replicated.

Further research may want to examine how this cooperation takes place and its effects, as well as consider transport vulnerability in the context of PEDs, which was beyond the scope of this paper. It would also have been interesting to include a further group comprising of former Eastern-bloc PED stakeholders, particularly as this is a part of Europe where energy poverty is a significant concern but there are currently few PED projects in these countries, and requests for interviews were unsuccessful (excepting Kladno, Czechia which is included).

In addition, PEDs have to be positioned within the wider context of the cities they are in, the decarbonization and energy poverty mitigation

[3] BancDenergia: https://bancdenergia.org/.

drives that occur more widely within the city. Whilst they are useful as concepts and as levers for stimulating change, they do not exist in a vacuum and will have a potential effect on surrounding areas which should not be forgotten.

There are significant differences between the ways that PED stakeholders consider the guiding principles as set out by JPI Urban Europe, and it may be necessary to draw attention to this for future PED replication, in order to ensure that they are truly inclusive. PEDs may be a way of enabling those with limited income to participate in the energy transition, but the current manner in which PED guiding principles are presented may need to be changed and clear guidance provided to stakeholders. Having established that PEDs can become a reality and that the technology available is sufficient, more consideration needs to be given to ensure the social dimension and corresponding potential social benefits are included in decisions on new PED creation.

CRediT authorship contribution statement

Adam X. Hearn: Conceptualization, Methodology, Writing – original draft, Visualization, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Actions, Innovative Training Networks, Grant Agreement No 812730.

The author is grateful for comments, feedback and support from Paul Burger, Annika Sohre, and Darja Mihailova from the University of Basel Sustainability Research Group, Susana Batel from the Centre for Social Research at ISCTE, University Institute of Lisbon, and Nestor Valero-Silva from the department of Human Resource management, NTU, Nottingham Trent University. The author is also grateful for the anonymous peer review comments which helped to further improve the article.

Appendix 1. Semi-structured interview themes

Interview Questions are divided into themes, within each theme we examine the policies, processes and main stakeholders:

I.Gentrification.

a) What measures are you planning/ do you have in place to mitigate the negative aspects of gentrification.

b) How much social housing, how is this managed and distributed?

c) How will/do rents compare to other districts in the same city?

D) how widely does/will the district reflect wider city demographics.

E) What policies are in place to encourage participation, particularly of those who are more vulnerable?

II.Fair and inclusive financing for retrofitting, or for access to new homes.

a) What forms of financing are available for retrofitting and how are these inclusive? (not applicable to new districts, hence for new districts: what financial measures are in place or being considered to include more vulnerable residents in the district?)

b) What are the main stakeholders involved in this and who is missing?

III. Energy Communities

(a) What forms of RET ownership are being considered/implemented in the district?

(b) How and to what extent are these inclusive?

IV. Mobility

a) What measures are in place to ensure inclusive mobility?

V. Energy Advice and Supporting shifts in energy consumption behaviour

a) Where and how is energy advice given to residents?

b) When considering new technologies (eg smart meters and IoT) what forms of training are given to residents?

c) Are there specific measures to ensure this is inclusive?

VI. Other aspects not previously covered, including energy justice

Appendix 2. , main positive energy districts associated to the stakeholders interviewed.

PED project, district, city, country	Share of residential	Size of project	Main energy characteristics and project website
SPARCS lighthouse city Espoo, Districtcs of Kera, Espoonlahti, Leppävaara, Finland	21%	52HA	Circular economy, Solar thermal energy, geothermal energy, district heating, Heat pump system, waste heat, seasonal storages, batteries, PV, biomass CHP, bi-directional eV charging; 2nd life battery; peer to peer energy transaction, Virtual Power Planthttps://www.sparcs.info/cities/espoo
Making-city lighthouse city Oulu, Kaukovainio district, Finland	75%	4 HA	Retrofitting, Geothermal technology and PV, ICT, district heating system using waste heat. https://makingcity.eu/oulu/
Brunnshogg Lund, Sweden	40%	225HA	Solar Thermal Energy, heat pump system, district heating, Industrial waste heat, PVhttps://lund.se/brunnshog
Reininghaus, Graz Austria	70% No social housing	100HA	Geothermal energy, district heating, heat pump system, industrial waste heat, PVhttps://xn–reininghausgrnde-vzb.at/
ATELIER lighthouse city,Buiksloterheim, Amsterdam, Netherlands	56% No social housing	2.85HA	Solar thermal energy, district heating, heat pump system, PV, peer to peer energy trading pilot, https://www.Smartcity-atelier.eu/about/lighthouse-cities/amsterdam/

(*continued on next page*)

(*continued*)

PED project, district, city, country	Share of residential	Size of project	Main energy characteristics and project website
Makingcity lighthouse city Groningen, North and South Districts Netherlands	Ca50%	17HA 27HA	PV, Solaroad (road surface is PV), waste digestion, geothermal and waste heat (from data centre), geothermal heatpumps, district heatinghttps:// makingcity.eu/groningen
Positive4North, North Quarter, Brussels, Belgium	Ca.50%	730HA	Retrofitting, geothermal energy, district heating, PVhttps:// jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf
Pfaff, Kaiserslautern, Germany	Ca.30%	23HA	PV, industrial waste heat, district heating, heat pumps, green roofshttps:// www.pfaff-quartier.de
Werksviertel, Munich, Germany	Ca.30%	390HA	District heating, heat pump system, PVhttps:// werksviertel.de/?page_id = 410&lang = en
SPARCS, (and Triangulum) Baumwollspinnerei and Leipzig-West, Leipzig, Germany	Ca 50% with social housing	300HA	Virtual Positive Energy Community, solar thermal plant, heat storage, ICT integration, intelligent EV charging and storage, micro gridhttps:// www.sparcs.info/cities/leipzig
SPARCS, Sports Area Sletiště, Růžová Pole Area Kladno, Czechia	Ca 20%	Not finalised	PV, E-mobility, retrofittinghttps:// www.sparcs.info/cities/kladno
Sharingcities, Porta Romana, Vettabbia Milan, Italy	100% with social housing	2.8HA	Citizen co-design, retrofit, emobility, Solar thermal energy, geothermal energy, heat pump system, PVhttps:// www.sharingcities.eu/sharingcities/city-profiles/milan
ATELIER lighthouse city, Zorotzaurre Island, Bilbao, Spain	30%, to include social housing	83HA	Geothermal energy, district heating, heat pump system, PVhttps:// smartcity-atelier.eu/about/lighthouse-cities/bilbao/
Triangulum, Sabadell,Spain	60% Mainly Social housing	378HA	Retrofitting, PV, network of soft mobility, LED public lighting, smart irrigation of parks, remote energy management of public buildingshttps:// triangulum-project.eu/?page_id=2350

Appendix 2. Main positive energy districts associated to the stakeholders interviewed.

PED project, district, city, country	Share of residential	Size of project	Main energy characteristics and project website
SPARCS lighthouse city Espoo, Districtcs of Kera, Espoonlahti, Leppävaara, Finland	21%	52HA	Circular economy, Solar thermal energy, geothermal energy, district heating, Heat pump system, waste heat, seasonal storages, batteries, PV, biomass CHP, bi-directional eV charging; 2nd life battery; peer to peer energy transaction, Virtual Power Planthttps:// www.sparcs.info/cities/espoo
Making-city lighthouse city Oulu, Kaukovainio district, Finland	75%	4 HA	Retrofitting, Geothermal technology and PV, ICT, district heating system using waste heat. https://makingcity.eu/oulu/
Brunnshogg Lund, Sweden	40%	225HA	Solar Thermal Energy, heat pump system, district heating, Industrial waste heat, PVhttps:// lund.se/brunnshog
Reininghaus, Graz Austria	70% No social housing	100HA	Geothermal energy, district heating, heat pump system, industrial waste heat, PVhttps:// xn–reininghausgrnde-vzb.at/
ATELIER lighthouse city,Buiksloterheim, Amsterdam, Netherlands	56% No social housing	2.85HA	Solar thermal energy, district heating, heat pump system, PV, peer to peer energy trading pilot, https://www.Smartcity-atelier.eu/about/lighthouse-cities/amsterdam/
Makingcity lighthouse city Groningen, North and South Districts Netherlands	Ca50%	17HA 27HA	PV, Solaroad (road surface is PV), waste digestion, geothermal and waste heat (from data centre), geothermal heatpumps, district heatinghttps:// makingcity.eu/groningen
Positive4North, North Quarter, Brussels, Belgium	Ca.50%	730HA	Retrofitting, geothermal energy, district heating, PVhttps:// jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf
Pfaff, Kaiserslautern, Germany	Ca.30%	23HA	PV, industrial waste heat, district heating, heat pumps, green roofshttps:// www.pfaff-quartier.de
Werksviertel, Munich, Germany	Ca.30%	390HA	District heating, heat pump system, PVhttps:// werksviertel.de/?page_id = 410&lang = en
SPARCS, (and Triangulum) Baumwollspinnerei and Leipzig-West, Leipzig, Germany	Ca 50% with social housing	300HA	Virtual Positive Energy Community, solar thermal plant, heat storage, ICT integration, intelligent EV charging and storage, micro gridhttps:// www.sparcs.info/cities/leipzig
SPARCS, Sports Area Sletiště, Růžová Pole Area Kladno, Czechia	Ca 20%	Not finalised	PV, E-mobility, retrofittinghttps:// www.sparcs.info/cities/kladno
Sharingcities, Porta Romana, Vettabbia Milan, Italy	100% with social housing	2.8HA	Citizen co-design, retrofit, emobility, Solar thermal energy, geothermal energy, heat pump system, PVhttps:// www.sharingcities.eu/sharingcities/city-profiles/milan
ATELIER lighthouse city, Zorotzaurre Island, Bilbao, Spain	30%, to include social housing	83HA	Geothermal energy, district heating, heat pump system, PVhttps:// smartcity-atelier.eu/about/lighthouse-cities/bilbao/
Triangulum, Sabadell,Spain	60% Mainly Social housing	378HA	Retrofitting, PV, network of soft mobility, LED public lighting, smart irrigation of parks, remote energy management of public buildingshttps:// triangulum-project.eu/?page_id=2350

Reference

[1] Alpagut, B., Akyürek, Ö., Mitre, E.M., 2019. Positive Energy Districts Methodology and Its Replication Potential, in: Multidisciplinary Digital Publishing Institute Proceedings. p. 8.

[2] Bal M, Stok FM, Van Hemel C, De Wit JBF. Including Social Housing Residents in the Energy Transition: A Mixed-Method Case Study on Residents' Beliefs, Attitudes, and Motivation Toward Sustainable Energy Use in a Zero-Energy Building Renovation in the Netherlands. Frontiers in Sustainable Cities 2021;3:25. https://doi.org/10.3389/frsc.2021.656781.

[3] Bardazzi R, Bortolotti L, Pazienza MG. To eat and not to heat? Energy poverty and income inequality in Italian regions. Energy Res Social Sci 2021;73:101946.

[4] Barrella R, Romero JC, Linares JI, Arenas E, Asín M, Centeno E. The dark side of energy poverty: Who is underconsuming in Spain and why? Energy Res Social Sci 2022;86:102428. https://doi.org/10.1016/j.erss.2021.102428.

[5] Bartiaux, F., European Sociological Association, R.N. of S. of C., 2018. Rethinking and extending the 'heat or eat' dilemma: an attempt to intersect 'normal' practices' deprivation and negative emotions' generation.

[6] Bartiaux F, Maretti M, Cartone A, Biermann P, Krasteva V. Sustainable energy transitions and social inequalities in energy access: A relational comparison of capabilities in three European countries. Global Transitions 2019;1:226–40.

[7] Bartiaux F, Vandeschrick C, Moezzi M, Frogneux N. Energy justice, unequal access to affordable warmth, and capability deprivation: A quantitative analysis for Belgium. Appl Energy 2018;225:1219–33.

[8] Betto F, Garengo P, Lorenzoni A. A new measure of Italian hidden energy poverty. Energy policy 2020;138:111237.

[9] Bienvenido-Huertas D, Sánchez-García D, Rubio-Bellido C, Pulido-Arcas JA. Applying the mixed-mode with an adaptive approach to reduce the energy poverty in social dwellings: The case of Spain. Energy 2021;237:121636. https://doi.org/10.1016/j.energy.2021.121636.

[10] Bossi S, Gollner C, Theierling S. Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases. Energies 2020;13:6083. https://doi.org/10.3390/en13226083.

[11] Bouzarovski S. Understanding energy poverty, vulnerability and justice. In: Bouzarovski S, editor. Energy Poverty. Cham: Springer International Publishing; 2018. p. 9–39.

[12] Bouzarovski S, Simcock N. Spatializing energy justice. Energy Policy 2017;107:640–8. https://doi.org/10.1016/j.enpol.2017.03.064.

[13] Bouzarovski S, Thomson H, Cornelis M. Confronting Energy Poverty in Europe: A Research and Policy Agenda. Energies 2021;14:858. https://doi.org/10.3390/en14040858.

[14] Bouzarovski S, Tirado Herrero S, Petrova S, Frankowski J, Matoušek R, Maltby T. Multiple transformations: theorizing energy vulnerability as a socio-spatial phenomenon. Geografiska Annaler: Series B, Human Geography 2017;99:20–41. https://doi.org/10.1080/04353684.2016.1276733.

[15] Bruck, Axel, Santiago Diaz Ruano, and Hans Auer. "One piece of the puzzle towards 100 Positive Energy Districts across Europe by 2025: An open-source approach to unveil favourable locations of PV-based PEDs across europe from a techno-economical perspective." Energy (2022): 124152.

[16] Bulkeley H, Marvin S, Palgan YV, McCormick K, Breitfuss-Loidl M, Mai L, et al. Urban living laboratories: Conducting the experimental city? Eur Urban Reg Stud 2019;26(4):317–35.

[17] Buzar S. Energy Poverty in Eastern Europe: Hidden Geographies of Deprivation. Routledge, London 2016. https://doi.org/10.4324/9781315256504.

[18] Carfora A, Scandurra G, Thomas A. Forecasting the COVID-19 effects on energy poverty across EU member states. Energy Policy 2022;161:112597.

[19] Carley S, Konisky DM. The justice and equity implications of the clean energy transition. Nat Energy 2020;5:569–77. https://doi.org/10.1038/s41560-020-0641-6.

[21] Castaño-Rosa R, Solís-Guzmán J, Rubio-Bellido C, Marrero M. Towards a multiple-indicator approach to energy poverty in the European Union: A review. Energy Build 2019;193:36–48. https://doi.org/10.1016/j.enbuild.2019.03.039.

[22] Day R, Walker G, Simcock N. Conceptualising energy use and energy poverty using a capabilities framework. Energy Policy 2016;93:255–64.

[23] Delclós C, Vidal L. Beyond renovation: Addressing Europe's long housing crisis in the wake of the COVID-19 pandemic. Eur Urban Reg Stud 2021;28:333–7. https://doi.org/10.1177/09697764211043424.

[25] EPAH, 2021. The EPAH Launch: How the event developed and access to the material [WWW Document], n.d. URL https://energy-poverty.ec.europa.eu/about-us/news/epah-launch-how-event-developed-and-access-material-2021-11-29_en (accessed 12.2.21).

[26] EERA, 2021. The European Commission strongly calls the SET Plan to take a people-centred approach in a foreseen revamp [WWW Document], December 2021. Coordinating energy research for a low carbon Europe | EERA. URL https://www.eera-set.eu/news-resources/3052:the-european-commission-strongly-calls-the-set-plan-to-take-a-people-centred-approach-in-a-foreseen-revamp.html (accessed 12.6.21).

[27] European Commission, 2016. EU Buildings Factsheets [WWW Document]. Energy - European Commission. URL https://ec.europa.eu/energy/eu-buildings-factsheets_en (accessed 11.30.21).

[28] European Commission, 2020, Energy Poverty Publications [WWW Document], n.d. URL https://energy-poverty.ec.europa.eu/discover/practices-and-policies-toolkit/publications_en (accessed 11.2.21).

[30] European Commission, 2019. Energy poverty [WWW Document]. Energy - European Commission. URL https://ec.europa.eu/energy/topics/markets-and-consumers/energy-consumer-rights/energy-poverty_en (accessed 11.1.21).

[31] EuroPACE [WWW Document], 2021. EuroPACE. URL https://www.europace2020.eu/ (accessed 3.2.21).

[32] Feenstra M, Middlemiss L, Hesselman M, Straver K, Tirado Herrero S. Humanising the Energy Transition: Towards a National Policy on Energy Poverty in the Netherlands. Frontiers in Sustainable Cities 2021;3:31. https://doi.org/10.3389/frsc.2021.645624.

[33] Feenstra M, Özerol G. Energy justice as a search light for gender-energy nexus: Towards a conceptual framework. Renew Sustain Energy Rev 2021;138:110668.

[34] Fell MJ. Just flexibility? Nat Energy 2020;5:6–7. https://doi.org/10.1038/s41560-019-0510-3.

[35] Gabaldón Moreno A, Vélez F, Alpagut B, Hernández P, Sanz Montalvillo C. How to Achieve Positive Energy Districts for Sustainable Cities: A Proposed Calculation Methodology. Sustainability 2021;13:710. https://doi.org/10.3390/su13020710.

[36] Galvin R. How many interviews are enough? Do qualitative interviews in building energy consumption research produce reliable knowledge? Journal of Building Engineering 2015;1:2–12.

[37] Giacomini, 2021. Superbonus 110%: how does it work in 2021? [WWW Document], Giacomini S.p.A. URL https://www.giacomini.com/en/news/2021/05/12/superbonus-110-how-does-it-work-2021 (accessed 11.30.21).

[38] C. Gollner, EUROPE towards POSITIVE ENERGY DISTRICTS, (2020) 182. https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf (accessed September 2021).

[39] Gouveia JP, Seixas J, Palma P, Duarte H, Luz H, Cavadini GB. Positive Energy District: A Model for Historic Districts to Address Energy Poverty. Frontiers in Sustainable Cities 2021;3:16.

[40] Guest G, Bunce A, Johnson L. How many interviews are enough? An experiment with data saturation and variability. Field methods 2006;18(1):59–82.

[41] Hachem-Vermette C, Guarino F, La Rocca V, Cellura M. Towards achieving net-zero energy communities: Investigation of design strategies and seasonal solar collection and storage net-zero. Solar Energy, Thermal Energy Storage for Solar Applications 2019;192:169–85. https://doi.org/10.1016/j.solener.2018.07.024.

[42] Halkos GE, Gkampoura E-C. Evaluating the effect of economic crisis on energy poverty in Europe. Renew Sustain Energy Rev 2021;144:110981. https://doi.org/10.1016/j.rser.2021.110981.

[43] Hanke F, Guyet R, Feenstra M. Do renewable energy communities deliver energy justice? Exploring insights from 71 European cases. Energy Res Social Sci 2021;80:102244.

[44] Hearn AX, Castaño-Rosa R. Towards a Just Energy Transition, Barriers and Opportunities for Positive Energy District Creation in Spain. Sustainability 2021;13:8698. https://doi.org/10.3390/su13168698.

[45] Hearn AX, Sohre A, Burger P. Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. Energy Res Social Sci 2021;78:102127. https://doi.org/10.1016/j.erss.2021.102127.

[46] Heffron RJ. Applying energy justice into the energy transition. Renew Sustain Energy Rev 2022;156:111936. https://doi.org/10.1016/j.rser.2021.111936.

[47] Herrero ST. Energy poverty indicators: A critical review of methods. Indoor Built Environ 2017;26(7):1018–31.

[48] Hesselman M, Varo A, Guyet R, Thomson H. Energy poverty in the COVID-19 era: Mapping global responses in light of momentum for the right to energy. Energy Res Social Sci 2021;81:102246. https://doi.org/10.1016/j.erss.2021.102246.

[49] Hoffman J, Davies M, Bauwens T, Späth P, Hajer MA, Arifi B, et al. Working to align energy transitions and social equity: An integrative framework linking institutional work, imaginaries and energy justice. Energy Res Social Sci 2021;82:102317. https://doi.org/10.1016/j.erss.2021.102317.

[50] Jenkins K, McCauley D, Heffron R, Stephan H, Rehner R. Energy justice: A conceptual review. Energy Res Social Sci 2016;11:174–82. https://doi.org/10.1016/j.erss.2015.10.004.

[51] Jenkins K, Sovacool BK, McCauley D. Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change. Energy Policy 2018;117:66–74. https://doi.org/10.1016/j.enpol.2018.02.036.

[53] Jones A, Valero-Silva N. Social impact measurement in social housing: a theory-based investigation into the context, mechanisms and outcomes of implementation. Qualitative Research in Accounting & Management 2021;18(3):361–89.

[55] JPI Urban Europe, 2020, White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods, (2020) 1–22. https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White-Paper-PED-Framework-Definition-2020323-final.pdf. (Accessed September 2021).

[56] Karpinska L, Śmiech S. Will energy transition in Poland increase the extent and depth of energy poverty? J Cleaner Prod 2021;328:129480. https://doi.org/10.1016/j.jclepro.2021.129480.

[57] Lalljee, J., 2021 Spanish renters are declaring "war" on the American investors that bought up all the apartments in their neighborhoods [WWW Document]. Business Insider. URL https://www.businessinsider.com/spanish-renters-tenants-declare-war-on-american-private-equity-firms-2021-11 (accessed 3.14.22).

[58] Legnér M, Leijonhufvud G. A Legacy of Energy Saving: The Discussion on Heritage Values in the First Programme on Energy Efficiency in Buildings in Sweden, c. 1974–1984. The Historic Environment: Policy & Practice 2019;10:40–57. https://doi.org/10.1080/17567505.2018.1531646.

[59] Lieu, J., Sorman, A.H., Johnson, O.W., Virla, L.D., Resurrección, B.P., 2020. Three sides to every story: Gender perspectives in energy transition pathways in Canada, Kenya and Spain. Energy Research & Social Science 68, 101550.

[60] C. Marggraf, A. Hearn, L. Lamonaca, R. Ackrill, K. Galanakis, Report on "must-read" factors in policy design to tackle energy poverty through PED creation, (2021). https://smart-beejs.eu/wp-content/uploads/2021/08/D5_3-Must-Read-Factors.pdf (Accessed September 2021).

[61] März S. Assessing the fuel poverty vulnerability of urban neighbourhoods using a spatial multi-criteria decision analysis for the German city of Oberhausen. Renew Sustain Energy Rev 2018;82:1701–11. https://doi.org/10.1016/j.rser.2017.07.006.
[62] Mayring, P., 2014. Qualitative content analysis: theoretical foundation, basic procedures and software solution.
[63] McCauley D, Ramasar V, Heffron RJ, Sovacool BK, Mebratu D, Mundaca L. Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research. Appl Energy 2019;233–234:916–21. https://doi.org/10.1016/j.apenergy.2018.10.005.
[64] Merriam SB, Tisdell EJ. Qualitative research: A guide to design and implementation. John Wiley & Sons; 2015.
[65] Middlemiss L, Gillard R. Fuel poverty from the bottom-up: Characterising household energy vulnerability through the lived experience of the fuel poor. Energy Res Social Sci 2015;6:146–54. https://doi.org/10.1016/j.erss.2015.02.001.
[66] Mihailova D, Schubert I, Burger P, Fritz MMC. Exploring modes of sustainable value co-creation in renewable energy communities. J Cleaner Prod 2022;330:129917. https://doi.org/10.1016/j.jclepro.2021.129917.
[67] Minh-Thu, Nguyen; Batel, Susana, 2021. A Critical Framework to Develop Human-Centric Positive Energy Districts: Towards Justice, Inclusion, and Well-being.
[68] Nagaj R, Korpysa J. Impact of COVID-19 on the Level of Energy Poverty in Poland. Energies 2020;13:4977. https://doi.org/10.3390/en13184977.
[69] Nordholm A, Sareen S. Scalar containments of energy justice and its democratic discontents: Solar power and energy poverty alleviation. Frontiers in Sustainable Cities 2021;3:13.
[71] Parés M, Boada J, Canal R, Hernando E, Martínez R. Challenging collaborative urban governance under austerity: How local governments and social organizations deal with housing policy in Catalonia (Spain). Journal of Urban Affairs 2017;39:1066–84. https://doi.org/10.1080/07352166.2017.1310531.
[72] Primc K, Dominko M, Slabe-Erker R. 30 years of energy and fuel poverty research: A retrospective analysis and future trends. J Cleaner Prod 2021;301:127003. https://doi.org/10.1016/j.jclepro.2021.127003.
[73] Recalde M, Peralta A, Oliveras L, Tirado-Herrero S, Borrell C, Palència L, et al. Structural energy poverty vulnerability and excess winter mortality in the European Union: Exploring the association between structural determinants and health. Energy Policy 2019;133:110869. https://doi.org/10.1016/j.enpol.2019.07.005.
[74] Roberts K, Dowell A, Nie J-B. Attempting rigour and replicability in thematic analysis of qualitative research data; a case study of codebook development. BMC Med Res Methodol 2019;19:66. https://doi.org/10.1186/s12874-019-0707-y.
[75] Sánchez, C.S.-G., Fernández, A.S., Peiró, M.N., Muñoz, G.G., 2020. Energy poverty in Madrid: Data exploitation at the city and district level. Energy Policy 144, 111653.
[76] Sareen S, Thomson H, Herrero ST, Gouveia JP, Lippert I, Lis A. European energy poverty metrics: Scales, prospects and limits. Global Transitions 2020;2:26–36.
[77] SET Plan 3.2., 2019 European Commission, SET Plan setplan_smartcities_implementationplan-2.pdf.
[78] Sorman AH, García-Muros X, Pizarro-Irizar C, González-Eguino M. Lost (and found) in Transition: Expert stakeholder insights on low-carbon energy transitions in Spain. Energy Res Social Sci 2020;64:101414. https://doi.org/10.1016/j.erss.2019.101414.
[79] Sougkakis V, Lymperopoulos K, Nikolopoulos N, Margaritis N, Giourka P, Angelakoglou K. An Investigation on the Feasibility of Near-Zero and Positive Energy Communities in the Greek Context. Smart Cities 2020;3:362–84. https://doi.org/10.3390/smartcities3020019.
[80] Sovacool BK. The methodological challenges of creating a comprehensive energy security index. Energy Policy, Special Section: Frontiers of Sustainability 2012;48:835–40. https://doi.org/10.1016/j.enpol.2012.02.017.
[81] Sovacool BK, Lipson MM, Chard R. Temporality, vulnerability, and energy justice in household low carbon innovations. Energy Policy 2019;128:495–504. https://doi.org/10.1016/j.enpol.2019.01.010.
[82] Statista, 2020. Completed housing units per citizens by country Europe 2020 [WWW Document], 2020. Statista. URL https://www.statista.com/statistics/650790/completed-dwellings-per-citizens-by-country-europe/ (accessed 11.30.21).
[84] Stojilovska A. Energy poverty and the role of institutions: exploring procedural energy justice – Ombudsman in focus. J Environ Plann Policy Manage 2021:1–13. https://doi.org/10.1080/1523908X.2021.1940895.
[85] Streimikiene D, Balezentis T. Innovative policy schemes to promote renovation of multi-flat residential buildings and address the problems of energy poverty of aging societies in former socialist countries. Sustainability 2019;11:2015.
[86] Thellufsen JZ, Lund H, Sorknæs P, Østergaard PA, Chang M, Drysdale D, et al. Smart energy cities in a 100% renewable energy context. Renew Sustain Energy Rev 2020;129:109922. https://doi.org/10.1016/j.rser.2020.109922.
[88] Thomson H, Bouzarovski S, Snell C. Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. Indoor Built Environ 2017;26:879–901. https://doi.org/10.1177/1420326X17699260.
[89] Thomson H, Simcock N, Bouzarovski S, Petrova S. Energy poverty and indoor cooling: An overlooked issue in Europe. Energy Build 2019;196:21–9.
[90] Times TS. Italy: 4.4 billion Super Bonus 110 scams. The Switzerland. accessed 2.14.22 Times 2022. https://www.theswitzerlandtimes.com/italy-4-4-billion-super-bonus-110-scams/.
[91] Tirado Herrero S, Nicholls L, Strengers Y. Smart home technologies in everyday life: do they address key energy challenges in households? Current Opinion in Environmental Sustainability, Sustainability governance and transformation 2018;2018(31):65–70. https://doi.org/10.1016/j.cosust.2017.12.001.
[92] Trivellato B. How can 'smart' also be socially sustainable? Insights from the case of Milan. Eur Urban Reg Stud 2017;24:337–51. https://doi.org/10.1177/0969776416661016.
[93] Weber G, Cabras I. The transition of Germany's energy production, green economy, low-carbon economy, socio-environmental conflicts, and equitable society. J Cleaner Prod 2017;167:1222–31. https://doi.org/10.1016/j.jclepro.2017.07.223.
[94] Zhang X, Penaka SR, Giriraj S, Sánchez MN, Civiero P, Vandevyvere H. Characterizing Positive Energy District (PED) through a Preliminary Review of 60 Existing Projects in Europe. Buildings 2021;11:318. https://doi.org/10.3390/buildings11080318.
[95] Hedman Å, et al. IEA EBC Annex83 Positive Energy Districts. Buildings 2021;11(3):130. https://doi.org/10.3390/buildings11030130. In press.
[96] Eurostat 2019; 2019 . [Accessed 11 February 2022].