The potential of Positive Energy Districts as energy governance tools for a Just Transition

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Adam Xavier Hearn

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Acronyms

CA: Capability Approach

CIECB: Change of Individual Energy Consumption Behaviour

ICT: Information and communication technology

JPI: Joint programming Initiative, part of the Urban Europe group, European Commission

NZEB: Near-zero energy building

PEB: Positive Energy Building

PEC: Positive Energy City

PED: Positive Energy District

PEN: Positive Energy Neighbourhood

PER: Positive Energy Region

REC: Renewable Energy Community

RED II: Renewable Energy Directive from the European Commission 2018/2001

RES: Renewable Energy Sources

SDG: Sustainable development goal

SET: Strategic Energy and technology plan

SHEDS: Swiss Household Energy Demand Survey

SILC: Survey on income and living conditions

UN: United Nations

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1. Introduction

Within the field of sustainable development there are a number of major themes, which are integrated in the United Nations (UN) 17 Sustainable Development Goals (SDGs) [1]. These can be divided into reducing poverty and deprivations, improving health and education, reducing inequality and promoting sustainable economic growth, preserving the oceans and forests, and both mitigating and tackling the challenges brought about through climate change.

Figure 1, The UN Sustainable Development Goals

In order to meet these goals, the topic of energy is of crucial importance. Not only is the need for clean and affordable energy a UN goal in and of itself in the form of SDG7 (Fig. 1), interlinked with energy poverty and the goal of reducing poverty (SDG1), improving wellbeing (SDG3), stimulating economic growth (SDG8), making industry more sustainable (SDG9), reducing inequalities (SDG10), the creation of sustainable cities and communities (SDG11) and the mitigation of climate change (SDG13). One potential way in which energy-related sustainable development goals can be met in urban areas across Europe is through the creation of Positive Energy Districts (PEDs) which are powered through locally produced renewable energy.

These are districts which are not only highly energy efficient, and meet or surpass all of their energy needs through the use of renewable energy, but also incorporate cutting edge information and communication technology (ICT) systems and local soft mobility plans. The European Commission's Strategic Energy Technology (SET) Plan 3.2, together with the Joint Programming Initiative (JPI) Urban Europe[2], plan to create 100 PEDs by 2025. According to the SET Plan and JPI Urban Europe, PED creation is to be guided by principles (Fig. 2) of quality of life, sustainability, and inclusiveness (specifically focusing on affordability and energy poverty prevention), which reiterates the link between PEDs and the SDGs.

> *"A Positive Energy District couples built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumer."* JPI Urban Europe

PEDs build on previous concepts including passive houses in the case of Germany [3,4] or Minergie in Switzerland [5], NZEBs, or "Near Zero Energy Buildings" [6,7], Positive Energy Buildings, or Positive Energy Blocks (PEBs) [8]. Groups of PEBs connected together in a smart grid, create neighbourhoods that are able to become Positive Energy Districts (PEDs) [9]. PEDs can in turn form the building blocks for the eventual creation of positive energy cities (PECs) and positive energy regions (PERs) and are seen as strategically vital for the decarbonization of urban spaces in Europe [10,11].

There are currently a number of different types of PED models. Firstly, there are autonomous PEDs, producing all of their energy within the district including a net surplus that may in some cases be exported to the grid. Of the current PED projects (as of March 2022), there are no projects that fall into this category, but there are a number of projects that may become autonomous PEDs, particularly those which are island based (eg., Åland Islands [12]). PEDs may also be dynamic, importing energy at certain times but still producing an annual surplus from Renewable Energy Sources (RES) within the district boundaries [13]. Finally, virtual PEDs incorporate the use of RES which is outside of the geographic boundaries of the PED. Currently most of the existing PED projects could be classified as PED-like areas as they may be striving to become full PEDs, but do not produce an annual surplus of energy from the district. Districts such as the Hunziker Areal in Zurich produce almost half of their energy onsite through photovoltaics, and use waste heat for district heating, but still import just over half of the necessary electricity for the district. This is renewably sourced electricity, but comes from commercial providers rather than from designated areas of production which are specifically connected to the district.

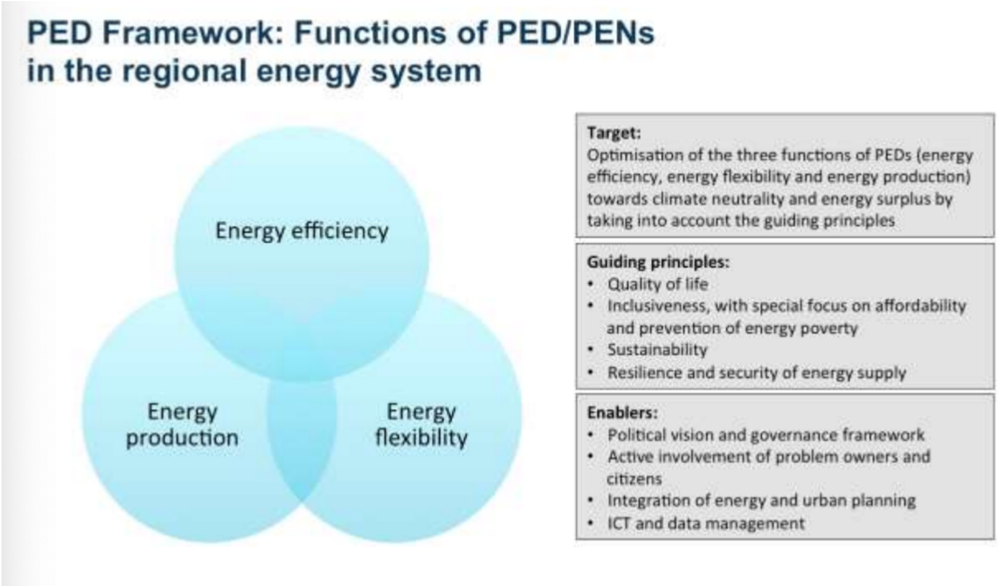

Figure 2 Functions of PED/PENS in the regional energy system, from [30].

Simultaneously, as part of the "Clean Energy for All Europeans" Package, European directives such as 2018/2001(RED II) enshrine the rights of citizens to create renewable energy communities (RECs) in which they produce, share and sell energy. EU directive RED II on RECs makes it clear that RECs which can be applied in PEDs are to be used as tools to reduce energy poverty as well as increase decarbonization, and increase the democratization of European energy systems.

1.1. Introduction to the project environment

This doctoral research took place as part of the *Smart Value Generation by Building Efficiency and Energy Justice for Sustainable Living (SMART-BEEjS [14]) Marie Skłodowska-Curie Actions, Innovative Training Networks (ITN)*. This Horizon2020 project involves 15 PhD candidates at universities across Europe, each focusing on different themes within PED creation, ranging from technical aspects, through to economics- and the social sciences-related perspectives. The SMART-BEEjS programme involved the co-publication of deliverables, in-depth training through Winter schools, as well as public diffusion of information both online and through participation in numerous conferences and workshops (see Appendix 1) to ensure a wider impact to the research. In addition to this, the PhD requirements of the University of Basel were met through the publication of peer-reviewed papers.

My particular area of research focusses on energy justice and the notion that PEDs could support a just transition. The idea of PEDs as decarbonised urban areas that produce enough power to export an annual surplus is to be lauded, but it is not without problems.

Indeed, PEDs have the potential to contribute to a more just transition – that is, only if their implementation is done in an equitable way that focuses on affordability across population segments [15,16].

1.2. Research gaps, research aims and questions

One segment of the population that is at risk of being excluded from PEDs is that of those that live in energy poverty (see section 2.5 for further information on energy poverty). Energy poverty affects at least 34 million Europeans, and is likely to increase significantly owing to both the COVID19 pandemic and the energy price rises in 2021/22. In order to mitigate energy poverty (as part of SDG1) whilst decarbonizing the energy system, PEDs and RECS may provide a useful tool.

However, owing to their novelty, this has not yet been fully investigated. In the social sciences energy research literature, issues of energy poverty and vulnerability in general have often been examined and addressed through an energy justice lens [17–19], focusing on the main three tenets of distributional, recognitional and procedural energy justice [19–22]. My specific area of focus is on whether PEDs are able to contribute towards a just transition and to what extent those living in energy poverty are included, from an energy justice perspective.

1.1.1. Research gaps

As mentioned above, because of the relative novelty of PEDs and RECs, their potential role in mitigating energy poverty has not been fully investigated. Indeed, most PED research focuses on technical aspects and neglects social issues [13,23]. Furthermore, there are scant studies on the link between technologically innovative living spaces such as smart cities or PEDs and justice [24]. There has been some prior use of the capability approach as the basis for energy justice research but it is also noted that there is a need for research into the adaptation of energy capabilities for smart technology districts such as PEDs [25]. Moreover, the capability approach is normally operationalized based on adapted lists of core capabilities following Nussbaum [26] while an approach which is more open to individual cultural interpretations of what is considered a valued life (more in line with Sen [27]) has not received as much attention.

In addition, although there has been research on consumer preferences for individual innovative technologies such as solar PV [28], there has been little research into consumer preferences for bundles of innovative technologies of the sort likely to be found in PEDs (these may include things such as vehicle-to-grid charging, solar PV, district heating, smart home controls amongst others).

Further to this, some research points out that smart technologies such as those that might be encountered in a PED could exacerbate inequalities [29,30], hence indicating a need to investigate the effect of a package of assorted technologies as provided in PEDs on justice issues. There is also some research to indicate that energy poverty numbers are systematically underestimated [31] which is exacerbated by the reliance on different indicators in different nations, and a lack of national definitions of energy poverty. Furthermore, there is currently no conceptual framework that links energy vulnerability overtly with SDG7 (access to clean and affordable energy). Providing such a link would provide a potential way of enhancing policymaker ability to directly target those that are energy vulnerable in more effective ways.

1.1.2. Research aims and questions

To address these gaps, the overarching aims of the dissertation are:

- To contribute to the shift in the energy discussion from a focus on the energy transition, to a focus on an inclusive energy transition.
- To contribute to energy poverty research by demonstrating that there is a potential for PEDs to become policy instruments that combine both decarbonization and energy poverty mitigation.
- To create a conceptual framework connecting SDG7 (access to clean and more specifically affordable energy) to energy vulnerability as this does not currently exist.

PEDs are novel forms of urban governance which have received some scholarly attention since their conception in 2018. However, most of this attention has focused on technical aspects, namely related to energy balances and establishing designated boundaries for such districts. This most certainly contributes to the energy transition, but research to determine justice aspects such as inclusion are underrepresented and need to be considered if the transition is to leave no one behind. The novelty this brings is in determining in which ways PEDs may or may not contribute to a just and inclusive transition. Thus, by examining ways in which bundles of technological innovations that incorporate the use of innovative building solutions, ICT, smart mobility solutions and novel forms of production, consumption and storage of energy affect justice issues is vital if the transition is to include all sectors of society. Hence, the main research question of my thesis is:

RQ_main: **In what ways can PED-like areas be considered a part of a just transition that leaves no one behind?**

In order to meet these aims and answer this main research question, I present a further set of research questions which I answer through five peer-reviewed published papers.

Owing to the lack of research in social aspects of PED creation, there is a clear necessity for a conceptual framework that links energy vulnerability with SDG7 (access to clean and affordable energy). Such a framework could help policymakers identify ways to support energy vulnerable with suitable interventions and policies. In order to create such a framework, examining different energy justice and wellbeing related elements is the first step to determine how and where injustices may occur in the case of PEDs. Wellbeing is considered, because by examining the Opportunity Spaces for realizing wellbeing that are created in PEDs, one may also see where injustices are or will occur. Doing so provides new ways of examining PEDs which are novel and necessary for future research, in addition to being of use to policymakers working on PED creation and replication. Thus, I ask:

RQ1: What are the main energy justice and wellbeing related elements that need to be accounted for in order to ensure PED-like areas are part of a just transition?

There is research into barriers to the creation of renewable energy communities (RECs) but much of this does not focus on how RECs may be used as an opportunity to reduce inequalities and bringing about a more inclusive transition. Indeed, a significant proportion of research on this topic focuses on either technological or economic barriers, but often neglects social barriers. By framing RECs as potential forms of energy sharing for PEDs, I bring a novel approach to the study of RECs and PEDs, focusing on social aspects. This contributes to the literature on RECs and the literature on PEDs, also providing information which may contribute to REC and PED stakeholders in order to ensure that they are justice-informed. Hence, I ask:

RQ2: What are existing barriers to PED creation as part of a just transition?

Until now there has also been no research into citizens' preferences of PED attributes. This is a significant gap in the research, as determining citizens preferences could have a major effect on future PED creation, as well as opening up new avenues for research which assist in the tailoring of these districts. Ensuring that PEDs are attractive to citizens can be seen as a delicate balance between reducing overall energy consumption whilst simultaneously maintaining conditions for a high standard of life for residents. There has been some research into sufficiency [32] which focuses on ensuring that quality of life remains unaffected by reductions in energy consumption, but this has not examined PEDs or PED-like districts. Furthermore, studies of citizens' preferences have focused on individual aspects, such as mobility [33], shared spaces [34] or energy sources [35] rather than on bundles of preferences as one might encounter in PEDs. In order to determine citizens preferences for PEDs I ask:

RQ3: What PED-like attributes do citizens prefer?

There are multiple definitions of energy poverty (see section 2.5), but in recent years research has moved towards wider notions of energy vulnerability [36,37]. Within the research, this is either used as a definition for macrolevel vulnerability of a nations' energy resources [38], or as a term used to denote the potential for energy poverty, depending on an individuals' exposure, sensitivity and capacity to adapt [39,40]. Although this incorporates the element of time to some extent, with the recognition that states of vulnerability are fluid, this definition does not take into account the potential of inter-generational energy vulnerability caused through present day actions. A novel framework incorporating this would provide a stronger social case for decarbonization, whereby potential costs of future vulnerability could be off-set against the costs of current decarbonization efforts. Thus, redefining energy vulnerability could strengthen the case for decarbonization and climate change mitigation, as well as provide a new starting point from which to re-examine what it means to be energy vulnerable. In order to create this framework, I ask:

RQ4: What are the characteristics of energy vulnerability?

There has been little research on energy vulnerability or energy poverty in the case of Switzerland, and research in this area contributes to a wider understanding of energy vulnerability in Europe. What little research there is relies on the Eurostat Survey for

Income and Living Conditions (SILC) [41], and often information on Switzerland is minimal [42]. This is partially because of its status outside of the EU, and partially because energy poverty data from SILC indicates that energy poverty levels are amongst the lowest in Europe [42]. Researching the topic of energy vulnerability in a nation where there are no specific policies designated to tackle this may also stimulate further research in other countries where this is also not believed to be a major issue. Further, it may encourage policymakers to reassess beliefs on energy vulnerability and develop targeted measures to address this. In order to address this gap, I ask:

RQ5: What are the drivers of energy vulnerability in the case of Switzerland?

Although there is research that focuses on vulnerability to energy poverty in urban districts, the novelty of my approach is that it also focuses on key PED stakeholders directly involved in the creation and replication of these districts. Most European energy poverty research involves either using large datasets [43] such as the Eurostat SILC, contact with those vulnerable to energy poverty [44], or broader examination of policymaking [45]. My approach rather focuses on stakeholders who may be in a position to implement policies that could be of help in mitigating energy vulnerability to determine whether this is perceived of as an issue and how it is addressed. Although this is problematized further by cultural-historical differences throughout Europe, a focus on the district or city level also contributes to growing research which highlights multi-level governance [46,47] and the roles of cities in recognition of the way that these often function semi-independently [48]. This line of reasoning leads to two further interconnected research questions which connect energy vulnerability with PEDs:

RQ6: How is energy vulnerability perceived by stakeholders in different PED contexts?

RQ7: Which measures are used (or planned) in order to mitigate vulnerability to energy poverty in PEDs?

Answering these two additional research questions contributes to energy vulnerability research as well as to research on the social aspects of PEDs.

By answering the abovementioned questions, this dissertation aims to contribute to understanding how PEDs can form part of a “just” transition, contributing to energy justice research as well as to research on energy poverty/ energy vulnerability.

2. Theoretical foundations and previous research

In the following chapter, I detail the main theoretical foundations of this research as well as discuss some of the pre-existing research.

2.1. *Energy Governance*

Governance refers to the multiplicity of procedures and institutions through which different actors determine and enforce the strategies necessary for multiple desired goals and the creation of different instruments. This can be seen in Fig. 3, which identifies the importance of the Policy-Polity-Politics triangle for Change of Individual Energy Consumption Behaviour (CIECB) [49].

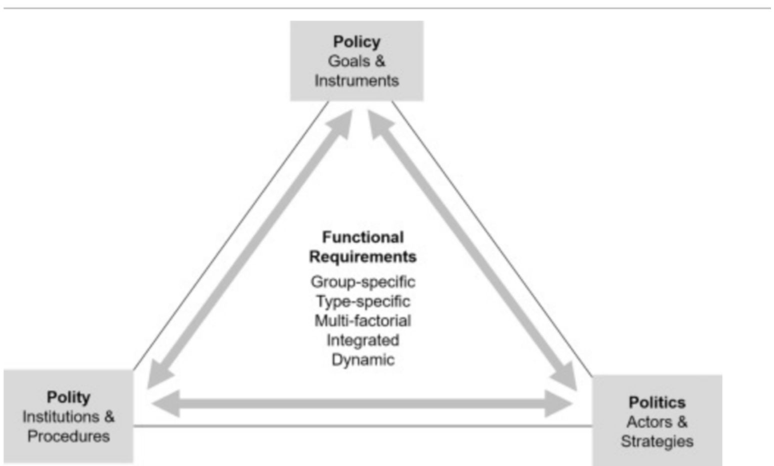

Figure 3 Framework of CIECB-Oriented Governance Design from Bornemann, Sohre and Burger [49]

When it comes to energy governance, it is clear that this is often uncoordinated, piecemeal, and even incoherent at times, operating on local, regional, national and international levels [50]. There are multiple areas where energy governance intersects with other forms of governance, and its importance has grown exponentially as the reality of climate change calls for a rapid acceleration of the transition [51].

In the context of PEDs, the integrating of different actors and multiple layers of governance is important in order to better cover innovative settings than through traditional policies. PED governance needs to take into account multiple perspectives and fulfil different functions such as:

- Reducing energy demand, for example, through introducing policies to instigate CIECB, and increasing energy flexibility, whilst protecting the most vulnerable [52].
- Maintaining an accessible and secure energy supply, for example, ensuring that supply is sufficient to meet demand through the use of renewable energy only, thus also considering storage issues.
- Financing for energy efficiency measures and renewable energy. Ensuring this is inclusive and easily available to all if the transition is to be just.
- Governance to reduce the likelihood of negative effects of gentrification in terms of spiralling house prices, and excluded populations. Thus, assuring the affordability of homes is also crucial.
- Recognizing differing energy needs and practices and ensuring that sufficient support is in place to train and advise residents.

A PED focus for governance also involves the recognition that governance is multilevel and that there are roles at the district and city level, as well as the regional, national and international level, such as through the Covenant of Mayors [53]. Ensuring that PED governance is inclusive and fair can be done through the use of the concept of energy justice.

2.2. *Energy Justice*

Energy justice as a concept has received growing interest from researchers in different disciplines [54], as both normative concept and an analytical tool for energy researchers, as well as an aid for policy-makers intent on ensuring that the transition is inclusive [55]. Energy justice is often taken to refer to the environmental threats as a result of energy choices, ranging from climate change and global warming, through to the multiplicity of negativities that result from the extraction, refining, transportation, production and consumption of energy.

The main three tenets of energy justice were initially identified as distributional, procedural and recognitional justice [18,21,56]. Distributional justice refers to the unequal distribution of both the benefits and the burdens brought about by the energy system in its entirety [57]. Recognitional justice centres on the misrecognition or ignoring of certain groups of people (e.g., ethnic minorities) [17], or those who may also have differing needs (e.g., physical health issues). Procedural justice meanwhile focuses on the transparent/opaque ways in which communities are encouraged to participate by stakeholders [58]. Further to these three main tenets, the area of restorative justice has also received some scholarly attention [59,60]. This refers to the need to offer redress to those that carry greater burdens associated with the energy system, and remediate procedural failures and both misrecognition and a lack of recognition. Examples of this include restitution and compensation to individuals and communities affected by the extraction of oil [61]. Other main tenets of energy justice which have been examined in the literature include global (or cosmopolitan) justice, as well as intra- and inter-generational justice. Global justice is the application of energy justice principles to all people in all nations [62], hence for example the use of photovoltaic solar panels may reduce burdens on a local or regional scale but may also increase energy injustices in regions which provide the necessary raw materials for their construction [63]. Intragenerational equity in energy justice serves as a way of drawing attention to the need to ensure that all people have access to energy services [55,64]. Inter-generational justice is concerned with ensuring that choices made in the present do not cause future injustices for the coming generations. Both intra and inter-generational justice issues can be exemplified in the phasing out of fossil fuel technologies in Germany [65].

2.3. *The Capabilities Approach*

A normative approach to human welfare which can be used to enrich the concept of energy justice [66] is the capabilities approach (CA), initially conceived of by Amartya Sen [27] . The CA is used as an alternative way of evaluating human development to economics based methodology (such as GDP). In the context of a fair transition, the CA is of particular use as it can be used to determine what is fair and how to ensure that the needs of all citizens are considered at the very least. Sen [27] combines both economics and philosophy in order to determine how justice may be measured, recognizing diversity in both peoples' needs and abilities to make use of their resources.

The concept is based on subjective wellbeing, and the notion that people should have lives with choices and actions that they personally value (beings and doings, referred to as functionings). Thus, a person is given the option to make choices (referred to as capabilities) that result in valued functionings. The CA was further developed by Nussbaum [26], who contrary to Sen, provided a list of capabilities that are necessary for a full and valued life, and this list has been operationalized in the context of energy justice by different scholars [67,68]. One way in which the CA can be incorporated into energy justice discussions is through the use of the doughnut economics framework, which calls for both a minimal social foundation and the recognition of an ecological ceiling as the basis from which full and valued lives can be enjoyed.

2.4. *Doughnut economics*

The doughnut economics model (Fig. 4) [69,70] could be considered to build on the capabilities approach in that it takes into account a social foundation which is necessary for human prosperity. However, it also takes into account an ecological ceiling based on the numerous life-supporting natural systems. In order to prosper, the doughnut model calls for all human activity to take place in the "safe and just space for humanity" between the social and ecological boundaries. The doughnut economics model is gaining in popularity and has been adopted by the city of Amsterdam in 2020 [71] as a template for the future, focusing on what this would mean both locally and globally in terms of both the social foundation and ecological ceilings [72].

Figure 4 Doughnut economics model [73]

The implications of the doughnut economic model for PEDs have been explored to some extent [74] but there has been little research into how this may apply to energy poverty.

2.5. *Energy poverty and energy vulnerability*

A clear form of energy justice is the phenomenon known as energy poverty. Energy poverty, sometimes referred to as fuel poverty, is often understood as a household being unable to access sufficient energy to meet their needs, and is connected to high prices, low income and poor energy efficiency of homes and appliances [39]. This is a multidimensional concept [75,76], with different factors often intersecting to result in energy poverty. Until 2019 energy poverty in Europe was a problem that affected at least 36 million Europeans. Since the onset of the COVID19 pandemic, energy poverty is an increasingly growing problem [77,78] and hence mitigation policies are likely to become more prominent, particularly in the light of the rapidly escalating energy prices caused by an overdependence on Russian oil and gas following the invasion of Ukraine [79].
Furthermore, there is no official definition of energy poverty in many European nations, and differing definitions are used in different places [80].

The term energy vulnerability is preferable to the term energy poverty for a number of reasons. First, for the person living in these conditions, the term energy poor or energy poverty is value laden and there is some stigma attached to this label [67]. Second, using the term energy vulnerability allows for the consideration of energy poverty as a state of precarity affected by the dimension of time. People are not necessarily perpetually energy poor, and there is a time element to the term, with people drifting in and out of the different official definitions which exist in different European nations.

Thomson et al [81] build on a series of energy vulnerability factors to consider, which were originally proposed by Bouzarovski and Petrova [82] (see Fig. 5).

Factor	Driving force
Access	Poor availability of energy carriers appropriate to meet household needs.
Affordability	High ratio between cost of fuels and household incomes, including role of tax systems or assistance schemes. Inability to invest in the construction of new energy infrastructures.
Flexibility	Inability to move to a form of energy service provision that is appropriate to household needs.
Energy efficiency	Disproportionately high loss of useful energy during energy conversions in the home.
Needs	Mismatch between household energy requirements and available energy services; for social, cultural, economic or health reasons.
Practices	Lack of political recognition or knowledge about support programmes, and ways of using energy efficiently in the home.

Figure 5. Energy vulnerability factors summary from Thomson et al [81].

These factors are further explained within the context of PEDs in paper 4 (Hearn, 2022). They can be used to understand and determine vulnerability to energy poverty, particularly when combined with an energy justice framework, as I do in paper 4 (Hearn, 2022). Further, energy vulnerability can be understood within the context of the doughnut economics framework as I present in paper 5 (Hearn et al 2022).

I bring these theoretical foundations together through my research by first creating a framework normatively based on the capabilities approach. This is combined with the main energy justice tenets, and presented through the use of a livelihoods-informed model which allows for the examination of opportunity spaces. I focus on energy vulnerability as a form of energy injustice and build a framework of vulnerability based on the doughnut economics model informed with the livelihoods-based CA energy justice framework.

3. Presentation of the papers

The aim of this chapter is to give a brief overview of the main focus, the methods used and the results obtained in each of the five papers which form part of this cumulative dissertation. Furthermore, I give a short description of the research process and the author contributions. The original research papers are appended to the synopsis (see Appendix).

3.1. *Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. [31] (Paper 1, Hearn Burger, Sohre, 2021)*

The first paper is published in *Energy Research & Social Sciences*. The paper aims to provide a novel framework for ex ante assessments of justice in PEDs, using the Hunziker Areal in Zurich as an example. This paper emerged from justice research where I specifically focused on the capabilities approach and how this may be applied in order to create a framework which my other papers build upon.

3.1.1. Summary

The paper adapts and applies a livelihoods based capabilities framework [83] to the case of PEDs, using an energy justice basis, to create a conceptual framework. This can be used to determine the main justice-related issues for the creation of PEDs (Fig. 6), contributing to the discussion on how to frame clusters of technological innovations such as PEDs so that they may better contribute to a just transition.

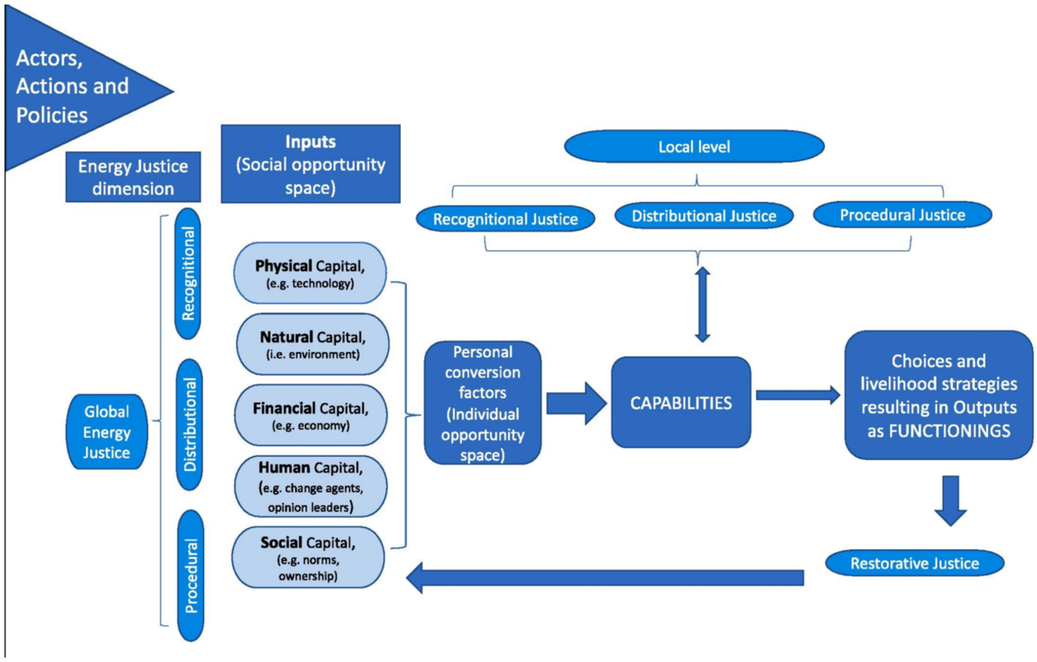

Figure 3 Livelihoods based capabilities approach energy justice framework based on Lienert-Burger 2015 [83].

The paper's main strengths are in providing a normative approach to a just energy transition, through the proposal of a framework that incorporates both low carbon innovations and energy justice. This kind of research has been underrepresented in the literature and there was no existing framework at the time. The paper notes that energy justice issues need to be considered if PEDs are to be recognized as part of a just transition, and that living spaces have an influence on wellbeing hence the use of the CA as a normative framework. The framework is not a full framework in that it does not include individual wellbeing, but focuses on the opportunity spaces which give rise to the potential for wellbeing. In order to make this into a full framework, further research (e.g., through the use of surveys) on individual levels of wellbeing would be required but this was not practical given that most PEDs are still in their early development and the COVID pandemic made such research less feasible.

The aim of the paper was to provide a robust theoretical basis to energy justice issues in PEDs, in order to examine these emerging innovative districts to ensure that they do not simply take a market-based approach but genuinely provide inclusive living spaces. This adds to energy justice research whilst also encouraging the consideration of justice issues in PED planning and development.

3.1.2. Research process and author contributions

The paper was co-authored with Annika Sohre and Paul Burger who both contributed to the structure and manuscript drafting. I conceived of the idea for this paper, developed the analytical framework, conducted interviews and wrote the first draft of the manuscript. All three authors shape the research and edited the final manuscript.

3.2. *Towards a Just Energy Transition, Barriers and Opportunities for Positive Energy District Creation in Spain [84] (Paper 2, Hearn and Castaño-Rosas, 2021)*

The second paper is published in a special issue of *Sustainability*, as the outcome of a secondment (Feb-June 2019) at the University of Carlos III, Madrid. This emerged from a collaborative response to a public consultation on energy communities in Spain (17th Nov-2nd Dec 2019), which is also published online (in Spanish, not peer reviewed [85]). I conducted semi-structured interviews online through zoom, which formed the basis of the article. The novelty of this paper is in analysing PED barriers and opportunities based on the energy justice livelihoods-based capabilities framework which was published in paper 1 (Hearn, Sohre, Burger, 2021). This analysis enabled the identification of previously undocumented barriers and opportunities.

3.2.1. Summary

This paper sets out to shed light on the PED landscape in Spain, where there were four official PED projects at the time of research. In total I conducted expert semi-structured interviews with 13 stakeholders involved in PEDs or renewable energy projects, which were recorded, transcribed and translated into English, and were uploaded to the FORS (Now SWISSUbase) data bank under FAIR principles (Findable, Accessible, Interoperable, Reusable).

A number of barriers and opportunities were apparent from the literature review. However, the legal situation regarding RECs is in a state of transition as European directives are brought into the national legal framework, and the interviews were able to allow for the identification of previously unresearched barriers and opportunities.

The results show that although there is potential for PEDs to form part of a just transition, there are significant barriers which need to be addressed. One of the novel barriers identified is that people who are given a social tariff for energy prices (those that are officially identified as energy poor) are in effect excluded from participation in any community energy initiative as these are legally not permitted to offer this tariff. Furthermore, it revealed that at the time of research, the term PED was not one that stakeholders were familiar with even if they were working in districts officially designated as PEDs.

The paper uses the framework that was developed in Paper 1, and notes a number of barriers to fair PED creation in respect to the capitals. Natural barriers related to climate change already limit the use of hydropower even in places where this has been used in the past. However, the number of sunlight hours on the Iberian Peninsula make PV a suitable form of energy generation, provided that storage can be addressed. Physical barriers included the lack of district heating/cooling, hence the need for these to first be created and installed, with associated higher costs. This linked in to financial barriers, where stakeholders reflected intense debate on whether a PED model of decentralized energy production made sense when the installation costs of this are likely to be significantly higher than larger, utility-based PV and wind farms. Human barriers included numerous references to conflicts within multi-home buildings and emphasized the difficulties in coming to a consensus for simpler decisions, let alone energy sharing. Furthermore, results indicated a need for impartial intermediaries (such as town councils) who can advocate on behalf of those who are most vulnerable, and who are not always involved as equal partners (e.g., the PED in Paterna, Valencia is privately owned by one individual as a for-profit venture).
Social barriers mainly focused on the lack of trust in what many perceive to be a very corrupt sector, and lack of information, as well as barriers to participation brought about through opaque processes.

The paper concludes, reiterating that there is a need for a national strategy to enable the rapid deployment of PEDs, and that there is the potential for PEDs that include RECs to support energy poverty mitigation.

3.2.2. Research process and author contributions

I submitted a successful application for ethical approval and a data management plan to SMART-BEEjS. I conducted a literature review on community-owned energy projects in Spain and identified a series of barriers and opportunities that had already been researched prior to conducting interviews. I completed formal analysis, investigation conducted interviews, transcriptions, translations and data curation alone, as well as an initial draft preparation. Dr. Castaño-Rosas assisted with conceptualization, reviewing and editing the final paper.

3.3. *Preferences for configurations of Positive Energy Districts– Insights from a discrete choice experiment on Swiss households [33] (Paper 3, Mihailova et al, 2022)*

The third paper is published in *Energy Policy*. This paper is based on a discrete choice experiment (DCE) conducted as part of the Swiss Household Energy Demand Survey (SHEDS) in 2020.

The paper identifies consumer preferences for PED creation, based on a series of hypothetical choices respondents made when presented with several PED configuration options. Engaging prospective citizens in the design of future communities can allow for tailored value propositions to a diversity of preferences. Further, while previous studies have used discrete choice experiments to investigate preferences for individual technologies, no study had yet investigated the holistic package that PEDs represent. This paper's contribution lies in the policy recommendations it makes regarding PED development. The main policy implications derived from this research are that PEDs can and should be tailored to differing populations in order to ensure wider voluntary uptake. It is also suggested that policymakers should consider multiple pathways to meet mobility needs, and actively engage citizens in re-imagining urban areas for the future.

3.3.1. Summary

The paper provides findings from a discrete choice experiment (N = 1486) investigating different PED configurations, created from existing PED-like areas. Under the premise that the PED is a socio-technological innovation, we used the discrete choice experiment methodology to gather end-user feedback for future PED development. Thus, PEDs were positioned as final product, made up of a variety of configurations.

In the experiment, respondents were asked to make choices between hypothetical PED configurations made up of three attributes: ownership of renewable energy technology and expected citizen participation, mobility options and available shared spaces options. These attributes were chosen based on six PED-like renewable energy projects (see Appendix A1 in Mihailova et al., 2022 for more details). The result of the experiment yielded five segments of preferences that were described by socio-demographic and psychographic variables, including car and home ownership, age, household size, and values. Mobility considerations were shown to be an area of particular concern to respondents.

Although the survey was conducted in Switzerland and thus results need to be considered within the national framing of the survey, it is possible to deduce that mobility may be even more important in countries that have less well-connected public transportation systems than Switzerland, particularly in countries where transport poverty is greater [37,86,87].

3.3.2. Research process and author contributions

The paper is co-authored by Darja Mihailova, Iljana Schubert, Adan L. Martinez-Cruz, Annika Sohre and myself. I participated in the developing of the idea for the paper, conceptualization, methodology, and development of the SHEDS experiment. The first draft was written by Darja Mihailova, and was reviewed and edited by us all. Most of the statistical analysis was conducted by Darja Mihailova, Adan L. Martinez-Cruz and Iljana Schubert. All authors helped to develop the focus of the paper, shaped the research, read, and approved the final manuscript.

3.4. *Positive Energy District Stakeholder perceptions and measures for energy vulnerability mitigation (Paper 4, Hearn, 2022)*

The fourth paper is a single author paper based on qualitative research, published in *Applied Energy*. The paper aims to contribute to energy poverty research through the use of semi-structured PED stakeholder interviews, in order to determine how the topic of energy vulnerability mitigation is perceived and acted upon. This paper addresses the gap in social sciences research on energy vulnerability and PEDs, specifically addressing the call for research into the need to identify and evaluate energy transition models that are more inclusive [88] at a district level [89].

3.4.1. Summary

Most research conducted on PEDs to date has focused on techno-economic aspects such as their stated goals of decarbonization. However, PEDs are meant to be guided by principles such as sustainability, inclusiveness and quality of life, but there is little research on how these principles are applied. I conducted 20 interviews with different PED stakeholders in Italy, Spain, Germany, Belgium, Czechia, Netherlands, Austria, Finland and Sweden, in order to understand how these projects consider energy vulnerability in light of the PED guiding principles.

I divided countries into low, medium and high in terms of energy poverty as measured using the self-report indicator: “Are you able to keep your home adequately warm?” (As reported in the Eurostat survey of Statistics on Income and Living Conditions (SILC) data for 2019).

The results show that the greater the level of energy poverty reported in a country, the more likely that PED stakeholders are planning or taking action to address this. However, more importantly, all stakeholders see a huge potential for PEDs to mitigate energy vulnerability, particularly in light of the energy price rises following the COVID19 pandemic.

In terms of affordability of homes and energy supply, the inclusion of social housing and the use of locally generated renewable energy combined with high levels of energy efficiency will have a mitigating effect of energy vulnerability for residents. Access and affordability of retrofitting programmes are crucial elements to consider if PEDs are to play a role in mitigating energy vulnerability, and this will become all the more important as PED replication is likely to occur in existing districts as well as new-build tailor-made districts (new districts make up less than 1% of housing in Europe each year). Current retrofitting in Europe is approximately 0.4-1.2% of total building stock [90], but the European Green Deal calls for a renovation wave of a minimum of at least double this [91], and retrofitting entire districts into PEDs would help in meeting multiple Green Deal targets. Although there has been some research into the effect of this on energy poverty [92], how this is to be financed is still not clear and different PEDs had widely differing solutions.

Another major focus of the paper is the area of energy flexibility and access, which I connect to the creation of renewable energy communities (RECs) which I had focused on in paper 2 (Hearn and Castaño-Rosas, 2021). RECs are not currently permitted under national legislation in many European countries but European directives [93] mean that these will shortly become interesting possibilities. This was particularly so for the case of Milan, where one of the stakeholders explained that a series of energy communities were planned specifically to help reduce energy poverty and provide power to those that are most vulnerable, through the use of public roof spaces.

The paper notes the importance of defining the guiding principles for PEDs to ensure that these are taken into account, at the very least for any form of inclusive PED replication.

3.4.2. Research process

I built on the literature searches that I had conducted for Deliverable 5.3 to conceptualise this paper. I presented the concept in the *Sustainability Science Research Colloquium* at the University of Basel in October 2021, and at a paper writing retreat in Nice (November 2021) where I got initial feedback.

3.5. *Redefining Energy Vulnerability, considering the future (Paper 5, Hearn et al, 2022)*

The fifth paper is a mixed methods paper, based on data gathered from 1486 respondents in SHEDS 2020, and interviews with 8 stakeholders which were carried out as part of an ethically approved SMART BEEjS foresight report [14]. One of the major contributions of this paper was in the application of the doughnut economics framework to energy vulnerability, giving rise to a new definition of energy vulnerability, which is conceptually robust. The new definition of energy vulnerability includes the notion that the use of non-renewable energy sources in the present may increase energy vulnerability in the future (Fig. 7).

3.5.1. Summary

The aim of this paper is to provide additional insight into energy vulnerability, and to emphasize the need for an understanding of this as a form of capabilities deprivation. The paper uses Switzerland as a case study.

One of the contributions from this paper is in providing a conceptual framework for energy vulnerability which includes inter-generational considerations owing to the use of fossil fuels both currently and in the past. Quantitative results show that energy poverty is an issue, and qualitative results indicate that energy vulnerability is a phenomenon which has not been given much attention in the case of Switzerland, where there are no policies to specifically target this. To investigate the issue of energy poverty in Switzerland, we specifically asked energy poverty questions in SHEDS:

- Are you able to keep your home sufficiently warm in winter?
- Are you in arrears on your utility bills?
- Do you think you spend more than 10% of your income on heating in winter after rent/mortgage payments?

These three measures are used widely as measures of energy poverty, but there is no consensus as to how energy poverty or vulnerability should be defined in Switzerland. We defined somebody as energy vulnerable if they answered affirmatively to any of the three energy poverty questions. Our results show that there is a group of people who could be referred to as energy vulnerable in Switzerland, with 177 (11.9%) answering affirmatively to at least one of our measures (19 respondents answered positively to two measures).

We also referred to SILC data which is gathered for Switzerland, and which showed very different results to ours, namely in that only 0.2% of SILC Swiss respondents were unable to keep their home adequately warm in 2020 compared to 3.9% of SHEDs respondents in our sample. The almost twenty times difference can be explained by the phrasing of the SILC question on keeping the home adequately warm in Winter. Rather than the "yes/no/prefer not to answer" responses included in SHEDS, the Federal Office of Statistics (FSO offers three possible responses: "Yes", "No, due to financial reasons" or, crucially, "No, due to technical reasons". The FSO then removes any of the responses which are "No, due to technical reasons", under the premise that SILC gathers data on material deprivation and that because the inability to heat the home properly is not financial it should be discarded. Thus, the statistics for this question for Switzerland show a reduction from 7.5% in 2010 to only 0.8% in 2011, with a continuous drop since then.

Following on from our quantitative data analysis, it seemed clear that the issue of energy vulnerability was closely connected to energy efficiency measures, and so we conducted a series of 8 semi-structured interviews with stakeholders, which were part of a SMART-BEEjS foresight report, in which we were able to ask about different energy efficiency and renewable energy policies, uptake and how this may affect energy vulnerability. The interviews detailed how inter-generational energy vulnerability can be mitigated through energy efficiency improvements, as well as highlighting the risk of summer energy vulnerability in Switzerland, which may increase due to climate change.

The definition we settled on was that those who are energy vulnerable are *"those that are identified as energy poor as well as those at risk of falling into energy poverty both in the present, and in the future."* We applied the same capitals that had been used in paper 1 (Hearn, Sohre and Burger, 2021) in our framework and analysis, providing a novel and hitherto unexamined perspective (Fig. 7).

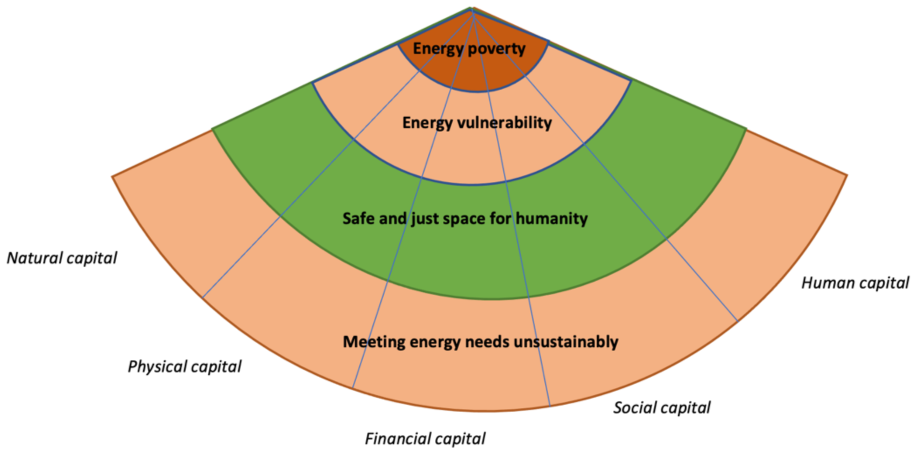

Figure 7 Situating energy poverty and vulnerability in the doughnut economic model, author's own elaboration (included in paper 5)

3.5.2. *Research process and author contributions*

This paper is co-authored with Darja Mihailova, Iljana Schubert and Annika Sohre. We presented the energy poverty questions forming the basis of this paper at a SCCER CREST meeting in November 2019 and these were accepted into SHEDS for 2020. Quantitative data was presented at the Sustainability Colloquium in Basel on several occasions as we conducted our analysis, and a final presentation including this data was given at the Swiss Social Sciences and Humanities energy research workshop in June 2022. I led in developing of the idea for the paper, conceptualization and methodology. Interviews were conducted by Darja Mihailova and myself. I coded the interviews and wrote the first draft of the paper, which was reviewed and edited by all authors. All authors helped to develop the focus of the paper, shaped the research, read, and approved the final manuscript. The paper was accepted in July, and published 8th August 2022.

3.6. *Other scientific papers*

Although the focus of the PhD has been on peer-reviewed scientific published papers, the SMART-BEEjS project required participation in the creation of a number of deliverables which were not peer-reviewed.

I was second author of Deliverable D5.3 *Evidence-based policy propositions to tackle energy poverty through PEDs* [94], published in July 2021. I was also a contributor for Deliverable D6.4 – *Value Generation Systems for PEDs: Archetypes for a Networked Europe, 2040: Foresight Report* [95] for which I participated in discussions regarding the conceptualization of the deliverable and co-conducted interviews in Switzerland in order to co-produce the Swiss part of the foresight report.

Furthermore, I suggested literature and edited language and content on *Deliverable D3.2 Socio-economic factors & Citizens' practices, enabling Positive Energy Districts Challenging 'silo thinking' for promoting PEDs* [96]. I also assisted in editing and suggesting literature for *Deliverable D4.2 – Status quo and framework conditions as a basis for developing techno-economic pathways in selected case studies* [97]. Additionally, I drafted initial versions of *Deliverable D5.2 – Development of a Standardised Method for Impact Evaluation of PEDs* [98].

The deliverables provided an opportunity to collaborate and discuss with other PhD candidates and researchers. However, because these are not published in peer-reviewed journals Deliverable D5.3 is in the appendix but is not discussed further.

4. Discussion of the results according to the research questions

In this section I discuss the results for each research question, drawing from the five published papers.

4.1. *RQ1: What are the main energy justice and wellbeing related elements that need to be accounted for to ensure PED-like areas are part of a just transition?*

In order to truly account for energy justice and wellbeing within PEDs, an approach that relies on purely economic measures is deemed to be insufficient. There is significant literature [99,100] that suggests replacing measures such as GDP with more nuanced evaluation methods based on the capability approach. Indeed this can be illustrated by the Human Development Index (HDI) for which the dimensions measured are health (measured through metrics such as life expectancy), knowledge (measured through mean years of schooling) and standard of living (measured through GDP per capita) [101]. The basis of the HDI is the capability approach, which is what I used to create a framework for the ex-ante assessment of justice issues in PEDs in Paper 1 (Hearn, Sohre, Burger, 2021). This first paper focuses on just PED creation, or the *policy* aspects, with the distinct goal of just PED creation, very much addressing RQ1.

This framework from this paper is divided into 5 capitals which need to be examined in order to ensure that PEDs can be incorporated as part of a just transition. The main justice and wellbeing considerations of PEDs are also covered to some extent in Paper 2 (Hearn and Castaño-Rosas, 2021), but specifically with regards to Spain. Further to this, the paper identifies a distinction between energy justice and climate justice in the form of how rapid decarbonisation is to take place. Climate justice requires the perception of a climate emergency which necessitates immediate and robust action. As such, the implementation of large-scale PV and wind farms is likely to be more affordable, easier to deploy, and considerably faster. This type of action does not necessarily mean that energy justice does not occur, but certainly makes this less likely, because using existing energy suppliers is more expedient than creating multiple new community owned projects. Moreover, the paper notes that powering all urban areas renewably in situ is not currently possible, with studies estimating that Catalonia could for example produce half of the required energy within urban areas. However, this is still a significant amount of energy, and the additional benefits of local production are manifold. In terms of energy justice, the use of small-scale energy generation, be this via individual prosumers or collective energy production through RECs, allows for greater energy democracy and could have an effect on mitigating energy poverty. This is likely to result in the creation of more jobs and have a stimulating effect on local economies.

The third paper (Mihailova et al. 2022) provides insight into justice and wellbeing preferences for Swiss respondents to a discrete choice experiment conducted in SHEDS 2020. Although the justice considerations in this are not overt, respondents were asked who they would prefer to manage PV within a PED, and ownership of renewable energy production, bringing in elements of justice that can be at the very least inferred. Respondents asserted heterogenous responses for the managing of PV within a PED, with utility company, cooperatives and private management all rating highly. Offering some sort of combination of these would likely enable greater levels of wellbeing and incorporating cooperative forms of management would also enhance the prospects of these districts being energy just. The preference for different characteristics of PV ownership indicates that offering a choice of private, with some cooperative and some utility ownership may enhance acceptance of new PEDs for potential residents. Furthermore, the availability of multiple mobility options was also very highly rated by respondents and planning for these may also help to enhance wellbeing.

Paper 4 (Hearn, 2022) calls for the inclusion of those that are energy vulnerable in PEDs, and examines the different policies that are already in place to ensure that PEDs are inclusive and affordable. One of the results is that PEDs in nations with higher levels of self-reported energy poverty tend to have given more consideration to ensuring that districts are inclusive.

Further, Paper 5 (Hearn et al, 2022) gives a novel definition of energy vulnerability, which includes the need for energy to be produced as renewably as possible in order not to create inter-generational injustices or energy vulnerability in the future. Although this paper does not directly address this research question, the energy vulnerability definition it provides may be seen to encourage the creation of inclusive PEDs for the future.
Answering this research question also helps to meet the aim of contributing to a shift away from discussions on the energy transition and towards an inclusive energy transition.

4.2. *RQ2: What are existing barriers to PED creation as part of a just transition?*

The first paper (Hearn, Sohre, Burger, 2021) goes some way towards providing a framework that can help to identify barriers to justice informed PEDs. Thus, the second paper (Hearn and Castaño-Rosas, 2021) builds on this framework and focuses specifically on the stakeholders involved in PED and REC creation in Spain, exploring the *politics* aspect as mentioned above. This paper (Hearn and Castaño-Rosas, 2021) revealed that the barriers to justice and wellbeing considerations also need to be taken into account if PEDs are to be truly inclusive. Whilst there were novel barriers revealed in the creation of justice informed PEDs, some of these are case specific and only applicable to Spain, such as issues with the legal processes and the numerous institutions (the *polity* aspects). One such clear example, outlined in the paper, is the issue surrounding the social tariff which is only available to those who are recognised as living in energy poverty and who are customers of one of the major energy providers. Those that are with any of the smaller providers are excluded. Notwithstanding this, the issue of legislative barriers remains salient in different countries, although naturally the exact set of barriers is likely to differ. Conversely, Spain has been quick to adopt EU directives regarding RECs compared to countries such as Germany, Austria, Finland or Sweden, where energy-sharing of the sort which is to occur in RECs is still not fully permitted.

Some potential barriers are also clear from responses to the discrete choice experiment in the third paper (Mihailova et al, 2022) as some strong preferences were expressed. For example, respondents in segment 1 were labelled car defenders and expressed a clear preference for individual private mobility options. Unless consumer preferences are taken into account, these can function as barriers to PED creation, and may result in swathes of the population deliberately self-excluding from becoming residents.

The fourth paper (Hearn, 2022) provides a more international set of responses regarding barriers to the creation of just PEDs noting that the lack of official definitions for PED guiding principles may lead to confusion and greater disparity between PEDs. In order to ensure that PED creation can truly form a part of a just transition may mean that these need to be defined fully and clear steps outlined for their inclusion in PED design. Answering this research question also contributes to the first aim of this thesis, to shift the discussion towards a more inclusive energy transition.

4.3. *RQ3: What PED-like attributes do citizens prefer?*

For this research question, Paper 3 (Mihailova et al,2022) provides the greatest insight from Swiss respondents, but not solely from PED residents. However, a site visit of the Hunziker Areal PED in Zurich took place in November 2019 and provided an opportunity to speak directly with residents. This was followed with interviews conducted for papers 2, 4 and 5, with PED stakeholders who were able to share what they believed were the preferred attributes. A 10-day residential stay in a PED in Amsterdam in April 2022 further helped to bring understanding to this research question. The attributes preferred by citizens are clearly varied and the heterogeneity of PEDs makes this harder to definitively answer. The Hunziker Areal which was used as a detailed example in Paper 1 (Hearn, Sohre and Burger 2021) is cooperatively run and private spaces are limited. Although the district is has a waiting list for future residents, results from Mihailova et al (2022) clearly show that there is a segment of Swiss society that is not in favour of living in districts that are run by such cooperatives. Furthermore, results from the DCE published in Mihailova et al (2021) show that for the case of Switzerland multiple population segments can be identified with varied preferences, ranging from those that are staunch car defenders to those that would prefer cooperative-run living and greater public transportation options.

Until the number of implemented PEDs rises, gaining insights into residents preferences remains difficult. In interviews conducted for Paper 4 (Hearn, 2022) stakeholders (e.g., Amsterdam) revealed that co-creating new districts with residents is complex, with citizens from nearby areas being used as a proxy for residents in the district. In Paper 2, (Hearn and Castaño-Rosas, 2021) one PED in Spain detailed how future residents are able to help co-create the district, but that in order to do so a non-refundable deposit on future accommodation is necessary, hence excluding those that are unable to afford this. The stakeholders reported that earlier workshops and meetings to discuss co-creation had occurred without this requirement and therefore they believed that their own inclusion criteria had been met.

4.4. *RQ4: What are the characteristics of energy vulnerability?*

I discuss the characteristics of energy vulnerability in both Paper 4 (Hearn, 2022) and Paper 5 (Hearn et al, 2022). In Paper 4, I examine the main factors of energy vulnerability based on the literature, noting that access to energy and differing suppliers, affordability, flexibility, efficiency, mismatched needs and a lack of recognition and support are considered to be the main factors (See Fig. 5, [81]). However, I expand on this in Paper 5 (Hearn et al 2022) where the doughnut economics framework is used to create a new framing of energy vulnerability, which incorporates energy vulnerability caused for future generations through the use of unsustainable energy sources. This framing of energy vulnerability is likely to gain considerable traction as the unwanted effects of climate change become more marked in the form of extreme weather events. The increasing popularity of the doughnut economics framework, which was adopted by the city of Amsterdam in 2020 [71], may also mean that this framework of energy vulnerability continues to be developed. Answering this research question also meets the aim of creating a conceptual framework that overtly connects SDG7 (access to clean and more specifically affordable energy) to energy vulnerability. Although this framework does not directly contribute to the second aim of demonstrating that PEDs show potential as policy instruments to both reduce energy vulnerability and decarbonize the energy system, it does set the basis for answering this by providing a clear definition of energy vulnerability.

4.5. *RQ5: What are the drivers of energy vulnerability in the case of Switzerland?*

The use of Switzerland as a case study in Paper 5 (Hearn et al 2022) provides a rich and detailed amount of hitherto unresearched and unpublished information on energy vulnerability in Switzerland. There is no Swiss definition of energy poverty, and so multiple indicators that are used in different countries were gathered through SHEDs in order to create an energy vulnerability measure. Using this measure, it can be said that drivers of energy vulnerability in Switzerland are income and age, with higher incomes and older respondents being less likely to be energy vulnerable. However, the caveat here is that

SHEDs is completed online and there were very few elderly respondents (80 and above), and it is possible that the very elderly become energy vulnerable once more. From the data we gathered it would appear that younger people in rented accommodation were most likely to be energy vulnerable, with no significance measured for gender differences, rural-urban differences or household size. We had hoped that the SHEDS dataset would reveal a "smoking gun" of drivers for Swiss energy vulnerability but this was not the case. We can speculate that one of the main drivers is poor quality building stock, based on interviews with different Swiss stakeholders. However, there was insufficient data in SHEDS on building efficiency for us to determine that this was as significant as we believe it to be. Answering this research question also connects to the first aim of the thesis; by connecting energy vulnerability to forms of energy production that are unsustainable I help to contribute to the shift towards a more inclusive transition.

4.6. *RQ6 How is energy vulnerability perceived by stakeholders in different PED contexts?*

This research question was largely answered by both Paper 4 (Hearn 2022) and Paper 5 (Hearn et al 2022). Paper 4 specifically set out to answer this research question through the use of stakeholder interviews. Furthermore, Paper 5 also used interviews for the case of Switzerland, and was hence also of use in providing an answer to this question, particularly as two of the stakeholders interviewed were directly involved in Swiss PED projects. PED stakeholders in countries with low levels of energy poverty were detached from the issue and did not perceive it to be problematic, on a national, regional or a district level. In the case of Finland, one stakeholder claimed that the energy poor in Finland were only rural elderly people, and a Swedish stakeholder claimed that there was no energy poverty in Sweden. Of the two Swiss PED stakeholders interviewed, neither believed that energy poverty was an issue at the district level, and both seemed to think that this was not a serious issue in Switzerland. This was echoed by other Swiss energy stakeholders who did not work in PEDs. In countries with mid-levels of energy poverty, stakeholders perceived multiple benefits as possible in tackling both decarbonization and energy vulnerability through PED creation, and rising energy costs made PED creation all the more appealing as a cost-effective way to target both of these major policies.

4.7. *RQ7: Which measures are used (or planned) in order to mitigate vulnerability to energy poverty in PEDs?*

Paper 4 (Hearn, 2022) divided stakeholders into three separate groups depending on self-reported levels of energy poverty, based on a household' s ability to keep the home warm in winter. Countries where energy poverty was high and where targeted measures already exist to tackle this issue were at the forefront of those looking at how PEDs could mitigate energy vulnerability. Multiple different measures were reported in both Spain and Italy in order to mitigate energy vulnerability. In the case of Spain, one consumer rights energy charity was also campaigning to use the term energy vulnerable rather than energy poor in an effort to reduce stigma. Countries with mid-levels of energy poverty also reported a number of measures that could mitigate energy vulnerability, from inclusive forms of financing for retrofitting, through to the inclusion of energy sharing and social housing in PEDs. Countries with very low levels of energy poverty reported the least number of measures to mitigate energy vulnerability, but even so Swedish and Finnish PEDs incorporated affordable (but not social) housing.

4.8. *Overarching RQ: In what ways can PED-like areas be considered a part of a just transition that leaves no one behind?*

PEDs currently remain a niche development, and as such form a very minor part of the energy transition. However this is set to change and there is significant impetus behind plans to replicate PEDs all across Europe. In Paper 1 (Hearn, Sohre, Burger, 2021) the case of the Hunziker Areal is detailed, which shows that PEDs can be a part of a just transition. However, the Hunziker Areal resulted from 30 cooperatives coming together and co-creating a district, giving careful thought to measures to ensure this is as inclusive as possible. In Paper 2 (Hearn and Castaño-Rosas, 2021) I detail a number of the barriers that prevent PEDs and RECs from being inclusive in the case of Spain, but a clear argument is made that there is significant potential for such innovative districts to be a part of a just transition. Paper 4 (Hearn, 2022) takes this further by examining how the PED guiding principles are applied, and finds that for some PED projects these are relegated to buzzword status that have little meaning. PEDs such as the Reininghaus project in Graz, Austria, are governed by market principles, and the focus is almost entirely on the technological aspects of reaching net positive energy. Although such a district most definitely contributes to the energy transition, its lack of social or low-cost housing and reliance on market forces makes it relatively exclusive. However, even here, if PEDs are taken to be a concept rather than just an empirical reality, the effect of seeing this concept in operation may act as a stimulus for further changes, and have a much wider effect than in the PED itself. Seeing PEDs as a lever for stimulating social change was identified by a PED stakeholder in Brussels, who indicated that this was as important as achieving energy positivity.

On the other hand, there are multiple PED projects such as in Bilbao, Spain, or Milan, Italy, where significant effort is being made to ensure that the districts include people from a variety of socio-economic backgrounds, and these PEDs can be said to contribute to a just transition. If this is the format of PEDs that are replicated in the future, there is no doubt that they will contribute to a just transition.

The tension between the need for rapid decarbonisation and the need for an inclusive transition highlights the need to broaden the debate, ensure greater citizen participation and engagement of vulnerable groups in order to responsibly decarbonise [102]. The rapid replication of inclusive PEDs could contribute significantly to the socially just decarbonisation of urban areas.

5. Scientific and societal relevance, limitations and scope for further research

This chapter outlines the scientific relevance of this dissertation, its novelty and its contribution to sustainability research. Furthermore, I point to limitations as well as prospects for further research. The chapter concludes by stating the societal relevance of the findings obtained in this dissertation.

5.1. *Scientific relevance*

This dissertation aims to contribute to energy justice debates by highlighting the potential role of PEDs in bringing about a transition which is inclusive and "leaves nobody behind". This connects directly to the UN 2030 Agenda for Sustainable Development [103], on eradicating poverty, ending discrimination and exclusion and reducing inequalities, which is echoed throughout the EU [104,105]. The contribution to research is most notably through its aims:

- To contribute to the shift in the energy discussion from a focus on the energy transition, to a focus on an inclusive energy transition.
- To contribute to energy poverty research by demonstrating that there is a potential for PEDs to become policy instruments that combine both decarbonization and energy poverty mitigation.
- To create a conceptual framework that overtly connects SDG7 (access to clean and more specifically affordable energy) to energy vulnerability, as this does not currently exist.

The shift in energy transition debates towards a more socially inclusive transition is an important one, particularly in light of the global climate emergency which is increasingly being recognized. Indeed, shedding light on the tension between the need for rapid decarbonization and an inclusive transition highlights this issue and contributes to the scientific discourse on transitions. The scientific contribution to energy poverty research is in both adding PEDs as a subject matter for such research as well as reiterating overlaps in aims of decarbonisation and energy poverty mitigation. This contribution is further strengthened by the creation of a conceptual framework in Paper 5 that brings together notions of sustainability and energy vulnerability. Furthermore, this thesis contributes to the knowledge gap in energy vulnerability data for Switzerland, which in turn provides the basis for the argument that the energy vulnerable, both in Switzerland and beyond, suffer from misrecognition.

Overall, the five papers have significant scientific relevance because they provide a novel and coherent approach to PEDs. The significance of this approach can also be illustrated through the number of citations that these articles have already received- noting that the first paper was published in Summer 2021, by July 2022, excluding self-citations, Paper 1 (Hearn, Sohre, Burger, 2021) had been cited 11 times, Paper 2 (Hearn and Castaño-Rosa, 2021) had been cited 7 times, and Paper 3 (Mihailova et al., 2022) had been cited twice. Although these figures may not seem high, given the very short time span between publication of these papers and submission of the thesis dissertation they illustrate that the research is already having some scientific impact.

5.2. *Relevance to society*

In conjunction, the five papers provide a clear and coherent message: that vulnerable populations in particular need to be considered if PEDs are to form part of a just transition. Whilst addressing researchers is a given, the applied aspects of this PhD thesis are also a major consideration. Providing clear direction for policymakers by highlighting the need to incorporate justice issues in the early planning stages of PEDs may have some effect in ensuring that future districts pay more attention to different ways in which they may do this. However, some of the research also shows some conflicting results. For example, Paper 2 (Hearn and Castaño- Rosas, 2021) indicates that for the case of Spain, grid decarbonization may be more affordably carried out through largescale renewable farms (Wind, PV and solar-thermal). This reiterates the tension between the need for rapid decarbonisation and the need for inclusive policies that do not leave anyone behind. Large scale agrivoltaics [106] could reduce or complement the need for local energy generation in PEDs, specifically in places where this is unlikely to be cost effective and in the context of a climate emergency that requires rapid decarbonisation, however, ensuring that these are socially just and benefit those that are most vulnerable is not a given.

PEDs have a role to play in the decarbonisation of urban areas and it is tempting to overlook the above arguments and focus on the potential synergistic benefits of PEDs such as the creation of local jobs, the potential to reduce energy vulnerability and so on. But if we are to accept that there is an ongoing climate emergency then perhaps PEDs need to remain a niche development to be fully developed once the majority of the energy system is decarbonised.

Ensuring that PEDs are as inclusive as possible is increasingly important given that there are replication plans for all over Europe, and that potentially a significant proportion of European urban residents may be living in a PED in the future. If these districts are to be replicated and adopted as a mainstream urban decarbonization policy, they cannot neglect to represent those that are most vulnerable within them.

5.3. *Limitations of the dissertation and prospects for further research*

Although this dissertation advances energy justice research in low carbon urban developments, owing to their constant evolution it is only natural that there are many questions that still remain open. In this section I detail some limitations of my research as well as prospects for future research.

5.3.1. SHEDS

SHEDS, the large-scale survey used in Papers 3 and 5, had the advantage of providing a large number of observations, and providing a representative sample of the Swiss population (except Ticino). However, although a more general international application of the results can be inferred, this cannot be proved beyond the Swiss context. Furthermore, the timing of data collection coincided with the COVID19 pandemic and SHEDs was completed following an extended lockdown. This may have influenced responses, and delayed the onset of data collection for SHEDS by one month which may have had an effect on responses (e.g., questions on heating in winter were more removed from everyday reality as they were answered at the end of spring).

5.3.2. COVID19

Furthermore, the largest COVID19 lockdown impact on my research was the cancellation of a secondment planned in Spain where data collection was going to take place. This was replaced by an online secondment which involved conducting interviews online. Conducting interviews online invariably results in different data gathered to those conducted in person as well as some data loss through poor connections, the inability to read body language as well and a myriad of other issues. However, the interviews were conducted at a time when most people had become fairly used to working remotely, and by the time data gathering occurred for Paper four, this had become standard practice for most people. Moreover, although online interviews have their shortcomings, they also presented an opportunity in that data could be gathered from multiple PEDs around Europe, bringing a degree of richness to the research that would not have been feasible in person.

5.3.3. Local actions taken globally

With regards to the reach of PEDs, the use of net-positive districts as levers for reducing GHG emissions in urban areas is currently limited to Europe. Focusing on a city or district level makes sense given that more than 60% of global emissions are from urban areas, and more than 78% of energy globally is consumed in urban areas [107]. However, a Eurocentric approach fails to address GHG emissions elsewhere, and also fails to consider global energy justice issues (such as those that arise from the sourcing of raw materials needed for decarbonisation, as well as those that may arise from continued dependence on fossil fuels in the global South). In order to address this, I have worked as part of a group of European Climate Pact Ambassadors and will present a proposal to establish a PED programme in Africa as part of the GHG Emissions Session at the Science Summit, United Nations, General Assembly [108].

5.3.4. *Prospects for further research*

There are a number of avenues where further research is warranted and could be fruitful. Firstly, as mentioned above, creating PED programmes in the Global South would enable a range of new approaches in PED research as although there will be some crossover, successful replication on other continents will require tailoring PED design.

Further, as RECs enter into national law in different nations across the EU, these offer an interesting potential avenue for research into how these are created, by whom, and to what effect. The fact that the EU specifically calls for RECs to include the energy poor could result in these becoming embraced as a significant tool for mitigating energy vulnerability, but this really depends on the extent to which those who are energy poor are included. Despite encouraging signs from RECs in Spain [84] and Italy [109], it is also possible that greater guidance will be required if these are to become effective in energy poverty mitigation.

Transport poverty is an area of growing interest to scholars and policymakers alike [37,86,87], and this is an aspect of PED creation and replication which has not been researched so far and which may prove fertile for future research.

Ultimately, it is clear that PEDs are positioned as stepping stones on the path to carbon neutrality. A recent announcement from the European Commission [110] details the plan to create 100 carbon-neutral cities by 2030 [111], and it is no coincidence that a number of these are cities which contain PEDs in different stages of development. Research into how PEDs can be both replicated and scaled-up to city size may reveal that these are suitable levers for creating carbon-neutral cities, but could conversely show that these districts do not meet required social inclusion levels that would be necessary for scaling-up PEDs to city level.

6. Conclusion

PEDs are still relatively new concepts and although there is some political impetus behind the idea of PED replication at an EU level, this is not homogenous throughout all nations. PEDs are currently niche forms of district development and despite the push for decarbonization it is not clear if this is to be amongst the main policy routes followed, or indeed if this is to be advised. However, if there is to be PED replication beyond the original 100 districts that are due to be created by 2025, these need to consider justice issues from the start so that they are able to form part of a just transition. This is particularly important in order to avoid the creation of exclusive districts for the wealthy which may further encourage misplaced anti-green sentiment amongst those who are excluded and could be seized upon by far-right groups. Evidence pointing towards this is clear in places such as Germany where a series of posters appeared prior to the national elections accusing the green party of climate socialism, eco-terror, and wealth destruction [112].

Creating inclusive PEDs may help to reduce social inequities, increase social cohesion, and stimulate new ways of living which are citizen-led. The published papers that this thesis is based on clearly show that there is room for multiple synergistic benefits to occur if these are planned for in advance. In addition, encouraging greater citizen participation in co-creation processes may enhance these benefits significantly.

Throughout these three years I have engaged in dissemination and diffusion exercises in order to reach relevant policymakers, and the mainly qualitative nature of this research has put me in direct contact with multiple stakeholders that work directly in PED creation. Although I did not set out to influence these stakeholders, the results of my research may have an influence of its own, particularly as all of the stakeholders interviewed for Paper 4 (Hearn, 2022) requested a copy of the published paper.

In the first paper, I met the aim of shedding light on aspects where energy injustices may occur if energy justice is not considered in PEDs. I further contributed to energy poverty research in both Paper 2 (Hearn and Castaño-Rosa, 2021), Paper 4 (Hearn, 2022) demonstrating how there is a potential benefit for PEDs to become policy instruments for both energy vulnerability mitigation and decarbonization. In addition, the second paper (Hearn and Castaño-Rosa, 2021) contributes to the aim of researching energy communities and how these may fit in with PEDs, a topic which I also covered to some extent in Paper 4 (Hearn, 2022). The third paper contributed to research on citizens' preferences for PEDs, a topic which had not been previously researched, contributing both to discrete choice experiment research as well as to having a potential effect on policymaker decisions regarding PED creation. The fourth paper contributes to both PED and energy poverty research, showing that stakeholders see potential for energy poverty reduction through PEDs which can synergistically address this and decarbonization goals simultaneously. Furthermore, increasing levels of energy poverty make PEDs more financially viable as mitigatory tools, and there is a clear need for PED guiding principles to be considered in more structured and clear ways within PED creation.

Finally, the fifth paper (Hearn et al, 2022) provides a novel framework for energy vulnerability which includes future energy vulnerability caused through the unsustainable use of fossil fuels in the present. Further research in this field will likely take place given the rapid increase in energy poverty across Europe following the COVID19 pandemic and the search for alternative fuel sources owing to the Russian aggression in Ukraine.

The results of this dissertation focusing on social aspects of energy research provide a contribution to sustainability research in the topic of energy, but also provide a contribution for policymakers to draw on in order to consider how PEDs may be created in more inclusive ways.

7. References

[1] THE 17 GOALS | Sustainable Development, (n.d.). https://sdgs.un.org/goals (accessed June 22, 2022).
[2] Positive Energy Districts (PED), JPI Urban Eur. (n.d.). https://jpi-urbaneurope.eu/ped/ (accessed July 15, 2022).
[3] Passivhaus bauen: Das sind die Anforderungen - DAS HAUS, (n.d.). https://www.haus.de/thema/passivhaus (accessed March 29, 2021).
[4] Passivhaus Institut, (n.d.). https://passivehouse.com/ (accessed March 29, 2021).
[5] Home, MINERGIE Schweiz. (n.d.). https://www.minergie.ch/fr/ (accessed February 23, 2021).
[6] D. D'Agostino, L. Mazzarella, Data on energy consumption and Nearly zero energy buildings (NZEBs) in Europe, Data Brief. 21 (2018) 2470–2474. https://doi.org/10.1016/j.dib.2018.11.094.
[7] S. Attia, Chapter 2 - Evolution of Definitions and Approaches, in: S. Attia (Ed.), Net Zero Energy Build. NZEB, Butterworth-Heinemann, 2018: pp. 21–51. https://doi.org/10.1016/B978-0-12-812461-1.00002-2.
[8] A. Magrini, G. Lentini, S. Cuman, A. Bodrato, L. Marenco, From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example, Dev. Built Environ. 3 (2020) 100019. https://doi.org/10.1016/j.dibe.2020.100019.
[9] D. Ahlers, P. Driscoll, H. Wibe, A. Wyckmans, Co-Creation of Positive Energy Blocks, IOP Conf. Ser. Earth Environ. Sci. 352 (2019) 012060. https://doi.org/10.1088/1755-1315/352/1/012060.
[10] A. Gabaldón Moreno, F. Vélez, B. Alpagut, P. Hernández, C. Sanz Montalvillo, How to Achieve Positive Energy Districts for Sustainable Cities: A Proposed Calculation Methodology, Sustainability. 13 (2021) 710. https://doi.org/10.3390/su13020710.
[11] X. Zhang, S.R. Penaka, S. Giriraj, M.N. Sánchez, P. Civiero, H. Vandevyvere, Characterizing Positive Energy District (PED) through a Preliminary Review of 60 Existing Projects in Europe, Buildings. 11 (2021) 318. https://doi.org/10.3390/buildings11080318.
[12] M. Child, A. Nordling, C. Breyer, Scenarios for a sustainable energy system in the Åland Islands in 2030, Energy Convers. Manag. 137 (2017) 49–60. https://doi.org/10.1016/j.enconman.2017.01.039.
[13] O. Lindholm, H. ur Rehman, F. Reda, Positioning Positive Energy Districts in European Cities, Buildings. 11 (2021) 19. https://doi.org/10.3390/buildings11010019.
[14] Horizon2020 | MARIE SKŁODOWSKA-CURIE ACTIONS | Innovative Training Network – Smart Value Generation by Building Efficiency and Energy Justice for Sustainable Living, (n.d.). https://smart-beejs.eu/ (accessed November 2, 2021).
[15] A.-M. Valdez, E. Wigley, O. Zanetti, G. Rose, Chapter 12 - Learning lessons for avoiding the inadvertent exclusion of communities from smart city projects, in: A. Aurigi, N. Odendaal (Eds.), Shap. Smart Better Cities, Academic Press, 2021: pp. 221–237. https://doi.org/10.1016/B978-0-12-818636-7.00003-2.
[16] R.W. Foley, S. Nadjari, J. Eshirow, R. Adekunle, P. Codjoe, Towards Digital Segregation? Problematizing the Haves and Have Nots in the Smart City, Front. Sustain. Cities. 4 (2022) 706670. https://doi.org/10.3389/frsc.2022.706670.
[17] S. Bouzarovski, N. Simcock, Spatializing energy justice, Energy Policy. 107 (2017) 640–648.
[18] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, R. Rehner, Energy justice: A conceptual review, Energy Res. Soc. Sci. 11 (2016) 174–182.
[19] B.K. Sovacool, M.H. Dworkin, Energy justice: Conceptual insights and practical applications, Appl. Energy. 142 (2015) 435–444.

[20] F. Hanke, R. Guyet, M. Feenstra, Do renewable energy communities deliver energy justice? Exploring insights from 71 European cases, Energy Res. Soc. Sci. 80 (2021) 102244.
[21] B.K. Sovacool, M. Burke, L. Baker, C.K. Kotikalapudi, H. Wlokas, New frontiers and conceptual frameworks for energy justice, Energy Policy. 105 (2017) 677–691.
[22] D.A. McCauley, R.J. Heffron, H. Stephan, K. Jenkins, Advancing energy justice: the triumvirate of tenets, Int. Energy Law Rev. 32 (2013) 107–110.
[23] A. Bruck, S. Díaz Ruano, H. Auer, A Critical Perspective on Positive Energy Districts in Climatically Favoured Regions: An Open-Source Modelling Approach Disclosing Implications and Possibilities, Energies. 14 (2021) 4864. https://doi.org/10.3390/en14164864.
[24] Jenkins: Humanizing sociotechnical transitions through... - Google Scholar, (n.d.). https://scholar.google.com/scholar_lookup?title=Humanizing%20sociotechnical%20transitions%20through%20energy%20justice%3A%20An%20ethical%20framework%20for%20global%20transformative%20change&publication_year=2018&author=K.%20Jenkins&author=B.K.%20Sovacool&author=D.%20McCauley (accessed July 13, 2022).
[25] Hillerbrand: Using the Capability Approach as a normative... - Google Scholar, (n.d.). https://scholar.google.com/scholar_lookup?title=Using%20the%20Capability%20Approach%20as%20a%20normative%20perspective%20on%20energy%20justice%3A%20Insights%20from%20two%20case%20studies%20on%20digitalisation%20in%20the%20energy%20sector&publication_year=2021&author=R.%20Hillerbrand&author=C.%20Milchram&author=J.%20Schippl (accessed July 13, 2022).
[26] M. Nussbaum, Human Rights and Human Capabilities Twentieth Anniversary Reflections, Harv. Hum. Rights J. 20 (2007) 21–24.
[27] A. Sen, Equality of What?, Tann. Lect. Hum. Values. I (1980) 197–220.
[28] T. Islam, N. Meade, The impact of attribute preferences on adoption timing: The case of photo-voltaic (PV) solar cells for household electricity generation, Energy Policy. 55 (2013) 521–530.
[29] S.T. Herrero, L. Nicholls, Y. Strengers, Smart home technologies in everyday life: do they address key energy challenges in households?, Curr. Opin. Environ. Sustain. 31 (2018) 65–70.
[30] J. Fernanda Medina Macaya, S. Ben Dhaou, M.A. Cunha, Gendering the Smart Cities: Addressing gender inequalities in urban spaces, in: 14th Int. Conf. Theory Pract. Electron. Gov., Association for Computing Machinery, New York, NY, USA, 2021: pp. 398–405. https://doi.org/10.1145/3494193.3494308.
[31] D.S. Robic, Energy poverty in times of crisis: Has the EU failed to protect its most vulnerable citizens?, (n.d.) 7.
[32] P. Burger, A. Sohre, I. Schubert, Governance for sufficiency: A new approach to a contested field, in: Sustain. Gov. Hierarchy, Routledge, 2019: pp. 157–177.
[33] E.O.D. Waygood, Y. Sun, J.-D. Schmöcker, Transport sufficiency: Introduction & case study, Travel Behav. Soc. 15 (2019) 54–62.
[34] Y. Wang, B.J. Dewancker, Q. Qi, Citizens' preferences and attitudes towards urban waterfront spaces: a case study of Qiantang riverside development, Environ. Sci. Pollut. Res. 27 (2020) 45787–45801. https://doi.org/10.1007/s11356-020-10419-6.
[35] P. Ertör-Akyazı, F. Adaman, B. Özkaynak, Ü. Zenginobuz, Citizens' preferences on nuclear and renewable energy sources: Evidence from Turkey, Energy Policy. 47 (2012) 309–320. https://doi.org/10.1016/j.enpol.2012.04.072.
[36] L. Middlemiss, R. Gillard, Fuel poverty from the bottom-up: Characterising household energy vulnerability through the lived experience of the fuel poor, Energy Res. Soc. Sci. 6 (2015) 146–154. https://doi.org/10.1016/j.erss.2015.02.001.
[37] M. Martiskainen, B.K. Sovacool, M. Lacey-Barnacle, D. Hopkins, K.E. Jenkins, N. Simcock, G. Mattioli, S. Bouzarovski, New dimensions of vulnerability to energy and transport poverty, Joule. 5 (2021) 3–7.

[38] A. Gatto, F. Busato, Energy vulnerability around the world: The global energy vulnerability index (GEVI), J. Clean. Prod. 253 (2020) 118691. https://doi.org/10.1016/j.jclepro.2019.118691.
[39] H. Thomson, C.J. Snell, C. Liddell, Fuel poverty in the European Union: a concept in need of definition?, People Place Policy Online. (2016) 5–24.
[40] S. Bouzarovski, S. Tirado Herrero, S. Petrova, J. Frankowski, R. Matoušek, T. Maltby, Multiple transformations: theorizing energy vulnerability as a socio-spatial phenomenon, Geogr. Ann. Ser. B Hum. Geogr. 99 (2017) 20–41. https://doi.org/10.1080/04353684.2016.1276733.
[41] Eurostat, EU Statistics on Income and Living Conditions microdata 2004-2019, release 1 in 2021, (2021). https://doi.org/10.2907/EUSILC2004-2019V.2.
[42] A. Maxim, C. Mihai, C.-M. Apostoaie, C. Popescu, C. Istrate, I. Bostan, Implications and Measurement of Energy Poverty across the European Union, Sustainability. 8 (2016) 483. https://doi.org/10.3390/su8050483.
[43] S. Bouzarovski, Energy poverty in the European Union: landscapes of vulnerability, WIREs Energy Environ. 3 (2014) 276–289. https://doi.org/10.1002/wene.89.
[44] A. Horta, J.P. Gouveia, L. Schmidt, J.C. Sousa, P. Palma, S. Simões, Energy poverty in Portugal: Combining vulnerability mapping with household interviews, Energy Build. 203 (2019) 109423. https://doi.org/10.1016/j.enbuild.2019.109423.
[45] S. Bouzarovski, S. Petrova, R. Sarlamanov, Energy poverty policies in the EU: A critical perspective, Energy Policy. 49 (2012) 76–82. https://doi.org/10.1016/j.enpol.2012.01.033.
[46] H. Bulkeley, M. Betsill, Rethinking sustainable cities: Multilevel governance and the'urban'politics of climate change, Environ. Polit. 14 (2005) 42–63.
[47] J. Corfee-Morlot, L. Kamal-Chaoui, M.G. Donovan, I. Cochran, A. Robert, P.-J. Teasdale, Cities, climate change and multilevel governance, (2009).
[48] B.R. Barber, If mayors ruled the world, in: Mayors Ruled World, Yale University Press, 2013.
[49] B. Bornemann, A. Sohre, P. Burger, Future governance of individual energy consumption behavior change—A framework for reflexive designs, Energy Res. Soc. Sci. 35 (2018) 140–151.
[50] A. Florini, B.K. Sovacool, Who governs energy? The challenges facing global energy governance, Energy Policy. 37 (2009) 5239–5248. https://doi.org/10.1016/j.enpol.2009.07.039.
[51] Z. Tzankova, Public policy spillovers from private energy governance: New opportunities for the political acceleration of renewable energy transitions, Energy Res. Soc. Sci. 67 (2020) 101504. https://doi.org/10.1016/j.erss.2020.101504.
[52] M.J. Fell, Just flexibility?, Nat. Energy. 5 (2020) 6–7. https://doi.org/10.1038/s41560-019-0510-3.
[53] G. Melica, P. Bertoldi, A. Kona, A. Iancu, S. Rivas, P. Zancanella, Multilevel governance of sustainable energy policies: The role of regions and provinces to support the participation of small local authorities in the Covenant of Mayors, Sustain. Cities Soc. 39 (2018) 729–739. https://doi.org/10.1016/j.scs.2018.01.013.
[54] R.J. Heffron, D. McCauley, The concept of energy justice across the disciplines, Energy Policy. 105 (2017) 658–667. https://doi.org/10.1016/j.enpol.2017.03.018.
[55] B.K. Sovacool, M.H. Dworkin, Energy justice: Conceptual insights and practical applications, Appl. Energy. 142 (2015) 435–444. https://doi.org/10.1016/j.apenergy.2015.01.002.
[56] D.A. McCauley, R.J. Heffron, H. Stephan, K. Jenkins, Advancing Energy Justice: The Triumvirate of Tenets, Int. Energy Law Rev. 32 (2013) 107–110.
[57] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, R. Rehner, Energy justice: A conceptual review, Energy Res. Soc. Sci. 11 (2016) 174–182.

[58] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, R. Rehner, Energy justice: A conceptual review, Energy Res. Soc. Sci. 11 (2016) 174–182. https://doi.org/10.1016/j.erss.2015.10.004.
[59] D. McCauley, R. Heffron, Just transition: Integrating climate, energy and environmental justice, Energy Policy. 119 (2018) 1–7. https://doi.org/10.1016/j.enpol.2018.04.014.
[60] M. Lacey-Barnacle, Proximities of energy justice: contesting community energy and austerity in England, Energy Res. Soc. Sci. 69 (2020) 101713. https://doi.org/10.1016/j.erss.2020.101713.
[61] M. Hazrati, R.J. Heffron, Conceptualising restorative justice in the energy Transition: Changing the perspectives of fossil fuels, Energy Res. Soc. Sci. 78 (2021) 102115. https://doi.org/10.1016/j.erss.2021.102115.
[62] D. McCauley, V. Ramasar, R.J. Heffron, B.K. Sovacool, D. Mebratu, L. Mundaca, Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research, Appl. Energy. 233–234 (2019) 916–921. https://doi.org/10.1016/j.apenergy.2018.10.005.
[63] B.K. Sovacool, M. Martiskainen, A. Hook, L. Baker, Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions, Clim. Change. 155 (2019) 581–619. https://doi.org/10.1007/s10584-019-02521-7.
[64] P. Calver, N. Simcock, Demand response and energy justice: A critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures, Energy Policy. 151 (2021). https://doi.org/10.1016/j.enpol.2021.112198.
[65] M. David, The role of organized publics in articulating the exnovation of fossil-fuel technologies for intra- and intergenerational energy justice in energy transitions, Appl. Energy. 228 (2018) 339–350. https://doi.org/10.1016/j.apenergy.2018.06.080.
[66] R. Hillerbrand, C. Milchram, J. Schippl, Using the Capability Approach as a normative perspective on energy justice: Insights from two case studies on digitalisation in the energy sector, J. Hum. Dev. Capab. 22 (2021) 336–359. https://doi.org/10.1080/19452829.2021.1901672.
[67] F. Bartiaux, C. Vandeschrick, M. Moezzi, N. Frogneux, Energy justice, unequal access to affordable warmth, and capability deprivation: A quantitative analysis for Belgium, Appl. Energy. 225 (2018) 1219–1233.
[68] R. Hillerbrand, C. Milchram, J. Schippl, Using the Capability Approach as a normative perspective on energy justice: Insights from two case studies on digitalisation in the energy sector, J. Hum. Dev. Capab. (2021) 1–24.
[69] K. Raworth, Why it's time for Doughnut Economics, IPPR Progress. Rev. 24 (2017) 216–222.
[70] K. Raworth, Doughnut economics: seven ways to think like a 21st-century economist, Chelsea Green Publishing, 2017.
[71] A. Peters, Amsterdam is now using the 'doughnut' model of economics: What does that mean?, Fast Co. (2020). https://www.fastcompany.com/90497442/amsterdam-is-now-using-the-doughnut-model-of-economics-what-does-that-mean (accessed July 11, 2022).
[72] K. Raworth, Introducing the Amsterdam City Doughnut | Kate Raworth, (2020). https://www.kateraworth.com/2020/04/08/amsterdam-city-doughnut/ (accessed July 15, 2022).
[73] About Doughnut Economics | DEAL, (n.d.). https://doughnuteconomics.org/about-doughnut-economics (accessed July 15, 2022).
[74] E. Derkenbaeva, S. Halleck Vega, G.J. Hofstede, E. van Leeuwen, Positive energy districts: Mainstreaming energy transition in urban areas, Renew. Sustain. Energy Rev. 153 (2022) 111782. https://doi.org/10.1016/j.rser.2021.111782.
[75] S. Okushima, Gauging energy poverty: A multidimensional approach, Energy. 137 (2017) 1159–1166. https://doi.org/10.1016/j.energy.2017.05.137.

[76] F. Martín-Consuegra, J.M. Gómez Giménez, C. Alonso, R. Córdoba Hernández, A. Hernández Aja, I. Oteiza, Multidimensional index of fuel poverty in deprived neighbourhoods. Case study of Madrid, Energy Build. 224 (2020) 110205. https://doi.org/10.1016/j.enbuild.2020.110205.
[77] M. Hesselman, A. Varo, R. Guyet, H. Thomson, Energy poverty in the COVID-19 era: Mapping global responses in light of momentum for the right to energy, Energy Res. Soc. Sci. 81 (2021) 102246. https://doi.org/10.1016/j.erss.2021.102246.
[78] A. Carfora, G. Scandurra, A. Thomas, Forecasting the COVID-19 effects on energy poverty across EU member states, Energy Policy. (2021) 112597. https://doi.org/10.1016/j.enpol.2021.112597.
[79] P.K. Ozili, Global Economic Consequence of Russian Invasion of Ukraine, (2022). https://doi.org/10.2139/ssrn.4064770.
[80] R. Castaño-Rosa, J. Solís-Guzmán, C. Rubio-Bellido, M. Marrero, Towards a multiple-indicator approach to energy poverty in the European Union: A review, Energy Build. 193 (2019) 36–48. https://doi.org/10.1016/j.enbuild.2019.03.039.
[81] H. Thomson, S. Bouzarovski, C. Snell, Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data, Indoor Built Environ. 26 (2017) 879–901. https://doi.org/10.1177/1420326X17699260.
[82] S. Bouzarovski, S. Petrova, A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary, Energy Res. Soc. Sci. 10 (2015) 31–40.
[83] J. Lienert, P. Burger, Merging capabilities and livelihoods: analyzing the use of biological resources to improve well-being, Ecol. Soc. 20 (2015). https://www.jstor.org/stable/26270215 (accessed February 11, 2021).
[84] A.X. Hearn, R. Castaño-Rosa, Towards a Just Energy Transition, Barriers and Opportunities for Positive Energy District Creation in Spain, Sustainability. 13 (2021) 8698. https://doi.org/10.3390/su13168698.
[85] L.G. de Mier Cortijo, M.L. Lopez, E.S.R.M.S. Curie, Consulta pública previa comunidades energéticas locales, (n.d.).
[86] K. Lucas, G. Mattioli, E. Verlinghieri, A. Guzman, Transport poverty and its adverse social consequences, in: Proc. Inst. Civ. Eng.-Transp., Thomas Telford Ltd, 2016: pp. 353–365.
[87] G. Mattioli, K. Lucas, G. Marsden, Transport poverty and fuel poverty in the UK: From analogy to comparison, Transp. Policy. 59 (2017) 93–105.
[88] S. Carley, D.M. Konisky, The justice and equity implications of the clean energy transition, Nat. Energy. 5 (2020) 569–577. https://doi.org/10.1038/s41560-020-0641-6.
[89] K. Primc, M. Dominko, R. Slabe-Erker, 30 years of energy and fuel poverty research: A retrospective analysis and future trends, J. Clean. Prod. 301 (2021) 127003. https://doi.org/10.1016/j.jclepro.2021.127003.
[90] D.A. Pohoryles, C. Maduta, D.A. Bournas, L.A. Kouris, Energy performance of existing residential buildings in Europe: A novel approach combining energy with seismic retrofitting, Energy Build. 223 (2020) 110024. https://doi.org/10.1016/j.enbuild.2020.110024.
[91] A European Green Deal, Eur. Comm. - Eur. Comm. (n.d.). https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed June 18, 2021).
[92] J.P. Gouveia, J. Seixas, P. Palma, H. Duarte, H. Luz, G.B. Cavadini, Positive Energy District: A Model for Historic Districts to Address Energy Poverty, Front. Sustain. Cities. 3 (2021) 16.
[93] European Commission, Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance), 2018. http://data.europa.eu/eli/dir/2018/851/oj/eng (accessed June 24, 2021).

[94] Deliverables – Horizon2020 | MARIE SKŁODOWSKA-CURIE ACTIONS | Innovative Training Network, (n.d.). https://smart-beejs.eu/deliverables/ (accessed July 11, 2022).
[95] D6.4_BMs-and-Value-Propositions_final.pdf, (n.d.). https://smart-beejs.eu/wp-content/uploads/2022/03/D6.4_BMs-and-Value-Propositions_final.pdf (accessed July 15, 2022).
[96] Kyul - Human-Centric Energy Districts Smart Value Genera.pdf, (n.d.). https://smart-beejs.eu/wp-content/uploads/2021/01/WP3-Deliverable-D3.2_Silo-thinking.pdf (accessed July 15, 2022).
[97] 20-09-30_D4.2_Final-Version.pdf, (n.d.). https://smart-beejs.eu/wp-content/uploads/2020/12/20-09-30_D4.2_Final-Version.pdf (accessed July 15, 2022).
[98] D5_2-Impact-Evaluation-Method-for-PEDs.pdf, (n.d.). https://smart-beejs.eu/wp-content/uploads/2021/08/D5_2-Impact-Evaluation-Method-for-PEDs.pdf (accessed July 15, 2022).
[99] R. Natoli, S. Zuhair, Measuring Progress: A Comparison of the GDP, HDI, GS and the RIE, Soc. Indic. Res. 103 (2011) 33–56. https://doi.org/10.1007/s11205-010-9695-3.
[100] J. Bilbao-Ubillos, Another Approach to Measuring Human Development: The Composite Dynamic Human Development Index, Soc. Indic. Res. 111 (2013) 473–484. https://doi.org/10.1007/s11205-012-0015-y.
[101] U. Nations, Human Development Index, United Nations, n.d. https://hdr.undp.org/data-center/human-development-index (accessed June 20, 2022).
[102] T.M. Skjølsvold, L. Coenen, Are rapid and inclusive energy and climate transitions oxymorons? Towards principles of responsible acceleration, Energy Res. Soc. Sci. 79 (2021) 102164. https://doi.org/10.1016/j.erss.2021.102164.
[103] UNSDG | Leave No One Behind, (n.d.). https://unsdg.un.org/2030-agenda/universal-values/leave-no-one-behind (accessed February 25, 2021).
[104] A Sustainable Europe must leave no one behind, Eur. Econ. Soc. Comm. (2019). https://www.eesc.europa.eu/en/news-media/news/sustainable-europe-must-leave-no-one-behind (accessed May 5, 2022).
[105] marlene CORBINAIS, Leaving no one behind in the transition to climate neutrality, Newsroom - Eur. Comm. (2019). https://europa.eu/newsroom/events/leaving-no-one-behind-transition-climate-neutrality_en (accessed May 5, 2022).
[106] H. Dinesh, J.M. Pearce, The potential of agrivoltaic systems, Renew. Sustain. Energy Rev. 54 (2016) 299–308. https://doi.org/10.1016/j.rser.2015.10.024.
[107] U. Nations, Generating power, U. N. (n.d.). https://www.un.org/en/climatechange/climate-solutions/cities-pollution (accessed June 1, 2022).
[108] Science Summit at UNGA – Science Summit at the 77 United Nation General Assembly, (n.d.). https://sciencesummitunga.com/ (accessed June 3, 2022).
[109] A.X. Hearn, Positive energy district stakeholder perceptions and measures for energy vulnerability mitigation, Appl. Energy. 322 (2022) 119477. https://doi.org/10.1016/j.apenergy.2022.119477.
[110] Directorate-General for Research and Innovation (European Commission), H. Gronkiewicz-Waltz, A. Larsson, A.L. Boni, K. Krogh Andersen, P. Ferrao, E. Forest, R. Jordan, B. Lenz, J. Lumbreras, C. Nicolaides, J. Reiter, M. Russ, A. Sulling, D. Termont, M. Vassilakou, 100 climate-neutral cities by 2030 - by and for the citizens: report of the Mission board for climate neutral and smart cities, Publications Office of the European Union, LU, 2020. https://data.europa.eu/doi/10.2777/46063 (accessed June 3, 2022).
[111] Cities - Eurocities, (n.d.). https://eurocities.eu/cities/ (accessed June 3, 2022).

[112] T. News, M. Wilms, Who's behind the anti-Green ads?, Berl. Ztg. (n.d.). https://www.berliner-zeitung.de/en/whos-behind-the-anti-green-ad-campaign-li.176626 (accessed July 11, 2022).
[113] dryfta.com, Can Positive Energy Districts Help To Mitigate Energy Poverty And Bring About A Just Transition?, (n.d.). https://reinventingthecity.dryfta.com/abstract-archive/abstract/public/36/can-positive-energy-districts-help-to-mitigate-energy-poverty-and-bring-about-a-just-transition (accessed July 11, 2022).
[114] Adam Hearn, Positive Energy Districts PEDs, 2021. https://www.youtube.com/watch?v=_ZABVMXg1zs (accessed July 11, 2022).

8. Appendix 1. Conference presentations, posters, videos

Throughout the doctorate, I gave a number of presentations to distribute the findings of my papers, both in person and online.

- 26.09.22 UNGA77 United Nations Science Summit. A call for high-quality, harmonised, reliable and comparable climate-related data with standardized guidance to boost investor confidence and generate financial investment flows to Africa. (online) Presentation. The potential for Positive Energy Districts in Africa
- 07.09.09.22 INUAS conference Winterthur, Switzerland. Presentation: A Just transition? Positive Energy Districts (PEDs), Renewable Energy Communities (RECs) and public spaces, an energy justice perspective, inclusion https://www.inuas.org/konferenz-2022/programm-2022/
- 13-16.07.22 European Science Open Forum (ESOF) conference, Leiden, Netherlands. Hybrid poster presentation and video (online) “What are positive energy district stakeholder perceptions and measures for mitigating energy vulnerability?”: https://www.esof.eu/
- 04-06.07.22 International Association of people and Environmental Studies (IAPS) conference, Lisbon, Portugal (online): Inclusive low-carbon transitions? PEDs and Energy Poverty
- 30.06–01.07.22, Swiss Social Sciences and Humanities Energy Research Workshop, Martigny, Switzerland. Presentation (in person), Positive Energy District Stakeholder perceptions and measures for energy vulnerability mitigation, and how this relates to Swiss districts.
- 19.05.22 Leipzig Public Climate School Climate Protection in Europe (online) – How to Make the Green Deal a Success presentation and panellist
- 16-18.02.22 AMS Reinventing the City. Conference, Amsterdam (online): Can Positive Energy Districts help to mitigate energy poverty and bring about a just transition? [113]
- 5-10.10.21 International conference on environmental psychology (ICEP) Siracusa, Italy, presentation (in person): PED creation in Spain and community energy initiatives; towards a just transition
- 24.09.21 Energy poverty and PED video, produced for the European Researchers Night, St Andrews University, intersections programme, online: [114]
- ENGAGER COST Mainstreaming Innovative Energy Poverty Metrics 26-30.04.21 (online) During this workshop I co-produced a short presentation and an essay on NECPS (National Energy and Climate Plans) and energy poverty: http://www.engager-energy.net/trainingschool2/

9. Paper 1, Hearn, A.X., Sohre, A. and Burger, P., 2021. Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. *Energy Research & Social Science*, *78*, p.102127.

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Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe

Adam X. Hearn *, Annika Sohre, Paul Burger

Sustainability Research Group, University of Basel, Basel, Switzerland

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A B S T R A C T

The current energy transition focuses on decarbonisation through the use of renewable energy sources, coupled with improvements in efficiency by means of technological innovations. However, there is also a clear call for realizing a just transition. The implementation of smart technology-led transitions and low-carbon energy system innovations is increasingly urged to become more people-centred by taking energy poverty and other justice related issues into account. Energy justice and energy poverty debates already transcend narrow foci on income and energy expenditure ratios and have moved towards multidimensional approaches (Bouzarovski and Petrova, 2015) [1]. In addition, the capability approach (CA) has been used to understand energy deprivation (Day et al., 2016) [2]. We further develop these approaches to better understand justice relevant issues within Positive Energy Districts, especially by looking at how opportunity spaces for realizing wellbeing are created. The primary goal is to establish a CA-informed framework for analysing justice-relevant issues within the development of Positive Energy Districts, based on a systematic literature search. Hereby we contribute to the discussion on usage of the CA within the field of energy and to the debate on how to frame technological innovations, such that they can contribute to a just transition.

1. Introduction

It is widely accepted that an energy transition is necessary [3–5], but timings, forms and potential pathways are manifold, and socio-technological innovations need to be critically examined in conjunction with energy justice [6]. Energy efficient or renewable energy technology is often costly to implement, leading to the potential creation of new energy systems that could exclude people who are not able to afford to adopt them [3,7]. In addition, the need to reduce overall energy use can be in conflict with the need to address issues of energy poverty [8]. Specifically, reducing consumer energy use through increasing costs is regressive and fails to protect the poorest in society. Basic energy services enable people to realize and maintain minimal wellbeing levels [9], but remunerating or subsidizing the energy vulnerable may lead to an increase in energy use and emissions [10]. Thus, it is not only about energy transitions, but specifically just transitions. Accordingly, in order to form part of a just transition, the implementation of technologically innovative living spaces, based primarily on renewable energy, needs to inherently take justice-related considerations into account.

Besides techno-economic approaches [11] and analyses of policy instruments fostering implementation [12], recent research has contributed towards a better understanding of some of the social dimensions of the energy transition [6,13,14] and has taken up concerns regarding energy poverty/vulnerability [8,15,16]. In addition, wellbeing issues related to energy have been examined [17,18] and there have been attempts towards broader multidimensional approaches to energy justice [1]. However, how Positive Energy Districts (PEDs) [19–22] can contribute to a just transition is unclear. Whilst there has been research on the low carbon energy transition [23], studies on the link between technologically innovative living spaces which incorporate multiple low carbon innovations and justice are underrepresented in the literature [24], and a systematic framework or approach, which especially allows ex ante study of justice and wellbeing issues related to PEDs, is missing.

PED-like areas are new and highly interesting study objects within the realm of the energy transition. The EU launched a programme to support the planning, deployment, and replication of one hundred PEDs by the year 2025 [19,22], aimed at speeding up decarbonization [20]. These could be considered to be holistic smart energy systems, as they

* Corresponding author.
E-mail address: Adam.hearn@unibas.ch (A.X. Hearn).

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are broader urban living- areas characterized by

1: Net-positive renewable energy production on a yearly basis (the "positive" part of PEDs); highly energy efficient buildings (enabling the district to rely purely on renewable energy may require significant reductions in energy consumption); and a degree of energy flexibility.

2: Inclusivity, affordability, sustainability and allowing for a high quality of life

3: A governance framework that actively encourages citizen participation [22].

Bringing together a variety of smart energy system innovations, such as smart meters, electric vehicles and renewable energy [25], energy flexibility [26,27], coupled with elements of social change and changes in energy ownership, makes PEDs captivating areas to study. Specifically, basing PED creation on principles of inclusivity and affordability encourage a focus on justice issues which may not be as prominent in other smart energy systems. PEDs are however still in their infancy, and currently more of an aim than a reality [21], because of the difficulty in achieving an annual surplus in renewably produced energy, and most districts aiming to become PEDs could be referred to as *PED-like* areas. Nevertheless, the initial 100 PEDs are likely to be followed with significant replication and these districts may become a new standard within a decarbonised Europe, making energy justice issues all the more important if there is to be a just transition.

Whilst the energy justice potential of renewable energy has been examined [28], the novelty and innovation of these districts is that they represent not a single technology but require diverse (smart) technologies. Moreover, they are not only based on technological innovations but call for behavioural changes of the inhabitants. PED-like areas also go beyond the individual ownership-level of prosumers [29,30], extending to the scale of neighbourhoods or communities. As such, PED-like urban areas are enabled by a multiplicity of innovations and are thought to contribute to a just transition. However, in what respect they do so is an open question.

Our goal is to pave the way for a framework that allows ex ante study of justice and wellbeing issues in PED-like areas. To this aim, we employ the Capability Approach (CA) to inform the public discourse on energy justice because it provides a multidimensional normative approach suitable for linking justice and wellbeing [31,32]. Specifically, we fill the gap highlighted by Hillerbrand et al. [32], who identify the need for further research on whether and how energy capabilities need to be adapted for large-scale smart technology districts such as PEDs, and more directly to understand energy justice issues in these settings. Embedding PED-like areas with justice and wellbeing issues (rather than energy supply and consumption only) could contribute substantially to a just energy transition. Accordingly, our research strives to answer the following research question: What are the main energy justice and wellbeing related elements that need to be accounted for to ensure PED-like areas are part of a just transition?

To answer our research question, we first detail our methodology in section II. In section III, we distil major energy justice categories characterising "just" from the literature and rely on the CA. Against this backdrop, in section IV, we develop a framework directed to analysing PED-like areas building on the livelihood-based capabilities framework of Lienert and Burger [33]. This framework thus provides a general basis for ex ante assessments of energy justice considerations to inform designs and potential governance regulations of such areas. Our discussion in section V is based on an explorative study to demonstrate its usefulness, followed by a conclusion and outlook section (VI). This research adds to the literature by providing a robust theoretical basis for understanding justice issues in PED-like areas, as well as ex ante evaluation criteria to influence PED design.

2. Method

In this section we explain the three different methods applied in this paper to develop our framework, and provide some background information on the Swiss PED-like example. In order to develop justice and wellbeing related criteria for assessing the creation and development of PEDs, we perform a systematic literature search (Fig. 1), based on the terms "energy justice", "energy poverty" and "energy transition" so as to determine relevant generic criteria. We include energy poverty in our search as this is an important trait of the prevailing European energy system. We do not claim that our literature review covers all aspects of energy justice, as we focused on what was within the scope of our research interest. Additionally, we removed papers where the focus was on Global South. As we are going to rely on the CA for our framework (see below), we also conducted a google scholar search on the terms "energy justice" and "capability approach". In addition, we use a snowball search of articles.

Following a careful reading of the abstracts, we determined which papers were deemed to potentially contain insights relevant to building an energy justice framework. Out of that sample, we identify major energy justice-related categories to be included in the framework as well as those categories representing our theoretical commitment to the CA (section III). In order to develop a framework, we adjust a former livelihood-based capabilities framework (see below) to include the distilled energy justice categories. This results in an integrated framework with the goal of analysing PEDs in terms of their possible contribution to a fair transition (section IV). To demonstrate the applicability of our framework in the intended ex ante (and ex post) analysis of justice issues, we chose one PED-like example from Switzerland (cf. below). For this exploratory study we rely on the following data: written documents, one 2-day site visit and key informant interviews (section V).

The Hunziker Areal (HA) in Zurich is a PED-like district that will serve as an example for applying the framework in an exploratory manner and was established with energy justice issues in mind. HA is designed and managed by the housing cooperative Mehr als Wohnen (MaW) [34]. The site is 40.000 m^2 including 370 apartments, shops, restaurants, a guesthouse and 1300 + residents. The HA is part of the "2000 W Society" [35] which aims to reduce potential energy usage to the global average of 2000 Watts at any given time per person [36]. Reasons for the selection of the HA are that it is one of the more established PED-like sites (completed in 2015), with some literature already available, as well as populated enough to warrant study, whereas many of the other sites are currently still in development or smaller in size [21].

3. Major energy justice categories and the capability approach

In the following, we extract elements of the energy justice literature and the energy related CA-literature that allow us to consider generic criteria regarding what makes a transition a just transition.

Looking at said literature, the three-tenet approach to energy justice [24] has become quite dominant. It encompasses distributional, recognitional, and procedural dimensions [15,37–39]. Together with the additional dimensions of global and restorative justice (e.g. [40]), the three-tenets are thought to capture major types of inequalities [23].

The *distributional* part encompasses the distribution of material outcomes or public goods, as well as injustices suffered by ignored or misrepresented groups [24,41–43]. A just energy transition requires considerations to avoid negative impacts, including potentially novel negative justice impacts [44] and work to eradicate existing inequalities [45,46]. This is salient because the energy transition occurs in a sphere that is already regulated by a swathe of governance [39], with pre-existing distributional patterns for benefits and burdens. Recognizing pre-existing actors, processes and policies [47] as well as new variations which may arise throughout the transition allows us to identify potential distributional injustices. Distributional justice includes locational impacts arising from the production, transport and consumption of energy, such as the retraining of coal industry workers in Germany in the 1990s (some in renewable energy) to reduce social costs resulting from declines in coal output [48]. However, there is also growing evidence of

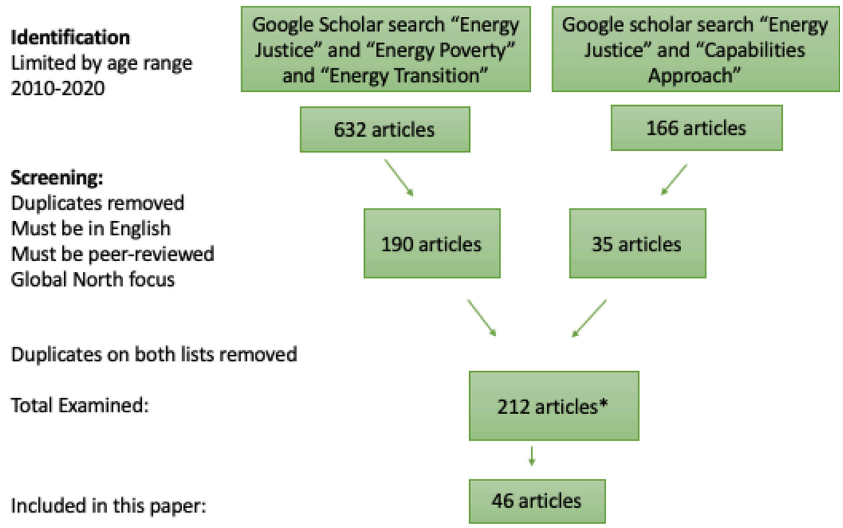

Fig. 1. Flow chart of the literature selection process.

job losses, greater public scepticism towards renewables and a slowdown in the sector's growth in Germany based on perceived unfair distributions of burdens and benefits [11] .

The focus on *recognitional* energy justice examines whether groups with differing energy needs (e.g. elderly or disabled people) are partially or completely overlooked, and how better to include these [16,37]. When it comes to just energy transitions, communities which are negatively affected by the distribution of burdens, such as those situated near large scale private wind parks [37,44,49], may see valid objections dismissed as illegitimate and NIMBYism.

Procedural aspects, related to decisions on the allocation of costs and burdens, are characterised by calls for greater inclusion in fair decision-making processes [16]. Procedural justice has become a more pressing topic because new types of actors, such as prosumers, challenge the longstanding dichotomy of consumer/producer [50]. For PED-like areas, this dichotomy is further challenged, with multiple new forms of energy production, ownership and management [51].

Global justice issues refer to the application of energy justice notions of distribution, recognition, and procedure, on a global scale, throughout the entire energy lifecycle [3] including aspects of resource extraction (e.g. Cadmium mining for photovoltaic panels production; [52]), production (e.g. nuclear energy production; [53]), distribution, and consumption of energy to ensure that it is just [23].

Restorative justice [40] focuses on mitigating energy injustices that have already occurred. Past injustices, unequal distribution of burdens, lack of recognition and procedural failures can be remediated through restorative justice [54].

An alternative approach [55] sees energy justice through the 10 principles of availability, affordability, due process, transparency, sustainability, intragenerational equity, intergenerational equity, responsibility, resistance and intersectionality. Without entering into a detailed discussion, we claim that most of them can also be seen as aspects of the previous five justice elements, with the exceptions of intra- and intergenerational equity. Both intra and intergenerational equity are elements which we believe should be included in an energy justice framework as they are fundamental justice dimensions within sustainability.

There are other approaches such as for example Bell et al. [56] that analyses energy systems through four intersecting dimensions, political, economic, socio-ecological and technological. This approach emphasises the injustices in the existing system and, accordingly that transitioning to renewable energy systems may require greater transparency and active intervention in order to truly support wellbeing. This once again highlights the need for frameworks that encourage examining justice issues within the context of fair energy transitions.

Although the referenced literature reveals manifold dimensions and approaches for analysing justice and wellbeing issues in an energy transition context, we take the five dimensions discussed above as a stable denominator guiding the discussion on just transitions, together with intragenerational equity (through the use of the CA) and intergenerational equity (through the use of a livelihood-based framework, cf. below). In addition, the sub-topic of energy poverty/vulnerability (energy deprivation in the home [1,8]) has also attracted scholarly attention and led to the development of multidimensional sets of criteria going well beyond income and share of spending for energy (e.g. [57]). This is an important line related to our topic because technological innovation is often only affordable to the wealthier. Furthermore, the development of PED-like areas will necessitate retrofitting programmes, revealing difficulties stemming from the complex interaction between relative poverty, technological measures, and how they are integrated into daily life [37,58]. However, energy poverty can be seen as encompassing and mirroring all the already discussed dimensions (distributive, procedural, recognitional, global, and restorative aspects). Furthermore, in terms of the CA, energy poverty is a form of capability deprivation [41,59]. It prevents individuals from having adequate energy services to the effect that they are deprived from opportunities necessary for living what they subjectively consider to be a full and valued life.

Whereas we can take the five dimensions of justice as sketched above as a basis for analysing justice related issues within the energy transition, the literature discussed is often lacking (a) a sound normative justice approach and (b) a qualitative understanding of human wellbeing. Both lead us to the normative dimension of what ought to be the case. Ex ante assessments of technologically innovative settings like PEDs become possible only by adding an approach highlighting desirable energy future. For this normative dimension we adopt the CA (We debate its merits extensively in further publications, e. g. [92]).

As mentioned earlier, the CA has been applied to energy poverty providing a normative foundation [2], which we build on to synthesize the CA with energy justice. The CA has been used as a metric of wellbeing and justice, and takes opportunity spaces [31], freedoms to choose what one has reason to value, as normative currency (metric of justice). The underlying normative criterion for wellbeing is to be able to live the life that people have reasons to value. Moreover, the CA follows a multidimensional understanding of wellbeing, not taking an aggregated criterion like life-satisfaction. Capabilities are formed through societal and natural conditions and unjust states of affairs come about through the missing of central capabilities, normally labelled as capabilities deprivation [2,41]. The justice criterion is that the normative metric holds for all (currently living and in future living) individuals. In our field of interest, energy injustices (e.g., lack of access to clean energy) display capabilities deprivation. Moreover, the underlying multidimensional understanding of wellbeing goes well together with multidimensional understandings of energy poverty or vulnerability. In addition, energy consumption or overconsumption could also adversely affect the opportunities of other people (whether in the present or the future) to live a life they value [60].

Relying on the CA, a just transition is then one in which manifold capabilities are available for all, intra- and intergenerationally, and not impinging on the capabilities available for others elsewhere. Lists of core capabilities such as those given by Nussbaum [41] have also been used to examine energy justice [32,61] with a focus on distributional justice. A significant difference in our approach is that like Sen [62], we leave capabilities undefined, accepting that different people and societies may value capabilities in divergent ways [42]. There is also an ongoing debate within the CA on whether to empirically examine achieved functionings, what people actually do or have based on their available options, or input factors, that create the opportunity spaces. However, achieved functionings are beyond the scope of this paper, and primarily relevant when assessing realized impacts coming out of interventions/ policies, whereas we are mainly interested in ex ante criteria for designing PED-like areas. In addition, and methodologically speaking, realized functionings need to be identified by asking the affected individual. In parallel to what is being done by the HDI (Human Development Index) [63], we look at inputs (in our terminology, *capitals*), that create opportunity spaces through the design of PEDs and related policies. This is also similar to Belda-Miquel et al. [64] who incorporate the CA into an energy justice framework in terms of people's ability to achieve a life they value, by looking at the need to include the structures that enable human flourishing, for grassroots energy innovations. We go beyond this by focusing on PEDs which are a form of top-down governance energy innovation.

Hence, we take out of the existing literature that our approach should (a) display the five dimensions of recognitional, distributional, procedural, global and restorative justice discussed in the energy justice literature and (b) be informed by a normative sound justice approach based on a multidimensional understanding of wellbeing, for which we have chosen the CA.

4. Integrated framework of energy justice and wellbeing in energy transitions

Whereas section III focused on generic criteria for what could make up a just transition, this section is directed to the specific topic of technologically innovative living spaces. In line with section III our framework builds on the following considerations:

(a) As far as justice related issues are involved, distributional, procedural, recognitional, global and restorative justice, as well as intergenerational and intragenerational justice need to be included.
(b) PED-like areas are interesting because they create living spaces, hence they influence people's wellbeing. They are thought to contribute to a just transition and are meant to be human-centred. Hence, wellbeing considerations take centre stage.
(c) As (a) and (b) are different, albeit strongly interlinked, we have chosen a theoretical approach that offers an established approach to both, the CA.
(d) However, as the CA provides a normative framework but not necessarily a framework for empirically examining the relation between innovation and how people will embed it into their daily life (behaviour) to realize wellbeing, we need to consider additional frameworks for analysing such topics.
(e) Among the two possible options here, analysing input factors (opportunity spaces) or realized individual wellbeing, we opted for the first. A full framework would also include the individual wellbeing or output. Research highlights that although wellbeing cannot be reduced to happiness or emotionally feeling well, the latter is a significant component [65,66]. Including realized individual wellbeing would not only ask for further theoretical resources that go beyond the scope of this paper, but is hardly feasible given that most PED-like areas are in a very early stage of being realized.
(f) Accordingly, we adapted the livelihood-based capabilities framework ([33], Fig. 2 below) developed in a different context as this provides an approach to analyse input factors for realizing wellbeing. This framework merges a sustainable livelihoods approach with the CA, recognizing that access to different types of resources (capitals) is a prerequisite for wellbeing [67].

Originally, the framework has been used for assessing impacts on human wellbeing stemming from the valuation of biological resources in rural parts of Nepal. One of the benefits of this framework is that it includes the element of intergenerational justice which may be somewhat neglected with the use of the CA alone. However, the focus of this framework was also on input-factors rather than the perception of wellbeing. Moreover, looking at these five types of capitals or input resources is a standard in the livelihood literature. The framework invites us to examine opportunity spaces, the basic building blocks which are necessary for building assorted capabilities. From these capabilities, individual choice and livelihood strategies are developed, resulting in valued functionings. In what follows, we adjust the original framework to serve for our analytic endeavour (Fig. 3).

A first specific element to look at are energy services provided by PEDs. This is also in line with Day, Walker and Simcock [2] who consider access to energy services a crucial input factor for capability spaces. Moreover, and also in line with recent research in the social sciences energy services are key to understanding energy demand. People do not consume energy for the sake of energy, but *use* energy services [68]. As such, energy consumption as well as the related CO_2-emissions are a side-product of mostly routinized behaviour [7,69]. Energy services also establish a direct link to smart technology innovations, because innovative energy services are almost always smart technology-based. Moreover, energy services also outline the purpose for which they are used. However, when looking at PED-like areas, there are broader sets of input factors to look at than just technology. The five capital dimensions captures the following:

Physical capital deals with infrastructure and technology, heating and electricity system and provides and restricts effective opportunities by inducing trade-offs if the quality of the physical capital is not optimal [67]. Energy justice issues such as those concerning flexibility products in smart energy systems would be situated under physical capital [26].

Natural capital is concerned with the environment; land availability, geographic setting, water and natural resources, including sunlight hours, vital for electricity generation through PV panels, as well as wind (for wind turbines) and proximity to bodies of water (hydropower). Natural capital is spatial [70], and also deals with the ecology of a district and how this is affected by energy justice choices. We include the environmental frame conditions from the original framework within Natural capital. *Financial capital* refers to income generating activities, available property, affordability, financial resilience and good governance. Access and availability are crucial in the context of implementing technological smart energy innovations, and in addition transport poverty and mobility issues (e.g. fuel prices and vulnerability, [71]) could be included under this heading. *Human capital* refers to the education and knowledge base, a person or group of people have access to. For people to reduce their energy consumption it is, for example, imperative that they understand what they consume and when to adopt new energy saving behaviours. Human capital includes examining

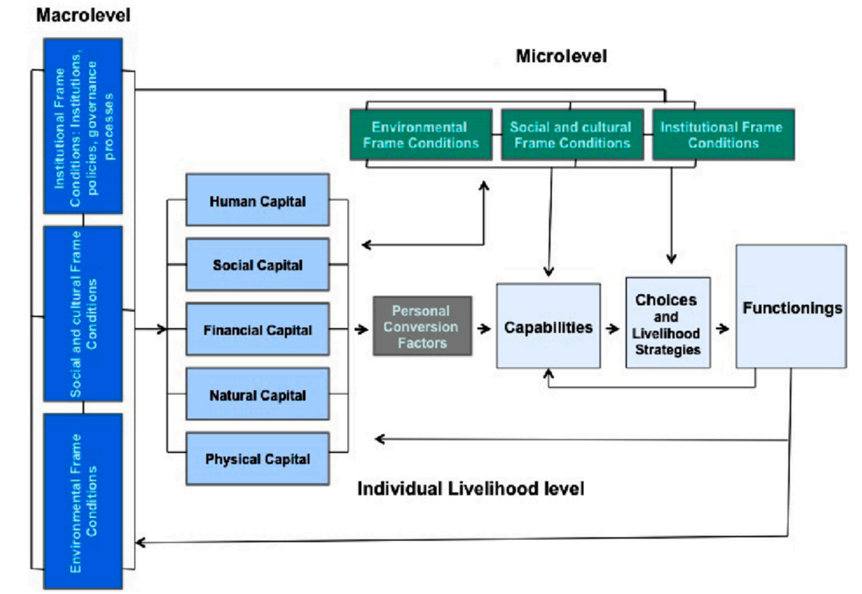

Fig. 2. Lienert-Burger 2015 livelihood-based capabilities framework from a sustainability perspective.

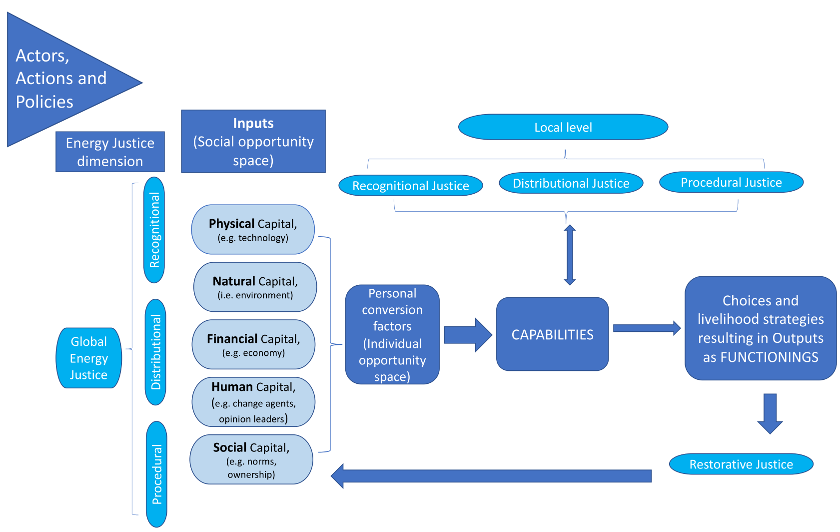

Fig. 3. The five capitals Burger Lienert model adapted to provide an energy justice framework.

change agents, as in the case of small business owners in Germany following the Chernobyl disaster [70], or energy cooperatives in Spain [50]. This relates to *Social capital*, which includes all kind of social relations like membership of groups, participatory processes health and medicine, and a social circle that enables or supports a person in her agency. Social capital also includes race and gender issues [56,72], and we include the social and cultural frame conditions from the original Burger-Lienert framework within social capital.

The five capitals set the scene for the opportunities available to residents, who are then able to choose those that they as individuals prefer. However, the capitals are embedded in a broader setting and can also be influenced by political actors, structures and actions [47]. In order to adapt the framework to smart technology innovation settings, we replaced the environmental, social and cultural, and institutional frame conditions with distributional, procedural and recognitional justice dimensions as well as situating these under global justice, and adding restorative justice. The original frame conditions would be unproblematic if we were solely examining wellbeing and sustainability (as intergenerational justice) but we believe it important to highlight other significant energy justice dimensions. Examining these elements and their effect on the physical, natural, financial, human and social capitals allows us to see the capabilities which are available to residents after also taking into account personal conversion factors. By framing energy justice in this way and enriching the livelihood-framework with conceptualizations of the energy justice discourse, we can see that it is not solely about what people have reason to value and the individual capability set they may choose, but also about providing the opportunity spaces for all, including future generations. We place the framework under a triangular flag of "Actors, actions and policies", indicating that these play a significant role in determining the capitals available to a district.

To summarize, the following four points are essential if PED-like areas are to be considered from an energy justice perspective, informed by the CA approach, with a focus on wellbeing and opportunity spaces. First, the framework distinguishes generally between the individual and aggregated levels for energy justice and energy poverty, by looking at individual wellbeing as well as structural enabling conditions. Second and regarding PEDs, it examines justice considerations *within* PED-like areas along the dimensions of distributional, recognitional, procedural, global and restorative justice and puts opportunity spaces and how these enable wellbeing through the capitals (Fig. 3) centre stage. Simultaneously, the incorporation of global justice serves as a reminder that the impact of decisions taken related to the capitals may be international. This is mainly an ex-ante assessment, however it can also be used to examine PED-like areas ex post. Third, it opens the door for looking at governance implications. Although it can also be used for ex post analysis (looking at realized wellbeing for example), it can be used for ex ante assessments regarding requirements for *creating (designing)* energy just PED-like areas.

Fourth, this capitals informed capabilities framework could, for example, be linked to change of behaviour-related frameworks as outlined in Burger et al. [47]. Bringing such a behavioural framework into the picture draws the analytic attention beyond the enabling conditions to include how people adapt technology innovations to their daily life. This not only concurs with recent research on reducing energy consumption pointing to both structural and individual aspects [73,74], but mirrors again that the framework displays individual and aggregated structural levels. However, we did not carry out that last step due to the existing space limitations.

5. An application to the Hunziker Areal, Discussion.

In this section, we seek to demonstrate the usefulness of our framework with an application to the Hunziker Areal (HA). We look at the five types of capitals to see in what respect ex ante decisions in the creation of the HA provided opportunity spaces by taking justice dimensions into account. The following tables chart some of the energy justice issues related to each of the capitals in the example of the HA, which we will also discuss in relation to other PED-like areas. Moreover, we discuss the benefits of our framework and point to limitations.

The HA was purpose-built, and the extensive planning phase incorporated the voices of multiple experienced collectives (see social capital below). It is likely that this will not be the case for all PEDs, impacting physical capital and natural capital as the spatial distribution is less flexible and existing infrastructure is likely to be used as the basis for improvement. This may lead to very different debates, as retrofitting existing multi-occupancy buildings and those in co-ownership may have complex legal and governance issues when it comes to energy saving and generating installations [75]. The retrofitting of older housing stock [37,58] could be viewed through the lens of restorative justice, perhaps giving further impetus to the creation of PED-like areas in deprived areas.

All 2000-W society districts in Switzerland have common energy reduction aims [76] and are purpose-built with long term tenants in mind (cf. [77]; 65% of housing stock in Switzerland is tenanted, [78]). The 2000-W society is part of the national energy policy and is promoted by the Swiss Federal Office of Energy (SFOE). Having a supportive policy context is a significant benefit when it comes to creating PED-like areas, and drawing policy makers attention to the five capitals could potentially lead to more energy-just districts.

In the area of technology and infrastructure, i.e. *physical capital* (Table 1), there has been research on the need for public acceptance, as well as the need to guard against unintended social consequences; areas of procedural and recognitional justice [11,14]. Decisions made regarding physical capital at the HA were reached through a variety of activities such as an ideas competition, ideas market, working committees, events and themed workshops, between 2010 and 2015. Cooperative members, the wider public and the project developer exchanged ideas on sustainability, building services technology and new apartment typologies [79]. The way these decisions were made has repercussions

Table 1
Physical Capital and justice issues in the Hunziker Areal.

PHYSICAL CAPITAL	Hunziker Areal MaW 2000-W	Energy Justice Dimension
Electricity	60% of energy imported from national grid, around 40% from PV panels	*Distributional:* costs and benefits of production, storage, transmission; location of PV panels *Procedural:* how decisions regarding energy supplier are reached *Global:* choice of energy mix, where PV panels are produced
Heating	Waste heat harnessed for district heating	*Distributional:* not all districts can harness this, future residential areas may not be able to benefit from this. *Global:* no incentive to reduce waste heat if this is to be harnessed, could lead to increased emissions. Potential rebound effect *Intergenerational:* long term reduced costs and wellbeing standard
Infrastructure	Purpose-built to Swiss Minergie standards	*Global/Intergenerational:* Minergie buildings are not necessarily sustainable to build with lots of concrete and high embodied carbon emissions. *Distributional:* benefits and burdens of Minergie, such as not opening the windows for lengthy periods, but also high energy efficiency.

for procedural and recognitional justice, going beyond using participation as a means of gaining public acceptance. The shape and direction of the district was determined through participatory processes which attempted to gather together the best choices and preferences for a new district from an actively engaged public. Indeed physical capital is not normally part of the decision-making remit for tenants, and PED-like areas such as Carquefou (Nantes, France, [21]) offer apartments for sale, excluding some of those who are unable to afford to purchase them (although some 20% social housing is planned [21]). On the other hand, decisions regarding energy consumption and heating in the HA may result in global justice issues, specifically with regards to the choices of building materials used, source of energy and heating mix and its impact on GHG emissions. This is also the case in connection with social capital in solar communities in Portugal [6] which were hesitant to invest in new technologies due to global justice issues, such as the working conditions and source of raw materials for PV panel production. The choice building material for the HA is cement which in turn means the buildings have high embodied carbon emissions [80] and although these are more sustainable to live in, they are not necessarily sustainably built.

In terms of *natural capital* (Table 2), living in an area with no other residential buildings around it may have initially resulted in a reduction of the opportunities associated with city living, whilst the surrounding

Table 2
Natural Capital and justice issues in the Hunziker Areal.

NATURAL CAPITAL	Hunziker Areal MaW 2000-W	Energy Justice Dimension
Spatial within city	No other residential buildings (surrounded by light industry). Outside city centre, accessible via bike trail, footpath, train or bus	*Distributional:* not in a standard urban area *Recognitional:* easily established boundaries of those affected by decisions made in the district, and easier to identify vulnerable residents
Distribution within district	Smaller private spaces, larger shared spaces (shared guest rooms for visitors, party rooms, freezer room, parks etc)	*Distributional:* particularly during the COVID-19 pandemic where shared spaces may be perceived as riskier

industrial area would have also meant none of the expected benefits associated with living in less populated areas with green spaces materialised (Distributional injustices). Private spaces are small, with an emphasis on shared spaces (both indoors and outdoors) and shared living, which could be taken as meaning that there is greater spatial equity within the district. This spatial distribution [70] makes for more efficient energy use but also raises wellbeing issues. Although there are alternate ways of enhancing capabilities provided, this form of semi-communal living may not be easy to adjust to for those that are used to larger private spaces. The need to quarantine and social distance during the COVID19 pandemic also brings the benefits of this type of spatial distribution into question.

In terms of *financial capital* (Table 3), we identify affordability, income generating activities and mobility as key areas. A significant deposit is required from residents (10.000–28.000 CHF depending on property size), representing around eight months' worth of rent. Rents are estimated to be 20% lower than in similar sized properties elsewhere in Zurich and it is claimed that owing to this, banks may be amenable to loaning a deposit making the funds potentially easier to secure. Additionally, 10% of the housing available is given to social institutions and provided to people who cannot pay the deposit, thus enabling some energy vulnerable people to benefit, with rent varying from case to case depending on need. Energy prices within the HA are set by the collective to deliberately be among the highest in Zurich, in order to encourage energy-saving behaviour. This is counter-balanced by the highly energy-efficient infrastructure, and may indeed be considered to have an effect on global justice as the implication is that emissions from the district will be mitigated. On the other hand, the extra cost of this may be perceived as an energy injustice for the 10% living in social housing.

There is a risk that PED-like areas will result not just in the exclusion of energy vulnerable people, but also in the exacerbation of energy poverty [58] and the potential ghettoization of the energy poor. PED-like areas such as La Pinada (Valencia Spain, [21]) already face some public objections along the lines of exclusion, as future residents are encouraged to sign up and co-design the neighbourhood, but for a price of €600 [81] which is likely to be beyond the reach of the energy vulnerable.

Table 3
Financial Capital and justice issues in the Hunziker areal.

FINANCIAL CAPITAL	Hunziker Areal MaW 2000-W	Energy Justice Dimension
Affordability	Rents 20% lower than average for Zurich, energy deliberately priced as highest in Zurich, Large deposit required.	*Global:* high energy prices may help reduce demand and associated emissions *Distributional:* greater negative effect on those in social housing *Procedural:* who gets to live in the district and how are they selected?
Mobility	All residents (bar disabled and shift workers) sign a car waiver Ecar sharing scheme Ebike/cargobike/bike rental	*Intergenerational:* more sustainable mobility options promoted *Intragenerational:* potential negative effect on elderly and families with small children *Recognitional:* some people with different needs are treated differently
Income-generating activities, available commercial property, financial resilience	Ground floors kept for businesses Approx. 150 people employed in or by the HA	*Distributional:* who benefits from working in the area? How do salaries compare? *Procedural:* how are decisions reached on which businesses should operate within the district?

Furthermore, in terms of mobility, which we include under financial capital, there are significant justice issues within the HA. Effectively trade-offs have to be made in deciding whether sustainability is more important, with a focus on global and intergenerational energy justice, or whether some elements of subjective wellbeing such as the convenience of owning a vehicle/being able to park in the district etc. may need to be curtailed. Ultimately, the decision to provide an electric car-share scheme in the district may mitigate this, but the embodied emissions in these vehicles and the global energy injustices associated with them make this potentially a "less-unjust" option rather than a truly just option. Ensuring that the district is walkable and cyclable and that residents are able to meet their needs without venturing further on a regular basis has perhaps a great impact on mobility energy justice.

For the development of PED-like areas, it is worth noting the potential energy injustices connected to *where* finance comes from and for what purpose. This is particularly important because JPI Urban Europe estimates that the €0.74 billion public investment will be met with minimum of €100 billion from private investment and cities [82]. If these districts are to be run for profit (such as the case of La Pinada, Valencia [81]), reiterating the need for a just transition becomes all the more important to avoid them becoming exclusively the domain of the wealthy. Whilst potential impacts of energy finance on justice issues have been previously examined [83], putting this in the greater context of the 5 capitals allows a wider picture of energy injustices to be revealed.

There has been significant focus on *human capital* (Table 4) from a gender perspective [56,72,84], however within the example of HA gender remains to be examined, and this would indeed be grounds for future research. Having an experienced knowledge base formed from multiple other cooperatives may have led the HA to make the decision that the district should mirror demography in the greater Zurich area in terms of inhabitants age, gender, income-bracket and nationality.

As apartments become available, these are not rented on a first-come first served basis, but interested parties are invited to apply, and a committee has the final say on who gets to rent the place (note: there is a shortage of apartments in the Zurich area and it is common for landlords to select tenants based on their own sets of criteria [78]). This suggests that the assessment is not needs-based which could further add to injustice.

The demography of HA was meant to mirror the wider community but salaries are slightly lower than average, and there is significantly greater representation of international residents (in terms of recognitional justice, this may cause some difficulties in communication) as well as those with special needs. For those with special needs, car ownership is permitted (intersecting with financial capital, Table 3), and this may help mitigate some potential recognitional justice issues.

In terms of *social capital* (Table 5), it is possible to join the cooperative, without being a resident. This brings in a number of potential justice issues in that members of MaW do not have to live in the district

Table 4
Human Capital and Justice issues in the Hunziker Areal.

HUMAN CAPITAL	Hunziker Areal MaW 2000-W	Energy Justice Dimension
Knowledge base available Opinion leaders/change agents	Created by members of 30 different cooperatives. Participation actively encouraged with 300 + members of WhatsApp and Telegram groups for residents	*Procedural:* significant knowledge base *Recognitional:* newcomers may face established and entrenched roles. Some people may be excluded from forms of digital communication
Demographics	Greater representation of residents with special needs, immigrants and refugees (over 60 nationalities represented)	*Recognitional:* greater recognition of these groups, but potential language barriers

Table 5
Social Capital and Justice issues in the Hunziker Areal.

SOCIAL CAPITAL	Hunziker Areal MaW 2000-W	Energy Justice Dimension
Social groups	40 + social clubs (e.g., beekeeping, sauna users, carpentry) open to general public, minimal membership fees	*Procedural:* processes clearly set out, affordable and accessible *Recognitional:* require only 5 people to form a new club
Ownership	Cooperative, all residential units tenanted, no individual home owners	*Recognitional:* it is possible to be a member of the cooperative but not a resident. This would entail having a say in what is done but not necessarily being equally affected

to have a say in what occurs in the district. Decisions are made democratically, and the voice of the minority members that do not live in the HA may be instrumental when it comes to voting on issues upon which residents are relatively evenly divided. In addition, social clubs in the HA are open to the wider community outside of the HA, and membership is fee-based. However, clubs are also supported through the solidarity fund which receives income-dependent contributions from residents, meaning that most of the infrastructure is provided at a low cost or is free. This may mean that HA clubs are likely to be more affordable than those in other areas, but also raises questions on fairness and whether non-residents are contributing fairly. It also increases the social opportunity space for those who attend whilst attempting to encourage positive attitudes towards the HA from both residents and non-residents. There are, accordingly, numerous opportunity spaces created for social interaction, whereas it remains up to the individuals to participate.

Taken together, our justice framework expands the focus away from environmental (which we include as natural capital), technological and economic justice dimensions to include other dimensions which may otherwise be understudied. When applied to other PED-like areas, our framework may reveal that human and social capital will likely be crucial in ensuring energy injustices are minimized. A study on communal bioenergy projects in Germany [85] indicated the importance of human capital in the form of initiators. It is possible that PED-like areas will also better develop in areas where local participation is stimulated by change agents. Ownership and co-ownership issues in PED-like areas may arise where there is a need to motivate residents in order to increase demand side flexibility, improve energy efficiency and attempt to deal with energy poverty [86] bringing in multiple justice dimensions. Energy justice approaches to renewable electricity has been examined through geographic, temporal, technological, economic and socio-political dimensions [28].

Choosing the HA for validation of our framework could be biased as justice and wellbeing considerations were taken into consideration by the MaW cooperative from the very beginning in designing the innovative setting. This is by far not the case in general. Nevertheless, using the HA example demonstrates that our framework allows us to analyse energy justice issues for PED-like areas. Obviously, there are also elements to each of the capitals which will be different for each area, and the overarching themes of recognitional, procedural, and distributional justice overlap for some of these capitals. However, this overlap allows them to be considered from different perspectives which may provide added benefit when other such areas are examined. It is hard to discuss natural capital without also discussing physical capital, and human capital is often interlinked with both financial and social capital.

Hence, we believe that the framework considerably enriches debates on energy justice in PED-like areas. Providing the possibility for ex ante justice considerations in the creation of PED-like cases means that utilizing this framework in governance and planning could significantly increase the chances of these districts forming part of a just transition. Combining the capitals with distributional, procedural, recognitional, global and restorative justice, as well as including intergenerational and intragenerational equity allows for the expression of multiple facets which may produce some overlap, but which help to create a comprehensive picture of energy justice issues in PED-like areas. Future research will have to add evidence on this claimed usefulness and where to improve and adjust respectively.

6. Conclusion and outlook

Enhancing capabilities has been used as a metric for energy justice [7,60,61,87], but rather than focusing on people, our approach focuses on opportunities. Energy justice emerged from an environmental justice background [88,89], and owing to this, environmental concerns are often still taken to be central in looking at justice in the energy transition [90]. However, our framework expands the focus away from environmental (which we include as natural capital) to include other dimensions which may otherwise be understudied. Using the five capitals as outlined above offers an enhancement of previous frameworks [14,15,24,37–39,41,72] as we incorporate what we see as the most salient elements of these to identify potential energy injustices.

Besides academic progress in justice issues, our work has a potential for improving societal practice and encouraging proactive governance towards a just transition. Despite the often-made claim towards "human-centred", there is no inherent relation between striving for PEDs and PEDs taking energy justice issues into account, and there is a potential for increased inequalities and exclusion [91]. Our framework can be used in these contexts to enable stakeholders to address these aspects at the design stage. Only by applying careful considerations from the very beginning when planning PEDs and PED-like areas, will we be able to take justice and wellbeing considerations into account. The HA example also highlights that relying on technological solutions alone is not enough to bring about the required reduction in energy consumption to achieve a PED status. Inhabitants choose to live there not because of its fancy technological set up, but because of the whole package. Physical capital (technological innovation) is one element in an equation which also needs to include financial, social, natural and human capital.

The aim of this paper was to add to energy justice research by providing a robust theoretical basis to analysing PED-like areas with opportunity spaces and wellbeing at its centre. The first and most important result is that looking at the case through the lenses offered by the suggested framework can provide results. It allows approaching the relation between energy innovations and the often-opaque notion of opportunity spaces or capabilities by looking at how different capitals are set together. At the same time, the framework is normatively informed, i.e., the categories are normatively desired categories and allow the aforementioned justice criterion to be taken into account.

Second, examining justice issues in such transition settings really matters. If we are to avoid a business-as-usual approach from engineers or standard investors, it should be ensured that justice and wellbeing are considered when energy innovative living areas are planned and implemented. It seems clear that when developing innovative living spaces based on energy transition ideals of decarbonization, decentralized energy production, and smart innovation justice, wellbeing issues must be integrated from the very beginning in order to ensure residents capabilities are maintained, and ideally enhanced.

The framework promises to shed light on the relation between energy transition and how this can become a just transition in the upcoming field of PED-like areas. There are many potentials fields for future empirical as well as conceptual research, such as research related to planning or implementation processes, and looking at realized wellbeing or policy frame-conditions. The framework appears flexible enough to take different contexts of new energy systems into account in order to provide a solid and enhanced basis for analysis.

Adam Hearn is an Early Stage Researcher completing his PhD at Basel University, as part of the Horizon 2020 Marie Skłodowska-Curie Action SMART-BEEJS project. His research focus is on energy justice, energy poverty, and Positive Energy Districts.

Paul Burger is Professor and directs the Sustainability Research Group within the Department of Social Sciences, University of Basel, Switzerland. His research focuses on theoretical foundations for sustainable development including its normative basis, on governance of sustainable development and on understanding change of household energy consumption.

Dr. Annika Sohre is a Senior Researcher at the Sustainability Research Group, University of Basel, Switzerland. She has an interdisciplinary academic background in environmental sciences and political science. Currently, she works on a number of projects focusing on governance, energy transitions, particularly change of energy behaviour, energy and climate policies and sustainable development.

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.

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References

[1] S. Bouzarovski, S. Petrova, A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary, Energy Res. Social Sci. 10 (2015) 31–40.
[2] R. Day, G. Walker, N. Simcock, Conceptualising energy use and energy poverty using a capabilities framework, Energy Policy. 93 (2016) 255–264.
[3] N. Healy, J. Barry, Politicizing energy justice and energy system transitions: Fossil fuel divestment and a "just transition", Energy Policy. 108 (2017) 451–459, https://doi.org/10.1016/j.enpol.2017.06.014.
[4] K.E.H. Jenkins, D. Hopkins, Transitions in Energy Efficiency and Demand: The Emergence, Routledge, Diffusion and Impact of Low-Carbon Innovation, 2018.
[5] O. Akizu, G. Bueno, I. Barcena, E. Kurt, N. Topaloğlu, J.M. Lopez-Guede, Contributions of Bottom-Up Energy Transitions in Germany: A Case Study Analysis, Energies. 11 (2018) 849, https://doi.org/10.3390/en11040849.
[6] S. Sareen, H. Haarstad, Bridging socio-technical and justice aspects of sustainable energy transitions, Appl. Energy 228 (2018) 624–632, https://doi.org/10.1016/j.apenergy.2018.06.104.
[7] G. Walker, N. Simcock, R. Day, Necessary energy uses and a minimum standard of living in the United Kingdom: Energy justice or escalating expectations? Energy Res. Social Sci. 18 (2016) 129–138, https://doi.org/10.1016/j.erss.2016.02.007.
[8] E. Druică, Z. Goschin, R. Ianole-Călin, Energy Poverty and Life Satisfaction: Structural Mechanisms and Their Implications, Energies. 12 (2019) 3988, https://doi.org/10.3390/en12203988.
[9] B.K. Sovacool, M.H. Dworkin, Energy justice: Conceptual insights and practical applications, Appl. Energy 142 (2015) 435–444, https://doi.org/10.1016/j.apenergy.2015.01.002.
[10] H. Thomson, C. Snell, Quantifying the prevalence of fuel poverty across the European Union, Energy Policy. 52 (2013) 563–572, https://doi.org/10.1016/j.enpol.2012.10.009.
[11] S. Bosch, M. Schmidt, Wonderland of technology? How energy landscapes reveal inequalities and injustices of the German Energiewende, Energy Research & Social Science. 70 (2020), 101733.
[12] M.J. Burke, J.C. Stephens, Energy democracy: Goals and policy instruments for sociotechnical transitions, Energy Res. Social Sci. 33 (2017) 35–48.
[13] B.K. Sovacool, What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda, Energy Research & Social Science. 1 (2014) 1–29, https://doi.org/10.1016/j.erss.2014.02.003.
[14] S. Axon J. Morrissey Just energy transitions? Social inequities, vulnerabilities and unintended consequences 1 1 2020 2020 2020 393 411.
[15] R.J. Heffron, D. McCauley, Achieving sustainable supply chains through energy justice, Appl. Energy 123 (2014) 435–437, https://doi.org/10.1016/j.apenergy.2013.12.034.
[16] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, R. Rehner, Energy justice: A conceptual review, Energy Research & Social, Science 11 (2016) 174–182, https://doi.org/10.1016/j.erss.2015.10.004.
[17] L. Steg, R. Gifford, Sustainable transportation and quality of life, J. Transp. Geogr. 13 (1) (2005) 59–69, https://doi.org/10.1016/j.jtrangeo.2004.11.003.
[18] L. Godin, S. Laakso, M. Sahakian, Doing laundry in consumption corridors: wellbeing and everyday life, Sustainability: Science, Practice and Policy. 16 (2020) 99–113.
[19] A. Monti, D. Pesch, K. Ellis, P. Mancarella, Energy Positive Neighborhoods and Smart Energy Districts: Methods, Tools, and Experiences from the Field, Academic Press, 2016.
[20] B. Alpagut, Ö. Akyürek, E.M. Mitre, Positive Energy Districts Methodology and Its Replication Potential, in, Multidisciplinary Digital Publishing Institute Proceedings 20 (1) (2019) 8, https://doi.org/10.3390/proceedings2019020008.
[21] C. Gollner, EUROPE towards POSITIVE ENERGY DISTRICTS, (n.d.) 182.
[22] White-Paper-PED-Framework-Definition-2020323-final.pdf, (n.d.). https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White-Paper-PED-Framework-Definition-2020323-final.pdf (accessed April 23, 2021).
[23] D. McCauley, V. Ramasar, R.J. Heffron, B.K. Sovacool, D. Mebratu, L. Mundaca, Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research, Appl. Energy 233–234 (2019) 916–921, https://doi.org/10.1016/j.apenergy.2018.10.005.
[24] K. Jenkins, B.K. Sovacool, D. McCauley, Humanizing sociotechnical transitions through energy justice: An ethical framework for global transformative change, Energy Policy. 117 (2018) 66–74, https://doi.org/10.1016/j.enpol.2018.02.036.
[25] B.K. Sovacool, M. Martiskainen, A. Hook, L. Baker, Decarbonization and its discontents: a critical energy justice perspective on four low-carbon transitions, Clim. Change 155 (4) (2019) 581–619, https://doi.org/10.1007/s10584-019-02521-7.
[26] G. Powells, M.J. Fell, Flexibility capital and flexibility justice in smart energy systems, Energy Res. Social Sci. 54 (2019) 56–59, https://doi.org/10.1016/j.erss.2019.03.015.
[27] M.J. Fell, Just flexibility? Nat. Energy 5 (1) (2020) 6–7.
[28] A. Banerjee, E. Prehoda, R. Sidortsov, C. Schelly, Department of Social Sciences, Environmental and Energy Policy Program, Michigan Technological University, 1400 Townsend Drive, Houghton MI 49930, USA, Renewable, ethical? Assessing the energy justice potential of renewable electricity, AIMS Energy. 5 (2017) 768–797, https://doi.org/10.3934/energy.2017.5.768.
[29] S. Milčiuvienė, J. Kiršienė, E. Doheijo, R. Urbonas, D. Milčius, The Role of Renewable Energy Prosumers in Implementing Energy Justice Theory, Sustainability. 11 (2019) 5286, https://doi.org/10.3390/su11195286.
[30] L. Horstink, J.M. Wittmayer, K. Ng, G.P. Luz, E. Marín-González, S. Gährs, I. Campos, L. Holstenkamp, S. Oxenaar, D. Brown, Collective Renewable Energy Prosumers and the Promises of the Energy Union: Taking Stock, Energies. 13 (2020) 421, https://doi.org/10.3390/en13020421.
[31] I. Robeyns, An unworkable idea or a promising alternative? Sen's capability approach re-examined, (2000).
[32] R. Hillerbrand, C. Milchram, J. Schippl, Using the Capability Approach as a normative perspective on energy justice: Insights from two case studies on digitalisation in the energy sector, Journal of Human Development and Capabilities. 1–24 (2021).
[33] J. Lienert, P. Burger, Merging capabilities and livelihoods: analyzing the use of biological resources to improve well-being, Ecol. Soc. 20 (2015) (accessed February 11, 2021), https://www.jstor.org/stable/26270215.
[34] Mehr als Wohnen, Home - MORE THAN LIVING, (n.d.). https://www.mehralswohnen.ch/ (accessed February 11, 2021).
[35] R. Stulz, S. Tanner, R. Sigg, Chapter 16 - Swiss 2000-Watt Society: A Sustainable Energy Vision for the Future, in: F.P. Sioshansi (Ed.), Energy, Sustainability and the Environment, Butterworth-Heinemann, Boston, 2011, pp. 477–496, https://doi.org/10.1016/B978-0-12-385136-9.10016-6.
[36] D.L. Goldblatt, Sustainable Energy Consumption and Society: Personal, Technological, or Social Change? Springer Science & Business Media, 2007.
[37] R. Gillard, C. Snell, M. Bevan, Advancing an energy justice perspective of fuel poverty: Household vulnerability and domestic retrofit policy in the United Kingdom, Energy Res. Social Sci. 29 (2017) 53–61.
[38] J. Lee, J. Byrne, Expanding the Conceptual and Analytical Basis of Energy Justice: Beyond the Three-Tenet Framework, Front. Energy Res. 7 (2019), https://doi.org/10.3389/fenrg.2019.00099.
[39] G. Pellegrini-Masini, A. Pirni, S. Maran, Energy justice revisited: A critical review on the philosophical and political origins of equality, Energy Res. Social Sci. 59 (2020) 101310, https://doi.org/10.1016/j.erss.2019.101310.
[40] R.J. Heffron, D. McCauley, The concept of energy justice across the disciplines, Energy Policy. 105 (2017) 658–667, https://doi.org/10.1016/j.enpol.2017.03.018.
[41] F. Bartiaux, M. Maretti, A. Cartone, P. Biermann, V. Krasteva, Sustainable energy transitions and social inequalities in energy access: A relational comparison of capabilities in three European countries, Global Transitions. 1 (2019) 226–240.
[42] C. Groves, F. Shirani, N. Pidgeon, C. Cherry, G. Thomas, E. Roberts, K. Henwood, 'The bills are a brick wall': Narratives of energy vulnerability, poverty and adaptation in South Wales, Energy Res. Social Sci. 70 (2020) 101777, https://doi.org/10.1016/j.erss.2020.101777.
[43] N. DellaValle, S. Sareen, Nudging and boosting for equity? Towards a behavioural economics of energy justice, Energy Research & Social Science. 68 (2020), 101589.
[44] S. Avila, Environmental justice and the expanding geography of wind power conflicts, Sustain Sci. 13 (3) (2018) 599–616, https://doi.org/10.1007/s11625-18-0547-4.

[45] E. Creamer, G.T. Aiken, B. van Veelen, G. Walker, P. Devine-Wright, Community renewable energy: What does it do? Walker and Devine-Wright (2008) ten years on, Energy Res. Social Sci. 57 (2019), 101223.
[46] C.G. Monyei, B.K. Sovacool, M.A. Brown, K.E.H. Jenkins, S. Viriri, Y. Li, Justice, poverty, and electricity decarbonization, The Electricity Journal. 32 (1) (2019) 47–51, https://doi.org/10.1016/j.tej.2019.01.005.
[47] P. Burger, V. Bezençon, B. Bornemann, T. Brosch, V. Carabias-Hütter, M. Farsi, S. L. Hille, C. Moser, C. Ramseier, R. Samuel, Advances in understanding energy consumption behavior and the governance of its change–outline of an integrated framework, Front. Energy Res. 3 (2015) 29.
[48] C.A. Miller, A. Iles, C.F. Jones, The Social Dimensions of Energy Transitions, Science as Culture. 22 (2) (2013) 135–148, https://doi.org/10.1080/09505431.2013.786989.
[49] U. Liebe, G.M. Dobers, Measurement of Fairness Perceptions in Energy Transition Research: A Factorial Survey Approach, Sustainability. 12 (2020) 8084, https://doi.org/10.3390/su12198084.
[50] I. Campos, E. Marín-González, People in transitions: Energy citizenship, prosumerism and social movements in Europe, Energy Res. Social Sci. 69 (2020), 101718.
[51] O. Lindholm, H.u. Rehman, F. Reda, Positioning Positive Energy Districts in European Cities, Buildings. 11 (1) (2021) 19, https://doi.org/10.3390/buildings11010019.
[52] D. Mulvaney, Opening the Black Box of Solar Energy Technologies: Exploring Tensions Between Innovation and Environmental Justice, Science as Culture. 22 (2) (2013) 230–237, https://doi.org/10.1080/09505431.2013.786995.
[53] F. Gralla, D.J. Abson, A.P. Møller, D.J. Lang, H. von Wehrden, Energy transitions and national development indicators: A global review of nuclear energy production, Renew. Sustain. Energy Rev. 70 (2017) 1251–1265, https://doi.org/10.1016/j.rser.2016.12.026.
[54] M. Lacey-Barnacle, Proximities of energy justice: contesting community energy and austerity in England, Energy Res. Social Sci. 69 (2020) 101713, https://doi.org/10.1016/j.erss.2020.101713.
[55] B.K. Sovacool, M. Burke, L. Baker, C.K. Kotikalapudi, H. Wlokas, New frontiers and conceptual frameworks for energy justice, Energy Policy. 105 (2017) 677–691, https://doi.org/10.1016/j.enpol.2017.03.005.
[56] S.E. Bell, C. Daggett, C. Labuski, Toward feminist energy systems: Why adding women and solar panels is not enough☆, Energy Res. Social Sci. 68 (2020), 101557.
[57] F. Martín-Consuegra, J.M. Gómez Giménez, C. Alonso, R. Córdoba Hernández, A. Hernández Aja, I. Oteiza, Multidimensional index of fuel poverty in deprived neighbourhoods. Case study of Madrid, Energy Build. 224 (2020) 110205, https://doi.org/10.1016/j.enbuild.2020.110205.
[58] N. Willand T. Moore R. Horne S. Robertson Retrofit Poverty: Socioeconomic Spatial Disparities in Retrofit Subsidies Uptake 1 1 2020 2020 2020 14 35 10.5334/bc.13.
[59] F. Bartiaux, C. Vandeschrick, M. Moezzi, N. Frogneux, Energy justice, unequal access to affordable warmth, and capability deprivation: A quantitative analysis for Belgium, Appl. Energy 225 (2018) 1219–1233.
[60] J. Assa, C. Lengfelder, Can Enhancing Capabilities Promote Energy Justice? An Agent-Based Model Approach, Mendeley Data. 1 (2020).
[61] T.E. De Wildt, E.J.L. Chappin, G. van de Kaa, P.M. Herder, I.R. van de Poel, Conflicted by decarbonisation: Five types of conflict at the nexus of capabilities and decentralised energy systems identified with an agent-based model, Energy Res. Social Sci. 64 (2020), 101451.
[62] A. Sen, Commodities and Capabilities, Oxford University Press, 1999 https://ideas.repec.org/b/oxp/obooks/9780195650389.html (accessed February 19, 2021).
[63] Human Development Index (HDI) | Human Development Reports, (n.d.). http://hdr.undp.org/en/content/human-development-index-hdi (accessed February 12, 2021).
[64] S. Belda-Miquel, V. Pellicer-Sifres, A. Boni, Exploring the Contribution of Grassroots Innovations to Justice: Using the Capability Approach to Normatively Address Bottom-Up Sustainable Transitions Practices, Sustainability. 12 (2020) 3617.
[65] M.E.P. Seligman, Flourish: A Visionary New Understanding of Happiness and Well-being, Simon and Schuster, 2012.
[66] N.D. Rao, J. Min, Decent Living Standards: Material Prerequisites for Human Wellbeing, Soc Indic Res. 138 (1) (2018) 225–244, https://doi.org/10.1007/s11205-017-1650-0.
[67] D. Coates, P. Anand, M. Norris, Housing, happiness and capabilities: A summary of the international evidence and models, Open Discussion Papers in Economics, 2015.
[68] B.K. Sovacool, R.J. Heffron, D. McCauley, A. Goldthau, Energy decisions reframed as justice and ethical concerns, Nat. Energy 1 (2016) 1–6, https://doi.org/10.1038/nenergy.2016.24.
[69] S. Higginson, M. Thomson, T. Bhamra, "For the times they are a-changin": the impact of shifting energy-use practices in time and space, Local Environment. 19 (5) (2014) 520–538, https://doi.org/10.1080/13549839.2013.802459.
[70] D. McCauley, A. Brown, R. Rehner, R. Heffron, S. van de Graaff, Energy justice and policy change: An historical political analysis of the German nuclear phase-out, Appl. Energy 228 (2018) 317–323, https://doi.org/10.1016/j.apenergy.2018.06.093.
[71] G. Mattioli, I. Philips, J. Anable, T. Chatterton, Vulnerability to motor fuel price increases: Socio-spatial patterns in England, J. Transp. Geogr. 78 (2019) 98–114, https://doi.org/10.1016/j.jtrangeo.2019.05.009.
[72] M. Feenstra, G. Özerol, Energy justice as a search light for gender-energy nexus: Towards a conceptual framework, Renew. Sustain. Energy Rev. 138 (2021) 110668, https://doi.org/10.1016/j.rser.2020.110668.
[73] L. Steg, G. Perlaviciute, E. van der Werff, Understanding the human dimensions of a sustainable energy transition, Front. Psychol. 6 (2015), https://doi.org/10.3389/fpsyg.2015.00805.
[74] B. Bornemann, A. Sohre, P. Burger, Future governance of individual energy consumption behavior change—A framework for reflexive designs, Energy Res. Social Sci. 35 (2018) 140–151.
[75] J. Pitt, C. Nolden, Post-Subsidy Solar PV Business Models to Tackle Fuel Poverty in Multi-Occupancy Social Housing, Energies. 13 (2020) 4852, https://doi.org/10.3390/en13184852.
[76] S. Yang, J.G. Pernot, C.H. Jörin, H. Niculita-Hirzel, V. Perret, D. Licina, Energy, indoor air quality, occupant behavior, self-reported symptoms and satisfaction in energy-efficient dwellings in Switzerland, Build. Environ. 171 (2020) 106618, https://doi.org/10.1016/j.buildenv.2019.106618.
[77] Das 2000-Watt-Areal, 2000-Watt-Areale. (n.d.). https://www.2000watt.swiss/ (accessed February 11, 2021).
[78] J. Lawson, Path Dependency and Emergent Relations: Explaining the Different Role of Limited Profit Housing in the Dynamic Urban Regimes of Vienna and Zurich, Housing, Theory and Society. 27 (3) (2010) 204–220, https://doi.org/10.1080/ 14036090903326437.
[79] M. Probst, «mehr als wohnen» und die 2000-Watt-Gesellschaft, mehr als wohnen. (n.d.) 56.
[80] J. Drouilles, S. Lufkin, E. Rey, Energy transition potential in peri-urban dwellings: Assessment of theoretical scenarios in the Swiss context, Energy Build. 148 (2017) 379–390.
[81] Vivir aquí, La pinada. (n.d.). https://www.barriolapinada.es/vivir-aqui/ (accessed February 17, 2021).
[82] setplan_smartcities_implementationplan.pdf, (n.d.). https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf (accessed February 11, 2021).
[83] S. Hall, K.E. Roelich, M.E. Davis, L. Holstenkamp, Finance and justice in low-carbon energy transitions, Appl. Energy 222 (2018) 772–780, https://doi.org/10.1016/j.apenergy.2018.04.007.
[84] E. Allen, H. Lyons, J.C. Stephens, Women's leadership in renewable transformation, energy justice and energy democracy: Redistributing power, Energy Res. Social Sci. 57 (2019) 101233, https://doi.org/10.1016/j.erss.2019.101233.
[85] A. Wüste, P. Schmuck, Bioenergy Villages and Regions in Germany: An Interview Study with Initiators of Communal Bioenergy Projects on the Success Factors for Restructuring the Energy Supply of the Community, Sustainability. 4 (2012) 244–256, https://doi.org/10.3390/su4020244.
[86] J. Lowitzsch, C.E. Hoicka, F.J. van Tulder, Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 122 (2020) 109489, https://doi.org/10.1016/j.rser.2019.109489.
[87] A. Melin, D. Kronlid, Energy Scenarios and Justice for Future Humans : An Application of the Capabilities Approach to the Case of Swedish Energy Politics, Etikk i Praksis. 13 (2019) 39–54.
[88] S.H. Baker, The Energy Justice Stakes Embedded in the Net Energy Metering Policy Debates, Beyond Zero-Sum Environmentalism (Sarah Krakoff et al., Eds., Environmental Law Institute 2019). (2019).
[89] S. Bouzarovski, S. Tirado Herrero, S. Petrova, D. Ürge-Vorsatz, Unpacking the spaces and politics of energy poverty: path-dependencies, deprivation and fuel switching in post-communist Hungary, Local Environment. 21 (2016) 1151–1170.
[90] M. Graff, S. Carley, M. Pirog, to 2017 with a Closer Look at the Energy Justice Field, Policy Studies Journal. 47 (S1) (2019) S17–S44, https://doi.org/10.1111/psj.v47.S110.1111/psj.12316.
[91] B.K. Sovacool, Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation, Energy Res. Social Sci. 73 (2021) 101916, https://doi.org/10.1016/j.erss.2021.101916.
[92] P. Burger, M. Christen, Ed. Basil Bornemann, Sustainability, Well-Being and Justice. Handbook of Democracy and Sustainability, Routledge, London, 2021. In preparation.

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Towards a Just Energy Transition, Barriers and Opportunities for Positive Energy District Creation in Spain

Adam X. Hearn [1,*] and Raul Castaño-Rosa [2,3]

[1] Sustainability Research Group, University of Basel, CH-4051 Basel, Switzerland
[2] Appropriate Technologies for Sustainable Development Group, Universidad Carlos III de Madrid, 28903 Madrid, Spain; raul.castanodelarosa@tuni.fi
[3] Faculty of Built Environment, Tampere University, Korkeakoulunkatu 1, 33720 Tampere, Finland
* Correspondence: adam.hearn@unibas.ch; Tel.: +49-152-5230-0448

Abstract: To mitigate the effects of climate change, the European Commission created a Strategic Energy Technology Plan committing to forming 100 Positive Energy Districts (PEDs) by 2025. These are considered to potentially be major instruments for decarbonization in a just transition. This plan has led to some districts being defined as PEDs, although none have fully met the criteria to be a PED yet. Research shows that new forms of energy ownership and production, as could potentially be found in PEDs, could help reduce energy poverty, which affects a significant segment of the population, as households can reduce their energy expenditure as well as improve their energy behavior. This paper set out to shed light on the PED landscape, investigating the barriers and opportunities to PED creation in Spain and its potential to mitigate energy poverty. We conducted a literature review on community-owned energy in Spain, followed with expert interviews (energy researchers, stakeholders, and NGOs) who focus on sustainability issues in Spain. Results show a number of barriers (lack of knowledge and awareness, and lack of trust from consumers) and opportunities connected with the creation of PEDs. In conclusion, policymaker engagement and support play a key role in successfully implementing PEDs.

Keywords: Positive Energy Districts (PEDs); Local Energy Communities (LECs); energy justice; energy transition; energy poverty

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1. Introduction

A significant decline in the costs associated with PV production and innovative PV efficiency improvements, coupled with the high number of solar days makes a strong case for PV energy in Spain [1] to meet and exceed national energy requirements [2]. However, until 2018, regressive legislation (specifically RD900/2015) protected dominant market interests and penalized PV energy production. The Royal Decree 244/2019 (RD244) ended taxation on self-production, and also defined the conditions for creating energy communities in Spain [1].

In a concerted attempt to speed up the decarbonization of urban areas within the EU, a project to establish 100 Positive Energy Districts (PEDs) in Europe by the year 2025 [3] was set in motion by the Joint Programming Initiative Urban Europe [4]. PEDs are defined as highly energy efficient districts that are wholly powered by Renewably Energy Technology (henceforth RET), and produce a yearly net surplus of energy, whilst also offering affordable living for residents [5]. The concept of PEDs arose as a natural extension from pre-existing low-carbon developments, such as Positive Energy Buildings [4] and Positive Energy Blocks [6], and is seen as a step towards Nearly Zero Energy Cities (NZECs) [7] and Positive Energy Cities (PECs). The creation of an initial 100 PEDs across Europe also focuses on replicability as these have been identified as a potentially significant tool in decarbonizing urban areas in Europe, which could be further expanded once these have been fully evaluated [5]. A PED booklet containing 61 different projects in Europe [4,8] includes four in Spain; Atelier project in Bilbao (in implementation [9]), Paterna, Valencia (in planning), Mieres, Asturias District heating (implemented towards PED), and Mostoles Madrid Ecoenergias District Heating (implemented towards PED).

There are potentially three different types of PEDs. Autonomous PEDs are entirely self-sufficient and produce all their energy on-site, whilst Dynamic PEDs may import energy, but produce a net surplus on a yearly basis. Virtual PEDs incorporate RET, which is located outside of the boundaries of the PED [10]. Whilst it is clear that PEDs are to be renewably powered, and the topic of where energy production is to be situated has been examined [10], novel forms of community energy ownership could support PED development.

Energy communities in the form of Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) are enshrined in EU directives [11]. PEDs, CECs and RECs have similar goals of reducing emissions, as well as increasing active citizen participation in decentralizing energy markets, leading to the terms often being wrongly used interchangeably (see Table 1). Both RECs and CECs are often referred to as Local Energy Communities (Comunidades Energéticas in Spanish, henceforth LECs), but the term LEC is more closely aligned with the legal term REC. Table 1 (below) summarizes the main similarities and differences between prosumers, energy cooperatives, RECs, CECs and PEDs.

Table 1. Differences between Prosumers, RECs, CECs and PEDs (Authors own elaboration).

	Self-Consumption/ Prosumers [12]	**Energy Cooperative [13]**	**Renewable Energy Community (REC) [14]**	**Citizen Energy Community (CEC) [15]**	**Positive Energy District (PED) [10]**
Membership	Household, or within same building	Multiple households	Individuals, local authorities, enterprises, but must not be primary commercial/professional activity. Must be accessible to low-income households	Individuals, local authorities, enterprises	Can incorporate households, individuals, local authorities, enterprises. Must be inclusive
Location of energy production	On the property	Can be anywhere	Must be local	Can be anywhere	Must be local for Autonomous and Dynamic PEDS, but can be anywhere for Virtual PEDs
Innovations/ Technologies	Mainly PV, solar hot water, energy storage, heatpumps	Bottom up network of sustainable innovation	Only renewable energy (May not meet full demand)	Any form of energy (May not meet full demand)	Only renewables (Must aim to eventually exceed demand)
Legally permitted activities in energy sector	Production, consumption of own energy, sale of excess to grid or Peer-to-peer trading Installed capacity per household/user is limited unless they are in a cooperative or a CEC [16]	Production and Marketing	All segments of the energy chain	May engage in generation, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders	Not legally determined as may include Prosumers, RECs and CECs

The flexibility afforded to PEDs in not having any specified legally permitted activities in the energy sector allows for the inclusion of both RECs and CECs within them. Although there is no requirement for PEDs to include any form of community energy, it is very likely that these will be used to support PED development and they have been linked to PEDs in research [17]. However, PEDs may also include individual prosumers, and renewable energy supplied by utilities or energy cooperatives. In this paper we focus on PEDs, and include LECs as we believe these increase the potential for PEDs to form part of a just transition.

The growth of LECs across Europe is no longer isolated to specific countries [18], and there is evidence to show that the number of LECs within the EU has dramatically increased since the Clean Energy for All Europeans package [19] was launched in 2019. Although the distribution of LECs across Europe remains uneven, they are established as important stakeholders in the energy systems of nations such as Germany and Denmark [20], whilst being in early development in others such as Spain, where a public consultation on LECs took place in December 2020 [21,22].

The residential building sector accounts for 18.3% [23] of energy demand in Spain, and the need to decarbonize this is undisputable. However, the benefits of doing so through the creation of PEDs are manifold. PEDs can potentially bring about significant technical, financial and social benefits as a part of a decentralized energy system [24,25]. On the technical side, a distributed energy system can alleviate pressure on centralized grids, increasing security reliability and resilience in the event of price volatility or energy emergencies [26]. From a financial perspective, although costs per unit and installation costs are liable to vary widely, more companies are likely to be involved, with benefits spread over significantly greater numbers of interested parties, leading to greater financial resilience [27]. In Spain, it is currently cheaper to produce a KWh of energy through PV than purchasing it from the grid [26], making decentralized forms of energy production attractive as an investment to households and communities. Both of these aspects (technological and financial) are equally applicable in the case of prosumers. However, the big difference between individual prosumers and LECs is that for PEDs, shared forms of energy production, management and distribution can be tailored to ensure that energy poverty is mitigated, as well as to assist in the (re)creation of flourishing shared communities that go beyond energy, incorporating other social benefits [28].

Energy poverty refers to a household that is unable to meet its energy needs, and has been identified as a significant problem throughout Europe, including in Mediterranean countries like Spain [29,30]. LECs have been considered from the perspective of energy poverty [25,31], as a tool for mitigating energy poverty [32,33], especially within the Mediterranean, such as in Greece [34,35], Italy [36] and Portugal [37]. From the literature it is clear that LECs are able to identify local energy needs and foster community participation [38], and as such could be utilized as an enduring method to reduce energy poverty. Therefore, LECs can potentially provide free or reduced cost energy and an additional income stream (should energy be sold) for those in energy poverty. On a PED scale, research in Portugal indicates the potential of PEDs as a tool for mitigating energy poverty in the historic district of Alfama in Lisbon [39].

Research in smart energy systems has included different technologies (i.e., energy storage [40]; district heating [41], or the Internet of Things [42]), but there has been little research into LECs or PEDs development in the Spanish context so far. Indeed, in the case of Spain, academic attention has often focused on individual prosumers [43] or energy cooperatives such as Som Energia [13,44–47], largely because legislation has meant that such cooperatives were able to function where LECs were not. Research into LECs and PEDs in Spain is sparse, with little research on their potential effect on energy poverty mitigation or from an energy justice perspective.

In this respect, this research aims at identifying what the existing barriers are to PED creation as part of a just transition in Spain, based on expert interviews with developers of LECs and PEDs, and energy researchers. We detail our methodology below, followed by the framework behind our approach and a literature review. The potential for PEDs to form part of a just energy transition and mitigate EP is discussed using an analysis of the interviews conducted, based on our framework. This is followed by a section on LECs, PEDs and energy poverty, which is seen as a form of capability deprivation [48] that mitigation or from an energy justice perspective.

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2. Materials and Methods

To address this gap, we first conducted a literature review by using Scopus searches for the terms "Positive Energy Districts"; "Energy Communities" and "Spain"; and "Energy Communities" and "Energy Poverty" (Figure 1), which resulted in the inclusion of thirty-nine articles. In addition, we conducted a snowball search of articles related to LECs elsewhere in Europe, together with searches of grey and non-academic literature on PEDs and LECs in Spain. Figure 1 below shows graphically the methodology used for the Scopus literature review.

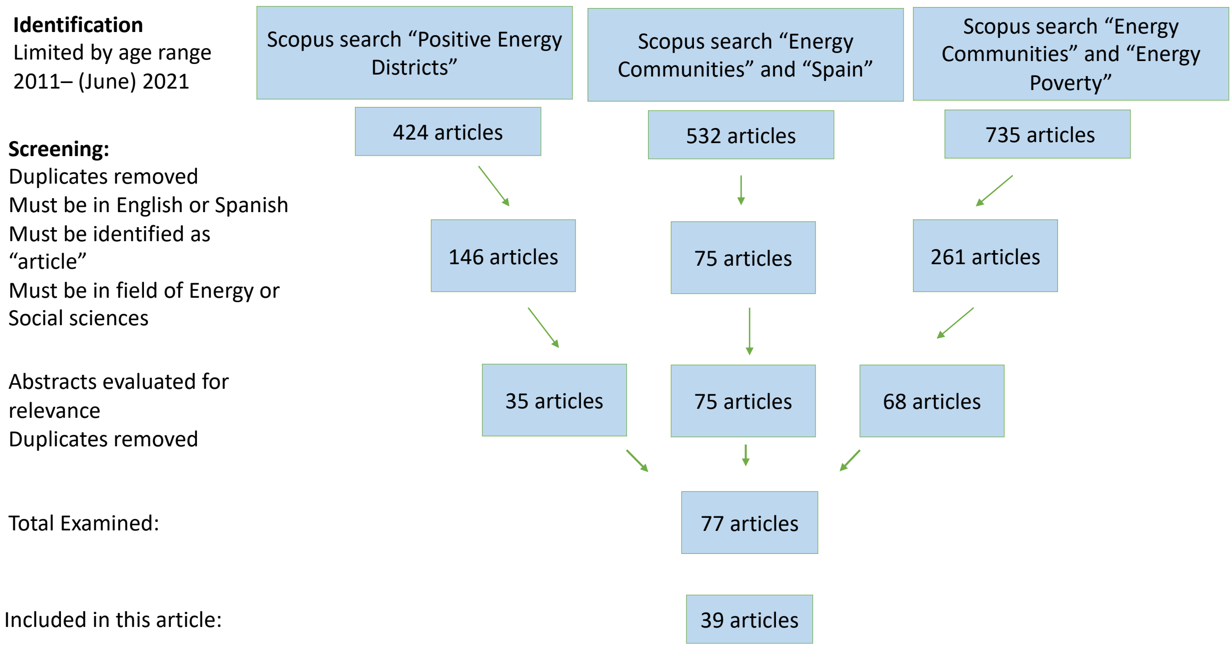

Figure 1. Literature search methodology.

Secondly, potential candidates to interview were initially located online using the four Spanish projects listed in the PED booklet as a starting point, together with a major energy cooperative, Som Energia, which was able to put us in contact with a number of LECs. 13 semi-structured in-depth interviews from thirty to sixty minutes duration, with a total of 16 key stakeholders (12 male, 4 female) from LECs, cooperatives, local, regional and national government, private enterprise (PED designers), researchers and NGOs, were conducted (see Table 2). We struggled to get female respondents, which is broadly in line with research indicating that women's viewpoints are often absent or underrepresented in energy transition pathways [49]. Ethical approval for the interviews was granted by the SMART BEEjS consortium. Table 2 provides an overview of the different interviewee typologies according to their main roles.

Interviews were conducted online using the Zoom platform, transcribed and translated before coding and content analysis using MaxQDA2020. Many of those interviewees had multiple roles, such as working for local authorities and LECs, as well as being members of different energy cooperatives.

Table 2. List of different interviewee typologies.

Principle Interviewee Role	Number of Interviews	Codes Assigned to Interviewees	Region Located in	Gender
Researcher:	4	ER1, ER2, ER3, ER4	Madrid Madrid Castilla y Leon, Barcelona	Male Female Male Female
Public office (i.e., councilor for energy and sustainability)	2	P1, P2; Mo1, Mo2	Madrid Madrid	Male Male, Male
Energy-related NGO	1	NGO1	Madrid	Male
Private firm	1	PR1; M1, F1	Valencia	Male, Female
EC organisation	4	EC1, EC2, EC3, EC4:V1, V2	Andalucia Navarra, Andalucia Catalonia	Male, Male, Male Male, Male
Cooperative association	1	C1	Catalonia	Female

3. Literature Review: The Case of Spain

A prominent framework that has been used to analyze LECs in Spain is the Multilevel Perspective (MLP) [50]. The MLP has been used in some research on LECs in Spain, in which the socio-technical system is divided into niches, regimes, and landscapes [13,45]. These form a nested hierarchy in which shared energy initiatives such as cooperatives and LECs are perceived as forming and operating in a niche. Innovations formed in the niche are sometimes able to become a dominant aspect of the regime, depending on their ability to compete with pre-existing forms that dominate the regime (in this case the oligarchy of major energy suppliers). The regime in this case is also under pressure from the landscape level, which refers to the external factors that influence the regime such as climate change and EU directives.

However, in order to ensure the creation of PEDs is justice-informed that they might be a part of a fair and inclusive transition, an energy justice framework may be more feasible.

An energy justice framework incorporating the MLP is put forwards by Jenkins, Sovacool and McCauley [51], and this approach notes the importance of further research that considers non-traditional actors such as users and marginalized groups in transitions. We build on this by incorporating energy poverty, but we consider PEDs to be socio-technical niches [52], which may be routed in technology, but which are also social innovations. Owing to this, we focus on an energy justice approach which is informed by the capability approach (CA) [53]. The CA has been used as a metric for wellbeing and justice in research focusing on LECs in the global South [54–56], as well as on energy justice research that focuses on energy poverty [48] providing a multidimensional definition of energy poverty as a capability deprivation. Ensuring that PEDs are embedded within energy justice, by using a CA based framework, may assist in meeting the European Green Deal requirement of a "just and inclusive" transition [57].

Our approach is to examine different aspects of the physical, economic, social and technical setting through a justice informed lens, which includes the triumvirate of energy justice tenets (distributional, procedural, and recognitional justice [58]), but also includes global, redistributive, intergenerational and intragenerational justice [59,60].

For the case of PEDs, *distributional* justice focuses on the benefits and burdens of being included in an energy community in terms of where the energy producing technology is placed. We also consider *recognitional* justice, asking about how inclusive PEDs are/plan to be. Further, we enquire on *procedural* justice aspects, how decision-making processes are created and to what degree these are transparent in the face of the energy industry in Spain. Additionally, we attempt to understand to what extent intergenerational and intragenerational justice are considered in the forming of PEDs, whilst also raising the question of global justice which is significant when it comes to the extraction of raw materials and the included in an energy community in terms of where the energy producing technology is placed. We also consider *recognitional* justice, asking about how inclusive PEDs are/plan to be. Further, we enquire on *procedural* justice aspects, how decision-making processes are created and to what degree these are transparent in the face of the energy industry in Spain. Additionally, we attempt to understand to what extent intergenerational and intragenerational justice are considered in the forming of PEDs, whilst also raising the question of global justice which is significant when it comes to the extraction of raw materials and the production of PV panels [61]. For those that are adversely affected, we question whether restorative justice principles could increase overall support for such projects.

To do this, Figure 2 depicts the framework used for the analysis that incorporates energy justice into the ex-ante assessment of PEDs [59] (Figure 2, below), examining the aforementioned energy justice dimensions considered in terms of opportunity spaces (or Capitals).

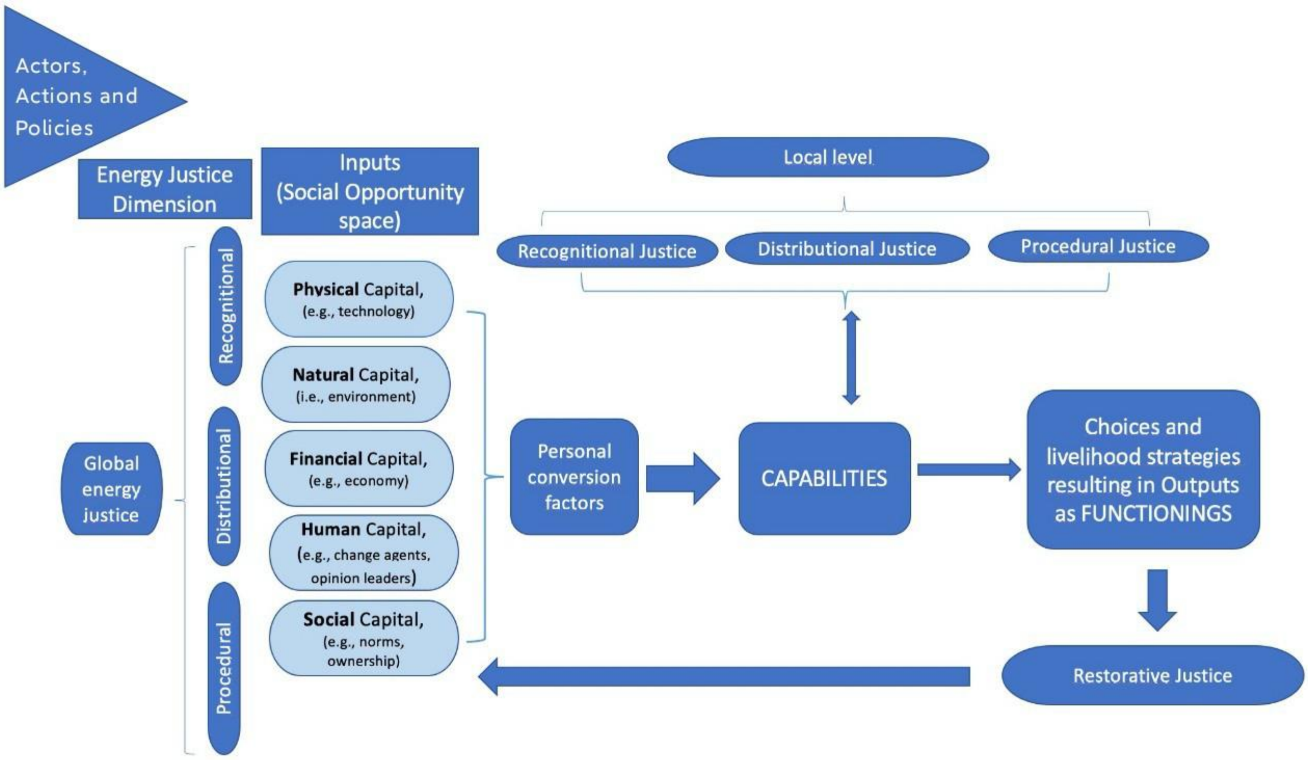

Figure 2. Livelihoods-Capabilities based energy justice framework from Hearn, Sohre and Burger 2021.

Although PEDs are newcomers to the field of energy in Spain, there has been some research into potential barriers and opportunities for new forms of energy ownership in Spain such as cooperatives and LECs, as well as research on an international scale, which may be applicable to PED creation [62]. In terms of barriers, these can be divided into technological, financial, social, political and regulatory. We link these to opportunity spaces within the energy justice framework:

Physical Capital. This refers to issues surrounding the infrastructure and technology available for the PED.

Natural Capital. This focuses on environmental issues that may arise in connection to the PED, and natural barriers and opportunities.

Financial Capital refers to the access and availability of finance, income generating activities and affordability of the PED.

Human Capital examines the knowledge base available for the PED as well as change agents and opinion leaders. Within this we incorporate political and legislative barriers and opportunities.

Social Capital focuses on the social and cultural frame conditions for the PED.

Technical barriers or *physical capital* include the fact that there has not been much experience in managing reverse power flows from high PV generation in the system [1] and that the increasing number of prosumers (both collective and individual) could lead to overall grid costs increasing [12]. Barriers to *Financial capital* relate to the financial investment required to set up a PED. In Spain, two main barriers have already been identified: the high costs of a distributed system [1], and the current energy auction system which might discriminate smaller citizens initiatives in favor of larger operators [13]. In the area of *Social capital*, barriers include issues of unequal participation [63] and engrained patterns of energy consumption behaviors which may be difficult to change [64]. Research has also identified gender issues with women voices being underrepresented within LEC initiatives [49]. Political and regulatory barriers relate to the political context. In Spain, the stagnation of the energy system under the oligopoly [65] has already been outlined together with regime resistance [13,47]. The regulatory framework (included under *human capital*) has been recognized as a significant barrier in the case of Spain [12], despite the recent legislative changes and the clear need for a supportive legal framework for LECs [12] and PEDs. Research conducted prior to the change in legislation (RD244 overturned the so-called "Tax on the Sun") paints an even bleaker picture of prior legislative barriers to LEC initiatives [66].

PEDs may bring many opportunities, and these can broadly be divided into environmental, technological, social, financial, political and legislative. From an environmental perspective (*natural capital*), there is general consensus on the high potential for significantly reduced greenhouse gas emissions in Spain and the EU [1,46,67]. Technological opportunities (*physical capital*) include a potential improvement in the efficiency of the energy system through local power generation as this will not need to be transported long distances [1], and a more resilient and adaptable energy system overall [26,63].

Social advantages and opportunities (*social capital*) that have been researched include the transformative potential of LECs [13], including increased social justice [47], reciprocity and added co-activities [26,63]. Furthermore, there has been some research on the potential benefits of similar energy initiatives in rural areas of Spain [68]. Other research has examined the benefits of incorporating sustainability and renewable energy issues into school communities, through educational programs which often focus on energy consumption behavior change, but which also sometimes incorporate the installation of PV panels for self-consumption [69].

Financial opportunities (*financial capital*) include reducing national energy imports [70], improved competitiveness within the national energy market [12], which could be key to democratizing a new decentralized energy system [13], high rates of job creation, and benefits being shared between an increased number and range of actors [1]. Political and legislative opportunities (*human capital*) are seen as arising directly from European Directives [63] which means that the Spanish government is likely to encourage new forms of shared energy ownership [68].

Understanding that the current situation for PEDs positions firmly within the niche level, we examine each of the social opportunity spaces and what the barriers and opportunities for PEDs are with energy justice in mind, understanding that not all forms of energy justice will be displayed within each capital.

4. Analysis of the Interviews

In this section, we detail the results from our interviews, initially discussing problems with terminology, followed by three sections on physical and natural capital, financial capital, and human and social capitals. We then examine the barriers and opportunities in using PEDs that include LECs as tools to mitigate energy poverty.

4.1. What Is a PED?

A significant issue in terminology became clear in the interviews. All of the parties interviewed were involved in the field of energy, and yet almost all of them were unfamiliar with the term PED, including those working in districts that were listed in the PED booklet. Of the sixteen people interviewed, one city councilor in Viladecans was aware of the concept, and responded *"Our idea is to produce an excess. For example, we are now implementing the action of PV panels in municipal facilities with the aid of the Ministry and that comes from Europe, and we are always looking for the maximum production. Why? Because we are looking for this model of producing excess energy that we can share with others. Our idea is in some cases to make bi-directional energy communities"* (EC4, V1). A second councilor in the same interview

(EC4, V2) quickly interjected that the high energy demand from the industrial sector made it impossible for the entire town to become a PED. However, if the industrial area were to be excluded it would seem that the LECs in Viladecans (EC4) could be extended to form PEDs, or RET from outside the geographic area could be used to create a virtual PED. Conversely, during the interview with two PED designers from Valencia (PR1), it became clear that there is interest in the inclusion of LECs in the Valencia PED [71] after residents move in, with the potential for around 45% of energy needs to be met in this way. This demonstrates that the PED-LEC link could function both ways, with PEDS incorporating LECs, but also with the potential for LECs to amalgamate or grow to the point where they could be considered PEDs.

Only two of the researchers interviewed had heard of the term previously, but neither of them was familiar with its meaning (ER1, ER4). The interviewee from an energy related NGO (NGO1) understood PEDs as synonymous with LECs, highlighting the confusion over terminology *"Our interpretation is energy communities, which we are promoting as a representative organization of people with concerns about the environment, not only that it is renewable and clean energy-but that we are working to reduce and even completely eliminate fossil fuels ... but also the opportunity to democratize the energy system"* (NGO1). Another interviewee from a Cooperative (C1) believed that rather than a surplus of energy, PEDs/LECs could grow in size to match production by incorporating more residents, and that the borders of a PED or LEC could be malleable. This goes beyond current notions of PEDs replication [17,72], which assume fixed boundaries, and could provide an interesting and viable means of growing and up-scaling PEDs for the future. Once a definition of PEDs had been given, one town councillr (P1) said: *"we have no interest in becoming a PED, absolutely not, because we do not want to have any surplus energy that goes to the supplier. What we really want to do is make sure that our consumption is met almost completely by our own production, but no more than that. If you are not a distributor then it really needs to be about meeting your energy needs and nothing more."* (P1).

This seems to indicate that the low price currently given to excess energy sold to the grid from forms of prosumership (both individual and collective) is a significant barrier when it comes to encouraging the creation of PEDs which by their very definition are meant to produce a surplus. This could be remedied through direct government policy. It seems that the term PED has not fully entered into the vocabulary of experts, and there may be good grounds for policymakers to engage in a media campaign in order to make the term more familiar, at least in the case of Spain. Whilst LECs in Spain can be situated within the niche currently according to the MLP, it seems that PEDs are perhaps in a pre-niche state, where they are still yet to be formed in such a way as to enter the niche, let alone the regime level, despite the pressure from the landscape. This may change in the near future as the term PED may evolve according to how it is used across different EU countries.

4.2. Physical Capital and Natural Capital—The Infrastructure and Environment

Geographical and climatic conditions make solar energy be the most common renewable energy source used for the creation of PEDs in Spain. Conversely, windfarms are often seen as contentious [55] due to acceptance issues which are sometimes portrayed as NIMBYism [73]. However, there has been some energy justice research which suggest that increasing citizen participation can lead to greater acceptance in places where this is possible [74]. One LEC in Andalusia (EC1) rued the fact that in the past the community was able to create its own hydro-energy system but water levels were no longer reliable enough to make this possible, showing the negative impact of climate change on intergenerational energy justice. In a town in Navarra (EC2), an old abandoned hydro-electric plant was restored, but this was only possible because local water rights had been maintained for irrigation purposes, allowing the use of the water. In two other cases, a UNESCO world heritage town, and a mediaeval walled town, PV was not permitted within the center, but according to ER1, large scale PV farms are planned in the surrounding area. As NGO1 highlighted, a just energy strategy is needed: *"In Spain, there are a lot of useful materials for* *renewables, however, they are opening many licenses and many prospections for open-cast mines, and this of course destroys biodiversity, the landscape, and so on"*.

In terms of distributional justice, having suitable natural capital is a prerequisite to installing physical capital such as PV. Home-owners may be more likely to opt for becoming individual prosumers, whilst those in rented or multi-occupancy accommodation may not have the legal right to install PVs, increasing energy inequalities. According to P1, the town of Soto del Real in Madrid reported that since the overturning of RD900/2015, the number of homes installing PV in the town has increased, from 2 in 2018, to 9 in 2019, to 22 in 2020, to over 20 in the first 3 months of 2021, meaning that RET might well be reaching the point of becoming an established part of the regime. In order to counter existing inequalities, multiple respondents explained that they relied on the local authorities to cede the roof-space of public buildings, such as schools (EC1), abandoned buildings (EC2), sports centers (P1, E4). Interviewee C1 suggested making suitable private roofs (i.e., industrial estates or office buildings) available to produce energy for those who need it the most: *"I think that it is even an obligation for all of us who live in a built environment in cities, in towns, in villages, to make the most of the space that we already have, that is not being used to generate energy"* (C1).

Some policymakers from local authorities (P1 and E4) were already engaged in this, and encouraging such engagement could greatly reduce distributional energy injustices in this form of physical capital. Using surplus energy generated on local authority buildings for LECs was seen as preferable to creating a surplus instead of giving it to the grid for a fraction of what it was sold on for (P1).

A further form of physical (and natural) capital is district heating and cooling (DH), and three of the official Spanish PED-like cases include or center around this. DH used to be commonplace but were replaced in a concerted campaign which one interviewee perceived as *"A real social scam in my opinion, because what is really efficient are the centralized systems for community and for security."* (P2, Mo2). Returning to more prevalent use of DH may reduce overall costs and reduce energy poverty, but the installation of DH in existing districts is costly and disruptive.

The developer who set up a DH network in Mostoles, Madrid using biomass, is currently applying for permission for a further DH which will be combined with the creation of some form of LEC, potentially in connection with solar assisted DH [75,76], but this once again raises issues of energy justice. How are the benefits and burdens going to be distributed when a private firm manages it? Are there barriers to citizen participation? How transparent are the processes connected with this? It seems clear that having a third party assist or take control and develop LECs within a PED may make things substantially easier for residents, but there are more questions than answers when it comes to exactly how this is to take place. According to P2 Mo2: *"It has to be someone who, for example, in this case like (Company name), who presents them with the idea, who is willing to receive it, who has to stay, who has to adapt it"*.

Community energy storage has been researched [77] but this is in its infancy in Spain. In the interviews none of the LECs or PEDs had made any arrangements for energy storage due to its perceived cost and complexity. *"We have ruled out storage also for simplicity"* (EC3).

Resistance to the idea of energy storage seems to imply that this is a barrier for the creation of autarchic PEDs which do not rely on energy imports at all, *"In fact, you're going to need batteries, you're going to need storage, in other words, you're already entering into a scheme that in the end, in order to buy in isolation, all this material is going to be much more expensive."* (ER2,). However, this barrier disappears when one considers the fact that PEDs can be autonomous, dynamic or virtual [10]. Dynamic PEDs need to produce an annual net surplus but are also able to import energy (i.e., at night for those that rely on PV, and virtual PEDs can take advantage of larger scale storage solutions such as the wind-pumped hydropower station on El Hierro [78], or combine different forms of renewable energy in order to reduce intermittency, such as hydro, wave and wind [79,80]. Furthermore, innovative solutions to the issue of energy storage have been implemented in the PED in

Évora, Portugal, where the use of second life batteries from electric vehicles is currently being tested [81].

Overall, it would appear, that local barriers connected to the physical and natural capitals of PEDs and LECs are not insignificant, but their local nature might be overcome by harnessing the ingenuity of residents to find viable solutions. From the interviews, the ceding of public roof space presents novel opportunities for existing natural capital to be harnessed for the creation of justice-informed PEDs.

4.3. Financial Capital: Barriers and Opportunities

The high initial costs involved in purchasing and installing the necessary technology to create LECs and PEDs may make the involvement of multiple private and public partners essential. One issue identified through our interviews concerning financial capital relates to intergenerational justice: *"In the end if we make this type of system, a critical mass of consumers with the possibility of paying their electricity bill to the grid are not going to do so in the long term"* (ER2). This means that if large numbers of people create microgrids, this could lead to underfunding of the national grid and, consequently, threaten national energy security. On the other hand, the benefits of a decentralized energy system using LECs on national energy security may well exceed any potential downside, i.e., PEDs could incorporate mixed forms of energy ownership which would allow continued payments to the grid, albeit on a reduced scale.

Although overall increases to grid costs have been considered in the literature [12], a novel significant barrier for PEDs that include LECs is that there is no organization nor group with any financial incentive to support their development. Although energy cooperatives are largely supportive, there is little benefit to cooperatives in assisting in the setting up of LECs. A member of the Som Energia cooperative (EC1) noted that some years ago they were almost the only option for consumers who wanted renewable energy. Now, LECs have to compete with the potential of people to become prosumers, with cooperatives, and with renewable models from all the major existing energy providers (e.g., [82,83]), all of which can be incorporated into PEDs albeit with differing outcomes in terms of a just transition. However, there seems to be ample evidence that cooperatives such as Som Energia, and NGOs such as Amigos de la Tierra, have been instrumental in supporting the creation of LECs [84]. One interviewee went on to say *"We would never have started anything of what I'm telling you if it hadn't been for the initial, disinterested and altruistic support, and without anything asked for in return, from Som Energía"* (EC1).

The use of a facilitator was seen as crucial for the planning of LECs [85], connecting financial capital with human and social capitals. When it comes to PEDs, could LECs and cooperatives be financially supported to co-create such districts?

4.4. Human and Social Capitals

The opaqueness of the energy market is perceived as a significant and deliberate barrier, with some LECs setting up energy advice centers as a major part of their activities (EC1, EC2, EC3) because energy bills and different tariffs are hard for consumers to understand. In terms of procedural justice, some interviewees went as far as suggesting that false or deliberately confusing information is given by the major utility companies (NGO1). Energy advice centers have been used to alleviate energy poverty [86] (See Section 4.5), and having these services embedded within the local community through LECs may contribute to their efficacy [87], particularly if the advice is given face-to-face [88].

The *"...asymmetry of information"* (ER2) is seen as a way of ensuring that consumers settle for simpler contracts that may well be more expensive (EC1, EC2, EC3). Embedding energy advice centers in PEDs may have an effect in creating energy literate prosumers who are better able to make decisions regarding their own energy consumption. This becomes all the more important from the 1 June 2021 in Spain, as a new energy tariff (The new electricity tariff which starts on the 1 June in Spain will mean that consumers will pay different amounts depending on the time of use; valley (13.49/Kwh, plain (17.95/kwh), and peak (30.12/Kwh).

However, the fixed part of electricity bills will also be reduced. [89]. It was implemented, promoting households' energy behavior: *"The new electricity tariff has a very clear rationale, I mean, change in behavior, rationale, and that's why it is very problematic"* (EC4). Although there seems to be some concern that energy poverty and issues of recognitional energy justice will increase with the new tariff, it might be possible that the electricity prices increase *" . . . may motivate people to engage, to get together for a community energy project"* (EC4).

Research has suggested that LECs may assist in overcoming indifference or uncertainty [90], and it may also be the case that current state of uncertainty and change in the Spanish energy sector with the new pricing system acts as a catalyst for promoting PED creation that includes community energy initiatives. However, a further significant barrier is that there are no "turn-key" models for LECs. Creating a PED that incorporates LECs is likely to involve a significant investment in time and effort which may simply not be feasible for many people. In contrast, consumers can sign up for a "green" energy supply, provided by most major suppliers, which does not involve any additional time, effort or knowledge. This might mean that there are some intragenerational justice issues, as the demographic that tends to be attracted to LECs may be younger people without families, or retired people with more time on their hands (C1). When it comes to PED creation, incorporating LECs may increase energy justice, but it is likely that a model in which community energy initiatives are pre-established in conjunction with either cooperatives or major energy suppliers will be simpler for the end user.

Furthermore, there is a lack of awareness on how the energy system works in Spain and what the new laws are, with an enduring negative social effect related to the former regressive "Sun Tax" (RD900/2015) which was widely publicized. One interviewee voiced that *"there wasn't strong enough publicity to reverse that* "(EC3), and that even though there are now EU directives that help enshrine LECs legal position, they have encountered a fear that government policies could be reversed from some prospective members. This fear and lack of awareness on how the energy system works is further exacerbated by the rapid speed of change in the current energy system. The uncertainty caused by rapid change and confusing terminology is enhanced by a perception that the energy industry is corrupt, with an EU survey showing that 86% of Spaniards believe corruption to be a big problem [91] and a third believing that it has increased in 2020 [92]: *"Historically it is very, very corrupt. We have many former presidents and former ministers working on the boards of directors of the big electricity companies when they finish in office. This means that, well, governments directly legislate in favor of these companies"* (EC4, V2). Indeed, a simple internet search reveals multiple newspaper articles highlighting recognitional justice issues such as a revolving door between politics and the major utility companies [93,94], as well as more recent articles with allegation of corruption and price fixing [95,96]. One interviewee (EC1) noted that a change in supplier had resulted in a technician knocking on their door and threatening them the next day, and that this gave them the additional impetus that they needed to go ahead and start to create a LEC.

There is widespread consensus on the need for greater citizen participation in the energy sector [97], and influences on community engagement in renewable energy projects in Spain, such as on the Island of La Graciosa [80], indicating that a pre-existing sense of community might have an effect, as do attitudes and norms, and awareness of other similar projects. This last point may indicate that there are tipping points that can be reached in LEC participation once it has become sufficiently diffuse, potentially leading to change at the regime level. Encouraging participation is no easy task: *"everyone wants participation to be established, but then, when it comes down to it, getting this participation to be real and effective is not easy. You have to constantly encourage this participation and find actors who really want to participate"* (EC4, V1).

In one PED project near Valencia [71], participation in the early stages of the co-design of the district involved numerous meetings, but interviewees from this project expressed how difficult it was to encourage longer term attendance, when these meetings would be scheduled for after work hours or at weekends, and people simply cannot be expected to volunteer significant amounts of time on a regular basis. This is even more so for vulnerable households who may need some assistance in participating [98]. In the later stages of co-creation, participants were asked to pay a €600 deposit towards accommodation in a district which may take several years to be created, raising potential issues of recognitional justice (PR1). Participation and reaching a consensus within the community on what is to be done, by whom, how, and how the benefits are to be shared, is no easy matter. Reaching agreement, even within a small block of flats is perceived as difficult: *"if we don't agree on storing bikes downstairs in the (shared) entranceway, I doubt we will agree"* (ER2). Existing conflicts between neighbors over shared spaces coupled with the complexity of LEC and PED creation may mean that some kind of neutral third party or intermediary is crucial if they are to succeed.

There are numerous social benefits to PED creation, beyond energy, which were mentioned in different interviews, for instance, increasing a local circular economy as in the case of Viladecans in Catalonia which created a local currency [99], and built a sense of community as a starting point for discussions on community mobility, community gardening and more; *"Energy is like an excuse to get in the same boat... all on the same course, with the same objectives"* (EC2). Similarly, one interviewee used the metaphor of planting tomatoes: *"It's the metaphor we use for energy. If we plant tomatoes and we share them, why don't we plant energy? Because we're going to plant kilowatts. Yes, and share it"* (EC1). Increasing a shared community beyond energy enables further distributional, recognitional and procedural justice issues to be considered and resolved within the community. This also opens up the possibility for restorative justice to be applied, when necessary, which may be most visible with the use of this type of initiative to counter energy poverty.

4.5. PEDs and Energy Poverty

Energy poverty encompasses multiple energy injustices [100–102], and Spain has a National Strategy [103] which defines energy poverty mainly as a consequence of low incomes and energy-inefficient housing. The National Strategy uses four main indicators to determine who falls into energy poverty, which are sourced from the European Energy Poverty Observatory (EPOV) [104]. The National Strategy identified between 3.5 to 8.1 million people living in energy poverty in Spain in 2019, setting a target of 50% reduction in energy poverty by 2025 [103].

Methods that have been identified and are used in Spain to deal with energy poverty include a focus on consumer advice improvements, greater consumer protection, structural energy-efficiency measures and short-term financial assistance, such as the Social Tariff [105]. The use of rooftop PV to alleviate energy poverty has been considered in Spain [106], but potential community ownership of PV has not been fully addressed. Furthermore, PED projects such as "Making-city" in León, specifically target lower income neighborhoods for establishing PEDs [107] in order to mitigate energy poverty through energy efficiency improvements and RET.

The Social Tariff was set up in 2009 for electricity and 2018 for heating, and provides a discount for vulnerable families of either 25% or 40% on the electricity price (but not on fixed standing charges). This discount is available to vulnerable families directly from eight utility companies and was given to over 1.3 million households in 2020 [108]. It also includes extended payment periods (consumers are given four months to pay instead of the usual two), simplified bills, and some disconnection protection. However, it does not address the underlying causes of energy poverty, which has not decreased despite the Social Tariff [109].

Moreover, there is no means for other organizations, outside of the eight major utility companies, to offer the Social Tariff, which creates a powerful barrier countering the participation of those suffering from energy poverty in LECs, cooperatives, and, potentially, PEDs. Despite this, there is some evidence that some people who suffer from energy poverty still prefer to be members of an energy cooperative or LEC, even if this means that they do not receive the Social Tariff [109–111]. Nevertheless, the inclusion of energy vulnerable households in LECs and cooperatives is likely to be severely impaired if these are not able to offer the Social Tariff, and this will have repercussions on PEDs which include these forms of community energy initiatives.

From our interviews, it became clear that excluding LEC initiatives from the Social Tariff is a significant issue when it comes to the use of these to mitigate energy poverty within PEDs, *"if being part of an energy community project means you cannot access the Social Tariff and the associated protection, that means that it's not a very good solution for the household in energy poverty"* (EC4). Furthermore, this also puts LECs at a disadvantage compared to similar forms of shared energy ownership which are managed by the major utility companies. This was also raised in an interview with an energy researcher who noted that *"the issue of costs is contradictory because in the end the best offer, as happened with our neighbor, is being given by Endesa or Repsol"* (ER2).

The Social Tariff's issue does not stop LECs from having a focus on energy poverty, indeed, a researcher involved in the creation of LECs in Northern Spain said: *"We work from the perspective of how energy communities can help or can be a tool to solve fuel poverty"* (ER3). This was repeated throughout the interviews with a general consensus that even without the Social Tariff, LECs can help reduce future vulnerability to energy poverty and can also have an effect on those in energy poverty. The NGO involved in assisting in the creation of LECs went as far as to say that they believed that when it comes to energy poverty, LEC creation *"could even be the solution"* (NGO1). Similarly, ER2 said: *"I see that energy communities could be another vehicle to also solve energy poverty."*.

There is no doubt that there is an opportunity for PEDs that incorporate LECs to become a part of a new strategy for energy poverty mitigation in Spain, replicating the situation in other countries. However, owing to the current situation with the Social Tariff, it is likely that utility owned energy initiatives within PEDs may be better suited at mitigating energy poverty, and that a legislative change is needed if other energy initiatives are to be as successful. In the case of the UK, research has been conducted on how energy poverty can be alleviated through the use of novel business models which allow citizen participation in the energy market beyond individual prosumer, specifically considering social housing and multi-occupancy buildings [112]. However, this also recognizes the need for support from third party intermediaries [113] who may be able to help arrange buy-as-you-use arrangements, which are affordable and available to a greater part of the population.

Tackling energy poverty may create some tension with decarbonization aims, as energy consumption can end up increasing [114]. This was reported as the case in Vildecans in Catalonia, where energy poverty mitigation policies (including installing heating systems) led to an increase in energy consumption despite these being combined with energy-efficiency measures and full retrofitting, including façade and windows (EC4).

5. Conclusions

This work shows the potential role that PEDs that incorporate LECs could play in decarbonizing and perhaps more significantly democratizing the energy system [115]. LECs have been embedded in EU policy, but PEDs are still very new concepts and need to be fully embedded in national and regional policies, as there is no official national strategy yet. There seem to be clear regional differences in Spain which may reflect political differences, as well as urban-rural differences, which may be exacerbated as urban areas are growing rapidly [116].

PEDs could contribute to a just transition in Spain, but there are significant barriers, such as energy illiteracy, and a lack of trust and awareness, which need to be overcome in order for this to be the case. The main strategies that this work proposes to address existing barriers are: Firstly, there may be good grounds for policymakers to engage in a media campaign in order to make the term more familiar to the general population. Secondly, although available technology is enough for considerable gains to be made in decarbonization through PED creation, the added benefits, such as energy poverty reduction, make these interesting propositions to be considered in tandem with the creation of larger scale RET farms. Finally, note that to truly harness the energy poverty mitigating benefits of PEDs and LECs, legislative changes may need to occur. In this respect, the current Social Tariff limits the inclusion of those most vulnerable in community initiatives of this type, thus, allowing LECs, PEDs and cooperatives to offer this could greatly increase their social impact. There may be a need to consider a move of energy poverty mitigation from social policy to energy policy [117], where incorporating LECs and PEDs into the arsenal of mitigation tools makes most sense, as the opportunity for synergies [118] between energy poverty mitigation and climate change mitigation can be better taken advantage of.

In conclusion, policymaker engagement in PED creation is crucial if these are to be successfully implemented. There is a clear opportunity to explore the use of LEC initiatives in tandem with PED creation, leading to multiple benefits in the future.

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References

1. Gallego-Castillo, C.; Heleno, M.; Victoria, M. Self-Consumption for Energy Communities in Spain: A Regional Analysis under the New Legal Framework. *Energy Policy* **2021**, *150*, 112144. [CrossRef]
2. Girard, A.; Gago, E.J.; Ordoñez, J.; Muneer, T. Spain's Energy Outlook: A Review of PV Potential and Energy Export. *Renew. Energy* **2016**, *86*, 703–715. [CrossRef]
3. Civiero, P.; Pascual, J.; Arcas Abella, J.; Bilbao Figuero, A.; Salom, J. PEDRERA. Positive Energy District Renovation Model for Large Scale Actions. *Energies* **2021**, *14*, 2833. [CrossRef]
4. Bossi, S.; Gollner, C.; Theierling, S. Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases. *Energies* **2020**, *13*, 6083. [CrossRef]
5. SETIS. SET Plan Information System. Setplan_Smartcities_Implementationplan.Pdf. Available online: https://setis.ec.europa.eu/index_en (accessed on 20 June 2021).
6. EXCESS. PEB Case Studies. Available online: https://positive-energy-buildings.eu/peb-case-studies (accessed on 16 March 2021).
7. Villa-Arrieta, M.; Sumper, A. Economic Evaluation of Nearly Zero Energy Cities. *Appl. Energy* **2019**, *237*, 404–416. [CrossRef]
8. Gollner, C. *Europe towards Positive Energy Districts. 182*. Urban Europe. Available online: https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf (accessed on 20 June 2021).
9. Bilbao. ATELIER. Available online: https://smartcity-atelier.eu/about/lighthouse-cities/bilbao/?cn-reloaded=1 (accessed on 13 July 2021).
10. Lindholm, O.; Rehman, H.u.; Reda, F. Positioning Positive Energy Districts in European Cities. *Buildings* **2021**, *11*, 19. [CrossRef]
11. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources (Recast). EUR-Lex. Available online: https://eur-lex.europa.eu/legal-content/EN/LSU/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG (accessed on 22 April 2021).
12. 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]

13. Capellán-Pérez, I.; Campos-Celador, Á.; Terés-Zubiaga, J. Renewable Energy Cooperatives as an Instrument towards the Energy Transition in Spain. *Energy Policy* **2018**, *123*, 215–229. [CrossRef]
14. Roberts, J.; Frieden, D.; d'Herbemont, S. *Energy Community Definitions. 13.* Available online: https://www.compile-project.eu/wp-content/uploads/Explanatory-note-on-energy-community-definitions.pdf (accessed on 20 June 2021).
15. Sokołowski, M.M. Renewable and Citizen Energy Communities in the European Union: How (Not) to Regulate Community Energy in National Laws and Policies. *J. Energy Nat. Resour. Law* **2020**, *38*, 289–304. [CrossRef]
16. Hedman, Å.; Rehman, H.U.; Gabaldón, A.; Bisello, A.; Albert-Seifried, V.; Zhang, X.; Guarino, F.; Grynning, S.; Eicker, U.; Neumann, H.-M.; et al. IEA EBC Annex83 Positive Energy Districts. *Buildings* **2021**, *11*, 130. [CrossRef]
17. 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. [CrossRef]
18. Horstink, L.; Wittmayer, J.M.; Ng, K. Pluralising the European Energy Landscape: Collective Renewable Energy Prosumers and the EU's Clean Energy Vision. *Energy Policy* **2021**, *153*, 112262. [CrossRef]
19. user_administrator. Clean Energy for All Europeans Package. Available online: https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en (accessed on 11 March 2021).
20. Koirala, B.P.; van Oost, E.C.; van der Waal, E.C.; van der Windt, H.J. *New Pathways for Community Energy and Storage*; Multidisciplinary Digital Publishing Institute: Basel, Switzerland, 2021.
21. de Mier Cortijo, L.G.; Lopez, M.L.; Castaño-Rosa, R.; Hearn, A. Consulta Pública Previa Comunidades Energéticas Locales. Available online: https://hogaressaludables.getafe.es/wp-content/uploads/2021/01/Consulta-publica-Comunidades-Energ%C3%A9ticas.pdf (accessed on 20 June 2021).
22. El MITECO Abre el Proceso de Consulta Pública Previa Para el Desarrollo de Comunidades Energéticas Locales. Available online: https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-miteco-abre-el-proceso-de-consulta-p%C3%BAblica-previa-para-el-desarrollo-de-comunidades-energ%C3%A9ticas-locales-/tcm:30-516684 (accessed on 28 June 2021).
23. Garriga, S.M.; Dabbagh, M.; Krarti, M. Optimal Carbon-Neutral Retrofit of Residential Communities in Barcelona, Spain. *Energy Build.* **2020**, *208*, 109651. [CrossRef]
24. Wiersma, B.; Devine-Wright, P. Decentralising Energy: Comparing the Drivers and Influencers of Projects Led by Public, Private, Community and Third Sector Actors. *Contemp. Soc. Sci.* **2014**, *9*, 456–470. [CrossRef]
25. Torabi Moghadam, S.; Di Nicoli, M.V.; Manzo, S.; Lombardi, P. Mainstreaming Energy Communities in the Transition to a Low-Carbon Future: A Methodological Approach. *Energies* **2020**, *13*, 1597. [CrossRef]
26. Rodríguez, A.S. *Potenciales de La Energía Distribuida En España*; Revista de Obras Públicas: Organo Profesional de los Ingenieros de Caminos, Canales y Puertos: Madrid, Spain, 2017; pp. 8–19.
27. Gjorgievski, V.Z.; Cundeva, S.; Georghiou, G.E. Social Arrangements, Technical Designs and Impacts of Energy Communities: A Review. *Renew. Energy* **2021**, *169*, 1138–1156. [CrossRef]
28. Caramizaru, A.; Uihlein, A. *Energy Communities: An Overview of Energy and Social Innovation*; Publications Office of the European Union: Luxembourg, 2020.
29. Castaño-Rosa, R.; Solís-Guzmán, J.; Marrero, M. Energy Poverty Goes South? Understanding the Costs of Energy Poverty with the Index of Vulnerable Homes in Spain. *Energy Res. Soc. Sci.* **2020**, *60*, 101325. [CrossRef]
30. 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. [CrossRef]
31. Savelli, I.; Morstyn, T. Better Together: Harnessing Social Relationships in Smart Energy Communities. *Energy Res. Soc. Sci.* **2021**, *78*, 102125. [CrossRef]
32. Hanke, F.; Lowitzsch, J. Empowering Vulnerable Consumers to Join Renewable Energy Communities—Towards an Inclusive Design of the Clean Energy Package. *Energies* **2020**, *13*, 1615. [CrossRef]
33. Lee, J.; Kim, H.; Byrne, J. Operationalising Capability Thinking in the Assessment of Energy Poverty Relief Policies: Moving from Compensation-Based to Empowerment-Focused Policy Strategies. *J. Hum. Dev. Capab.* **2021**, *22*, 292–315. [CrossRef]
34. Douvitsa, I. The new law on energy communities in Greece. *Coop. Econ. Soc.* **2018**, *40*, 31–58. [CrossRef]
35. García, G.F.; Frantzeskaki, M. Las comunidades energéticas en Grecia. *REVESCO Rev. Estud. Coop.* **2021**, *137*, 57–72.
36. Barroco Fontes Cunha, F.; Carani, C.; Nucci, C.A.; Castro, C.; Santana Silva, M.; Andrade Torres, E. Transitioning to a Low Carbon Society through Energy Communities: Lessons Learned from Brazil and Italy. *Energy Res. Soc. Sci.* **2021**, *75*, 101994. [CrossRef]
37. Algarvio, H. The Role of Local Citizen Energy Communities in the Road to Carbon-Neutral Power Systems: Outcomes from a Case Study in Portugal. *Smart Cities* **2021**, *4*, 840–863. [CrossRef]
38. Koirala, B.P.; Koliou, E.; Friege, J.; Hakvoort, R.A.; Herder, P.M. Energetic Communities for Community Energy: A Review of Key Issues and Trends Shaping Integrated Community Energy Systems. *Renew. Sustain. Energy Rev.* **2016**, *56*, 722–744. [CrossRef]
39. Gouveia, J.P.; Seixas, J.; Palma, P.; Duarte, H.; Luz, H.; Cavadini, G.B. Positive Energy District: A Model for Historic Districts to Address Energy Poverty. *Front. Sustain. Cities* **2021**, *3*, 16. [CrossRef]
40. Ajanovic, A.; Hiesl, A.; Haas, R. On the Role of Storage for Electricity in Smart Energy Systems. *Energy* **2020**, *200*, 117473. [CrossRef]
41. Østergaard, P.A.; Johannsen, R.M.; Lund, H.; Mathiesen, B.V. Latest Developments in 4th Generation District Heating and Smart Energy Systems. *Int. J. Sustain. Energy Plan. Manag.* **2021**, *31*, 1–4.

42. Ahmad, T.; Zhang, D. Using the Internet of Things in Smart Energy Systems and Networks. *Sustain. Cities Soc.* **2021**, *68*, 102783. [CrossRef]
43. López Prol, J.; Steininger, K.W. Photovoltaic Self-Consumption Is Now Profitable in Spain: Effects of the New Regulation on Prosumers' Internal Rate of Return. *Energy Policy* **2020**, *146*, 111793. [CrossRef]
44. Som Energia | La Cooperativa d'Energia Verda. Available online: https://www.somenergia.coop/ca/ (accessed on 29 March 2021).
45. Cuesta-Fernandez, I.; Belda-Miquel, S.; Calabuig Tormo, C. Challengers in Energy Transitions beyond Renewable Energy Cooperatives: Community-Owned Electricity Distribution Cooperatives in Spain. *Innov. Eur. J. Soc. Sci. Res.* **2020**, *33*, 140–159. [CrossRef]
46. Kunze, C.; Becker, S. Collective Ownership in Renewable Energy and Opportunities for Sustainable Degrowth. *Sustain. Sci.* **2015**, *10*, 425–437. [CrossRef]
47. Pinker, A.; Argüelles, L.; Fischer, A.; Becker, S. Between Straitjacket and Possibility: Energy Initiatives and the Politics of Regulation. *Geoforum* **2020**, *113*, 14–25. [CrossRef]
48. Day, R.; Walker, G.; Simcock, N. Conceptualising Energy Use and Energy Poverty Using a Capabilities Framework. *Energy Policy* **2016**, *93*, 255–264. [CrossRef]
49. Lieu, J.; Sorman, A.H.; Johnson, O.W.; Virla, L.D.; Resurrección, B.P. Three Sides to Every Story: Gender Perspectives in Energy Transition Pathways in Canada, Kenya and Spain. *Energy Res. Soc. Sci.* **2020**, *68*, 101550. [CrossRef]
50. Geels, F.W. Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study. *Res. Policy* **2002**, *31*, 1257–1274. [CrossRef]
51. Jenkins, K.; Sovacool, B.K.; McCauley, D. Humanizing Sociotechnical Transitions through Energy Justice: An Ethical Framework for Global Transformative Change. *Energy Policy* **2018**, *117*, 66–74. [CrossRef]
52. Dóci, G.; Vasileiadou, E.; Petersen, A.C. Exploring the Transition Potential of Renewable Energy Communities. *Futures* **2015**, *66*, 85–95. [CrossRef]
53. Sen, A. *Commodities and Capabilities*; Oxford University Press: Oxford, UK, 1999.
54. Arnaiz, M.; Cochrane, T.A.; Hastie, R.; Bellen, C. Micro-Hydropower Impact on Communities' Livelihood Analysed with the Capability Approach. *Energy Sustain. Dev.* **2018**, *45*, 206–210. [CrossRef]
55. Velasco-Herrejon, P.; Bauwens, T. Energy Justice from the Bottom up: A Capability Approach to Community Acceptance of Wind Energy in Mexico. *Energy Res. Soc. Sci.* **2020**, *70*, 101711. [CrossRef]
56. Fernández-Baldor, Á.; Boni, A.; Lillo, P.; Hueso, A. Are Technological Projects Reducing Social Inequalities and Improving People's Well-Being? A Capability Approach Analysis of Renewable Energy-Based Electrification Projects in Cajamarca, Peru. *J. Hum. Dev. Capab.* **2014**, *15*, 13–27. [CrossRef]
57. A European Green Deal. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 18 June 2021).
58. Jenkins, K.; McCauley, D.; Heffron, R.; Stephan, H.; Rehner, R. Energy Justice: A Conceptual Review. *Energy Res. Soc. Sci.* **2016**, *11*, 174–182. [CrossRef]
59. Hearn, A.X.; Sohre, A.; Burger, P. Innovative but Unjust? Analysing the Opportunities and Justice Issues within Positive Energy Districts in Europe. *Energy Res. Soc. Sci.* **2021**, *78*, 102127. [CrossRef]
60. McCauley, D.; Ramasar, V.; Heffron, R.J.; Sovacool, B.K.; 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*, 916–921. [CrossRef]
61. Mulvaney, D. Opening the Black Box of Solar Energy Technologies: Exploring Tensions Between Innovation and Environmental Justice. *Sci. Cult.* **2013**, *22*, 230–237. [CrossRef]
62. Guia_Para-Desarrollo-Instrumentos-Fomento_Comunidades_Energeticas_Locales_20032019_0.Pdf. Mapeo Normativa Energetica. Available online: https://www.scribd.com/ (accessed on 20 June 2021).
63. Atutxa, E.; Zubero, I.; Calvo-Sotomayor, I. Scalability of Low Carbon Energy Communities in Spain: An Empiric Approach from the Renewed Commons Paradigm. *Energies* **2020**, *13*, 5045. [CrossRef]
64. Axon, S.; Morrissey, J.; Aiesha, R.; Hillman, J.; Revez, A.; Lennon, B.; Salel, M.; Dunphy, N.; Boo, E. The Human Factor: Classification of European Community-Based Behaviour Change Initiatives. *J. Clean. Prod.* **2018**, *182*, 567–586. [CrossRef]
65. Balbás Egea, J.Á.; Eguren Egiguren, J.A. Bases for a Sustainable Energy Model. Case Study: Basque Autonomous Community. *Int. J. Sustain. Energy* **2019**, *38*, 884–903. [CrossRef]
66. Romero-Rubio, C.; de Andrés Díaz, J.R. Sustainable Energy Communities: A Study Contrasting Spain and Germany. *Energy Policy* **2015**, *85*, 397–409. [CrossRef]
67. Schram, W.; Louwen, A.; Lampropoulos, I.; van Sark, W. Comparison of the Greenhouse Gas Emission Reduction Potential of Energy Communities. *Energies* **2019**, *12*, 4440. [CrossRef]
68. Cabarcos, A.L.; Castro, N.R.; Viña, V.M. Autonomía Enerxética Local e Desenvolvemento Rural Sustentable: Análise Da Predisposición a Participar En Comunidades Enerxéticas Renovables. *Rev. Galega Econ.* **2020**, *29*, 141–166.
69. Lizana, J.; Manteigas, V.; Chacartegui, R.; Lage, J.; Becerra, J.A.; Blondeau, P.; Rato, R.; Silva, F.; Gamarra, A.R.; Herrera, I. A Methodology to Empower Citizens towards a Low-Carbon Economy. The Potential of Schools and Sustainability Indicators. *J. Environ. Manag.* **2021**, *284*, 112043. [CrossRef]
70. Camprubí, L. Whose Self-Sufficiency? Energy Dependency in Spain from 1939. *Energy Policy* **2019**, *125*, 227–234. [CrossRef]

71. Vivir Aquí. *La Pinada*. Available online: https://www.barriolapinada.es/vivir-aqui/ (accessed on 20 June 2021).
72. Alpagut, B.; Akyürek, Ö.; Mitre, E.M. Positive Energy Districts Methodology and Its Replication Potential. *Proceedings* **2019**, *20*, 8. [CrossRef]
73. Leiren, M.D.; Aakre, S.; Linnerud, K.; Julsrud, T.E.; Di Nucci, M.-R.; Krug, M. Community Acceptance of Wind Energy Developments: Experience from Wind Energy Scarce Regions in Europe. *Sustainability* **2020**, *12*, 1754. [CrossRef]
74. Avila, S. Environmental Justice and the Expanding Geography of Wind Power Conflicts. *Sustain. Sci.* **2018**, *13*, 599–616. [CrossRef]
75. Abokersh, M.H.; Vallès, M.; Cabeza, L.F.; Boer, D. A Framework for the Optimal Integration of Solar Assisted District Heating in Different Urban Sized Communities: A Robust Machine Learning Approach Incorporating Global Sensitivity Analysis. *Appl. Energy* **2020**, *267*, 114903. [CrossRef]
76. Tulus, V.; Abokersh, M.H.; Cabeza, L.F.; Vallès, M.; Jiménez, L.; Boer, D. Economic and Environmental Potential for Solar Assisted Central Heating Plants in the EU Residential Sector: Contribution to the 2030 Climate and Energy EU Agenda. *Appl. Energy* **2019**, *236*, 318–339. [CrossRef]
77. Parra, D.; Swierczynski, M.; Stroe, D.I.; Norman, S.A.; Abdon, A.; Worlitschek, J.; O'Doherty, T.; Rodrigues, L.; Gillott, M.; Zhang, X.; et al. An Interdisciplinary Review of Energy Storage for Communities: Challenges and Perspectives. *Renew. Sustain. Energy Rev.* **2017**, *79*, 730–749. [CrossRef]
78. Gorona Del Viento. Gorona Del Viento El Hierro, S.A. Available online: https://www.goronadelviento.es/ (accessed on 18 June 2021).
79. Robertson, B.; Bekker, J.; Buckham, B. Renewable Integration for Remote Communities: Comparative Allowable Cost Analyses for Hydro, Solar and Wave Energy. *Appl. Energy* **2020**, *264*, 114677. [CrossRef]
80. Jelić, M.; Batić, M.; Tomašević, N.; Barney, A.; Polatidis, H.; Crosbie, T.; Abi Ghanem, D.; Short, M.; Pillai, G. Towards Self-Sustainable Island Grids through Optimal Utilization of Renewable Energy Potential and Community Engagement. *Energies* **2020**, *13*, 3386. [CrossRef]
81. A Second Life for Batteries. POCITYF. Available online: https://pocityf.eu/news/a-second-life-for-batteries/ (accessed on 7 July 2021).
82. Nuestro Compromiso. Endesa. Available online: https://www.endesa.com/es/nuestro-compromiso (accessed on 27 May 2021).
83. Sustainability. Available online: https://www.iberdrola.com/sustainability (accessed on 27 May 2021).
84. Amigos de la Tierra. *Comunidades Energéticas*. Available online: https://www.tierra.org/comunidades-energeticas/ (accessed on 20 June 2021).
85. Hettinga, S.; Nijkamp, P.; Scholten, H. A Multi-Stakeholder Decision Support System for Local Neighbourhood Energy Planning. *Energy Policy* **2018**, *116*, 277–288. [CrossRef]
86. Martiskainen, M.; Heiskanen, E.; Speciale, G. Community Energy Initiatives to Alleviate Fuel Poverty: The Material Politics of Energy Cafés. *Local Environ.* **2018**, *23*, 20–35. [CrossRef]
87. Reeves, A. Exploring Local and Community Capacity to Reduce Fuel Poverty: The Case of Home Energy Advice Visits in the UK. *Energies* **2016**, *9*, 276. [CrossRef]
88. Baker, K.J.; Mould, R.; Stewart, F.; Restrick, S.; Melone, H.; Atterson, B. Never Try and Face the Journey Alone: Exploring the Face-to-Face Advocacy Needs of Fuel Poor Householders in the United Kingdom. *Energy Res. Soc. Sci.* **2019**, *51*, 210–219. [CrossRef]
89. Así es la Nueva Tarifa de la Luz: Cuándo es Más Barata y Trucos Para Ahorrar en la Factura. Available online: https://www.antena3.com/noticias/sociedad/cambio-tarifas-electricas-pagare-mas-cual-mejor-hora-usar-electrodomesticos_2021053160b5b8c175307d0001ad95ed.html (accessed on 23 June 2021).
90. Bauwens, T.; Devine-Wright, P. Positive Energies? An Empirical Study of Community Energy Participation and Attitudes to Renewable Energy. *Energy Policy* **2018**, *118*, 612–625. [CrossRef]
91. El 86 % de los Españoles ve la Corrupción Como un "Gran Problema", Según TI. Available online: https://www.swissinfo.ch/spa/corrupci%C3%B3n-espa%C3%B1a--previsi%C3%B3n-_el-86---de-los-espa%C3%B1oles-ve-la-corrupci%C3%B3n-como-un--gran-problema---seg%C3%BAn-ti/46705952 (accessed on 17 June 2021).
92. Global Corruption Barometer EU: People Worried about Unchecked Abuse of Power. Available online: https://www.transparency.org/en/news/gcb-eu-2021-survey-people-worry-corruption-unchecked-impunity-business-politics (accessed on 17 June 2021).
93. Dirigentes, G. Puertas Giratorias: Más de 50 Políticos Enchufados a la Energía. Available online: https://dirigentesdigital.com/hemeroteca/puertas_giratorias_mas_de_50_politicos_enchufados_a_la_energia-AVDD12013 (accessed on 17 June 2021).
94. 43 Políticos "Enchufados" En Eléctricas. Crónica. EL MUNDO. Available online: https://www.elmundo.es/cronica/2014/02/23/530881d922601da2168b456c.html (accessed on 17 June 2021).
95. Herrera, E. Catorce ex Cargos Políticos se Sientan en los Consejos de Grandes Empresas Energéticas. Available online: https://www.infolibre.es/noticias/politica/2018/08/28/expoliticos_empresas_sector_electrico_86148_1012.html (accessed on 17 June 2021).
96. El Gobierno Pide a Competencia Que Investigue a Las Eléctricas Por Una Posible Manipulación de Precios. Economía. Cadena SER. Available online: https://cadenaser.com/ser/2021/06/07/economia/1623088773_133664.html (accessed on 21 June 2021).
97. Koirala, B.P.; Araghi, Y.; Kroesen, M.; Ghorbani, A.; Hakvoort, R.A.; Herder, P.M. Trust, Awareness, and Independence: Insights from a Socio-Psychological Factor Analysis of Citizen Knowledge and Participation in Community Energy Systems. *Energy Res. Soc. Sci.* **2018**, *38*, 33–40. [CrossRef]

98. Southwell, B.; Ronneberg, K.; Shen, K.; Jorgens, E.; Hazel, J.; Alemu, R.; Ross, J.; Richman, L.; Vermeer, D. Energy Information Engagement among the Poor: Predicting Participation in a Free Workshop. *Energy Res. Soc. Sci.* **2014**, *4*, 21–22. [CrossRef]
99. Sánchez-Bayón, A.; García-Ramos, M.Á. How to Undertake with Digital Currencies as Csr 3.0 Practices in Wellbeing Economics? *J. Entrep. Educ.* **2020**, *23*, 1–8.
100. Medios de Comunicación y Stakeholders: Contribución al Debate Público de La Pobreza y Justicia Energética En España/Media and Stakeholders: Contribution to the Public Debate on Poverty and Energy Justice in Spain. *REIS* **2019**, *168*, 73–92. [CrossRef]
101. Groves, C.; Shirani, F.; Pidgeon, N.; Cherry, C.; Thomas, G.; Roberts, E.; Henwood, K. 'The Bills Are a Brick Wall': Narratives of Energy Vulnerability, Poverty and Adaptation in South Wales. *Energy Res. Soc. Sci.* **2020**, *70*, 101777. [CrossRef]
102. Walker, G.; Day, R. Fuel Poverty as Injustice: Integrating Distribution, Recognition and Procedure in the Struggle for Affordable Warmth. *Energy Policy* **2012**, *49*, 69–75. [CrossRef]
103. Spanish National Strategy for Energy Poverty Miteco.gob.es. Available online: https://www.miteco.gob.es/es/ministerio/planes-estrategias/estrategia-pobreza-energetica/ (accessed on 20 June 2021).
104. EU Energy Poverty Observatory. Available online: https://www.energypoverty.eu/eu-energy-poverty-observatory (accessed on 15 June 2021).
105. Bono Social de Electricidad. Available online: https://www.bonosocial.gob.es/#quees (accessed on 16 June 2021).
106. Romero Rodríguez, L.; Sánchez Ramos, J.; Guerrero Delgado, M.; Molina Félix, J.L.; Álvarez Domínguez, S. Mitigating Energy Poverty: Potential Contributions of Combining PV and Building Thermal Mass Storage in Low-Income Households. *Energy Convers. Manag.* **2018**, *173*, 65–80. [CrossRef]
107. City Profiles–Making City. Available online: http://makingcity.eu/city-profiles/ (accessed on 18 July 2021).
108. Bono Social Eléctrico: ¿cómo le Afecta la Nueva Factura de la luz y las Franjas Horarias? Available online: https://as.com/diarioas/2021/06/03/actualidad/1622724404_875070.html (accessed on 16 June 2021).
109. Alvarez, G.G.; Tol, R.S.J. *The Impact of the Bono Social de Electricidad on Energy Poverty in Spain*; Working Paper Series; Department of Economics, University of Sussex Business School: Brighton, UK, 2020.
110. Gabiola, E.J.; Gázquez, J.D.P.; Rodríguez, J.A.S. El Bono Social y Las Cooperativas Energéticas Verdes: Situación y Perspectivas. *Revesco. Rev. Estud. Coop.* **2016**, *122*, 165–190. [CrossRef]
111. Antepara, I.; Claeyé, F.; Lopez, A.; Robyns, B. Fighting against Fuel Poverty by Collaborating with Social Services through Energy Advice: An Innovative Case from Spain. *Rev. Vasca Econ. Soc.* **2020**, *17*, 71–96. [CrossRef]
112. Pitt, J.; Nolden, C. Post-Subsidy Solar PV Business Models to Tackle Fuel Poverty in Multi-Occupancy Social Housing. *Energies* **2020**, *13*, 4852. [CrossRef]
113. Saunders, R.W.; Gross, R.J.K.; Wade, J. Can Premium Tariffs for Micro-Generation and Small Scale Renewable Heat Help the Fuel Poor, and If so, How? Case Studies of Innovative Finance for Community Energy Schemes in the UK. *Energy Policy* **2012**, *42*, 78–88. [CrossRef]
114. Chakravarty, S.; Tavoni, M. Energy Poverty Alleviation and Climate Change Mitigation: Is There a Trade Off? *Energy Econ.* **2013**, *40*, S67–S73. [CrossRef]
115. Saintier, S. Community Energy Companies in the UK: A Potential Model for Sustainable Development in "Local" Energy? *Sustainability* **2017**, *9*, 1325. [CrossRef]
116. Boeri, A.; Longo, D.; Roversi, R.; Turci, G. Positive Energy Districts: European Research And Pilot Projects Focus on the Mediterranean Area. *Sustain. Mediterr. Constr.* **2020**, *12*, 22–27.
117. Primc, K.; Slabe-Erker, R. Social Policy or Energy Policy? Time to Reconsider Energy Poverty Policies. *Energy Sustain. Dev.* **2020**, *55*, 32–36. [CrossRef]
118. López, A.N. A Rolex o a setas. Comunidades Autónomas, cambio climático y modelo económico. *Rev. Catalana Dret Ambient.* **2020**, *11*, 1–30.

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Preferences for configurations of Positive Energy Districts – Insights from a discrete choice experiment on Swiss households

Darja Mihailova [a,*], Iljana Schubert [a], Adan L. Martinez-Cruz [b], Adam X. Hearn [a], Annika Sohre [a]

[a] Sustainability Research Group, Department of Social Sciences, University of Basel, Basel, Switzerland

[b] Department of Forest Economics, and Centre for Environmental and Resource Economics (CERE), Swedish University of Agricultural Sciences (SLU), Sweden

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ABSTRACT

By 2025, the EU aims to develop 100 Positive Energy Districts (PEDs) – communities that promote renewables for energy generation and an environment that enables sustainable lifestyles on the part of the resident. Despite rising interest in the topic, prospective residents' preferences for PED configurations have yet to be documented. This paper addresses this gap by implementing a discrete choice experiment (DCE) on Swiss residents to explore preferences for configurations of PEDs according to three attributes: ownership and expected citizen engagement, mobility options, and availability of shared spaces. We document that residents' preferences for PED configurations vary depending on respondents' car and home ownership, age, household size, and values. Findings suggest a variety of preferences for PEDs that policy-makers may want to consider when developing these communities. One key recommendation is that policymakers should pay attention to existing mobility patterns when designing mobility alternatives around PEDs. Helping citizens envision their energy system and recognize an alternative energy future may also be important to building familiarity and propensity for change.

1. Introduction

As part of the EU Green Deal, EU Member States have committed to reducing emissions by at least 55% by 2030, relative to 1990 levels (European Commission, 2020b). One of the supporting pillars in reaching this goal has been the Directive on common rules for the internal electricity market ((EU) 2019/944) which introduces rules that would enable citizens and energy communities to actively participate in the energy system (European Commission, 2020a). Further, the EU's 2019 'Clean energy for all Europeans package' has incorporated policies for "active consumer participation, individually or through citizen energy communities, in all markets, either by generating, consuming, sharing or selling electricity, or by providing flexibility services through demand-response and storage" (European Commission, 2020b). Energy communities, which can allow citizens to take an active part in the energy system, take on a variety of forms. While typically thought of as citizen-led efforts (Interreg Europe, 2018), energy communities can also be spearheaded by the private or public sector, or through public-private-people partnerships (PPP). For example, Positive Energy Districts (PEDs) are a concept that has been introduced by the EU to transition residential communities into neighborhoods relying on renewable energy technology to generate electricity and heat, while putting citizens at the core of the community and ensuring affordability in energy access to all. The implementation of these neighborhoods is envisioned to be a function of collaboration between the city, private sector, and public participation (European Commission, 2018). Overall, while a multitude of policies envision citizens participating actively in the energy system, even as energy producers and self-consumers (i.e., prosumers), it is imperative to first understand how citizens want these systems configured and to what extent they want to participate.

We explore this question by testing preferences for characteristics of Positive Energy Districts (PEDs) – residential communities that combine "built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emission and to create added value and incentives for the consumer" (European Commission, 2018, p. 6). PEDs and PED-like areas take on a variety of forms, whether the renewable energy technology is owned by the community or public and private sector (Derkenbaeva et al., 2020). This paper focuses on PEDs due to their salience to the EU's energy transition agenda – the EU aims to see the development of 100 PEDs by 2025 and current efforts to develop PEDs include a variety of EU Horizon 2020 projects (e.g., POCITYF, Atelier, Making City).

While a number of studies have examined factors influencing

* Corresponding author.
E-mail address: darja.mihailova@unibas.ch (D. Mihailova).

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Abbreviations to be used:

PED	Positive Energy District
REC	renewable energy community
DCE	discrete choice experiment

adoption or acceptance of individual renewable energy technologies and related products/services, no study, to our knowledge, has explored what characteristics citizens might prefer in a holistic environment like an REC. For example, previous studies have explored and identified varying consumer segments, including likely adopters, of sustainability technologies in vehicle-to-grid charging (Khan and Bohnsack, 2020), electricity conservation programs (Hille et al., 2019), solar PV (Vasseur and Kemp, 2015; Petrovich et al., 2019; Heng et al., 2020), and green electricity (Tabi et al., 2014). In these studies, socio-demographic and psychographic characteristics have been utilized to understand drivers of preferences for green innovation or to explain pro-environmental behavior. Other studies have explored factors driving acceptance of community renewable energies and renewable energy infrastructure (Musall and Kuik, 2011; Batel et al., 2013; Bauwens and Devine-Wright, 2018). However, very few academic studies have investigated PEDs (examples include Lindholm et al., 2021; Olivadese et al., 2021) and, as far as we know, no study has explored preferences for different PED characteristics. Yet, this question is important as building energy communities that are appealing to people may help facilitate not only their overall deployment, but also citizen participation. This paper addresses this gap by documenting preferences of Swiss residents for different configurations of PEDs using elements found in current PEDs or PED-like communities.

In order to investigate differences in preferences for a variety of PED characteristics we designed a discrete choice experiment (DCE) wherein respondents were asked to repeatedly make choices about which one, among a number of profiles of PEDs, they would want to live in. DCEs are a useful way to explore preferences for PEDs as they allow respondents to compare profiles of PEDs as packages of characteristics rather than individual characteristics. This is fitting as PEDs are a setting made up of a variety of products and services: PEDs can be described not only by the way energy is generated and distributed, but also by extra attributes such as available sustainable mobility options or a built environment that encourages a community feeling. Existing district-level renewable energy projects – such as the Hunziker Areal in Zurich, Switzerland, and the Vauban in Freiburg, Germany – have shown that the appeal of living in holistic energy communities goes beyond reliance on renewable energy technology and includes benefits such as green mobility options and shared spaces that build a sense of community.

Indeed, DCEs are a common technique to gauge preference for new products. DCEs are often utilized to segment respondents based on stated preferences (Green and Krieger, 1991; Camilleri and Azzopardi, 2011) and are useful for understanding attitudes, personal norms, and values of users (Daae and Boks, 2015). Following previous work studying end-users in green innovation (Zimmerling et al., 2017; Khan and Bohnsack, 2020; Wever et al., 2008; Tolkamp et al., 2018; Hille et al., 2019), we argue that collaboration with end-users is critical in sustainability innovation (also termed "green innovation" or "eco-innovation"). The end-user can be integrated into a business model innovation at various points of the process (Wever et al., 2008; Cui and Wu, 2015; Tolkamp et al., 2018). Engaging users in the development of the value proposition – the product or service being offered – can lead to offerings tailored to consumer needs (Tolkamp et al., 2018) and user-centric design can lead to faster adoption of sustainable innovations (Daae and Boks, 2015).

The research questions we seek to answer are:

1. What attributes commonly described in PED-like communities are preferred by citizens?
2. How can we describe the segments of PED preferences (in terms of sociodemographic and psychographic variables)?

Findings from these research questions can inform the design of communities that meet and adapt to user needs and can help shape tailored communications to different segments. By collating information on preferences, socio-demographic and psychographic characteristics, developers of PEDs can take advantage of this forward-looking approach to create appealing value propositions for end-users (Khan and Bohnsack, 2020). Creating appealing and suitable value propositions means successfully matching what customers desire with the value offered while leveraging contextual information that motivates customers' desires. Psychographic characteristics, such as the values a person holds, can be useful in understanding what drives customers' preferences and is thus critical to designing attractive value propositions (Khan and Bohnsack, 2020; Rintamäki and Kirves, 2017). We follow Hille et al. (2019) in exploring consumers' values, understood as the general guiding principles of the respondents (Steg et al., 2014). Understanding peoples' values can indicate their tendency for pro-environmental behavior, as ecological consciousness is positively related to altruistic and biospheric values and negatively related to egoistic values (Steg and Nordlund, 2018). This can offer additional information in not only describing preferences, but also designing value propositions that leverage these values and appeal to future users.

We also map PED preference segments to different propensities for innovation adoption. Different users play different roles in helping innovation move from emerging to wider diffusion (Wilkinson et al., 2020; Geels, 2005). The different roles users play can be described by their speed in adopting innovations – innovators, early adopters, early majority adopters, late majority adopters, and laggards (Rogers, 2003). Early adopters can act as opinion leaders for the other adopter segments, thus leading to innovation diffusion (Rogers, 2003). Other research has criticized this notion, positing that early innovation adoption does not necessarily diffuse to other adopter segments due to fundamental differences between the user groups (Moore, 2014). Nevertheless, researchers have used Rogers' (2003) adoption segmentation in various ways. For example, Wilkinson et al. (2020) study the role of adopter groups in understanding their role in shaping the innovation process of peer-to-peer electricity markets. Nygrén et al. (2015) used a combination of interview and survey methods to investigate how different types of innovators and early adopters could enable the diffusion of sustainable small-scale energy solutions in Finland. Noppers et al. (2015) mapped how the different adopter segments evaluated electric cars according to their symbolic, instrumental, and environmental attributes. In our research, we map preferences for PEDs to adopter classes in order to understand whether certain adopter segments have specific PED preferences.

This study reports findings from our DCE conducted with 1486 Swiss respondents. PEDs in the DCE were described according to three attributes – ownership of the renewable energy technology and expected engagement from the user, mobility options available in the district, and any extra benefits like shared spaces available. These attributes closely follow characteristics of existing communities that reflect some of the values of PEDs (described in Section 2).

This study holds importance for policy-makers for several reasons. Exploring preferences for PEDs can inform the design of PED communities and help policy-makers target the priorities of potential residents, thus accelerating PED adoption. By identifying segments of preferences, it is possible to plan ahead to cover a wide range of preferences. Creating suitable PED configurations for individuals may increase the likelihood that they engage in their community.

In the following sections we provide a background on PEDs (Section 2) and present the methodology of the DCE (Section 3). We then report results (Section 4) of the DCE in terms of preferences for PED configurations and characteristics of the segments, provide a discussion (Section 5) and conclude on important policy recommendations (Section 6).

2. Background on PEDs

While the majority of communities labeled PEDs across Europe are still in development stages (Gollner et al., 2020), it is clear that a number of different PED configurations are likely to arise. In a recent review, Lindholm et al. (2021) describe three types of PEDs based on boundaries and placement of renewable energy technologies: autonomous, dynamic, and virtual. An autonomous PED has clear geographical boundaries and energy demand is covered internally. Dynamic and virtual PEDs have less clear geographical boundaries. A dynamic PED might interact with other PEDs in the electricity grid (e.g., energy trading between district is an option) and heating network. A virtual PED may have renewable energy generation and storage systems outside of its boundaries.

Following Lindholm et al.'s (2021) discussion, this study explores the importance of boundaries and placement of renewable energy technology by varying ownership structures of renewable energy technology. Cooperative-owned PV allows cooperative members to take part in the energy transition without necessarily living in proximity to the technology. PV owned by a housing association may take a similar form, or the housing association may install it on the buildings roofs, thus moving the energy generation within the boundary of the community. The placement and boundary of renewable energy technologies may have consequences for how active a citizen can be in decision-making around energy generation and consumption – a notable issue if the EU's policies aim to foster active energy citizenship (see Bauwens and Devine-Wright (2018) for a discussion on a community as place vs. community of interest in driving attitudes toward renewable energy).

Attributes in this study resemble a PED or a PED-like community. In particular, we have collected information from three primary resources (see Appendix 1):

- Business Models for Prosumers in Europe (Hall et al., 2020)
- How Cities Can Back Renewable Energy Communities (Bolle, 2019)
- Value Generation by PEDs: Best Practices Case Book (Derkenbaeva et al., 2020)

The information gathered was distilled into three common elements that could describe profiles of PED-like communities:

Attribute 1. Ownership of PV solar panels and your involvement:

o Level 1: PV is owned privately[1] by respondent, the respondent is expected to buy and sell energy privately (full engagement)
o Level 2: A cooperative[2] owns the PV, the respondent may buy shares, receives dividends, and has voting power
o Level 3: Housing association owns the PV; the housing association reinvests part of the profits in the neighborhood and may ask for advice from residents
o Level 4: Utility company owns the PV and no extra involvement is expected from the respondent

Attribute 2. Availability of mobility options:

o Level 1: Great public transport; private vehicles are only permitted for shift workers and those with disabilities
o Level 2: Private cars allowed if they fulfil *low-carbon requirements* set by the district
o Level 3: Only shared fleet of electric vehicles (EV) allowed

Attribute 3. Available shared spaces in addition to those typically included (e.g. green spaces, bike racks, laundry room, storage):

o Level 1: None
o Level 2: Standard free communal spaces *and* for a small monthly fee, additional shared spaces such as work spaces, gym, toolshed, spaces for parties, and guest rooms will be available

Examples of PEDs and further information on derivation of attributes is provided in Appendix A1.

3. Method

3.1. Data

We implemented a DCE as part of the fifth wave of the Swiss Household Energy Demand Survey (SHEDS). The SHEDS is an online survey and was administered by Intervista AG who incentivized respondents to participate with bonus points for completing the survey. The sample is representative of the population in the German and French cantons of Switzerland with pre-defined quotas for age, biological sex, region, and housing status (mix of owners and tenants).[3] The survey was available in English, French and German. Participants were surveyed in May and June 2020, following the first wave of restrictions in Switzerland related to the COVID-19 pandemic. A sample of 1486 respondents successfully completed the DCE. Further details on sampling strategy and composition of SHEDS can be found in Weber et al. (2017).

3.2. Discrete choice experiment

Immediately before responding to our DCE, respondents were placed in a scenario wherein, in the year 2030, PEDs are being deployed nationwide to reduce carbon emissions and offer other benefits for residents. PED configurations would vary and residents would be asked to report the configuration they would most prefer to live in. Respondents were familiarized with potential PEDs through graphics that depict how it might look in a city setting, a suburban setting, and a rural setting. Respondents were told that any costs associated with the options are more or less the same – i.e. in terms of DCE design, price is not an attribute or, equivalently, price is kept fixed across PEDs.[4] Further details can be found in Appendix A2 that reports the full text and images presented to respondents.

Respondents were asked to choose between two options describing different PED configurations which result from the combinations of

[1] There was almost no difference in distribution of adopter types across the five segments, with all segments showing low percentages of innovators and high percentages of early majority adopters. No significant statistical differences were found in adopter segment membership among the five segments.

[2] Cooperative housing is quite popular in Switzerland and is a form of non-profit housing association (Balmer and Gerber, 2017).

[3] Quotas in SHEDS survey: Age: 18–34 = 30%, 35–54 = 40%, 55+ = 30%; Gender: males = 49%, females = 51%;• Region: French-speaking = 25%, German-speaking = 75%;• Living situation: tenants = 62.5%, owners = 37.5%.

[4] We are aware that it is common (and useful) to include a price attribute in order to infer willingness to pay for attribute levels. In this application, we have focused our attention on how preferences for non-monetary attributes vary when price is fixed –by assumption, indeed. Our motivation to keep price fixed is our interest in attributes that describe PEDs. We want to point out that keeping prices fixed is not an unrealistic assumption in itself. While price will vary depending on specific PED characteristics, it is also reasonable to think that several PED designs can be delivered at a given price. A strategy similar to ours has been implemented in previous DCEs. For instance, Garrod et al. (2012) explores heterogeneity in preferences for environmental benefits associated with ecosystem services by designing a discrete choice experiment that varies types of landscapes and does not include a price attribute.

attributes described in Section 2. Our DCE was generated using Ngene. As a full factorial design would have necessitated 276 choice tasks, we have followed a D-optimal design, and have implemented a DCE with a D-error of 0.094. The resulting design for our DCE was made up of six blocks with six choice sets in each block. Each choice set contained two options to choose from and no "none" option was included. The DCE design was uploaded in Stata and integrated into Qualtrics (the survey software) (Weber, 2019). Participants were randomly allocated to one of the six blocks.

A status quo option was not included which, consistent with the premise of our scenario, implies that preferences are stated under an "if all residential districts became PEDs" assumption.[5] Fig. 1 shows an example of a choice set.

The survey and language used in the choice sets for attribute levels was tested and refined with a sample of students and other researchers prior to full launch of the survey. Translations of the survey and choice experiment were confirmed by native speakers of the languages.

3.3. Segmentation and segment exploration

Through latent class analysis, we segmented respondents into groups based on their stated preference choices for different configurations of PEDs. This analysis was conducted using Sawtooth Software (2012)'s CBC/HB module which provides class membership information, part-worth utilities, and importance scores as an output. Part-worth utilities describe how much each level of an attribute contributes to the overall utility. Importance scores describe how much of an influence a particular attribute has on the choice (Orme, 2010). Together, these tools allow description of segments based on common stated preferences. Similar methods have been used by a number of authors exploring preferences for sustainable products and services (e.g. Hille et al., 2019; Petrovich et al., 2019; Tabi et al., 2014).

We confirmed the part-worth utilities and obtained more information on standard deviations by conducting secondary analysis with random parameters logit regressions in the Apollo package in R. This was done using both a maximum likelihood estimation and Bayesian estimation, both of which produced similar results (Huber and Train, 2001).

With the segment membership obtained through the latent class analysis, we conducted multinomial logit regressions with segment membership as the dependent variable to further describe the segments using a number of explanatory variables. Additionally, differences between segments were examined through the Tukey-Kramer means comparison test. The explanatory variables can be categorized as describing demographics and household characteristics, values and norms of the respondent, and adopter class of the respondent. Full information on variables and definitions can be found in Appendix A3.

Values and norms were included to explore their relationship to the respondents' choice of PED. Values and norms have previously been studied in relation to pro-environmental behavior (Stern, 2000; Steg and Nordlund, 2018). Information from SHEDS on respondents' values (egoistic, biospheric, hedonic, and altruistic) were included, as well information on intention to reduce carbon footprint in the next year, descriptive norms, and injunctive norms.[6]

Further, we included respondents' self-characterized adopter class to control for their proclivity to adopting new sustainability-related technologies and innovations (Rogers, 2003). For the identification question, respondents were asked about their willingness to adopt new smart-home technologies: products, gadgets, and apps that may help control different aspects of your home such as your room temperature, energy consumption, or water usage. Smart-home technologies were chosen as a proxy for technologies can support a change in lifestyle toward a more sustainable one and an early indicator for favorability toward PEDs.

4. Results

4.1. Segmentation

Solutions with two to seven segments were explored in the latent class analysis, and a five-segment classification was chosen. Table 1 reports measures of fit for the analysis, including the consistent Akaike information criterion (CAIC), Bayesian information criterion (BIC), and relative Chi-square values for each segmentation.[7] The five-segment solution yields the largest relative Chi-Square. While solutions with five and six segments are comparable in CAIC and BIC, the five-segment solution was chosen as it yields relatively large segment sizes that allow characterization analysis. Based on the five-segment solution, Segment 1 is the largest segment (N = 426) and Segment 3 is the smallest (N = 143) (see Table 3).

4.2. Estimation of utility values and importance scores for each segment

The Sawtooth latent class analysis yielded part-worth utilities and importance scores. Part-worth utilities depict how much utility each attribute level contributes to the overall option utility i.e., how important each attribute level is within the segment. Importance scores (shown in Fig. 3) for attributes further depict which attributes are most important to a segment's choice. We use information from part-worth utilities and importance scores together to summarize preferences of each segment. Additionally, we have labeled each segment based on its preferences.

We confirmed these results using a random parameters logit regression for each segment.[8] Random parameters logit specifications were estimated using a maximum likelihood estimation and Bayesian estimation, using the Apollo package in R – both led to similar results (Hess and Palma, 2019; R Core Team, 2020). We report Bayesian estimations as they had a lower BIC, but results from both Bayesian and maximum likelihood estimations, as well as the standard deviations of random parameters from the maximum likelihood estimation, are reported in Appendix A4. Part-worth utilities are summarized in Table 2

[5] The decision to not include a status quo alternative implies that our DCE does not yield information on whether and to what extent respondents prefer their current housing configuration over a positive energy district configuration. While this information is relevant, our DCE is able to yield information of preferences as if every resident is expected to live in a type of PED –which would be in line with medium- and long-run EU's goals. Had our DCE included a status quo option, respondents may have engaged less in trading-off the attributes describing a PED.

[6] Individuals with strong altruistic values place more importance on ideas like equality and world peace. Those with strong biospheric values find respecting the earth and nature important. Those with strong hedonic values place higher importance on personal pleasure and enjoying life. Finally, those with high egoistic values find social power and influence highly important. Descriptive norms refer to how others behave, while injunctive norms refer to how others expect you to behave.

[7] For more information on measures of fit, see Weller et al. (2020).

[8] We use a random parameters logit specification as it allows for heterogeneous tastes within the population, relaxes the assumption of independence from irrelevant alternatives (IIA) assumption, and allows for persistence of factors that impact choice over time (Train, 2009).

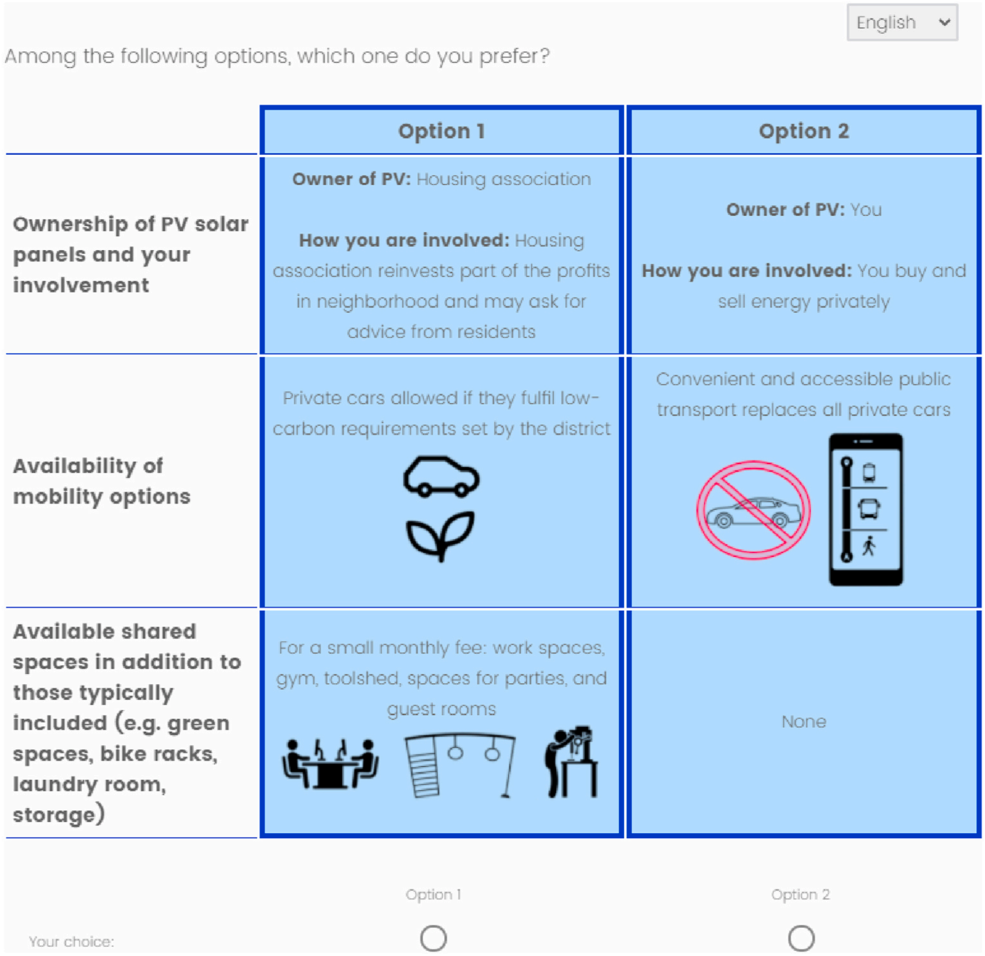

Fig. 1. Example of a choice set in the DCE.

Table 1
Summary of fit.

Number of segments	CAIC	BIC	Relative Chi-square
2	11,363	11,350	86.74
3	11,189	11,169	68.65
4	11,138	11,111	55.32
5	11,119	11,085	46.58
6	11,124	11,083	40.23
7	11,155	11,107	35.18

and depicted visually in Fig. 2.[9] Because attribute levels were coded using effects coding, we recovered part-worth utilities for the omitted levels (utility-owned PV, private cars with emissions restrictions, basic shared spaces) by calculating the negative sum of non-omitted levels by attribute (Hauber et al., 2016).

Importance scores in Fig. 3 show that characteristics of ownership and availability of mobility options were most important in determining choice of a PED. The attribute describing presence of shared spaces was less important in determining choice across segments. The part-worth utilities in Fig. 2 show that preferences for ownership of PV and engagement varied across the segments, with private ownership, cooperative ownership, and utility ownership creating the most distinction between segments. Although housing association was not the top choice or bottom choice for any segment, preferences for housing associations largely followed those of cooperatives i.e. both positive or both negative, with the exception of Segment 1. Shared EV was the least popular mobility preference and private cars with emissions restrictions were most popular among three of the segments. Preferences for shared spaces largely varied by segment as well.

For Segment 1, the biggest driving factor of choice was the mobility option present in the PED. The importance scores show that this was the most important attribute for Segment 1, and more important to this segment than all other segments. The part-worth utilities confirm this story: Segment 1 had the highest gain in utility from private cars with emissions restrictions (higher than any other part-worth utility presented). Among ownership options, Segment 1 preferred utility-owned PV over the other options. The presence of shared spaces was least important in Segment 1's choice of a PED. We label Segment 1 as *Car Defenders*.

The importance scores show that Segment 2's choice of PED is equally driven by ownership and mobility options present in the PED. This segment's preferences can be described as driven by a mix of communal and private preferences. The part-worth utilities indicate that Segment 2 prefers PV ownership by a cooperative, as well as private cars with emissions restrictions and extra shared spaces. We label Segment 2 as *Cooperative with car flexibility*.

The importance scores show that Segment 3's choice of PED is heavily driven by ownership of PV. This is also seen in the segment's high utility associated with private ownership of PV (the highest among all segments). Segment 3 has a high preference for private PV ownership and a moderate preference for private cars and basic shared spaces relative to other options. We label Segment 3 as *Private and autonomous*.

[9] Part-worth utilities in Fig. 2 have been re-centered for comparability across segments.

Table 2
Part-worth utilities by segment [aa] Note: Standard deviation of posterior after distributional transformation in parentheses, not included for levels omitted during effects coding. Shading reflects attribute level with highest utility (blue) and lowest utility (yellow) from each attribute. Preference for omitted level in effects-coding (utility-owned PV, private cars with emissions restrictions, basic shared spaces) recovered by calculation of negative sum of non-omitted levels by attribute (Hauber et al., 2016).

Attribute and levels	*Segment 1*	*Segment 2*	*Segment 3*	*Segment 4*	*Segment 5*
	N = 426	*N = 308*	*N = 143*	*N = 359*	*N = 250*
Ownership of PV solar panels and expected involvement of respondent					
Private ownership of PV; individual buys and sells energy privately	-1.01 (0.54)	0.45 (0.99)	5.66 (1.33)	0.27 (0.72)	-1.98 (0.90)
Cooperative-owned PV; individual buys shares in an energy cooperative, receive dividends, and have voting power	-0.35 (0.54)	2.14 (0.77)	-0.79 (1.03)	-0.80 (0.59)	1.98 (0.56)
Housing association; Housing association reinvests part of the profits in neighborhood and may ask for advice from residents	0.43 (0.49)	0.03 (1.27)	-1.49 (1.61)	-0.13 (0.49)	1.13 (0.68)
Utility-owned PV; No extra involvement	0.93	-2.64	-3.38	0.67	-1.13
Availability of mobility options					
Public transit only	-2.91 (0.52)	-2.41 (0.49)	-2.76 (1.35)	0.86 (0.42)	2.29 (0.63)
Private cars with emissions restrictions	3.18	2.34	2.35	-0.44	-1.92
Shared EV	-0.26 (0.65)	0.07 (0.52)	0.41 (2.04)	-0.43 (0.43)	-0.37 (0.82)
Availability of shared spaces in addition to those typically included					
No extra shared spaces	0.08	-1.24	2.10	-0.17	-1.41
Extra shared spaces for a small monthly fee	-0.08 (0.49)	1.24 (0.58)	-2.10 (0.38)	0.17 (0.05)	1.41 (0.60)

Similar to *Cooperative with car flexibility*, Segment 4's choice of PED is driven by ownership and mobility options. However, Segment 4 exhibits a strong negative preference for PV ownership by a cooperative, preferring utility ownership of PV, followed by privately-owned PV. When it comes to mobility, Segment 4's choice is positively driven by the option of public transit and negatively driven by private car ownership and the availability of a shared EV fleet. This segment also has a high preference for extra shared spaces. We label Segment 4 as *No cooperative PV, Public transit.*

Finally, Segment 5 has a high positive preference for cooperative ownership of PV, public transit, and extra shared spaces. Segment 5's choice of PED is almost equally driven by all three attributes. This segment's preferences for cooperative ownership of PV, public transit, and extra shared spaces point to a preference for a communal feeling. We label Segment 5 as *Community-focused.*

In terms of expected involvement on the part of the respondent, the *Private and autonomous* segment is the only segment that prefers complete involvement in ownership of PV including buying and selling to the smart grid. Both the *Cooperative with car flexibility* and *Community-focused* segments exhibit preferences for cooperative-owned PV, as well as potential involvement in voting on cooperative projects and receiving dividends. *Car defenders* and *No cooperative PV, Public transit* prefer utility ownership of the PV and no extra expected involvement on their part. *Cooperative with car flexibility* and *No cooperative PV, Public transit* are inverse of one another. Due to the nature of the levels and the coupling of ownership with expected involvement, it is difficult to distinguish whether ownership type or the explicit description of involvement lead to the PED choice. In this study, we consider them together as a package.

Table 3 summarizes the main combinations of attributes favored by the segments. Ownership of PV and mobility options were included due to the importance they played in a respondent's choice of PED. Further, only the attribute levels with top part-worth utility for each segment are included.

Almost 60% of the sample (*Car defenders*, *Cooperative with car flexibility*, and *Private and autonomous*) would prefer private cars with emissions restrictions in their hypothetical PED, while the rest prefer public transit. With regard to ownership of PV, the most popular options were cooperative-owned PV, utility-owned PV, and privately-owned PV. Overall, about 53% of the sample prefers utility owned PV when both mobility options are combined.

4.3. Characterization of segments

Next, we explore the segments in terms of explanatory variables. In this way, we can begin to understand motivations behind preferences and create a more holistic picture of each segment. Appendix A5 contains a selection of summary statistics by segment. Table 4 shows the average marginal effect of each variable as a result of the multinomial logit regressions conducted for each segment, with segment membership

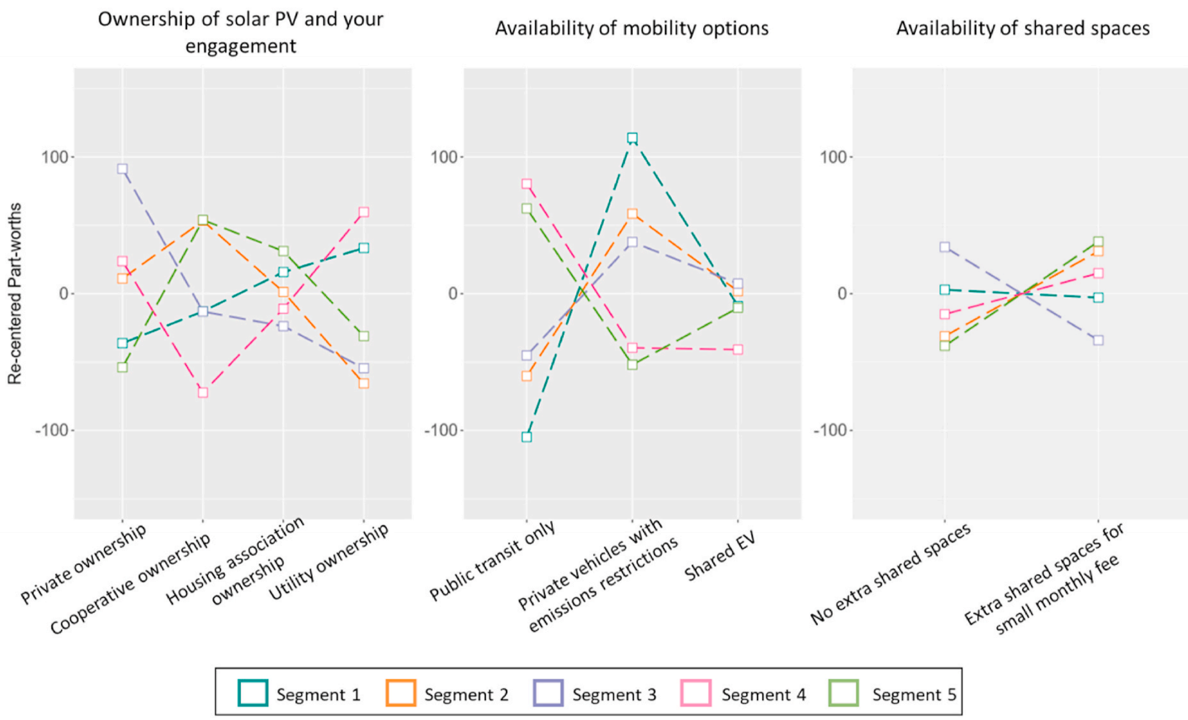

Fig. 2. Part-worth utilities resulting from random parameters logit, re-centered for comparability across segments[a.]
[a]Note: A positive part-worth utility indicates a positive gain from the attribute level in overall utility of an option. A negative part-worth utility indicates a negative gain from the attribute level in overall utility of an option.

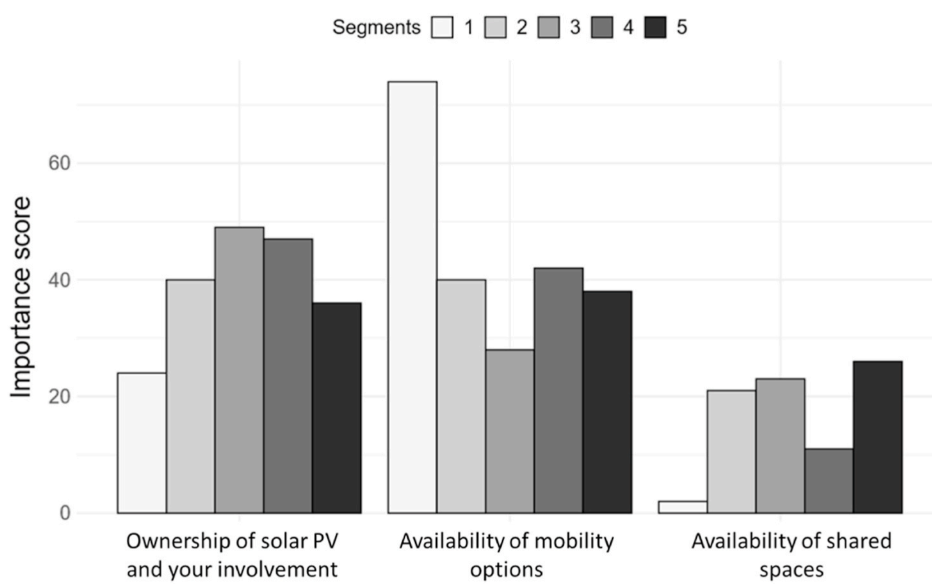

Fig. 3. Importance scores for attributes by segment[a]
[a]Note: Importance scores are calculated by taking the range of respondent utilities for a given attribute and dividing by the total range across attributes (McEwan, 2015; Sawtooth Software).

as the dependent variable. The average marginal effect denotes the average change in probability of belonging to a segment if the explanatory variable increased by 1 unit, keeping all other variables the same.

Results of the multinomial logit regression support choice of segment labels in section 4.2. Car ownership and living in the countryside were significant in increasing probability of being in the *Car defenders* segment. Biospheric values were found to be significant in decreasing probability of belonging to the *Car defenders* segment.

Being younger and car ownership increased probability of belonging in the *Cooperative with car flexibility segment*. Living in German-speaking Switzerland and having a household of 3 or more people were also significant in raising the probability of belonging to this segment. Respondents who were segmented into the Innovator, Late majority, or Laggard adopter classes also had a lower probability of belonging to this segment relative to the Early Majority.

Probability of belonging to the *Private and Autonomous* segment was positively impacted by house ownership. No other variables were found to be significant in predicting probability of membership in this

Table 3
Configurations of PED attributes contributing to segments' preferences.

		Mobility options	
		Private cars with emissions restrictions	Public transit only
Ownership of PV and expected involvement	*Cooperative owned PV; dividends, voting power*	Segment 2 (*Cooperative with car flexibility*): 20.73% of sample	Segment 5 (Community-focused): 16.82% of sample
	Utility owned PV; no extra involvement by individual	Segment 1 (*Car defenders*): 28.67% of sample	Segment 4 (*No cooperative PV, Public transit*): 24.16% of sample
	Privately owned PV (by individual); individual buys and sells energy privately	Segment 3 (*Private and autonomous*): 9.62% of sample	–

segment. This preference for privately-owned PV by the *Private and autonomous* segment is consistent with the higher average house ownership in this segment (as seen in Appendices A5 and A6). Private ownership may give owners more control of PV placement, meaning they are able to envision such a scenario.

Higher age, home ownership, and lower income were significant in increasing probability of belonging to the *No cooperative PV, Public transit* segment. Car ownership had a negative impact on probability of belonging to this segment. Living in an accommodation with solar panels also had negative impact on probability of belonging to the *No Cooperative PV, Public transit* segment. Respondents who had identified as Innovators were significantly more likely to be in the *No cooperative, Public transit* segment relative to those in the Early Majority.

Probability of belonging to the *Community-focused* segment was positively impacted by higher income, higher intention to reduce one's carbon footprint, and higher altruistic values. Probability of belonging to the *Community-focused* segment was lowered with car ownership and house ownership.

The sharpest distinctions in segments can be seen through differences in age and car ownership. Age created distinctions between the *Cooperative with car flexibility* segment and the *No cooperative PV, public*

Table 4
Average marginal effects calculated from multinomial logit regression. An interaction term between age and income was included in the multinomial logit regression.

	(1) Car defenders	(2) Cooperative with car flexibility	(3) Private and autonomous	(4) Utility-owned PV, public transit	(5) Community-focused
Age	0.00118	−0.00369***	0.000759	0.00253**	−0.000778
	(1.31)	(-4.37)	(1.24)	(3.05)	(-1.08)
Sex	0.0229	−0.0120	−0.00705	0.0296	−0.0335
	(0.89)	(-0.52)	(-0.40)	(1.20)	(-1.64)
Income (log of income used)	0.0415	−0.00322	−0.0143	−0.0726**	0.0486*
	(1.37)	(-0.12)	(-0.70)	(-2.69)	(2.01)
Years of education	0.00724	0.00691	0.000724	−0.00636	−0.00851
	(1.13)	(1.16)	(0.17)	(-1.06)	(-1.61)
Car ownership	0.211***	0.0666*	0.0289	−0.0953**	−0.211***
	(7.65)	(2.50)	(1.14)	(-2.76)	(-6.54)
House ownership	−0.0555*	−0.0192	0.0734**	0.0745*	−0.0732**
	(-1.97)	(-0.72)	(3.20)	(2.41)	(-3.09)
Lives in countryside	0.0693*	−0.0133	−0.00493	−0.0211	−0.0300
	(2.10)	(-0.47)	(-0.21)	(-0.65)	(-1.00)
Accommodation is outfitted with solar panels for electricity or heat	0.00934	−0.00449	0.0292	−0.0590*	0.0250
	(0.29)	(-0.15)	(1.28)	(-2.05)	(0.87)
Households living in German-speaking Switzerland	−0.0484	0.0753**	0.00207	−0.0432	0.0143
	(-1.65)	(3.13)	(0.11)	(-1.50)	(0.61)
Household with three or more people	−0.0321	0.0906***	−0.00815	−0.0415	−0.00885
	(-1.19)	(3.42)	(-0.45)	(-1.58)	(-0.39)
Adopter classes (Early majority as base)					
Innovators	−0.0115	−0.0926**	0.0197	0.123**	−0.0389
	(-0.27)	(-2.60)	(0.68)	(2.64)	(-1.12)
Early adopters	−0.0313	−0.0486	0.0336	0.0535	−0.00709
	(-0.82)	(-1.37)	(1.24)	(1.36)	(-0.21)
Late majority	0.0167	−0.0579*	0.0432	0.0412	−0.0431
	(0.52)	(-1.99)	(1.85)	(1.38)	(-1.77)
Laggards	0.0332	−0.111***	0.0208	0.0401	0.0171
	(0.83)	(-3.35)	(0.75)	(1.10)	(0.51)
Intend to reduce carbon footprint	−0.0289*	0.00694	0.00924	−0.00828	0.0210*
	(-2.41)	(0.62)	(1.12)	(-0.74)	(2.14)
Values					
Hedonic values	0.0323	−0.0141	0.0139	−0.0200	−0.0121
	(1.81)	(-0.85)	(1.12)	(-1.19)	(-0.84)
Egoistic values	0.00136	0.00823	0.0136	0.0249	−0.0480***
	(0.08)	(0.52)	(1.15)	(1.51)	(-3.36)
Altruistic values	−0.00861	−0.00577	−0.0278	−0.0329	0.0751***
	(-0.38)	(-0.28)	(-1.86)	(-1.52)	(3.77)
Biospheric values	−0.0444*	0.0338	0.000347	0.0119	−0.00168
	(-2.12)	(1.70)	(0.02)	(0.58)	(-0.09)
Norms					
Descriptive norms	0.00300	0.00785	−0.00794	−0.000870	−0.00205
	(0.19)	(0.56)	(-0.75)	(-0.06)	(-0.17)
Injunctive norms	−0.0132	−0.00160	0.00318	0.00872	0.00292
	(-0.88)	(-0.12)	(0.30)	(0.62)	(0.25)
Observations	1338	1338	1338	1338	1338

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Pseudo R2 = 0.094, Log-Likelihood = −1888.35.

transit segment. An increase of 10 years in age increased probability of falling into the *No cooperative PV, Public transit* segment by 0.253 and decreased probability of falling into the *Cooperative with car flexibility* segment by 0.369.

Car ownership also created sharp distinctions between segments. As seen in Fig. 5, the *Car defenders* and *Community-focused* segments can be seen as opposite sides of the spectrum: car ownership increases probability of belonging to the *Car defenders* segment by 0.211 and decreases probability of belonging to the *Community-focused* segment by 0.211.

These results are consistent with those presented in the Tukey-Kramer comparisons[10] (see Appendix A6). Consistent with the preferences for PED characteristics and the multinomial logit, the Tukey-Kramer test indicated that the largest impacts (in magnitude) on probability of car ownership. The *Car defenders* segment, whose attribute importance scores depicted mobility as the strongest driver of utility, held a significantly larger average number of car owners compared to all other segments. The segments with strong preferences for public transit – *Community-focused* and *No Cooperative, Public transit* – had lower average car ownership. The *Cooperative with car flexibility* segment also had a significantly higher average number of household members with three or more people, indicating more need for transportation service.

The Tukey-Kramer results also depict differences in values and intention to reduce one's carbon footprint between the *Car defenders* segment and the *Community-focused* segment. Respondents who were likely to state their intention to reduce their carbon footprint and had higher biospheric values were less likely to fall into the *Car defenders* segment. *Car defenders'* preferences seemed to be less driven by environmental concerns. Conversely, the respondents that had high altruistic values, low egoistic values, and high intention to reduce their carbon footprint were more likely to belong to the *Community-focused* segment. The *Community-focused* segment may be more environmentally-conscious and community conscious, supporting the segment's preference for cooperative-owned PV, public transit in the community, and extra shared spaces. Table 5 summarizes the findings of our analyses.

5. Discussion

The aim of this research has been to characterize the preferences people may have for PEDs, with the goal of tailoring attractive value propositions to future residents. In the following, we respond to our initial research questions.

Research Question 1 (RQ1). What attributes commonly described in PED-like communities are preferred by citizens?

We have uncovered a diverse set of preferences. The largest segment was that of *Car defenders* who are very mobility-driven and prefer private cars with emissions restrictions in their future PED. The smallest segment was that of *Private and autonomous* respondents who preferred private PV ownership, private car ownership, and even showed a dislike for extra shared spaces in a future PED configuration. The *Community-focused* segment held respondents who seemed to be attracted to communal living – cooperative-owned PV, public transportation, and extra shared spaces. More environmentally-conscious respondents and those with higher altruistic values were also likely to fall into this segment. The last two segments, *Cooperative with car flexibility* and *No cooperative PV, Public transit*, differed on multiple levels: they not only exhibited different preferences for PV ownership and transportation options, but also age. Those in the *Cooperative with car flexibility* segment tended to be younger while those in the *No cooperative PV, Public transit* segment tended to be older.

In Fig. 6, we have created a visualization of the dominant preferences for aspects of PEDs to answer RQ 1. Mobility options are located at the beginning of the funnel in Fig. 6 due to their dividing nature and importance in PED choice. Overall, around 60% of respondents prefer private cars with restrictions on emissions in PEDs of the future. Preferences for ownership are more distributed: around 10% preferred private ownership of PV, 38% preferred cooperative ownership of PV, and 53% preferred utility-owned PV. These results support the development of diverse PED configurations as there was no one unifying set of preferences for all respondents. Tailoring PEDs and messaging efforts according to sociodemographic and psychographic characteristics will be important in reaching a variety of consumer segments.

RQ 2. How can we describe the segments of PED preferences?

Respondents' stated preferences for PEDs configurations seem to be associated with current lifestyles. For example, mobility is connected to respondents' current mobility availability. Segments that contained respondents who were more likely to be car owners prefer PED options that allow for private car use, even with emissions restrictions, while the two segments that are less likely to contain car owners are more likely to prefer the PED option with public transportation. This finding points to the fact that current mobility practices guide future choice, even in hypothetical scenarios set in 2030. This is consistent with previous literature that points to the importance of routines and habits in determining transportation method (Schneider, 2013; Kurz et al., 2015; Lanzini and Khan, 2017).

In line with previous findings (Dargay, 2002; Nolan, 2010), location and household size play a factor in guiding mobility choice and will need to be considered in the design of mobility options in PEDs. Those living in the countryside were more likely to be *Car defenders*, indicating the need for private car use. Respondents in the *Cooperative with car flexibility* segment also exhibited larger households of three or more people, perhaps indicating the need for more flexible and/or private transportation options. Interestingly, shared EV was least preferred among the three options. In planning for future PEDs, it will be important to consider current mobility patterns, ways in which peoples' mobility patterns can be changed e.g., toward public transit (Beirão and Sarsfield Cabral, 2007) or shared and pooled vehicles (Stoiber et al., 2019), and how life events may shape these mobility patterns (Clark et al., 2016).

In terms of ownership of PV, the older segment, *No cooperative PV, Public transit* seemed to find cooperative owned PV less appealing and utility owned PV more appealing while the younger segment, *Cooperative with car flexibility*, found cooperative ownership more appealing. Drivers behind preference for ownership of PV may be tied to expected engagement. While no extra engagement on behalf of the respondent was expected in a scenario where PV is owned by a utility, cooperative ownership of PV offered the chance to act via voting rights and receive dividends from the organization.[11] Privately-owned PV and full engagement is also an attractive option for some, as shown by the *Private and autonomous* segment (see Ecker et al., 2017 for more on the value people place on energy autarky). Desire for participation and engagement may vary by age (as the younger segments preferred cooperative-owned PV), indicating that it is important to have a mix of residents from a variety of age groups if citizen participation is an objective in a PED.

It is worthwhile noting that the Swiss energy market may not be reflective of that of other countries in the EU; respondents' preferences for utilities and cooperatives may reflect their current energy supplier. Further, the Swiss energy landscape is comprised largely of utility companies (630 companies) (Axpo, 2021), although a large number of energy cooperatives (289) also exist (Rivas and Seidl, 2018). It is notable that 90% of electricity utilities are publicly-owned, either by cantons or municipalities (Axpo, 2021). Further, the electricity supply to homes in Switzerland is already largely based on renewables, although heating is still largely propelled by gas (Confederation Suisse, 2019). In

[10] The Tukey-Kramer test is used in place of the *t*-test in scenarios of multiple case comparisons by adjusting for error associated with multiple testing.

[11] Although it is also possible that desire for such opportunities in a cooperative may not be converted into actual consistent engagement (Yildiz et al., 2015).

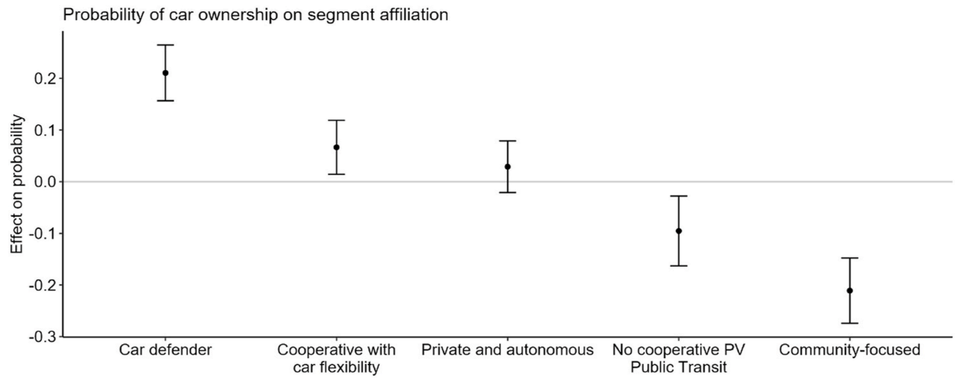

Fig. 5. Probability of car owners' membership across segments (based on average marginal effects from multinomial logit). A respondent's increase in probability of belonging to Car defenders given car ownership is highest, while belonging to the Community-focused segment sees the biggest drop in probability given car ownership.

Table 5
Summary of segments and their distinctive descriptors based on multinomial logit and Tukey-Kramer comparison test.

Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
Percent of sample				
29%	21%	10%	24%	17%
Preferences: This segment prefers …				
Utility owned PV, private car ownership; strongly mobility-driven	Cooperative ownership of PV, private car ownership	Private ownership of PV, private car ownership; strongly driven by ownership options	Strong negative preference for cooperative ownership, preference for utility ownership of PV, public transport	Cooperative ownership of PV, public transportation, extra shared spaces
Segment description				
• Likely to own a car • Higher income • Unlikely to be home owners • More likely to live in countryside • Less likely to have intention to reduce their carbon footprint • Lower levels of biospheric values	• Tend to be younger • Likely to be car owners • Likely to have a household of three or more people • Likely to live in German-speaking Switzerland	• Likely to be home owners • Higher average number of households equipped with solar panels relative to other segments	• Likely to be older • Likely to be lower income • Less likely to be car owners • Likely to be home owners	• More likely to have higher income • Less likely to be car owners • Less likely to be home owners • More likely to have intention to reduce their carbon footprint • Higher levels of altruistic values • Lower levels of egoistic values

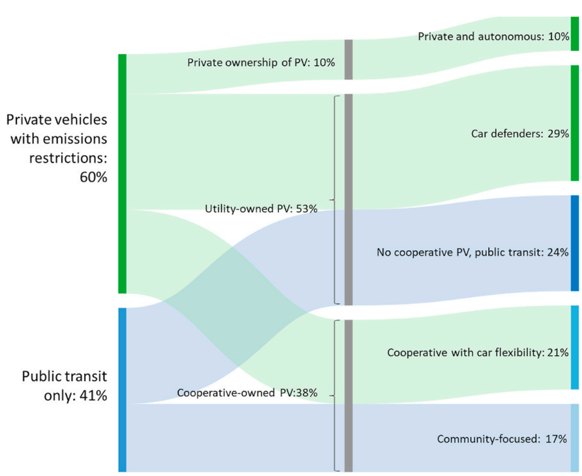

Fig. 6. Groupings of segments according to mobility and ownership preferences for PEDs (Note: percentages do not add up to 100 due to rounding).

Switzerland, tenants account for close to 60% of the population (Federal Statistical Office, 2019). Thus, private ownership of PV may not be a feasible option for all respondents. Due to this context-dependencies, the transferability of the results to PEDs in other countries probably need further investigation.

Exploring expectations for engagement in PEDs and desire for participation among future residents is important if active participation is expected in PEDs. However, given that the description of expected engagement and type of owner were combined in this study, it is uncertain what may actually have driven the choice – the nature of the ownership or the engagement potential. Future research could disentangle these factors to further understand what drives preference for ownership and engagement and whether the two are related.

Further, results indicate that private ownership of PV is less favored as an option relative to utility and cooperative ownership (only 10% of the sample). In creating opportunities, policy-makers should recognize the hesitations people may have around ownership of PV and heightened engagement with energy generation and trading. Barriers to adoption may include the high cost of purchasing such a system and the type of home the household occupies. This latter point is highly relevant for Switzerland where most households are in a tenant relationship and may not have the authority to install PV on their roofs. It is also telling that home owners were more likely to fall into the *Private and Autonomous* segment. Consistently, this segment had a higher number of homes equipped with solar panels compared to other segments – respondents in this segment are familiar with solar panel technology, with the corresponding capacity and control to install solar panels on their own property (see Vasseur and Kemp, 2015; Petrovich et al., 2019; Faiers et al., 2007; Hille et al., 2019; Baranzini et al., 2017; Balta-Ozkan et al., 2015; Dharshing, 2017; Briguglio and Formosa, 2017; Mattes, 2012 for motivations behind PV adoption).

Shared spaces play a smaller positive role or even a negative one in our respondents' preferences for PED configurations. The *Community-focused* segment reported shared spaces as important as mobility options and ownership options. On the other hand, the *Private and Autonomous* segment had a strong negative preference for shared spaces, consistent with the segment's tendency toward complete autonomy (e.g., privately owned PV, preference for private vehicles, no shared spaces). However, the role of shared spaces may increase in post-COVID-19 times as shared spaces may represent an alternative to work remotely, allowing for social gathering while keeping physical distance which ultimately would increase resilience of urban environments. As employers and employees around the world start conversations about whether and how remote work will be part of the new normal, it has become clear that employees find working from home advantageous but with some drawbacks. The conversation is evolving towards *hybrid working arrangements* that will allow remote work from a wide array of locations with flexibility on when and how frequently employees will be expected to commute to their employees' facilities (Beck and Hensher, 2021; Bojovic et al., 2020; Lara-Pulido and Martinez-Cruz, 2021; Microsoft Work Lab, 2021). Shared working spaces in PEDs can make the concept more holistic, meeting the needs of the energy transition and those of its residents, and aligning PEDs with the idea of developing self-sufficient neighborhoods or 15-min cities that has recently gained traction among policy makers and politicians in the EU (e.g., C40 Cities Climate Leadership Group (C40CCLG), 2020; Willsher, 2020). Thus, deepening the exploration into the preference for shared spaces –particularly, those equipped as offices— as part of residential configurations seems an area of research of relevance for the energy transition agenda.

Adopter classes were generally unclear predictors of segment affiliation and may play little role in understanding how adoption of an innovation like a PED can spread. The complexity of a PED and the number of features that describe such a community may contribute to this. The adopter segmentation based on proclivity to adopt smart-home technologies may also not be completely representative of the complexity of PEDs.

6. Conclusion and policy recommendations

The results of our study hold several implications for future development of PEDs. Given the heterogeneity of stated preferences, PED development will require careful examination of potential residents based on their sociodemographic and psychographic characteristics. At the same time, the achievability of implementing certain PED configurations needs to be assessed further. For example, can a PED for the *Community-focused* segment be developed in a rural area that may necessitate private car use? Also, can members of the *Private and autonomous* segment achieve full ownership of PV in a non-detached house? These questions are particularly relevant under the likely scenario that more people may decide to permanently live farther from urban centers as remote working becomes part of the new normal. These questions have implications for transportation and land use policy research agendas as their answers require examining how the existing built environment entrenches mobility patterns and guides capacity to install renewable energy technologies (Beck and Hensher, 2021).

It is significant that respondents' preferences depict mobility as a key determining element in PED choice. This means that mobility related preferences need to be taken as a main design factor, but not necessarily in only switching to e-mobility as smart city concepts set out to do (e.g., Paalosmaa and Shafie-khah, 2021; Cassinadri et al., 2019). Policymakers should carefully weigh options of the design and operation of PEDs in terms of mobility choices, i.e., bans of private cars in the PED, easy access to alternative transport modes, car sharing and distribution of space to different modes of mobility and recreation. While not explicitly tested in this study, possibilities of active modes of transport and public transit can complement e-mobility trends and allow policy-makers to reach a wider demographic (Liao and Correia, 2020), though development is dependent on local goals of the area (Akhatova et al., 2020). It is also important that policymakers tailor options to preferences (taking into account diversity), while also providing structure (e.g., mobility solutions beyond private cars) in order to break path dependencies and existing routines. This can be done by creating an environment that facilitates change to more sustainable modes of transport and taking time to understand the factors that drive current car ownership.

The finding that respondents choose PEDs that reflect their current mobility options may also indicate that respondents have difficulties in envisioning a future that differs from their current way of living, even in a scenario set in the future. Stated preferences may not be telling of what respondents want, but rather that they are unable to envision a different future. Policymakers should consider "visioning" exercises to explain that futures with alternative mobility and alternative energy ownership (such as privately owned PV) are possible. Building energy and environmental awareness and consciousness of our energy future may necessitate a more engaging and participatory approach to introducing citizens to their built and unseen environment (see Walking with Energy: Ambrose, 2020). Policies that support private PV ownership could also help people see it as a practical possibility.

Framing appealing value propositions to future residents of PEDs will require an understanding of both values and needs. Certain segments, like the *Community-focused* segment, may be more responsive to messages that recall the community's social justice focus or environmentally-beneficial features. This segment's respondents recall residents of car-free cooperative housing studied by Baehler and Rérat (2020), whose motivations were largely driven by their values. Other segments, like the *Car defenders*, may find such messages less appealing as they scored significantly lower on altruistic values, biospheric values, and intention to reduce their carbon footprint. Overall, the tailoring of value propositions of PEDs will need to rely not only on respondents' values but also other elements such as car and home ownership, household size, and age.

The diversity of preferences seen in the results of the DCE indicate a number of pathways for PED and REC development. Overall, policymakers may find it beneficial to make citizens aware of new possibilities that the future energy system can enable. Helping citizens understand that they can engage in a decentralized energy system e.g., as prosumers and showing them *how* will be important to fostering the engagement the EU aims for in developing PEDs.

CRediT authorship contribution statement

Darja Mihailova: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Iljana Schubert:** Supervision, Funding acquisition, Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Adan L. Martinez-Cruz:** Methodology, Formal analysis, Writing – review & editing. **Adam X. Hearn:** Conceptualization, Methodology, Writing – review & editing. **Annika Sohre:** Supervision, Funding acquisition, Conceptualization, Methodology, Writing – review & editing.

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.

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Appendix A1

Table 1

Examples of PED-like renewable energy projects in Europe described by three common attributes. Examples taken from Hall et al. (2020), Bolle (2019), and Derkenbaeva et al. (2020).

Example of PED-like renewable energy projects and RECs	Ownership of renewable energy technology	Mobility options available	Communal spaces
Hunziker Areal, Switzerland	Cooperative	Cars allowed in case of physical limitation or job-related necessity; shared fleet of bicycles, e-bicycles, and an electric car is provided	Work/tool room, gym for community use, parks and playgrounds
Vauban District, Germany	Cooperative	Car-free	Parks and playgrounds
IssyGrid, France	Municipality-private company partnership	Cars allowed; additional emphasis on car-pooling, experimentation with autonomous vehicles	Parks
German Mieterstrom model, Germany	Landlord or delegated energy services company	Any (not a physical community with boundary)	Not in scope (not a physical community with boundary)
Ecopower, Belgium	Cooperative	Any (not a physical community with boundary)	Not in scope (not a physical community with boundary)
Quartierstrom, Switzerland	Private	Any	Not in scope (focus on P2P trading)

More information on PED and PED-like communities described in table:

Hunziker Areal, Vauban District, and IssyGrid are examples of "contained" districts, operating with boundaries. These districts exemplify the goals of PEDs to varying extents by integrating renewables into the grid and fostering a human-centric focus. Hunziker and Vauban emphasize a community focus through a participative cooperative structure, a built environment that is pedestrian-friendly, and extra communal spaces like a tool room, gym, and many parks and playgrounds (Derkenbaeva et al., 2020).

The German Meiterstrom model is not a PED, but is an example of achieving the integration of renewables into the grid in a multi-family home. PV-plants are placed on multi-occupancy buildings and the landlord sells this energy to residents based on their metered usage. Tenants are able to fill any gaps in demand with a retail supplier of electricity (Hall et al., 2020). While not a PED, this model could be adapted to multi-family homes in a given district.

Ecopower is a cooperative based in Flanders, Belgium that seeks to provide citizens with an opportunity to invest in renewable energy by holding shares in renewable energy technology installations. Further, each shareholder is able to vote in the general meeting and receives a dividend if profit allows it. Those with solar power installations are also able to feed their electricity into the grid and receive payment (Bolle, 2019). While a regional cooperative like Ecopower does not explicitly meet the goals of PEDs due to its expansive boundaries, it nevertheless supports the energy transition and allows citizens to participate. Further, partnerships between cooperatives and municipalities can narrow the geographical scale while following a similar model.

Finally, the Quartierstrom pilot study is an example of a peer-to-peer (P2P) energy trading scheme that took place in Wallendstadt, Switzerland. Thirty-seven households connected to the microgrid were able to buy and sell solar power locally. Although this particular pilot ended in July 2020, many other initiatives that test P2P trading or enabling technology exist (Quartierstrom). For example, POCITYF, an EU Horizon 2020 project focused on developing PEDs, is integrating P2P trading into its Lighthouse city of Évora, Portugal (Oliviadese et al., 2021). The city of Groningen in the Netherlands has plans to engage households in P2P energy trading with the help of technological expertise from Spectral (Spectral). Finally, companies like Lumenaza and sonnenCommunity in Germany offer technology that enables a household to engage in P2P energy trading (IRENA, 2020). These initiatives indicate that P2P energy trading may have a place in PEDs of the future, transforming citizens into prosumers.

Appendix A2. Description of PED scenario prior to choice experiment

We are now going to ask you to imagine that you are in a hypothetical situation which is likely to happen in the future. Place yourself in the scenario to make decisions based on the information provided. It is 2030 and your neighborhood has begun its transition into a Positive Energy District (PED), as required by the Swiss Energy Transition Policy. This means your neighborhood will eventually produce more energy (through renewable resources) than is being consumed (thus becoming net energy positive). Each district will also ensure that each resident is able to track their energy consumed through tools like smart meters. Below are examples of what your neighborhood might look like in different settings:

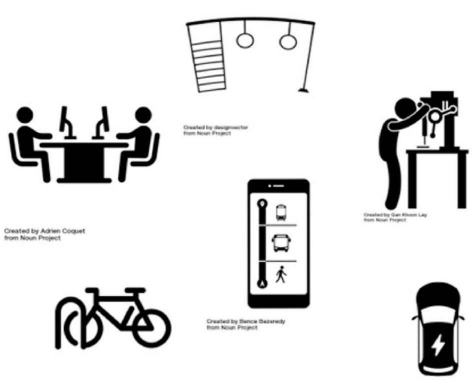
An apartment building might have solar panels on the roof.

A detached family home might have solar panels on the roof or somewhere close to the home.

The government envisions that each district will also offer other benefits such as:

- Communal spaces
- Environmentally friendly mobility options
- Social housing
- Citizens' abilities to play a greater role in their own energy management

However, the government is still exploring the demand for such aspects.



Each Positive Energy District will be organized differently and some people have even moved into a district model that they prefer. On the next pages you will see several choices showing how such a Positive Energy District might look like. Given the government's emphasis on energy affordability, the costs associated with each option are more or less the same and should not impact your preference. Please choose the Positive Energy District model you would be **most prefer to live in.**

Appendix A3. Definitions of explanatory variables

Variables		Questions/items
Demographic variables	Age Gender Income Years of education Car ownership House ownership Lives in countryside Accommodation with solar panels Households in German-speaking area Household with three or more people	Age (years) (information collected from Intervista) Gender: Male = 1, Female = 0 (information collected from Intervista) Income: Midpoint of the range chosen by respondent (3000 or less; 3000–4499; 4500–5999; 6000–8999; 9000–12,000; 12,000 or more; I prefer not to say; I do not know) (information collected from Intervista) Number of years of education (information collected from Intervista) Car ownership: Own at least 1 car = 1, Do not own a car = 0 House ownership: Own a house = 1, Other = 0 (information collected from Intervista) Lives in countryside = 1 (information collected from Intervista) Accommodation equipped with PV, either solar panels for electricity or to produce hot water = 1, None = 0 Households living in German-speaking: Households living in regions including Alpen and Voralpen, Westmittelland, Ostmittelland = 1 (information collected from Intervista) Household with three or more people: Households with three or more people = 1
Values	Hedonic values: concerning personal pleasure, enjoying life and self-indulgence. Egoistic values: concerning social power, wealth, authority, influence and ambition. Altruistic values: concerning equality, world peace, social justice and helpfulness (towards other people) Biospheric values: concerning respecting earth (and other species), nature, protecting the natural environment and preventing pollution.	Please rate how important each value is for you as a guiding principle in your life. Hedonic values (mean of 3 items): Psy4_4: Pleasure: joy, gratification of desires; Psy4_10: Enjoying life: enjoying food, sex, leisure, etc Psy4_15: Self-indulgence: doing pleasant things. Egoistic values (mean of 5 items): Psy4_3: Social power: control over others, dominance Psy4_7: Wealth: material possessions, money Psy4_8: Authority: the right to lead or command Psy4_12: Influential: having an impact on people and events Psy4_16: Ambition: hard-working, aspiring Altruistic values (mean of 4 items): Psy4_1: Equality: equal opportunity for all Psy4_6: A world at peace: free of war and conflict; Psy4_9: Social justice: correcting injustice, care for the weak Psy4_13: Helpfulness: working for the welfare of others Biospheric values (mean of 4 items): Psy4_2: Respecting earth: harmony with other species Psy4_5: Unity with nature: fitting into nature Psy4_11: Protecting the environment: preserving nature Psy4_14: Preventing pollution: protecting natural resources Scale: 1 (not important) – 5 (extremely important)
Intentions	Intention to reduce car carbon footprint in the next 12 months	1 item: In the next 12 months, are you planning on reducing your … Psy8_4: carbon footprint? Scale: 1 (very unlikely) – 5 (very likely)
Descriptive norms	Assessment of others' environmentally friendly behavior	1 item: Psy5a_2: I believe that most of my acquaintances behave in an environmentally friendly manner whenever it is possible. Scale: 1 (totally agree) to 5 (totally disagree)
Injunctive norms	Perception of others' expectations for self to act in an environmentally friendly way	Mean of 2 items: Psy5a_1: The members in my household expect that I behave in an environmentally friendly manner. Psy5a_3: Most of my acquaintances expect that I behave in an environmentally friendly manner. Scale: 1 (totally agree) to 5 (totally disagree)
Adopter segments	Classification of likelihood to adopt innovation according to Rogers (1983)	Multiple choice question: Ped_adopter: Which of the following describes you best? For your information: Smart-home technology products refer to products, gadgets, and apps that may help you control different aspects of your home such as your room temperature, energy consumption, or water usage. (1) Innovator: I am the type of person who closely follows new technological developments and who dares taking risks by being the first to purchase innovative smart-home technology products (2) Early adopter: I am the type of person who envisions potential advantages in innovative smart-home technology products and who is one of the first to make use of these advantages and to profit from those (3) Early majority: I am the type of person who is interested in innovative smart-home technology products but at the same time is pragmatic. First I would like to take time and be persuaded by the advantages that an innovative smart-home technology product possesses. My decisions are (mainly) based on recommendations of existing users (4) Late majority: I am the type of person who is not thrilled by innovative smart-home technology products, but who rather appreciates security. It is safe to purchase an innovative smart-home technology product when it has been on the market for some while and offers obvious advantages

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(*continued*)

Variables	Questions/items
	(5) Laggards: I am the type of person who is traditional and has little affinity with innovative smart-home technology products. I do not like changes in life and I purchase innovative smart-home technology products only when the existing methods I use do not work anymore

Appendix A4. Estimation of part-worth utilities for segments – results for Bayesian estimation and maximum likelihood estimation of random parameters logit – and standard deviation of parameters from maximum likelihood estimation. Results are to be interpreted relative to the base option (used as omitted levels in model): Ownership of PV by utility, private cars with emission restrictions, basic shared spaces

Attribute and levels	Random parameters logit, Bayesian estimation, standard deviation of posterior after distributional transformation in parentheses					Random parameters logit, maximum likelihood estimation, standard error in parentheses				
	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Ownership of solar PV and your involvement										
Private ownership	−1.01	0.45	5.66	0.27	−1.98	−0.87	0.24	3.45	0.21	−1.75
	(0.54)	(0.99)	(1.33)	(0.72)	(0.90)	(0.12)	(0.12)	(0.38)	(0.07)	(0.18)
Cooperative ownership	−0.35	2.14	−0.79	−0.80	1.98	−0.35	1.60	−0.26	−0.65	1.86
	(0.54)	(0.77)	(1.03)	(0.59)	(0.56)	(0.10)	(0.14)	(0.17)	(0.07)	(0.19)
Housing association	0.43	0.03	−1.49	−0.13	1.13	0.40	0.16	−0.95	−0.11	0.93
	(0.49)	(1.27)	(1.61)	(0.49)	(0.68)	(0.08)	(0.09)	(0.17)	(0.05)	(0.12)
Availability of mobility options										
Public transit only	−2.91	−2.41	−2.76	0.86	2.29	−2.52	−1.88	−1.62	0.70	2.02
	(0.52)	(0.49)	(1.35)	(0.42)	(0.63)	(0.16)	(0.12)	(0.19)	(0.05)	(0.17)
Shared EV	−0.26	0.07	0.41	−0.43	−0.37	−0.28	0.07	0.08	−0.35	−0.30
	(0.65)	(0.52)	(2.04)	(0.43)	(0.82)	(0.09)	(0.07)	(0.13)	(0.05)	(0.11)
Availability of shared spaces										
Extra shared spaces	−0.08	1.24	−2.10	0.17	1.41	−0.07	0.89	−1.30	0.15	1.15
	(0.49)	(0.51)	(0.58)	(0.38)	(0.60)	(0.06)	(0.09)	(0.14)	(0.04)	(0.13)
BIC	1604.75	817.08	369.78	2359.23	781.68	1935.69	1091.16	592.50	2685.75	1056.86

Attribute and levels	Standard deviation parameters from random parameters logit, maximum likelihood estimation				
	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Ownership of solar PV and your involvement					
Private ownership	0.004	0.009	0.011	0.008	0.580[a]
Cooperative ownership	0.001	0.00	0.267	0.0009	0.001
Housing association	0.164	0.008	0.003	0.0007	0.009
Availability of mobility options					
Public transit only	0.008	0.002	0.002	0.004	0.024
Shared EV	0.662[a]	0.004	0.015	0.006	0868[a]
Availability of shared spaces					
Extra shared spaces	0.167	0.0003	0.227	0.002	0.289

Note: A number of models with different distributions for random parameters were run. However, a normal distribution of random parameters with Bayesian estimation produced the best fit based on BIC.

Note: Standard deviations of the random parameters show significance for Segments 1 and Segment 5 indicating heterogeneity in respondents' preferences for these levels.

[a] = T-ratio greater than 1.96.

Appendix A5. A selection of summary statistics by segment; mean with standard deviation presented in parentheses

Variable	Segment				
	Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
N	426	308	143	359	250
Age	49.1	45.1	50.1	51.96	47.8
	(14.9)	(15.3)	(15.45)	(16.03)	(15.5)
Sex	0.49	0.45	0.41	0.48	0.46
	(0.50)	(0.50)	(0.49)	(0.50)	(0.50)
Income	8723.03[a]	8708.4[b]	8647.72[c]	7603.04[d]	8134.04[e]
	(3226.9)	(3141.8)	(3306.97)	(3248.5)	(3179.3)
Years of education	14.07	14.20[f]	14.16	13.83	14.02[g]
	(2.00)	(1.96)	(1.98)	(2.04)	(1.95)
Car ownership	0.88	0.81	0.87	0.67	0.48
	(0.31)	(0.39)	(0.34)	(0.47)	(0.50)
House ownership	0.29	0.29	0.48	0.29	0.15
	(.45)	(.45)	(.50)	(.45)	(.36)
Lives in countryside	0.29 (0.45)	0.24 (0.43)	0.25 (0.44)	0.20 (0.40)	0.14 (0.35)
Accommodation with solar panels	0.18	0.18	0.27	0.14	0.16

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Variable	Segment				
	Segment 1: *Car defenders*	Segment 2: *Cooperative with car flexibility*	Segment 3: *Private and autonomous*	Segment 4: *No cooperative PV, Public transit*	Segment 5: *Community-focused*
	(0.39)	(0.39)	(0.44)	(0.35)	(0.36)
Households living in German-speaking Switzerland	0.72	0.81	0.75	0.76	0.78
	(0.46)	(0.39)	(0.44)	(0.43)	(0.41)
Household with three or more people	0.31	0.43[f]	0.36	0.27	0.27[g]
	(0.46)	(0.50)	(0.48)	(0.45)	(0.44)
Adopter segment	3.21	3.06	3.11	3.187	3.192
	(1.1)	(.96)	(1.13)	(1.15)	(1.104)
Intention to reduce carbon footprint	3.01	3.25	3.23	3.11	3.39
	(1.10)	(1.05)	(1.00)	(1.18)	(1.03)
Values					
Hedonic values	3.77	3.72	3.76	3.59	3.67
	(0.73)	(0.75)	(0.70)	(0.85)	(0.73)
Egoistic values	2.73	2.74	2.81	2.70	2.5
	(0.75)	(0.73)	(0.71)	(0.79)	(0.66)
Altruistic values	3.9	3.99	3.86	3.95	4.22
	(0.68)	(0.66)	(0.63)	(0.79)	(0.60)
Biospheric values	3.95	4.09	4.03	4.07	4.24
	(0.77)	(0.71)	(0.64)	(0.835)	(0.65)
Norms					
Descriptive norms	3.38	3.39	3.38	3.41	3.44
	(0.87)	(0.87)	(0.86)	(0.92)	(0.90)
Injunctive norms	3.22	3.38	3.40	3.40	3.45
	(1.00)	(0.86)	(0.82)	(0.97)	(0.98)

[a] N = 380.
[b] N = 280.
[c] N = 132.
[d] N = 313.
[e] N = 235.
[f] N = 307.
[g] N = 249.

Appendix A6. Comparison of means using Tukey-Kramer test (only statistically significant differences are reported)

Variable	Means			
	Difference	Std. error		
Car ownership				
Car defenders vs.				
Utility-owned PV, public transit	0.213***	0.029	0.133	0.293
Community-focused	0.411***	0.033	0.322	0.500
Utility-owned PV, public transit vs.				
Cooperative with car flexibility	−0.134***	0.032	−0.221	−0.048
Private and autonomous	−0.193***	0.040	−0.304	−0.082
Community-focused vs.				
Cooperative with car flexibility	−0.332***	0.035	−0.428	−0.237
Private and autonomous	−0.391***	0.042	−0.508	−0.274
Utility-owned PV, public transit	−0.198***	0.034	−0.290	−0.106
House ownership Private and autonomous vs.				
Car defenders	0.189***	0.0423	0.072	0.306
Cooperative with car flexibility	0.190***	0.045	0.067	0.312
Utility-owned PV, public transit	0.186***	0.044	0.066	0.306
Community-focused	0.324***	0.047	0.196	0.451
Community-focused vs.				
Car defenders	−0.134**	0.035	−0.231	−0.038
Cooperative with car flexibility	−0.134**	0.038	−0.237	−0.031
Utility-owned PV, public transit	−0.138**	0.037	−0.238	−0.038
Accommodation with solar panels Private and autonomous vs.				
Utility-owned PV, public transit	0.126**	0.037	0.024	0.229
Community-focused	0.110*	0.040	0.001	0.218
Income Utility-owned PV, public transit vs.				
Car defenders	−1119.991***	245.333	−1790.12	−449.862
Cooperative with car flexibility	−1105.001***	264.381	−1827.158	−382.843
Private and autonomous	−1044.692*	333.560	−1955.814	−133.570
Live in countryside Car defenders vs.				
Utility-owned PV, public transit	0.085*	0.030	0.004	0.293
Community-focused	0.149***	0.033	0.058	0.500
Household with 3 or more people Cooperative with car flexibility vs.				
Car defenders	0.125**	0.034	0.030	−0.048
Utility-owned PV, public transit	0.157***	0.036	0.058	−0.082
Community-focused	0.161***	0.040	0.053	−0.237
Intention to reduce carbon footprint Cooperative with car flexibility vs.				

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(*continued*)

Variable	Means			
	Difference	Std. error		
Car defenders	0.240*	0.081	0.017	0.462
Community-focused vs. Car defenders	0.381***	0.087	0.144	0.618
Utility-owned PV, public transit	0.279*	0.090	0.034	0.524
Age Cooperative with car flexibility vs.				
Car defenders	−4.030**	1.154	−7.181	−0.880
Private and autonomous	−4.970*	1.561	−9.232	−0.707
Utility-owned PV, public transit	−6.910***	1.198	−10.181	−3.637
Community-focused vs.				
Utility-owned PV, public transit	−4.169**	1.270	−7.639	−0.699
Values: Hedonic values				
Utility-owned PV, public transit vs.				
Car defenders	−0.178*	0.055	−0.328	−0.029
*Values: Egoistic values*Community-focused vs.				
Car defenders	−0.232*	0.059	−0.393	−0.072
Cooperative with car flexibility	−0.239**	0.063	−0.410	−0.067
Private and autonomous	−0.306**	0.077	−0.518	−0.094
Utility-owned PV, public transit	−0.195*	0.061	−0.361	−0.029
Values: Altruistic values Community-focused vs.				
Car defenders	0.315***	0.055	0.165	0.465
Cooperative with car flexibility	0.229**	0.059	0.070	0.390
Private and autonomous	0.356***	0.072	0.159	0.553
Utility-owned PV, public transit	0.272***	0.057	0.117	0.427
Values: Biospheric values Community-focused vs.				
Car defenders	0.292***	0.060	0.129	0.454
Injunctive norms				
Community-focused vs.	0.230*	0.076	0.022	0.438
Car defenders				

Comparisons of means have been carried out for all variables listed in Appendix A2. This table reports only variables for which differences in means are statistically significant according to the Tukey–Kramer test for of multiple comparisons.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Consistent with their preference for public-transit only, the *Community-focused* segment exhibit a significantly lower mean car ownership relative to all other segments. Respondents in this segment also show a significantly higher intention to reduce their carbon footprint relative to *Car defenders* and the *No cooperative PV, Public transit* segment. The *Community-focused* segment exhibited a significantly lower average score on egoistic values relative to all other segments and a significantly higher average score on altruistic values. The number of home owners in this segment was significantly lower relative to all other segments.

On the other hand, the *Car defenders* segment demonstrated significantly higher average car ownership relative to all other segments, consistent with findings about their attribute preferences. They were more likely to live in the countryside than the *No cooperative PV, Public transit* and *Community-focused* segments. They also scored significantly lower on average scores in biospheric values and injunctive norms compared to the *Community-focused* segment and had a lower average intention to reduce their carbon footprint compared to the *Community-focused* segment and the *Cooperative with car flexibility* segment. The *Car defenders* segment had a higher average hedonic score relative to the *No cooperative PV, Public transit* segment.

Respondents in the *Cooperative with car flexibility* segment were, on average, significantly younger than most segments (*Car defenders*, the *Private and autonomous* segment, and the *No cooperative PV, Public transit* segments). They also had a significantly higher average number of households with three or more people compared to most segments (*Car defenders*, *No cooperative PV, Public transit*, and *Community-focused*).

Respondents in the *No cooperative PV, Public transit* segment were among the oldest in the sample, significantly older than respondents in both the *Cooperative with car flexibility* segment and the *Community*-focused segment. They also had significantly lower average car ownership and significantly lower average income compared to all segments but the *Community-focused* segment.

The *Private and autonomous* segment had high average house ownership relative to all other segments and significantly higher car ownership compared to the *No* cooperative *PV, Public transit* and *Community-focused* segments. Respondents in the segment also had higher average number of households equipped with solar panels relative to *No cooperative PV, Public transit* and *Community-focused* segments.

References

Ambrose, A., 2020. Walking with Energy: challenging energy invisibility and connecting citizens with energy futures through participatory research. Futures 117, 102528. https://doi.org/10.1016/j.futures.2020.102528.

Akhatova, A., Bruck, A., Casamassima, L., 2020. Techno-Economic Aspects and Pathways towards Positive Energy Districts, Project Deliverable Smart-BEEjS 2020. https://smart-beejs.eu/wp-content/uploads/2020/12/20-09-30_D4.2_Final-Version.pdf.

Axpo, 2021. Power market Switzerland. Electricity market facts and figures. Available at: https://www.axpo.com/ch/en/about-us/media-and-politics/power-market-switzerland.html.

Baehler, D., Rérat, P., 2020. Between ecological convictions and practical considerations – profiles and motivations of residents in car-free housing developments in Germany and Switzerland. Geograph. Helv. 75 (2), 169–181. https://doi.org/10.5194/gh-75-169-2020.

Balmer, I., Gerber, J.D., 2017. Why are housing cooperatives successful? Insights from Swiss affordable housing policy. Hous. Stud. 33 (3), 361–385. https://doi.org/10.1080/02673037.2017.1344958.

Balta-Ozkan, N., Yildirim, J., Connor, P.M., 2015. Regional distribution of photovoltaic deployment in the UK and its determinants: a spatial econometric approach. Energy Econ. 51, 417–429.

Baranzini, A., Carattini, S., Péclat, M., 2017. What drives social contagion in the adoption of solar photovoltaic technology?. In: GRI Working Papers. Grantham Research Institute on Climate Change and the Environment, p. 270.

Batel, S., Devine-Wright, P., Tangeland, T., 2013. Social acceptance of low carbon energy and associated infrastructures: a critical discussion. Energy Pol. 58, 1–5. https://doi.org/10.1016/j.enpol.2013.03.018.

Bauwens, T., Devine-Wright, P., 2018. Positive energies? An empirical study of community energy participation and attitudes to renewable energy. Energy Pol. 118, 612–625. https://doi.org/10.1016/j.enpol.2018.03.062.

Beck, M.J., Hensher, D.A., 2021. What might the changing incidence of Working from Home (WFH) tell us about future transport and land use agendas. Transport Rev. 41 (3), 257–261. https://doi.org/10.1080/01441647.2020.1848141.

Beirão, G., Sarsfield Cabral, J.A., 2007. Understanding attitudes towards public transport and private car: a qualitative study. Transport Pol. 14 (6), 478–489. https://doi.org/10.1016/j.tranpol.2007.04.009.

Bojovic, D., Benavides, J., Soret, A., 2020. What we can learn from birdsong: mainstreaming teleworking in a post-pandemic world. Earth System Governance 5, 100074. https://doi.org/10.1016/j.esg.2020.100074.

Bolle, A., 2019. How cities can back renewable energy communities: guidelines for local and regional policy makers. Available at: https://energy-cities.eu/wp-content/uploads/2019/06/EnergyCities_RNP_Guidebook_Web.pdf.

Briguglio, M., Formosa, G., 2017. When households go solar: determinants of uptake of a photovoltaic scheme and policy insights. Energy Pol. 108, 154–162.

C40 Cities Climate Leadership Group (C40CCLG), 2020. How to Build Back Better with a 15-minute City. URL. https://www.c40knowledgehub.org/s/article/How-to-build-back-better-with-a-15-minute-city?language=en_US. (Accessed 11 November 2020).

Cassinadri, E., Gambarini, E., Nocerino, R., Scopelliti, L., 2019. Sharing Cities: from vision to reality. A people, place and platform approach to implement Milan's Smart City strategy. International Journal of Sustainable Energy Planning and Management 24. https://doi.org/10.5278/ijsepm.3336.

Clark, B., Lyons, G., Chatterjee, K., 2016. Understanding the process that gives rise to household car ownership level changes. J. Transport Geogr. 55, 110–120. https://doi.org/10.1016/j.jtrangeo.2016.07.009.

Confederation Suisse, 2019. Energy – Facts and Figures. Available at: https://www.eda.admin.ch/aboutswitzerland/en/home/wirtschaft/energie/energie—fakten-und-zahlen.html.

Cui, A.S., Wu, F., 2015. Utilizing customer knowledge in innovation: antecedents and impact of customer involvement on new product performance. J. Acad. Market. Sci. 44 (4), 516–538. https://doi.org/10.1007/s11747-015-0433-x.

Daae, J., Boks, C., 2015. A classification of user research methods for design for sustainable behavior. J. Clean. Prod. 106, 680–689. https://doi.org/10.1016/j.jclepro.2014.04.056.

Dargay, J.M., 2002. Determinants of car ownership in rural and urban areas: a pseudo-panel analysis. Transport. Res. E Logist. Transport. Rev. 38 (5), 351–366. https://doi.org/10.1016/s1366-5545(01)00019-9.

Derkenbaeva, E., Heinz, H., Lopez Dallara, M.L., Mihailova, D., Galanakis, K., Stathopoulou, E., 2020. Business models and consumers' value proposition for PEDs value generation by PEDs : best practices case study Book. Available at: https://smart-beejs.eu/wp-content/uploads/2020/12/WP6-Deliverable-D6.2-Value-Generation-by-PEDs.pdf.

Dharshing, S., 2017. Household dynamics of technology adoption: a spatial econometric analysis of residential solar photovoltaic (PV) systems in Germany. Energy Resources & Social Science 23, 113–124.

Ecker, F., Hahnel, U.J.J., Spada, H., 2017. Promoting decentralized sustainable energy systems in different supply scenarios: the role of autarky aspiration. Front. Energy Res. 5 https://doi.org/10.3389/fenrg.2017.00014.

European Commission, 2018. SET-plan Action no.32 Implementation Plan – Europe to Become a Global Role Model in Integrated, Innovative Solutions for the Planning, Deployment, and Replication of Positive Energy Districts. https://setis.ec.europa.eu/system/files/2021-04/setplan_smartcities_implementationplan.pdf.

European Commission, 2020a. Clean energy for all Europeans package - energy European Commission. Energy - European Commission. https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en.

European Commission, 2020b. Energy communities. https://ec.europa.eu/energy/topics/markets-and-consumers/energy-communities_en.

Faiers, A., Cook, M., Neame, C., 2007. Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use. Energy Pol. 35, 4381–4390. https://doi.org/10.1016/j.enpol.2007.01.003.

Federal Statistical Office FSO, 2019. Rental Apartments. Online source. https://www.bfs.admin.ch/bfs/de/home/statistiken/bau-wohnungswesen/wohnungen/mietwohnungen.html.

Garrod, G., Ruto, E., Willis, K., Powe, N., 2012. Heterogeneity of preferences for the benefits of Environmental Stewardship: a latent-class approach. Ecol. Econ. 76, 104–111.

Geels, F.W., 2005. Technological Transitions and System Innovations: a Co-evolutionary and Socio-Technical Analysis. Edward Elgar Publishing.

Gollner, C., Hinterberger, R., Bossi, S., Theierling, S., Noll, M., Meyer, S., Schwarz, H.-G., 2020. Europe towards positive energy districts: a compilation of projects towards sustainable urbanization and the energy transition. PED Programme Management of JPI Urban Europe. https://jpi-urbaneurope.eu/wp-content/uploads/2020/06/PED-Booklet-Update-Feb-2020_2.pdf.

Green, P.E., Krieger, A.M., 1991. Segmenting markets with conjoint analysis. J. Market. 55, 20–31. https://www.jstor.org/stable/1251954.

Hall, S., Brown, D., Davis, M., Ehrtmann, M., Holstenkamp, L., 2020. Business models for prosumers in Europe. PROSEU - Prosumers for the Energy Union: Mainstreaming active participation of citizens in the energy transition (Deliverable N°D4.1). Available at: https://proseu.eu/sites/default/files/Resources/PROSEU_D4.1_Business%20models%20for%20collective%20prosumers.pdf.

Hauber, A.B., González, J.M., Groothuis-Oudshoorn, C.G., Prior, T., Marshall, D.A., Cunningham, C., IJzerman, M.J., Bridges, J.F., 2016. Statistical methods for the analysis of discrete choice experiments: a report of the ISPOR conjoint analysis good research practices task force. Value Health 19 (4), 300–315. https://doi.org/10.1016/j.jval.2016.04.004.

Heng, Y., Lu, C.-L., Yu, L., Gao, Z., 2020. The heterogeneous preferences for solar energy policies among US households. Energy Pol. 137, 111187. https://doi.org/10.1016/j.enpol.2019.111187.

Hess, S., Palma, D., 2019. Apollo: a Flexible, Powerful and Customisable Freeware Package for Choice Model Estimation and Application. Choice Modelling Centre. R package version 0.1.0. Available at: http://www.ApolloChoiceModelling.com.

Hille, S., Weber, S., Brosch, T., 2019. Consumers' preferences for electricity-saving programs: evidence from a choice-based conjoint study. J. Clean. Prod. 220, 800–815. https://doi.org/10.1016/j.jclepro.2019.02.142.

Huber, J., Train, K., 2001. On the similarity of classical and bayesian estimates of individual mean partworths. Market. Lett. 12, 259–269. https://doi.org/10.1023/A:1011120928698.

Interreg Europe, 2018. Renewable Energy Communities: A Policy Brief from the Policy Learning Platform on Low-Carbon Economy. https://www.interregeurope.eu/fileadmin/user_upload/plp_uploads/policy_briefs/2018-08-30_Policy_brief_Renewable_Energy_Communities_PB_TO4_final.pdf.

IRENA, 2020. Innovation Landscape Brief: Peer-To-Peer Electricity Trading. International Renewable Energy Agency, Abu Dhabi. Available at: https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Peer-to-peer_trading_2020.pdf?la=en&hash=D3E25A5BBA6FAC15B9C193F64CA3C8CBFE3F6F41.

Khan, S.A., Bohnsack, R., 2020. Influencing the disruptive potential of sustainable technologies through value proposition design: the case of vehicle-to-grid technology. J. Clean. Prod. 254, 120018 https://doi.org/10.1016/j.jclepro.2020.120018.

Kurz, T., Gardner, B., Verplanken, B., Abraham, C., 2015. Habitual behaviors or patterns of practice? Explaining and changing repetitive climate-relevant actions. Clim. Change 6 (1), 113–128. https://doi.org/10.1002/wcc.327.

Lanzini, P., Khan, S.A., 2017. Shedding light on the psychological and behavioral determinants of travel mode choice: a meta-analysis. T*ransport. Res. F Traffic Psychol. Behav.* 48, 13–27. https://doi.org/10.1016/j.trf.2017.04.020.

Lara-Pulido, J.A., Martinez-Cruz, A.L., 2021. Teleworking from a near-home shared office in Mexico city – a discrete choice experiment on office workers. Available at: https://doi.org/10.2139/ssrn.3763703. (Accessed 18 April 2021).

Liao, F., Correia, G., 2020. Electric carsharing and micromobility: a literature review on their usage pattern, demand, and potential impacts. International Journal of Sustainable Transportation 1–30. https://doi.org/10.1080/15568318.2020.1861394.

Lindholm, O., Rehman, H. ur, Reda, F., 2021. Positioning positive energy districts in European cities. Buildings 11 (1), 19. https://doi.org/10.3390/buildings11010019. Available at:

Mattes, A., 2012. Grüner Strom: verbraucher sind bereit, für Investitionen in erneuerbare Energien zu zahlen. DIW-Wochenbericht 79, 2–9.

McEwan, Brain, 2015. Attribute Importance. Sawtooth Software Forum. August 4. https://legacy.sawtoothsoftware.com/forum/8566/attribute-importance.

Microsoft Work Lab (MWL), 2021. The next Great disruption is hybrid work –are we ready? URL. https://www.microsoft.com/en-us/worklab/work-trend-index/hybrid-work. (Accessed 18 April 2021).

Moore, G.A., 2014. *Crossing The Chasm: Marketing And Selling Disruptive Products To Mainstream Customers* (Collins Business Essentials). Harper Collins, New York.

Musall, F.D., Kuik, O., 2011. Local acceptance of renewable energy—a case study from southeast Germany. Energy Pol. 39 (6), 3252–3260. https://doi.org/10.1016/j.enpol.2011.03.017.

Nolan, A., 2010. A dynamic analysis of household car ownership. Transport. Res. Pol. Pract. 44 (6), 446–455. https://doi.org/10.1016/j.tra.2010.03.018.

Noppers, E.H., Keizer, K., Bockarjova, M., Steg, L., 2015. The adoption of sustainable innovations: the role of instrumental, environmental, and symbolic attributes for earlier and later adopters. J. Environ. Psychol. 44, 74–84. https://doi.org/10.1016/j.jenvp.2015.09.002.

Nygrén, N.A., Kontio, P., Lyytimäki, J., Varho, V., Tapio, P., 2015. Early adopters boosting the diffusion of sustainable small-scale energy solutions. Renew. Sustain. Energy Rev. https://doi.org/10.1016/j.rser.2015.02.031.

Olivadese, R., Alpagut, B., Revilla, B.P., Brouwer, J., Georgiadou, V., Woestenburg, A., van Wees, M., 2021. Towards energy citizenship for a just and inclusive transition: lessons learned on collaborative approach of positive energy districts from the EU Horizon2020 smart cities and communities projects. Proceedings 65 (1), 20. https://doi.org/10.3390/proceedings2020065020. Available at:

Orme, B.K., 2010. Getting Started with Conjoint Analysis: Strategies for Product Design and Pricing Research. Research Publishers, Madison, WI.

Paalosmaa, T., Shafie-khah, M., 2021. Feasibility of innovative smart mobility solutions: a case study for vaasa. World Electr. Veh. J. 12, 188. https://doi.org/10.3390/wevj12040188, 2021.

Petrovich, B., Hille, S.L., Wüstenhagen, R., 2019. Beauty and the budget: a segmentation of residential solar adopters. Ecol. Econ. 164 https://doi.org/10.1016/j.ecolecon.2019.106353.

Camilleri, L., Azzopardi, L.M. 2011. Market Segmentation through Conjoint Analysis Using Latent Class Models. European Simulation and Modelling Conference: Modelling and Simulation 2011.

Quartierstrom, n.d. What you need to know at a glance. Available at:: https://quartier-strom.ch/index.php/en/the-essentials-in-brief/.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/.

Rintamäki, T., Kirves, K., 2017. From perceptions to propositions: profiling customer value across retail contexts. J. Retailing Consum. Serv. 37, 159–167. https://doi.org/10.1016/j.jretconser.2016.07.016.

Rivas, J., Seidl, B. Schmid y I., 2018. Energiegenossenschaften in der Schweiz: ergebnisse einer Befragung. WSL Berichte 71. Available at: https://www.wsl.ch/de/publikationen/energiegenossenschaften-in-der-schweizergebnisse-einer-befragung.html.

Rogers, E.M., 1983. Diffusion of Innovations. Free Press, New York.

Rogers, E.M., 2003. The Diffusion of Innovation, fifth ed. Free Press, New York.

Sawtooth Software, 2012. Latent class v4.5. https://www.sawtoothsoftware.com/download/techpap/lclass_manual.pdf.

Sawtooth Software, n.d. "Importances." https://sawtoothsoftware.com/help/discover/manual/index.html?importances.html.
Schneider, R.J., 2013. Theory of routine mode choice decisions: an operational framework to increase sustainable transportation. Transport Pol. 25, 128–137. https://doi.org/10.1016/j.tranpol.2012.10.007.
Spectral, n.d. Projects. Available at: https://spectral.energy/projects/.
Steg, L., Bolderdijk, J.W., Keizer, K., Perlaviciute, G., 2014. An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. J. Environ. Psychol. 38, 104–115. https://doi.org/10.1016/j.jenvp.2014.01.002.
Steg, L., Nordlund, A., 2018. Theories to explain environmental behaviour. In: Steg, L., Groot, J.I.M. (Eds.), Environmental Psychology, pp. 217–227. https://doi.org/10.1002/9781119241072.ch22.
Stern, P.C., 2000. New environmental theories: toward a coherent theory of environmentally significant behavior. J. Soc. Issues 56, 407–424. https://doi.org/10.1111/0022-4537.00175.
Stoiber, T., Schubert, I., Hoerler, R., Burger, P., 2019. Will consumers prefer shared and pooled-use autonomous vehicles? A stated choice experiment with Swiss households. Transport. Res. Transport Environ. 71, 265–282. https://doi.org/10.1016/j.trd.2018.12.019.
Tabi, A., Hille, S.L., Wüstenhagen, R., 2014. What makes people seal the green power deal? - customer segmentation based on choice experiment in Germany. Ecol. Econ. 107, 206–215. https://doi.org/10.1016/j.ecolecon.2014.09.004.
Tolkamp, J., Huijben, J.C.C.M., Mourik, R.M., Verbong, G.P.J., Bouwknegt, R., 2018. User-centred sustainable business model design: the case of energy efficiency services in The Netherlands. J. Clean. Prod. 182, 755–764. https://doi.org/10.1016/j.jclepro.2018.02.032.
Train, K., 2009. Discrete Choice Methods with Simulation, second ed. Cambridge University Press, Cambridge. Available at: https://eml.berkeley.edu/books/choice2.html.
Vasseur, V., Kemp, R., 2015. The adoption of PV in The Netherlands: a statistical analysis of adoption factors. Renew. Sustain. Energy Rev. 41, 483–494. https://doi.org/10.1016/j.rser.2014.08.020.
Weber, S., Burger, P., Farsi, M., Martinez-Cruz, A.L., Puntiroli, M., Schubert, I., Volland, B., 2017. Swiss Household Energy Demand Survey (SHEDS): Goals, Design, and Implementation. *SCCER CREST Working Paper WP2 - 2017/04*. Online. https://www.sccer-crest.ch/fileadmin/FILES/Datenbank_Personen_Projekte_Publikationen/Publications/Working_Papers/Work_Package_2/Weber_Burger_et_al_2017_SHEDS_Official_description.pdf.
Weber, S., 2019. A step-by-step procedure to implement discrete choice experiments in Qualtrics. Soc. Sci. Comput. Rev. 39 (5), 903–921. https://doi.org/10.1177/0894439319885317.
Weller, B.E., Bowen, N.K., Faubert, S.J., 2020. Latent class Analysis: a guide to best practice. J. Black Psychol. 46 (4), 287–311. https://doi.org/10.1177/0095798420930932.
Wever, R., van Kuijk, J., Boks, C., 2008. User-centred design for sustainable behaviour. International Journal of Sustainable Engineering 1 (1), 9–20. https://doi.org/10.1080/19397030802166205.
Willsher, K., 2020. Paris Mayor Unveils 15-minute City Plan Re-election Campaign. The Guardian. February 7. URL: https://www.theguardian.com/world/2020/feb/07/paris-mayor-unveils-15-minute-city-plan-in-re-election-campaign. (Accessed 17 November 2020).
Wilkinson, S., Hojckova, K., Eon, C., Morrison, G.M., Sandén, B., 2020. Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia. Energy Res. Social Sci. 66 https://doi.org/10.1016/j.erss.2020.101500.
Yildiz, Z., Rommel, J., Debor, S., Holstenkamp, L., Mey, F., Müller, J.R., Radtke, J., Rognli, J., 2015. Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. Energy Res. Social Sci. 6, 59–73. https://doi.org/10.1016/j.erss.2014.12.001.
Zimmerling, E., Purtik, H., Welpe, I.M., 2017. End-users as co-developers for novel green products and services e an exploratory case study analysis of the innovation process in incumbent firms. J. Clean. Prod. 162, S51–S58. https://doi.org/10.1016/j.jclepro.2016.05.160.

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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.

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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..

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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/.

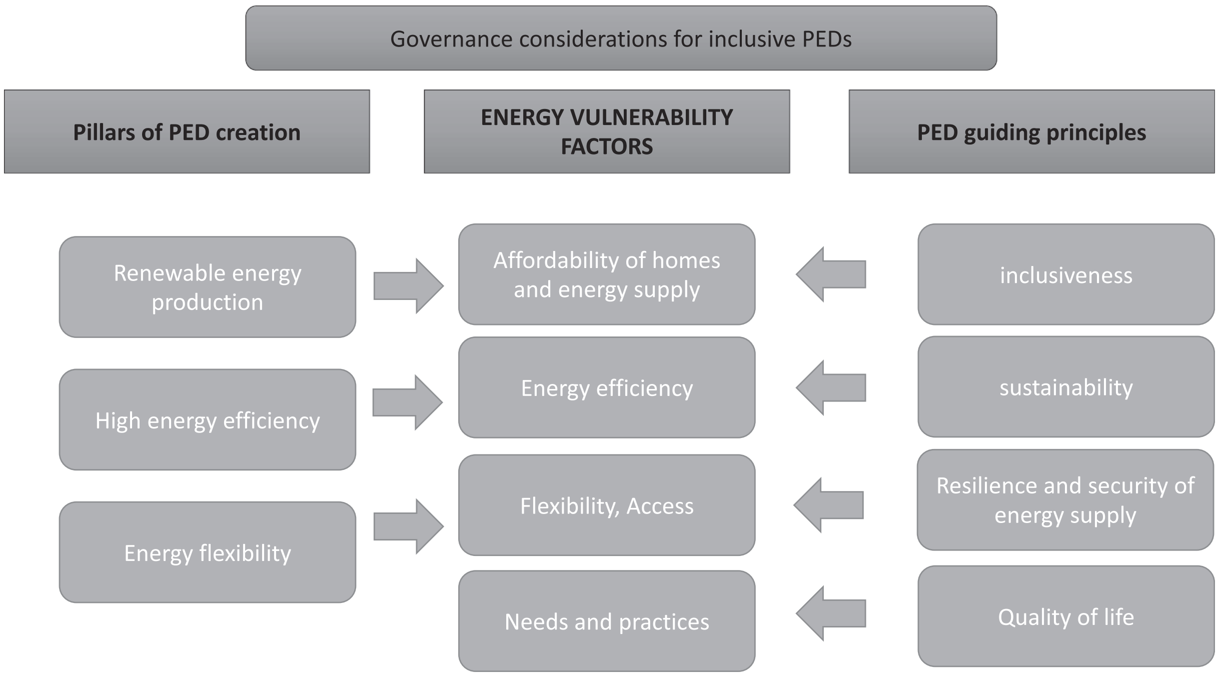

Fig. 1. Energy justice, PED Pillars, guiding principles and energy vulnerability, authors elaboration.

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.

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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/

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(*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

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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].

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EDITED BY
Keith Baker,
Glasgow Caledonian University,
United Kingdom

REVIEWED BY
Soufiane Boukarta,
University of Blida, Algeria
Trivess Moore,
RMIT University, Australia
Daranee Jareemit,
Thammasat University, Thailand

*CORRESPONDENCE
Adam X. Hearn
adam.hearn@unibas.ch

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Redefining energy vulnerability, considering the future

Adam X. Hearn*, Darja Mihailova, Iljana Schubert and Annika Sohre

Sustainability Research Group, University of Basel, Basel, Switzerland

Within the EU, energy poverty is believed to affect at least 9.8% of households. Energy poverty can be broadly defined as a households' inability to meet its energy needs. This is a problem that affects all European countries, but narrow interpretations of data based on notions of material deprivation may lead to energy poverty being overlooked or not considered an issue by policymakers. The EU Energy Poverty Advisory Hub makes a number of essential points when it comes to the measurement, definition, and potential policies and measures to deal with energy poverty. We build on this, using the term energy vulnerability in order to encompass the segment of population identified as living in energy poverty as well as those at risk of becoming energy poor in the future. We use a capabilities approach with a doughnut economics framework to expand on the concept of energy vulnerability as a form of capabilities deprivation, allowing for greater recognition of those that are affected in the present and intergenerationally. This framework is applied using mixed methods consisting of both a Swiss-wide survey of 1,486 people and 8 semi-structured interviews with energy stakeholders to investigate the knowledge gap on energy vulnerability in Switzerland. The framework may be applied and have wider repercussions for other parts of the world where energy poverty is not directly addressed, and where using the term of energy vulnerability may help direct policies in a more dynamic and responsive manner. Furthermore, this article identifies some limitations of basing energy vulnerability definitions on data which focuses on material deprivations as this may risk overlooking those that are vulnerable due to other reasons such as building energy efficiency. We find that levels of energy poverty/vulnerability are higher than estimated in official statistics, highlighting the need for tailored policies both in Switzerland and elsewhere. Levels of energy vulnerability in Switzerland may not be reflected elsewhere, but certainly draw attention to the potential misrecognition of energy vulnerability which may be more widespread than previously believed. We examine existing policies that may help to reduce energy vulnerability, as well as suggest other potential mitigation methods.

KEYWORDS

energy vulnerability, energy poverty, energy governance, energy efficiency, capability approach, doughnut economics

Introduction

Energy poverty is an area of research that has grown significantly since Boardman (1991) first defined it as households that spend more than 10% of their income on basic energy needs. Energy poverty (sometimes referred to as fuel poverty; Charlier and Legendre, 2021) is a global issue (Churchill and Smyth, 2020; Teariki et al., 2020; Che et al., 2021), which is often connected to a lack of access to electricity in the Global South (Lee et al., 2020). In the Global North it is defined differently in different countries (Castaño-Rosa et al., 2019), but generally refers to a household's inability to meet its energy needs. It is multidimensional (Okushima, 2017; Castaño-Rosa et al., 2019; Charlier and Legendre, 2019; Sokołowski et al., 2020) and hard to capture with any single indicator (Siksnelyte-Butkiene et al., 2021). Energy poverty in Europe is believed to have worsened in recent years, due to the economic crisis and rising energy prices (Castaño-Rosa et al., 2019), as well as the global COVID-19 pandemic (Nagaj and Korpysa, 2020). Even for countries where fuel poverty is said to only affect a small minority, it seems likely that the situation is worsening (Mastropietro et al., 2020).

Furthermore, owing to the fact that energy poverty indicators are often only considered in isolation (Deller et al., 2021), some population segments are likely overlooked, and thus it is probable that energy poverty numbers are systematically underestimated (Robić, 2021). There is a risk of "non-recognition" of vulnerabilities to energy poverty that translates into deficient policy for addressing this issue (Simcock et al., 2021). In this paper, we extend the term *energy vulnerability* to consider both the segment of the population that is identified as energy poor as well as those that may be potentially vulnerable to energy poverty in the future.

The research questions we seek to answer are:

1. What are the drivers of energy vulnerability in the case of Switzerland?
2. What do Swiss stakeholders see as potential ways of mitigating energy vulnerability?

Bouzarovski and Petrova (2015), identify six main factors of energy vulnerability: access, affordability, flexibility, energy efficiency, needs, and practices. These are further expounded upon by Thomson et al. (2017) to include issues such as the inability to invest in new energy infrastructures. In this paper, we argue that identifying the energy vulnerable requires an expansive approach, based on the capability approach. Following Day et al. (2016) and Hearn et al. (2021), we stress the usefulness of a definition of energy vulnerability as being connected to capability deprivation, to help to better understand the potentials of energy vulnerability in the local context, particularly when applied in tandem with intergenerational considerations. In order to do so we apply a doughnut economics approach (Raworth, 2017) to the topic of energy. This enables us to bring in energy vulnerability as something which occurs both in the present when the social boundaries of a safe and just space are not attained, as well as in the future through the current use of energy from unsustainable sources. It also allows for the creation of enduring mitigation policies which consider future levels of energy vulnerability.

A first contribution of this paper is therefore to provide a clear conceptual distinction between energy poverty and energy vulnerability. Further, this distinction enables the creation of differentiated energy policies which specifically target different segments of the population that experience different forms of energy vulnerability. An additional original contribution of the paper is that it provides evidence of different forms of energy vulnerability and its drivers for the case of Switzerland. Finally, energy vulnerability data from national surveys is shown to provide a potentially significant contribution to debates on energy vulnerability which often rely on the European Survey on Income and Living Conditions (SILC) data, smaller-scale surveys, and interviews, adding clarity and revealing hitherto neglected patterns.

By applying a capabilities approach framework to energy vulnerability (Hearn et al., 2021), we are able to identify factors that could increase risk of energy vulnerability. The capabilities approach framework goes beyond measures of energy poverty collected by EU Energy Poverty Observatory (EU Energy Poverty Observatory, 2017; EPAH, 2021), to include factors that fall within physical, natural, human, social, and financial capital. In this way, we are fully able to capture the drivers of energy vulnerability.

We focus on Switzerland because it is one of the wealthiest European countries, with the highest levels of income in Europe (second highest GDP per capita in the world; FDEA, 2020). In addition, Switzerland has a pragmatic cantonal welfare system which has long been considered to focus on alleviating poverty and reducing unintended and counterproductive results (Segalman, 1986). Both high income and a dynamic welfare support system should thus result in the lowest levels of energy poverty/vulnerability.

Globally, Switzerland ranks high in energy security, energy equity (accessibility and affordability) and environmental sustainability (World Energy Councils Trilemma index tool[1]). Nevertheless, there are clear signs that a proportion of the population lives in or is vulnerable to energy poverty, particularly taking into account the recent fuel price rises. Data from SILC (EU SILC, 2021), indicates that in 2019, 0.3% of the Swiss population were unable to keep their home adequately warm, and 4.1% were in arrears on their utility bills in 2018. Thus, our study in part explores the dissonance between Switzerland's wealth status and presence of energy poverty,

1 https://trilemma.worldenergy.org/

which may in part be due to the misrecognition of those that are energy vulnerable (Simcock et al., 2021).

To answer our research questions, we employ a mixed methods approach. Specifically, we rely on quantitative data on energy poverty indicators collected in the Swiss Household Energy Demand Survey (SHEDS, see Section Methods), as well as qualitative data collected through semi-structured interviews conducted among experts in the renewable energy transition in Switzerland. Such an approach allows us to fortify typical measurements of energy poverty with contextual information provided in interviews. In order to build our definition of energy vulnerability we rely on home electricity and heating data, but exclude mobility related energy poverty as this was beyond the scope of this article.

This paper is structured as follows: we first examine definitions of energy poverty and energy vulnerability in Section Definitions of energy poverty and vulnerability, then outline our method (Section Methods) and our results (Section Results) from the SHEDs survey and from semi-structured interviews. This is followed by a discussion section and an outlook which includes policy suggestions on how energy vulnerability can be better addressed (Section Outlook).

Definitions of energy poverty and vulnerability

Both scientific and gray literature offer multiple definitions and ways to measures energy poverty, highlighting the multidimensionality of energy vulnerability, and the way that this has developed since Boardman's (1991) initial definition. Although measures of energy poverty differ in their details, most recognize an inability to keep the home warm, energy bill debt, and high share of energy expenditure as indicators (often using Boardmans 10% of household disposable income on energy). EPOV defines households as energy poor if they are unable to achieve adequate levels of essential energy services due to a mixture of high energy expenditure, low household income, inefficient buildings, as well as inefficient appliances and varying household energy needs (EPOV, 2017). The EPOV definition is widely adopted and offers ways to compare statistics in countries across the EU, particularly as these are gathered in the SILC data.

There is a recognition in the literature that typical measurements of energy poverty may not be enough as they do not sufficiently capture the impact or scope of energy vulnerability. In fact, a household's capacity to meet and cope with energy challenges (related to both temperature and transport) may be the result of a variety of factors (Middlemiss and Gillard, 2015). Strict definitions of energy poverty may not assess whether households are able to achieve a decent standard of living (Middlemiss and Gillard, 2015) or meet essential capabilities that are energy-dependent (Thomson and Snell, 2013). These achievements are determined by more than material deprivation. Thus, we expand the definition in order to more fully capture the population that is energy vulnerable– those that are identified as energy poor as well as those at risk of falling into energy poverty both in the present, and in the future.

Following Day et al. (2016), who proposed the use of the capabilities approach and framed energy poverty as a form of capabilities deprivation, our conceptual framework builds on Hearn et al. (2021), who use a capabilities based energy justice framework that examines five different capitals where injustices may occur. Indeed, we apply elements of the Hearn et al. (2021) framework to the doughnut framework by Raworth (2017) to understand the drivers of energy vulnerability in a Swiss context. The doughnut economics framework (Raworth, 2017) sees a "safe and just space for humanity" which is positioned as the sweet spot between overshooting planetary ecological boundaries (such as biodiversity loss, climate change and unsustainable practices), and social parameters which are sufficient to enable a good and valued life (such as social equity, gender equality, and provision of sufficient healthcare and education; Stopper et al., 2016).

Through the use of the doughnut model (Raworth, 2017) we extend the definition of energy vulnerability, locating energy poverty and some forms of energy vulnerability as below the social boundary of what is considered necessary for a safe and just way of life. We also locate a form of energy vulnerability in the overshooting of the ecological boundary through the use of unsustainable sources of energy which may lead to energy vulnerability for future generations. However, we use only the slice of the doughnut framework relating to energy, rather than showing the whole doughnut (Raworth, 2017) (Figure 1).

The framework rests on five capitals (Figure 1): physical, natural, financial, and social capital. In the context of energy vulnerability, these are described as: (1) physical capital, referring to the energy efficiency of buildings, the heating and electric system, mobility-related issues and other technology aspects (such as smart meters); (2) natural capital, meaning environment and climate issues including altitude, weather patterns and vulnerability brought about through climate change; (3) financial capital, referring to the material means of residents, as well as the affordability of homes, energy and retrofitting; (4) human capital, referring to both the policy and regulatory framework as well as availability and suitability of energy advice; (5) social capital, referring to aspects such as levels of participation and awareness, norms and practices. We discuss our results using this framework in order to provide a clear and novel perspective on this topic.

Methods

In this paper, we use quantitative data from the Swiss Household Energy Demand Survey (SHEDS) and qualitative data based on interviews with stakeholders in the Swiss energy

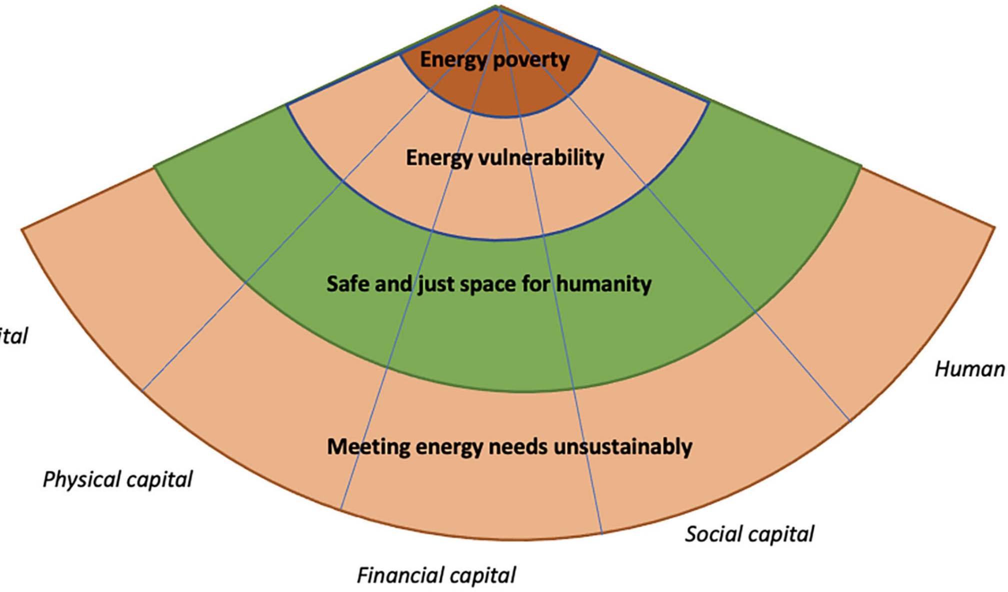

FIGURE 1
Situating energy poverty and vulnerability in the doughnut economic model, authors own elaboration.

sphere to answer our research questions, as can be seen in Figure 2.

Quantitative data collection

We collected data on four indicators of energy vulnerability in the Swiss Household Energy Demand Survey (SHEDS) (Weber et al., 2017) in 2020 where we were allocated 1,486 respondents. A comparison of SHEDS respondents and the general Swiss population on key characteristics can be seen in Table 1. Participants were surveyed in May and June 2020, following an extended quarantine due to the COVID-19 pandemic[2]. Data was analyzed using STATA.

To determine energy vulnerability levels in Switzerland, we collected similar data to that gathered by the EU Energy Poverty Observatory (EPOV, 2017). The questions used in EPOV and those included in SHEDS can be seen in Table 2. We did not collect data on hidden energy poverty (EPOV measure 4, Table 2), as a significant aspect of this is covered through the first self-reported question on inability to keep warm.

We deemed that a positive answer to any one of the three questions qualified a household as energy vulnerable. Positive answers are defined as:

- Respondents are not able to keep their home adequately warm.
- Respondents are in arrears on utility bills.
- Respondents spend more than 10% of income on heating in the winter after rent/mortgage.

Qualitative data collection

As part of our qualitative data collection, we carried out eight semi-structured interviews with Swiss energy stakeholders (Table 3). Our criteria for interview selection was that all interviewees had to be engaged directly in employment concerning the Swiss energy transition, able to speak English fluently enough to be interviewed in English, and be available for an interview. Each person contacted was sent an email requesting an interview, explaining that one of the main topics was the reduction of energy poverty and ensuring a fair energy transition. Interviewees were also asked if they could suggest further names to contact for an interview (snowball sampling). Eight interviews were conducted following Kuzel (1992) who recommends 6–8 interviews according to specific research objective. The semi-structured in-depth interviews lasted between 30 and 60 min and were conducted online using the Zoom platform, transcribed before coding and content analysis using MaxQDA2020. The interviewees represented a variety of sectors including consulting, energy-related start-ups, cantonal authorities, and energy cooperatives. We detail the

2 The pandemic delayed data collection which had originally been scheduled for April 2020.

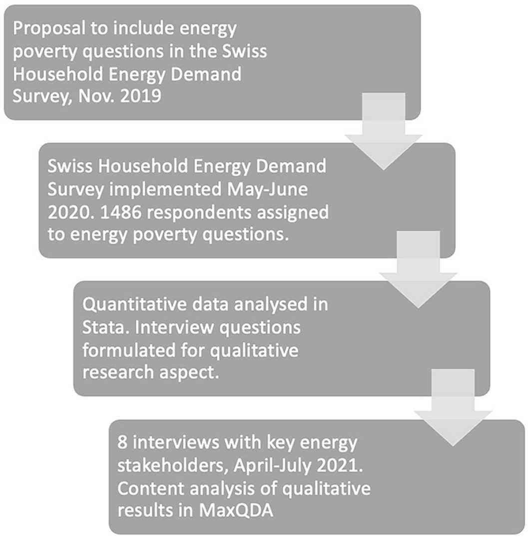

FIGURE 2
Quantitative and qualitative research calendar.

results from SHEDS in the next section and then discuss these together with interview data in our discussion section.

TABLE 1 Descriptive of key variables in SHEDS as compared to Swiss population.

	SHEDS sample ($N = 1{,}486$)	Swiss population statistics
Gender ratio (% female)	46.50%	50.39%[b]
Average age	48.82	42.6[c]
Average income	6,000–8,999 CHF/month[a]	6655 CHF/month[d]
Tenant or living in cooperative dwelling	60.26	61%[e]
Live in urban area (city or agglomeration)	71.09%	75%[f]

[a] *Responses to the income question in the SHEDS survey are based on categories: Less than 3,000; 3,000–4,500; 4,501–6,000; 6,001–9,000; 9,001–12,000; More than 12,000.*
[b] https://data.worldbank.org/indicator/SP.POP.TOTL.FE.ZS?locations=CH
[c] https://www.bfs.admin.ch/bfs/en/home/statistics/population/effectif-change/age-marital-status-nationality.assetdetail.18845603.html
[d] https://www.bfs.admin.ch/bfs/en/home/statistics/work-income/wages-income-employment-labour-costs/wage-levels-switzerland.assetdetail.21224921.html
[e] https://www.bfs.admin.ch/bfs/en/home/statistics/construction-housing/dwellings/rented-dwellings.html
[f] https://www.bfs.admin.ch/bfs/en/home/statistics/catalogues-databases/press-releases.assetdetail.16504127.html

Results

Quantitative results

Following the energy vulnerability questions shown in Table 2, our results showed that 177 respondents (11.9%) could be considered as energy vulnerable, having responded positively to at least one of the energy poverty measures in the survey. Out of this group, a small number of people (10.7% of energy vulnerable, 19 respondents) responded positively to more than one energy poverty measure and could be considered highly energy vulnerable. A detailed breakdown of responses to the three energy vulnerability questions is below (Table 4).

Among the three energy poverty questions, the question on percentage of income spent on heating had the most positive responses, with 8% of respondents stating they spend more than 10% of income on heating in the winter (Based on Boardman's, 1991; measure of energy poverty). The question regarding arrears on utility bills showed the lowest positive response, with only 1.3% of respondents stating they were in arrears on their utility bills.

Descriptive statistics show that the energy vulnerable are, on average, less wealthy and consist of a slightly higher population of tenants (Table 5). We explored the determinants of energy vulnerability in Switzerland using a logistic model with the energy vulnerability as the binary dependent variable. Table 6 shows the results of four models that included varying explanatory variables such as gender, age, income, household size, location e.g., whether the respondent lives in a city, and whether the respondent is a tenant. The coefficients in Table 6 are expressed in odds-ratios, that is the effect of the explanatory variable on the odds of being energy vulnerable. Results of logistic model with expected change in log odds can be found in Appendix Table A1.

Across three models, income and age were significant in increasing the odds of being energy vulnerable. Higher income was associated with lower odds of being energy vulnerable, while, holding all other variables constant, the odds of respondents in the lowest income category being energy vulnerable were 2.5 times higher relative to the base category (6,000–8,999 CHF/month). Increasing age was also associated with a lower probability of being energy vulnerable, while probability of adults ages 35–64 being energy vulnerable is affected by income (see Appendix Table A1 for interaction variable). Sex, living in a city, tenancy, and household size were not found to be significant, even though these are variables that are often considered to be significant in energy poverty literature (Bouzarovski and Petrova, 2015; Castaño-Rosa et al., 2019).

Given that the energy vulnerability measure combines three questions, two of which focus on income and one that focuses on perception of home temperature, we also explored the relationships of sociodemographic information with positive answers to individual energy poverty questions. The question asking whether respondents were in arrears on their utility bills was not included given the low number of positive responses and concerns over an unbalanced dataset. Results are shown in Table 7 (full results can be found in Appendix Table A2).

TABLE 2 EPOV energy poverty indicators and corresponding questions in SHEDS.

Measure from EPOV	Associated survey question used in this study (from SHEDS, 2020), all answers are self-reported
1. Inability to keep warm *Self-reported*	1. Are you able to keep your home adequately warm?
2. Arrears on utility bills *Self-reported*	2. Are you in arrears (debt) on your utility bills?
3. High share of energy expenditure, twice the national median *Identified in data*	3. Do you think you spend more than 10% of your income on heating in the winter after rent/mortgage?
4. Low absolute energy expenditure, below national median *Identified in data, termed as "hidden energy poverty"*	4. Not included in SHEDS

TABLE 3 Energy stakeholder interviews in Switzerland.

Interview number and code	Gender	Main stakeholder positions
1S	Male	Solarify[a]. Innovative PV panel company that allows individuals to participate in the Swiss energy transition without requiring a roof.
2Z	Male	Energie Zukunft Schweiz[b], Swiss PV, energy efficiency and renewable energy company
3M	Female	Mehr Als Wohnen (see text footnote[6]) Housing Cooperative, part of the 2000 Watts society[c], Zurich
4V	Male	Energy Department, cantonal level, Basel-Land
5T	Male	Sun2wheel[d] e-mobility vehicle to grid firm, and SustainTec energy advice and sustainability[e]
6K	Male	Consultant in sustainable finance
7C	Female	Cantonal Energy group, Energietal Toggenburg[f]
8H	Female	Green party representative, Zurich

[a]https://solarify.ch/so-funktionierts/
[b]https://energiezukunftschweiz.ch/
[c]https://www.2000watt.swiss/en/english.html
[d]https://sun2wheel.com/en/home/
[e]https://www.sustaintec.ch
[f]https://energietal-toggenburg.ch/home/

Results of the question breakdown indicate higher odds for younger people to be unable to keep their home warm. Being female reduces the odds of spending more than 10% of income on heating. The odds of those living in the countryside to pay more than 10% of income on heat is 1.7 more likely than those living in the city, though type of living area has no effect on ability to warm the home. Income has an inverse effect on probability of having a cold home and paying more than 10% of income on heat. Interestingly, the odds of being unable to keep the house warm are about 3 times more for respondents in the 4,500–5,999 CHF/month income category, while association between lower income categories and home warmth was not found to be significant. Household size and tenant status did not have a significant association with either inability to keep the house warm or paying more than 10% of income on heat.

Qualitative results

Stakeholders were interviewed following initial data analysis of the questions asked in SHEDS. This enabled us to focus on major areas of interest in our research, namely the perceptions of energy poverty, and how to ensure that this is reduced through energy efficiency measures. Stakeholders interviewed were not provided with information prior to the interviews in order to avoid influencing responses.

In the interviews, we asked about energy poverty, energy efficiency, policy aspects and subsidies, drivers and barriers for equity, and motivation and social consequences for users and businesses.

Stakeholders were very clear in stating that energy poverty was not perceived as being of significance in Switzerland, and the term itself needed explanation in multiple interviews.

> *≪I do not think you could actually really figure out who lives in energy poverty. But we do have some situations that are really hard for people. We actually have two examples. One would be people living in really old buildings where there is the gas line going through. They pay a lot for their gas bills and they usually also pay a lot for electricity, because the housing is just so old. Sometimes housing is even protected. So*

TABLE 4 Results of energy poverty questions included in SHEDS ($N = 1{,}486^{*}$).

Are you able to keep your home adequately warm?			
Yes	No	Prefer not to answer	
93.9%	3.9%	2.2%	
Are you in arrears on your utility bills?			
Yes	No	Prefer not to answer	
1.3%	97.5%	1.2%	
Do you think you spend more than 10% of your income on heating in the winter after rent/mortgage?			
Yes	No	Not sure	Prefer not to answer
8.0%	70.1%	17.6%	4.4%

[*] 1,398 respondents provided a response other than "Prefer not to answer" for all three questions.

> *if you want to invest in the infrastructure itself, which usually is not even the person that lives in there, but who is the owner, you know.*≫ (7C)

In terms of energy efficiency and mitigating energy vulnerability, one stakeholder (7C) noted that renovation policies were having some effect, with some communities already consuming 20% less energy compared to 2013. Another stakeholder (3M) explained how although the district was constructed to Minergie standards, none of the buildings are Minergie certified as doing so would have entailed additional certification costs, as well as limited the use of recycled building material (e.g., recycled concrete).

Discussions on policy aspects and subsidies centered on the need for extra subsidies that make renewable heating systems more appealing than fossil fuel systems (7C) as well as on the fact that subsidies currently heavily favor fossil fuels globally (6K). At the moment, subsidies are perceived as very important in promoting the energy transition and stakeholders saw these as a major tool in financing energy efficient renovations which would have an effect on reducing energy vulnerability (2Z). Non-subsidy ways of incentivizing change toward greater energy efficiency may require more risk-taking and innovation: risk-taking on the part of real estate and construction companies in trying new ideas (3M), risk-taking on the part of banks as the business case for loans may not always be clear (4V), and more innovation and start-up projects that demonstrate the viability of different solutions (3M, 1S, 7C).

One respondent noted the importance of working with multinational companies in the oil and gas sector as they are the current dominant players in the energy market. Working hand-in-hand with these companies may be more effective in guiding where money flows and convincing them of an alternative green future (1S).

Stakeholder positions on the motivation and social consequences for users and businesses included the premise that innovation requires greater spending, with one stakeholder noting that the vision plan assigned 1% of total revenues for innovation (3M).

Discussion

In this section we start by examining the discrepancies between SILC and SHEDs data. We then examine the results from SHEDs results together with interview data in the context of the five different capitals from the energy justice framework, we sketched in Section Definitions of energy poverty and vulnerability. We also bring in secondary material that provides context on Swiss climate, housing stock, and demographics. We start with the categories of Climate (Natural Capital), Financial and Social Capital (Socio-economic factors), and Physical Capital (facilities/housing). This is followed by a section on Social Capital (Participation/ awareness raising) and the policy and regulatory framework (emerging from Human Capital). From the results detailed above, as well as a series of targeted interviews with energy experts, we are able to provide answers to our two research questions.

We find that energy vulnerability in Switzerland appears to be related to age and income. However, we do not find a relationship between energy vulnerability and home ownership. This leads us to infer that income and costs will have some effect on energy vulnerability, but that targeted retrofitting of energy inefficient housing and a stronger policy and regulatory framework could significantly decrease energy vulnerability.

Discrepancies between SHEDS data and data gathered for SILC in Switzerland

Although the EU SILC has provided a significant source of information for energy poverty indicators

TABLE 5 Descriptive statistics for energy vulnerable and total sample.

	Energy vulnerable ($N = 177$)	Total sample of respondents with complete responses ($N = 1338$)
% of Females	44.63%	45.74%
Average age	46.2	48.7
Average income/month[a]	7,125 CHF/month	8352.21 CHF/month
Tenants	66.10%	59.27%
Live in city	47.46%	48.51%

[a]For analysis purposes, income was converted into a continuous variable by assigning each respondent the midpoint of each category of income.

TABLE 6 Results of logistic mode.

Dependent variable: Probability of being energy vulnerable	(1)	(2)	(3)	(4)
Female	0.753	0.721	0.713	0.713
	(−1.53)	(−1.84)	(−1.90)	(−1.90)
Age	0.982**			
	(−2.89)			
Household income CHF/month (base = 6,000 – 8,999 CHF/month)				
3,000 or less	2.552**			
	(2.90)			
3,000 – 4,499	1.349			
	(0.89)			
4,500 - 5,999	1.446			
	(1.40)			
9,000 – 11,999	0.628			
	(−1.79)			
12,000 or more	0.365**			
	(−3.18)			
HH income (midpoints)		0.999***	0.999***	0.999*
		(−5.12)	(−2.07)	(−2.07)
City dweller	0.914	0.903	0.907	0.907
	(−0.48)	(−0.56)	(−0.54)	(−0.54)
Household size	1.041	1.071	1.094	1.094
	(0.52)	(0.91)	(1.22)	(1.22)
Tenant	0.958	1.073	1.081	1.081
	(−0.20)	(0.34)	(0.38)	(0.38)
Age (base = ages under 35)				
Ages 35–49		0.591*		
		(−2.25)		
Ages 50–64		0.490**		
		(−2.92)		
Ages 65+		0.576*		
		(−2.07)		
Ages under 35			1.566	
			(1.67)	
Ages 35–64			2.569*	1.640
			(2.08)	(1.06)
Ages 65+				0.638
				(−1.67)
Observations	1,261	1,338	1,338	1,338

Coefficients show odds-ratios for main effects (t statistics in parentheses).
Models 3 and 4 included interaction variables for Ages 35–64 X Income which can be found in Appendix Table A1.
Exponentiated coefficients; t statistics in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

(Bouzarovski and Tirado Herrero, 2017), there may be gaps in the information collected. The focus on material deprivation may eclipse or underrepresent other potential causes of energy poverty and deprivation. Indeed, our results regarding the inability of achieving a preferred thermal comfort show energy vulnerability figures almost 20 times that of SILC 2020 for Switzerland (EU SILC, 2021)[3]. Conversely, SILC data for arrears on utility bills shows a figure almost 3 times that of SHEDS[4].

One further possible explanation for differences between SHEDS and SILC results may be the methodological differences by which data is obtained. SILC Data collection is predominantly based on phone survey with a small percentage of questionnaires complete face-to-face with a total sample size of 8,000 homes[5]. SHEDS data is collected using an online questionnaire which is completed at leisure by the respondent and remains anonymous. A long phone survey (the average completion time for the SILC survey is 62 min) may result in respondents suffering from an unwillingness to divulge information, particularly if this is perceived as portraying the respondent in a bad light. The stigma associated with poverty has been well documented (Day and Hitchings, 2011; Bartiaux et al., 2018; Middlemiss et al., 2019), and divulging an inability to keep the home adequately warm may go against social and cultural norms (Connon, 2017). Additionally, SHEDs data excludes the Tessin Italian speaking part of Switzerland, which may cause some minor variance in the data.

The discrepancy in results may also be due to question wording in SILC. The question "Is your home poorly heated?"

3 Inability of achieving a preferred thermal comfort: Comparison of percentage of Swiss population in the SHEDS 2020 data (3.9%) vs. SILC 2020 (0.2%).

4 Arrears on utility bills: SHEDS 2020 (1.3%, utility bills) vs. SILC 2020 (3.2%).

5 The FSO details a number of potential errors attributed to such methods, including potential population coverage errors, measurement errors (such as those [43, 51–53] caused by the survey itself, the interviewer or the mode of collection), processing errors (incorrect input, editing or weighting of data), and non-response errors. The 8000 homes figure represents approximately 18,000 people.

10.3389/frsc.2022.952034

TABLE 7 Results of logistic mode.

Dependent variable:	(1) Inability to keep home warm	(2) Inability to keep home warm	(3) Paying more than 10% income on heat	(4) Paying more than 10% income on heat
Female	0.955	1.006	0.674	0.626*
	(0.291)	(0.293)	(0.151)	(0.135)
Age	0.964**		0.992	
	(0.0109)		(0.00728)	
Household income CHF/month (base = 6,000 – 8,999 CHF/month)				
3,000 or less	1.416		3.701***	
	(0.842)		(1.304)	
3,000–4,499	1.306		1.299	
	(0.772)		(0.528)	
4,500–5,999	3.097**		1.064	
	(1.180)		(0.362)	
9,000–	0.243*		0.805	
11,999	(0.156)		(0.240)	
12,000 or	0.496		0.337**	
more	(0.247)		(0.137)	
HH income		0.999***		0.999***
(midpoints)		(0.0000480)		(0.0000357)
Type of living area (base = city)				
Agglomeration	0.518		1.431	
	(0.219)		(0.373)	
Countryside	1.030		1.715*	
	(0.379)		(0.467)	
Household	1.158	1.178	1.032	1.075
size	(0.127)	(0.129)	(0.0977)	(0.0954)
Tenant	0.843	0.927	0.918	1.047
	(0.303)	(0.319)	(0.233)	(0.251)
Ages <35		2.016*		1.504
		(0.640)		(0.379)
Ages 65+		0.588		1.297
		(0.281)		(0.356)
Lives in city		1.397		0.620*
		(0.422)		(0.136)
Observations	1,261	13,38	1,261	1,338

Coefficients show odds-ratios for main effects (t statistics in parentheses).
Exponentiated coefficients; t statistics in parentheses.
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

(DE: ≪*Ist ihre Wohnung/Ihr Haus ungenügend geheizt?* ≫) has been reworded as "Are you able to keep your home an agreeable temperature?" (DE: *Ist es für Ihren Haushalt möglich, dafür zu sorgen, dass es in der gesamten Wohnung/im gesamten Haus eine angenehme Temperatur hat?)* with multiple options for responses: (1) Yes, I am, (2) No, for financial reasons (DE: ≪*nein, aus finanziellen Gründen*≫ or (3) No, for technical reasons (DE: ≪*nein, aus technischen Gründen*≫). Only responses that gave the reason as financial were used in the reported statistics for energy poverty. Indeed, the figures dropped from 7.5% in 2010 to 0.8% in 2011, when the new question wording was introduced (FOS, 2021). This lends further credence to the fact that the causes for energy poverty in Switzerland are largely unconnected to financial status and more closely connected to highly inefficient building stock.

Natural capital: Climate

While changes in climate are not captured by current measurements of energy vulnerability, there is indication that they would be a useful indicator. The Federal Office of Meteorology for Switzerland (MeteoSwiss, 2020) notes that the climate in Switzerland has significant natural seasonal fluctuations which, when combined with the mountainous landscape, helps to explain the need for well-insulated buildings that are able to withstand temperature and cold weather extremes. However, heat waves, such as the ones experienced in the summers of 2003 and 2015, in which mortality increased by 5.4 and 7%, respectively (Ragettli et al., 2017), are likely to become more frequent. As a result of climate change, it is expected that cooling demand will increase over time, both for residential and office building stock (Li et al., 2012; Moazami et al., 2019; Silva et al., 2022). Summer heating may become an increasing threat that needs to be mitigated through targeted policies (SCNAT netzwerk, 2005). The impact of climate change may increase vulnerability to energy poverty exacerbated through summer heat (Bienvenido-Huertas et al., 2021), increasing intergenerational vulnerability.

This was corroborated in an interview with a board member of the Mehr Als Wohnen housing cooperative in Zurich who noted that all the buildings within the district are built to Minergie standards, and are heated using district heating which is controlled centrally, thus mitigating the impact of colder weather.

> "I do not actually see the winter as a problem. I see the summers as a problem." (3M)

However, in warmer weather, buildings that are designed to insulate against the cold may also struggle to cool down, and in the Hunziker Areal (Mehr Als Wohnen)[6] different solutions are being explored such as *via* water management, using ice batteries, and urban greening (including roof and façades).

On the self-reported question regarding heating costs, a total of 8% (119 respondents) believed that they did spend more

6 https://www.mehralswohnen.ch/

10.3389/frsc.2022.952034

than 10% of their income on heating in the winter. This may have been skewed owing to the timing of the survey, which was initially planned for early Spring, but which was delayed until May/June owing to the COVID-19 pandemic. This delay meant that those surveyed were asked about the winter period at a time when it was getting increasingly warm and sunny, and a period of lockdown was ending. Furthermore, winter 2019/2020 was particularly mild in Switzerland, with average temperatures of 3 degrees C over the 1981–2010 norm, and was followed by the third mildest spring (MeteoSwiss, 2021). This could have had an effect on increasing the number of people able to keep their homes warm.

Policies which may help to mitigate the effect of climate on energy vulnerability for Switzerland have been identified as those associated with improving building stock to ensure that this is better able to withstand the effects of climate change which may involve extreme weather. Examples include improved solar protection and night ventilation strategies (Frank, 2005). It is further important to note that precipitation levels and temperatures vary across Switzerland, depending on whether one is within the Alpine regions, at the foothills, or the northern plateau (MeteoSwiss, 2018). The effects of climate change on temperature and precipitation will also have a regional variation (Henne et al., 2018) and will require a geospatial approach to identify the different risks to energy vulnerability across Switzerland.

Financial and social capital: Socio-economic factors

As discussed in Section Discrepancies between SHEDS data and data gathered for SILC in Switzerland, socio-economic factors may not be enough to explain energy vulnerability in Switzerland. Although income plays a role in determining energy vulnerability, it is not always the lowest income categories that face these risks. As our analysis in Section Quantitative results showed, respondents from middle income categories were more prone to feeling cold at home. Although income is a factor in Swiss energy vulnerability, it is likely not the sole driver.

Our analysis of data from SHEDS also revealed that younger people are more likely to be afflicted by energy poverty, contrary to other studies which put pensioners and the elderly at risk (Mashhoodi et al., 2018). This may be owing to the types of buildings younger people occupy. Energy vulnerability among the younger population may be a result of tenancy in non-renovated homes.

Given the information that we received from the FSO on SILC data, a much larger group of people fall into the category of being unable to keep their home adequately warm owing to technical reasons rather than financial. One reason may be the low rates of home ownership in Switzerland, which make implementation of energy efficiency measures difficult (at least not without consent of the landlord). In fact, Swiss home ownership is low compared to many other countries with an average 36% recorded in 2021, dropping as low as 12% in more populated municipalities (Le News, 2021). For those that do own property, socio-economic factors may prevail as lack of affordability may be a barrier to energy efficiency retrofitting.

There is some indication from a stakeholder interview that the current financial situation may encourage those who are able (namely home owners) to afford home energy efficiency improvements to do so:

> *"I think one of the most important factors currently is that interest rates on banks are low to zero or even negative. So, the more money people have the more they are under pressure to find a good investment opportunity, which is at the same time safe but also has slightly bigger profits than a bank account."* (1S)

Low interest rates may also encourage landlords to commit to energy efficiency measures as they may be able to borrow money at better rates (against the value of the property for example), and receive a limited return albeit over a long period of time. In terms of strategies and policies which may help to reduce energy vulnerability, targeted financial benefits may provide short term relief rather than reliance on broader social assistance which may not be sufficient to mitigate conditions for those who are most vulnerable.

Physical capital: Facilities/housing

An analysis of physical capital offers another dimension by which to assess energy vulnerability. There is a need to improve housing quality in Switzerland (Pagani et al., 2021), recognized in the national Energy Strategy 2050 which now provides tax incentives for building renovation (SFOE, 2021a) with a targeted reduction of 43% in energy consumption by 2,035 compared to 2000 levels (SFOE, 2021b). In all, of the approximately 1.5 million buildings in Switzerland, over 75% were built before 1980 and renovation is required for many of these (Frank, 2005). So far, there have been a number of voluntary energy efficiency programmes such as the éco21 in the Canton of Geneva (Cho et al., 2019), as well as ProKilowatt[7], a national tender-based energy efficiency scheme which provides up to 30% of the investment costs necessary for energy efficiency measures. Schemes such as the Gebäudeprogramm are financed from the CO_2 levy (Patel et al., 2021), which may help to overcome the normally high upfront costs of retrofitting.

7 https://www.prokw.ch/

Switzerland benefits from a longstanding sustainable building certification, Minergie[8] which dates back to 1998, accounting for the certification of 50,000+ buildings. This can be partially financed through the Gebäudeprogramm[9], and Minergie buildings are required to be a minimum of 20% greater energy efficiency than MOPEC (Modele de Prescriptions Energetiques des Cantons) buildings (EnDK, 2021). One of the significant advantages of improving home energy efficiency is that this will have an impact on reducing carbon emissions but will also have a potentially significant effect on reducing vulnerability to energy poverty, including health improvements (Baniassadi et al., 2022). At the same time, one of the shortfalls of the Swiss system is that although the Federal Government is in charge of creating legislation, each canton is free to implement these according to their own interpretation, leading to potential confusion and uncertainty for the consumer.

A significant problem which is discussed frequently in the literature is the split incentive whereby landlords and tenants have no incentive to improve housing efficiency (Melvin, 2018). However, a recent study in Switzerland indicates that 70% of tenants would be willing to accept rental increases that are greater than the potential savings from energy efficiency retrofittings (Lang and Lanz, 2021). One of our interviewees noted the difficulties of retrofitting rented buildings that they have encountered:

> *"But on the other hand, people who rent, who are not owners, they are also very interesting. I mean first of all they can jeopardize a project of the building owner to make the building more efficient. We see this in practice because of many reasons, because then the owner can increase the rent. Sometimes they really do as much as possible, sometimes you can get kicked out." (4V)*

Furthermore, although the efficiency rating of buildings is important, and there is clearly much work still needed in order to improve this in Switzerland, the actual efficiency of a building is determined through its use, and not just its rating:

> *"You can also operate a very energy efficient building very inefficiently." (4V)*

For example, opening windows and airing for extended periods or sleeping with the windows open, which are often seen as culturally-related habits, has a significant effect on the efficiency of Minergie rated buildings. This connects to the next section on the importance of participation and raising awareness.

Tenants do not all have the same experience and the quality of homes varies dramatically. Of note are the multiple housing cooperatives in Switzerland which tend to be characterized by high quality energy efficient housing, which may partially account for their popularity (Balmer and Gerber, 2018; Hearn et al., 2021). Despite these initiatives, Switzerland suffers from a housing shortage, worsened by both escalating prices and a surge in the demand for second homes in 2020 (Swissinfo, 2021).

Furthermore, the housing cooperative stakeholder explained that indoor spaces are deliberately streamlined and smaller than in other districts, leading to reduced energy consumption and enhanced efficiency, which reduces energy costs for residents. Providing multiple shared spaces (including a shared freezer room, sauna, guest rooms) allowed residents to maintain a high quality of life despite these much smaller private spaces.

Clear policies that would help to mitigate energy vulnerability related to buildings involve not only increasing the speed and degree of renovations, but also comprehensive energy efficient building programmes to alleviate the current housing shortage and reduce market pressure. Furthermore, examining the uptake of energy efficiency measures by vulnerable households could provide an interesting additional indicator for energy vulnerability.

Within physical capital it is important to consider that in the case of Switzerland, electricity has been largely decarbonised. However, when it comes to heating systems, 56% of homes continue to use either oil or gas, thus contributing to potential energy vulnerability issues in the future (Burger et al., 2018).

Social capital: Participation/awareness raising

> *"In some municipalities the most important argument is that they include the local residents in the local energy transition." (1S)*

Switzerland is often held up as an example of participative or direct democracy, where participation is de rigeur (Ladner and Fiechter, 2012), which is reflected in the quote above. The requirement for citizen participation is held to be vital, and perhaps this helps to account for lower levels of energy poverty when compared to neighboring countries. However, as noted above regarding the differences between SILC and SHEDs data, misrecognition of groups that are energy vulnerable does occur:

> *"But we have about twenty five percent of the population who are foreigners. They cannot vote, as you're probably aware of. That's a problem because they're excluded from many things. And I think we need to find ways of rethinking democracy in the modern day, these representative*

8 https://www.minergie.ch/fr/

9 https://www.dasgebaeudeprogramm.ch/de/

> *parliaments are very valuable, but we should probably enrich them with new techniques, like this "Bürger panel" (German trans. as citizens)."* (8H)

This stakeholder considered the use of citizen or "Bürger panels," consisting of randomly chosen members of the public, as a method of ensuring that participation is best harnessed. These have been trialed in Urstalden and Winthertur (Bürgerpanel, 2022; RadioCentral, 2022) and use a lottery system to select residents who make recommendations and decide on concrete measures to tackle multiple issues. These citizen panels are open to all residents and not just to Swiss nationals so as to bring in a greater level of inclusiveness than other methods. This may in turn have an effect in ensuring that those who are energy vulnerable, including those who are non-Swiss, become better represented and that issues such as energy vulnerability become better known.

Awareness raising is very important when it comes to energy vulnerability in Switzerland, because the topic is not widely accepted as significant, and in some cases is deemed irrelevant. In some cases, characteristics of energy vulnerability are ascribed to quality of life. This may be the case in rural areas, among low-income farmers:

> *"Talking about farmers again, low-income farmers. They would never say they are living in energy poverty... for example if their heating system is with wood, they collect the wood themselves, they put the wood in their stove themselves. We still have houses, you know, where the... the windows are frozen in the winter, where you can see your own breath in the only part that is heated... But the question is always is it energy poverty or is it something (...) or is it sometimes also a quality of living, I do not know... So I guess, compared to other countries, there is no energy poverty, but I would say because we are in a rural region we still do have."* (7C)

Energy vulnerability reduction is often framed as part of climate mitigation policies through the use of energy efficiency retrofitting programmes. Awareness of energy efficiency schemes does seem to be permeating Swiss society and multiple stakeholders discussed the use of media campaigns to reach citizens:

> *"If we do the communication together (with the municipal authorities), usually newspapers are also interested in it. So, it is one way for municipalities to actually show to their citizens we are doing actually, you can even join this initiative, you can be part of it and let's do the energy transition together."* (S1)
>
> *"The most important part is communication. So, we are just very active. Every month we put something in the newspapers, we use social media, we use online marketing, we have different channels from the communities themselves."* (7C)

As a cantonal energy association, the Energietal Toggenburg offered over 100 different energy-related events within the canton during 2019. Although this was reduced and largely moved online temporarily during the COVID-19 pandemic, the idea of citizen participation is seen as crucial in order for people to fully engage with measures that may reduce energy vulnerability.

Taken nationally, increasing participation and spreading awareness of both energy efficiency schemes and energy vulnerability may result in greater uptake in efficiency programmes as well as more targeted treatment of those who are energy vulnerable on a cantonal level.

Understanding how those that are energy vulnerable are included in decision-making processes and the engagement level of vulnerable households within such procedural justice issues would provide an interesting novel indicator for energy vulnerability. This could be self-reported and assist in bringing procedural energy justice further into potential indicators for energy vulnerability and poverty.

Human capital: Policy and regulatory framework on energy vulnerability reduction

There is no national strategy to tackle energy poverty or vulnerability in Switzerland. Part of the reason for this may be that the topic is not considered to affect enough people. However, based on the results from SHEDS, it would seem that vulnerability to energy poverty is not well-represented through current forms of data collection which focus on material deprivation and do not allow for other potential causes of vulnerability. As mentioned earlier, Switzerland is a nation where most homes are not owned by the residents, and this brings about a different type of energy vulnerability which is far more closely connected to lack of building renovation and poor energy efficiency of buildings.

For those that rent, there may be reluctance on the part of landlords to engage with energy efficiency improvements as, although the cost can be recouped through rent, long payback times may make this undesirable. This may be connected to the rent regulations in Switzerland which protect sitting tenants from certain increases in market rents, setting limits on the percentage increase in rent per year which is permitted (Lind, 2001). There are also regulations already in place within Switzerland that ensure that landlords are not able to increase the rent based on the total cost of energy improvements made on tenants' homes, but may only increase rent based on their actual costs. This was corroborated by the stakeholders that we interviewed:

> "In the relationship between owners and the people living in a house, subsidies will also lead to positive drawbacks. First of all, if you invest in renewables, you

> have less costs for your energy consumption. But also, the owner has to minus the subsidies from the investment in renewables, which means also in order to increase the rent, he is not allowed to take this part. This is also settled by the law, which is good in that sense." (S1)

This may have some effect on protecting tenants from unscrupulous landlords that would overly increase rent. However, it does little to increase the uptake of energy efficiency retrofitting which needs to be addressed. Additionally, tenants, themselves, are unlikely to pay for renovations as they do not own their home, nor do they necessarily see an increase in prices that would motivate such improvements:

> *"...The tenant. Why would he invest if he does not have to pay for the costs of living in there? That is sometimes, you know, the gap that we have. They do not invest because they are not paying for the gas or for the electricity" (4V)*

From our data, it seems clear that energy vulnerability in Switzerland is less connected to energy prices than in other countries. Energy prices vary from canton to canton, but these costs remain minor compared to the costs of upgrading and improving buildings and heating systems. National and cantonal schemes could offer greater incentives and tax breaks in order to increase uptake of energy improvement schemes as well as setting dates for higher minimal standards to ensure that poorly insulated properties no longer cause energy vulnerability.

Limitations

Our quantitative study of energy poverty in Switzerland was limited by data availability. While the inclusion of variables related to spatial factors, certain personal factors, age of housing, and energy efficiency characteristics would have fortified the study, the limited sample size and low number of positive responses to energy poverty questions would have resulted in an unbalanced dataset. Nevertheless, the inclusion of explanatory variables related to sociodemographic characteristics coincides with those found to be significant in explaining energy poverty (e.g., Mashhoodi et al., 2018; Jessel et al., 2019; Longa et al., 2021; van Hove et al., 2022). Furthermore, the pandemic may have changed perceptions on energy vulnerability as SHEDs respondents had endured an initial lockdown, which also delayed the start of the survey until May 2020, when the weather was already improving.

Further, the SHEDs data on energy vulnerability is at the household level, and thus measuring energy vulnerability may perhaps be better achieved through examining individual responses rather than responses as a family. This may also help to reveal gender differences in energy vulnerability, which have been researched and which emphasize the risk of seeing households as homogenous units when it comes to the lived experience of energy poverty (Petrova and Simcock, 2021). We attempted to counter some of these limitations through including expert interviews in addition to quantitative data, which brought in more detailed aspects together with expert perceptions of energy vulnerability within Switzerland.

Outlook

A capabilities approach framework for energy vulnerability puts heavier emphasis on self-reported indicators of energy poverty, but allows for a greater understanding of local regional and national differences in main drivers. Our research shows that despite its reputation as a wealthy nation, energy vulnerability is an under-studied aspect of Swiss society which affects a significant swathe of the population. Although energy vulnerability is not at the forefront of current policies in Switzerland, this issue as revealed by our framework may be much more serious than previously considered, particularly owing to poor housing stock. There is a need for adaptive strategies to ensure that the population is robustly protected when it comes to energy vulnerability, including in terms of future cooling demand, as this may well increase owing to the effects of climate change (Bienvenido-Huertas et al., 2021). Further, it is important to understand how heterogeneity in impacts of climate change can lead to regional differences in risk of energy poverty. Understanding how socioeconomic characteristics differ geospatially may also lead to better understanding of the different policy approaches required to address the variability in risk to energy poverty (Bouzarovski and Simcock, 2017). An approach exploring spatial heterogeneity and homogeneity in energy poverty has previously been applied in the Netherlands (Mashhoodi et al., 2018) and may be used to study regional vulnerabilities to energy poverty in Switzerland.

One of the big challenges of the energy transition in Europe is to find ways of decarbonising the energy system without increasing energy vulnerability. In the case of Switzerland, the situation is slightly different as most of the energy system is already carbon free, but the phasing out of nuclear power brings with it further challenges (Díaz Redondo and van Vliet, 2015), such as rapidly replacing this with renewable energy that is able to meet national needs (Rüdisüli et al., 2022). It is clear that energy vulnerability is a problem in Switzerland, which may be closer connected to building efficiency than to income or cost. This may have international repercussions as other nations may wish to reconsider how energy vulnerability is evaluated and measured and add new policy tools to existing policies.

Further research on the topic of energy vulnerability, as a term which is more widely encompassing and perhaps less associated with stigma than energy poverty, is warranted both for the case of Switzerland and for further afield. A case could be made for all non-renewable energy as being a potential source of energy vulnerability due to the potential amplification of vulnerability through climate change caused by the use of fossil fuels. Reframing energy poverty in this way may allow for more joined-up policymaking that brings into account both climate change mitigation and energy vulnerability mitigation, such as Positive Energy Districts (Hearn et al., 2021) which bring together renewable energy with principles of sustainability, inclusiveness and quality of life.

Data availability statement

The datasets used in the study are available from the corresponding author on reasonable request.

Ethics statement

The studies involving human participants were reviewed and approved by Application No. 2021/109, Schools of Business, Law and Social Sciences Research Ethics Committee (BLSS REC), Nottingham Trent University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AH, DM, IS, and AS: conceptualization, methodology, writing–review and editing, and visualization. DM and AH: qualitative data collection. AH: writing–first draft. DM and IS: qualitative data analysis. AS and IS: supervision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2022.952034/full#supplementary-material

References

Balmer, I., and Gerber, J.-D. (2018). Why are housing cooperatives successful? Insights from Swiss affordable housing policy. *Hous. Stud.* 33, 361–385. doi: 10.1080/02673037.2017.1344958

Baniassadi, A., Heusinger, J., Gonzalez, P. I., Weber, S., and Samuelson, H. W. (2022). Co-benefits of energy efficiency in residential buildings. *Energy* 238, 121768. doi: 10.1016/j.energy.2021.121768

Bartiaux, F., Vandeschrick, C., Moezzi, M., and Frogneux, N. (2018). Energy justice, unequal access to affordable warmth, and capability deprivation: a quantitative analysis for Belgium. *Appl. Energy* 225, 1219–1233. doi: 10.1016/j.apenergy.2018.04.113

Bienvenido-Huertas, D., Sánchez-García, D., Rubio-Bellido, C., and Marín-García, D. (2021). Potential of applying adaptive strategies in buildings to reduce the severity of fuel poverty according to the climate zone and climate change: the case of Andalusia. *Sustain. Cities Soc.* 73, 103088. doi: 10.1016/j.scs.2021.103088

Boardman, B. (1991). *Fuel Poverty: From Cold Homes to Affordable Warmth.* Belhaven Pinter Pub Limited.

Bouzarovski, S., and Petrova, S. (2015). A global perspective on domestic energy deprivation: overcoming the energy poverty–fuel poverty binary. *Energy Res. Soc. Sci.* 10, 31–40. doi: 10.1016/j.erss.2015.06.007

Bouzarovski, S., and Simcock, N. (2017). Spatializing energy justice. *Energy Policy*107, 640–648. doi: 10.1016/j.enpol.2017.03.064

Bouzarovski, S., and Tirado Herrero, S. (2017). The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. *Eur. Urban Reg. Stud.* 24, 69–86. doi: 10.1177/0969776415596449

Burger, P., Schubert, I., Van Dijk, J., Puntiroli, M., Volland, B., Weber, S., et al. (2018). *Energieverbrauch der Haushalte in der Schweiz.* Highlights der Haushaltsbefragung zum Energieverbrauch. Available online at: https://www.sccercrest.ch/fileadmin/user_upload/Energiekonsumverhalten_in_der_Schweiz_07032018_final.pdf

Bürgerpanel (2022). *Esieben.* Available online at: https://esieben.ch/buergerpanel/ (accessed February 1, 2022).

Castaño-Rosa, R., Solís-Guzmán, J., Rubio-Bellido, C., and Marrero, M. (2019). Towards a multiple-indicator approach to energy poverty in the European Union: a review. *Energy Build.* 193, 36–48. doi: 10.1016/j.enbuild.2019.03.039

Charlier, D., and Legendre, B. (2019). A multidimensional approach to measuring fuel poverty. *Energy J.* 40, 7–54. doi: 10.5547/01956574.40.2.bleg

Charlier, D., and Legendre, B. (2021). Fuel poverty in industrialized countries: definition, measures and policy implications a review. *Energy* 236, 121557. doi: 10.1016/j.energy.2021.121557

Che, X., Zhu, B., and Wang, P. (2021). Assessing global energy poverty: an integrated approach. *Energy Policy* 149, 112099. doi: 10.1016/j.enpol.2020.112099

Cho, H., Freyre, A., Bürer, M., and Patel, M. K. (2019). Comparative analysis of customer-funded energy efficiency programs in the United States and Switzerland–Cost-effectiveness and discussion of operational practices. *Energy Policy* 135, 111010. doi: 10.1016/j.enpol.2019.111010

Churchill, S. A., and Smyth, R. (2020). Ethnic diversity, energy poverty and the mediating role of trust: Evidence from household panel data for Australia. *Energy Econ.* 806, 104663. doi: 10.1016/j.eneco.2020.104663

Connon, I. (2017). "Transcending the triad: political distrust, local cultural norms and reconceptualising the drivers of domestic energy poverty in the UK," in *Energy Poverty and Vulnerability* Routledge Explorations in Energy Studies., eds. N. Simcock, H. Thomson, S. Petrova, and S. Bouzarovski (England: Routledge) 46–60.

Day, R., and Hitchings, R. (2011). 'Only old ladies would do that': age stigma and older people's strategies for dealing with winter cold. *Health Place* 17, 885–894. doi: 10.1016/j.healthplace.2011.04.011

Day, R., Walker, G., and Simcock, N. (2016). Conceptualising energy use and energy poverty using a capabilities framework. *Energy Policy* 93, 255–264. doi: 10.1016/j.enpol.2016.03.019

Deller, D., Turner, G., and Waddams Price, C. (2021). Energy poverty indicators: inconsistencies, implications and where next? *Energy Econ.* 103, 105551. doi: 10.1016/j.eneco.2021.105551

Díaz Redondo, P., and van Vliet, O. (2015). Modelling the energy future of switzerland after the phase out of nuclear power plants. *Energy Procedia* 76, 49–58. doi: 10.1016/j.egypro.2015.07.843

EnDK (2021). *Politique énergétique.* Available online at: https://www.endk.ch/fr/politique-energetique/politique-energetique (accessed February 16, 2021).

EPAH (2021). *The EPAH Launch: How the Event Developed and Access to the Material.* Available online at: https://energy-poverty.ec.europa.eu/about-us/news/epah-launch-how-event-developed-and-access-material-2021-11-29_en (accessed December 2, 2021).

EPOV (2017). *What Is Energy Poverty.* Available online at: https://energy-poverty.ec.europa.eu/energy-poverty-observatory/what-energy-poverty_en (accessed December 15, 2021).

EU Energy Poverty Observatory (2017). *EU Energy Poverty Obs.* Available online at: https://www.energypoverty.eu/eu-energy-poverty-observatory (accessed June 15, 2021).

EU SILC (2021). *Inability to Keep Home Adequately Warm-EU-SILC Survey-Products Datasets-Eurostat.* Available online at: https://ec.europa.eu/eurostat/web/products-datasets/product?code=ilc_mdes01 (accessed December 20, 2021).

FDEA (2020). *Federal Department of Economic Affairs 'Swiss Economy - Facts and Figures'.* Available online at: https://www.eda.admin.ch/aboutswitzerland/en/home/wirtschaft/uebersicht/wirtschaft---fakten-und-zahlen.html (accessed March 28, 2022).

FOS (2021). *Privations matérielles, selon différentes caractéristiques socio-démographiques – 2007–2019.* Tableau. Off. Fédéral Stat. Available online at: https://www.bfs.admin.ch/bfs/fr/home/statistiques/catalogues-banques-donnees/tableaux.assetdetail.15344731.html (accessed January 27, 2022).

Frank, T. (2005). Climate change impacts on building heating and cooling energy demand in Switzerland. *Energy Build.* 37, 1175–1185. doi: 10.1016/j.enbuild.2005.06.019

Hearn, A. X., Sohre, A., and Burger, P. (2021). Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe. *Energy Res. Soc. Sci.* 78, 102127. doi: 10.1016/j.erss.2021.102127

Henne, P. D., Bigalke, M., Büntgen, U., Colombaroli, D., Conedera, M., Feller, U., et al. (2018). An empirical perspective for understanding climate change impacts in Switzerland. *Reg. Environ. Change* 18, 205–221. doi: 10.1007/s10113-017-1182-9

Jessel, S., Sawyer, S., and Hernández,. D. (2019). Energy, poverty, and health in climate change: a comprehensive review of an emerging literature. *Front. Public Health* 7, 357. doi: 10.3389/fpubh.2019.00357

Kuzel, A. J. (1992). "Sampling in qualitative inquiry," in *Doing qualitative research*, eds B. Crabtree and W. Miller (Newbury Park, CA: Sage), 31–44.

Ladner, A., and Fiechter, J. (2012). The influence of direct democracy on political interest, electoral turnout and other forms of citizens' participation in Swiss municipalities. *Local Govern. Stud.* 38, 437–459. doi: 10.1080/03003930.2012.698242

Lang, G., and Lanz, B. (2021). Energy efficiency, information, and the acceptability of rent increases: a survey experiment with tenants. *Energy Econ.* 95, 105007. doi: 10.1016/j.eneco.2020.105007

Le News (2021). Only 36% of Swiss own their homes. *Le News.* Available online at: https://lenews.ch/2021/04/23/only-36-of-swiss-own-their-home/ (accessed February 1, 2022).

Lee, K., Miguel, E., and Wolfram, C. (2020). Experimental evidence on the economics of rural electrification. *J. Polit. Econom.* 128, 1523-1565. doi: 10.1086/705417

Li, D. H. W., Yang, L., and Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones–a review. *Energy 0.42*, 103–112. doi: 10.1016/j.energy.2012.03.044

Lind, H. (2001). Rent regulation: a conceptual and comparative analysis. *Eur. J. Hous. Policy* 1, 41–57. doi: 10.1080/14616710110036436

Longa, D. F., Sweerts, B., and van der Zwaan, B. (2021). Exploring the complex origins of energy poverty in The Netherlands with machine learning. *Energy Policy*156, 112373. doi: 10.1016/j.enpol.2021.112373

Mashhoodi, B., Stead, D., and van Timmeren, A. (2018). Spatial homogeneity and heterogeneity of energy poverty: a neglected dimension. *Ann. GIS.* 25, 19-31. doi: 10.1080/19475683.2018.1557253

Mastropietro, P., Rodilla, P., and Batlle, C. (2020). Emergency measures to protect energy consumers during the COVID-19 pandemic: a global review and critical analysis. *Energy Res. Soc. Sci.* 68, 101678. doi: 10.1016/j.erss.2020.101678

Melvin, J. (2018). The split incentives energy efficiency problem: evidence of underinvestment by landlords. *Energy Policy* 115, 342–352. doi: 10.1016/j.enpol.2017.11.069

MeteoSwiss (2018). *The Climate of Switzerland.* Available online at: https://www.meteoswiss.admin.ch/home/climate/the-climate-of-switzerland.html (accessed March 18, 2022).

MeteoSwiss (2020). *MeteoSwiss.* Available online at: https://www.meteoswiss.admin.ch/home/climate/the-climate-of-switzerland/monats-und-jahresrueckblick.subpage.html/en/data/publications/2021/7/klimareport-2020.html (accessed December 21, 2021).

MeteoSwiss (2021). *Climate Change in Switzerland. MeteoSwiss.* Available online at: https://www.meteoswiss.admin.ch/home/climate/climate-change-in-switzerland.html (accessed December 17, 2021).

Middlemiss, L., Ambrosio-Albal,á, P., Emmel, N., Gillard, R., Gilbertson, J., Hargreaves, T., et al. (2019). Energy poverty and social relations: a capabilities approach. *Energy Res. Soc. Sci.* 55, 227–235. doi: 10.1016/j.erss.2019.05.002

Middlemiss, L., and Gillard, R. (2015). Fuel poverty from the bottom-up: characterising household energy vulnerability through the lived experience of the fuel poor. *Energy Res. Soc. Sci.* 6, 146–154. doi: 10.1016/j.erss.2015.02.001

Moazami, A., Nik, V. M., Carlucci, S., and Geving, S. (2019). Impacts of future weather data typology on building energy performance–Investigating long-term patterns of climate change and extreme weather conditions. *Appl. Energy*238, 696–720. doi: 10.1016/j.apenergy.2019.01.085

Nagaj, R., and Korpysa, J. (2020). Impact of COVID-19 on the level of energy poverty in poland. *Energies* 13, 4977. doi: 10.3390/en13184977

Okushima, S. (2017). Gauging energy poverty: a multidimensional approach. *Energy* 137, 1159–1166. doi: 10.1016/j.energy.2017.05.137

Pagani, A., Baur, I., and Binder, C. R. (2021). Tenants' residential mobility in Switzerland: the role of housing functions. *J. Hous. Built Environ.* doi: 10.1007/s10901-021-09874-5

Patel, M. K., Broc, J.-S., Cho, H., Cabrera, D., Eberle, A., Federici, A., et al. (2021). Why we continue to need energy efficiency programmes—a critical review based on experiences in Switzerland and elsewhere. *Energies* 14, 1742. doi: 10.3390/en14061742

Petrova, S., and Simcock, N. (2021). Gender and energy: domestic inequities reconsidered. *Soc. Cult. Geogr.* 22, 849–867. doi: 10.1080/14649365.2019.1645200

RadioCentral (2022). *Winterthur startet ein Bürgerforum zu nachhaltigem Konsum*. Radio Central Winterthur Startet Ein Bürgerforum Zu Nachhalt. Konsum. Available online at: https://radiocentral.ch/de/article/winterthur-startet-ein-buergerforum-zu-nachhaltigem-konsum-268649 (accessed February 1 2022).

Ragettli, M. S., Vicedo-Cabrera, A. M., Schindler, C., and Röösli, M. (2017). Exploring the association between heat and mortality in Switzerland between 1995 and 2013. *Environ. Res.* 158, 703–709. doi: 10.1016/j.envres.2017.07.021

Raworth, K. (2017). *Doughnut Economics: Seven Ways to Think like a 21st-Century Economist*. White River Junction, VT: Chelsea Green Publishing.

Robić, S. S. (2021). Energy Poverty in Times of Crisis: Has the EU Failed to Protect its Most Vulnerable Citizens?. *Policy Brief, European Energy Poverty Agenda Co-Creation and Knowledge Innovation, Engager Poverty Action*. Available online at: http://www.engagerenergy.net/wp-content/uploads/2021/11/PB-EP.pdf (accessed March 28, 2022).

Rüdisüli, M., Romano, E., Eggimann, S., and Patel, M. K. (2022). Decarbonization strategies for Switzerland considering embedded greenhouse gas emissions in electricity imports. *Energy Policy* 162, 112794. doi: 10.1016/j.enpol.2022.112794

SCNAT netzwerk (2005). *Hitzesommer 2003*. Available online at: https://scnat.ch/de/id/ZGWsy (accessed December 17, 2021).

Segalman (1986). *Welfare and Dependency in Switzerland*. https://www.nationalaffairs.com/public_interest/detail/welfare-and-dependency-in-switzerland (accessed March 28, 2022).

SFOE (2021a). *S. F. O. of E. Energy Strategy 2050*. Available online at: https://www.bfe.admin.ch/bfe/en/home/politik/energiestrategie-2050.html (accessed November 10, 2021).

SFOE (2021b). *S. F. O. of E. Measures for Increasing Energy Efficiency*. Available online at: https://www.bfe.admin.ch/bfe/en/home/politik/energiestrategie-2050/erstes-massnahmenpaket/massnahmen-zur-steigerung-der-energieeffizienz.html (accessed November 10 2021).

Siksnelyte-Butkiene, I., Streimikiene, D., Lekavicius, V., and Balezentis, T. (2021). Energy poverty indicators: a systematic literature review and comprehensive analysis of integrity. *Sustain. Cities Soc.* 67, 102756. doi: 10.1016/j.scs.2021.102756

Silva, R., Eggimann, S., Fierz, L., Fiorentini, M., Orehounig, K., and Baldini, L. (2022). Opportunities for passive cooling to mitigate the impact of climate change in Switzerland. *Build. Environ.*208, 108574. doi: 10.1016/j.buildenv.2021.108574

Simcock, N., Frankowski, J., and Bouzarovski, S. (2021). Rendered invisible: Institutional misrecognition and the reproduction of energy poverty. *Geoforum* 124, 1–9. doi: 10.1016/j.geoforum.2021.05.005

Sokołowski, J., Lewandowski, P., Kiełczewska, A., and Bouzarovski, S.(2020). A multidimensional index to measure energy poverty: the Polish case. *Energy Sources B Econ. Plan. Policy* 15, 92–112. doi: 10.1080/15567249.2020.17 42817

Stopper, M., Kossik, A., and Gastermann, B. (2016). "Development of a sustainability model for manufacturing SMEs based on the innovative doughnut economics framework," in *Proceedings of the International MultiConference of Engineers and Computer Scientists, Vol. 2* (Hong Kong), 16–18.

Swissinfo (2021). *swissinfo.ch/jc, K.-S. Pandemic Affects Swiss Housing Market*. SWI Swissinfoch. Available online at: https://www.swissinfo.ch/eng/business/pandemic-affects-swiss-housing-market-/46775392 (accessed February 1 2022).

Teariki, M. A., Tiatia, R., O'Sullivan, K., Puloka, V., Signal, L., Shearer, I., et al. (2020). Beyond home: exploring energy poverty among youth in four diverse Pacific island states. *Energy Res. Soc. Sci.* 70, 101638. doi: 10.1016/j.erss.2020.101638

Thomson, H., Bouzarovski, S., and Snell, C. (2017). Rethinking the measurement of energy poverty in Europe: a critical analysis of indicators and data. *Indoor Built Environ.* 26, 879–901. doi: 10.1177/1420326X17699260

Thomson, H., and Snell, C. (2013). Quantifying the prevalence of fuel poverty across the European Union. *Energy Policy* 52, 563–572. doi: 10.1016/j.enpol.2012.10.009

van Hove, W., Longa, F. D., and van der Zwaan, B. (2022). Identifying predictors for energy poverty in Europe using machine learning. *Energy Build.* 264, 112064. doi: 10.1016/j.enbuild.2022.112064

Weber, S., Burger, P., Farsi, M., Martinez-Cruz, A. L., Puntiroli, M., Schubert, I., et al. (2017). Swiss household energy demand survey (SHEDS): Objectives, design, and implementation. *IRENE Working Paper*.

14. **Deliverable D5.3 Marggraf, C., <u>Hearn, A.X.,</u> Lamonaca, L., Ackrill, R. Galanakis, K., 2021, Deliverable D5.3 Evidence-based policy propositions to tackle energy poverty through PEDs**

Smart-BEEjS

Human-Centric Energy Districts: Smart Value Generation by Building Efficiency and Energy Justice for Sustainable Living

Marggraf Clemens[1], Hearn Adam[2], Lamonaca Luca[3] Ackrill Robert [4], Galanakis Kostas [4]

[1] RWI, [2] University of Basel, [3] ISCTE-University Institute of Lisbon,

[4] Nottingham Trent University,

DELIVERABLE 5.3

Report on “must-read” factors in policy design to tackle energy poverty through PED creation

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Hearn Adam, Marggraf Clemens and Lamonaca Luca (in alphabetical order) conceived and wrote the first draft based on initial literature review and analysis of case studies;
Hearn Adam and Marggraf Clemens (in alphabetical order) reconceived and wrote the final draft based on editors’ and reviewers’ comments and added further literature and case studies analysis;
Galanakis, Kostas and Ackrill, Robert analysis of material, conceptualisation, review and editorial supervision of the final draft.

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Annika Sohre, University of Basel, for final review of the draft.

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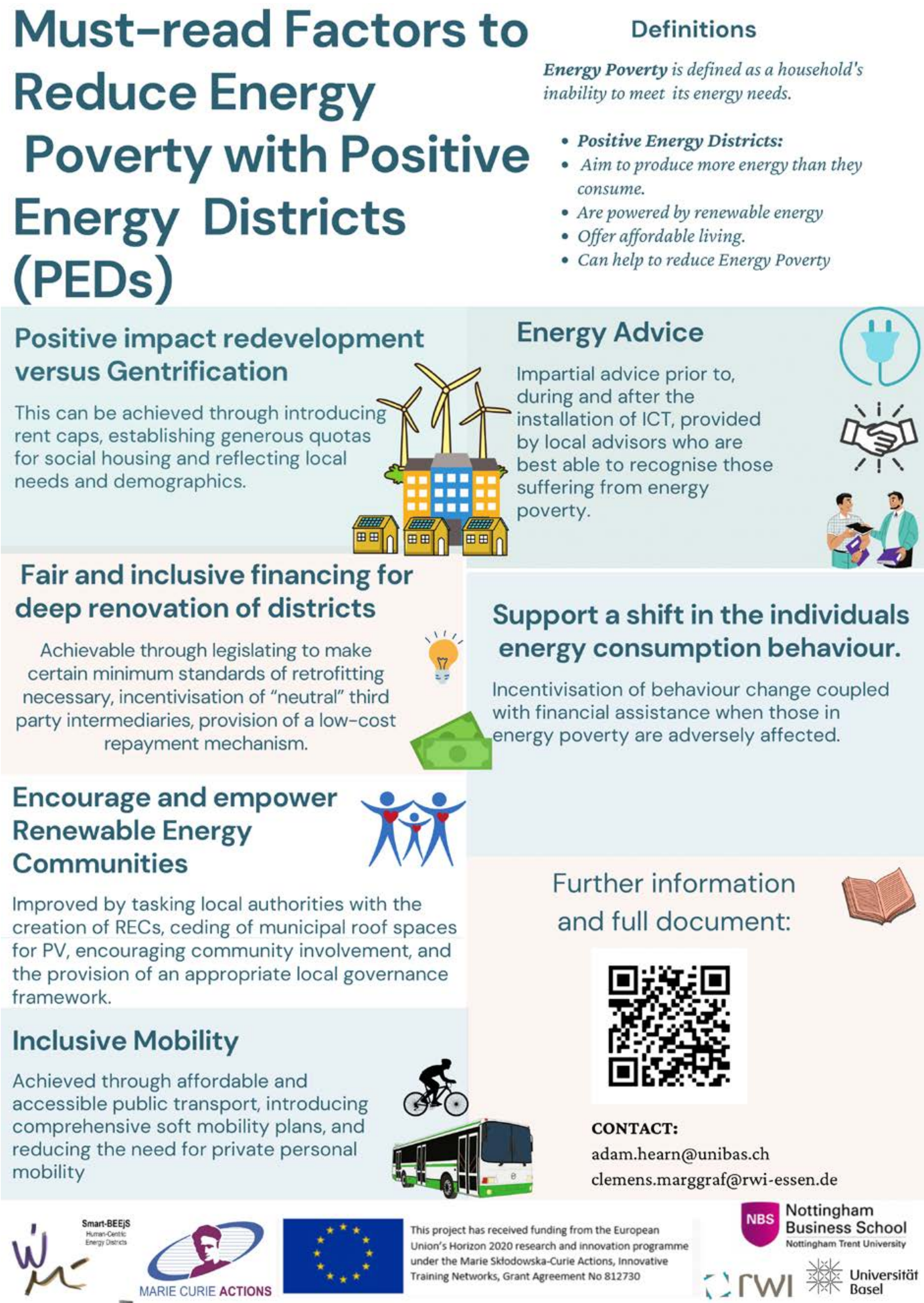
Graphical Abstract



Executive Summary

The main aim of this brief is to encourage policy makers and key stakeholders working on the creation of Positive Energy Districts (PEDs) and similar low carbon initiatives to incorporate energy poverty reduction within their district design.

Energy poverty mitigation and policies that reduce the impact of climate change are closely linked but have remained relatively separate in terms of policy planning[1] despite their intersections. Ensuring that reducing energy poverty does not, in turn, increase emissions is possible through synergistic policies. On the other hand, disjointed thinking within the policy design and implementation cycle could undermine attempts to reduce energy poverty.

The PED programme in the EU Strategic Energy Technology Plan (Set-Plan) aims to reduce GHG emissions from urban areas, as part of the broader energy and climate strategies of the EU[2]. Urban areas are acknowledged as major sources of GHG emissions, and PEDs have a target of optimising energy efficiency, flexibility and production aiming towards both climate neutrality and an energy surplus. One of the guiding principles of PEDs is a focus on affordability, and the prevention of energy poverty. Owing to the synergy in goals between reducing energy poverty and creating PEDs, planning and developing PEDs with energy poverty in mind assists in integrating policies that make PEDs more attractive for cities and citizens.

In order to develop and situate our insights we use an energy justice framework and rely on the policy design cycle to identify necessary must-read factors, drawing from scientific papers and grey literature on different PED projects.

Our research reveals that energy poverty is not considered in a uniform way across the EU. In order to ensure that energy poverty and PED creation are approached synergistically we have identified a number of must-read factors that can play a significant role either at the stage of policy design or policy implementation. Considering each of these factors will assist policymakers in establishing PEDs that are fully inclusive and have a long-term positive effect on energy poverty mitigation. In summary:

1. **Positive impact redevelopment versus Gentrification.**

This can be achieved through introducing rent caps, establishing generous quotas for social housing and reflecting local needs and demographics.

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[1] D. Ürge-Vorsatz, S.T. Herrero, Building synergies between climate change mitigation and energy poverty alleviation, Energy Policy. 49 (2012) 83–90.

[2] White-Paper-PED-Framework-Definition-2020323-final.pdf, (n.d.). https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White Paper-PED-Framework-Definition-2020323-final.pdf (accessed April 9, 2021).

2. **Fair and inclusive financing for deep renovation of existing districts**

Achievable through legislating to require certain minimum standards of retrofitting, incentivisation of “neutral” third party intermediaries, provision of a low-cost repayment mechanism.

3. **Encouragement and empowerment of energy communities.**

Improved by tasking local authorities with the creation of Renewable Energy Communities (RECs), ceding municipal roof spaces to PV, encouraging community involvement, and providing an appropriate local governance framework.

4. **Avoid, shift and improve transportation.**

Achieved through affordable and accessible public transport, introducing comprehensive soft mobility plans, and reduce the need for private personal mobility.

5. **Energy advice on the doorstep**

Impartial advice prior, during and after the installation of Information and Communications Technology (ICT), provided by local advisors who are best able to recognise those experiencing energy poverty.

6. **Support a shift in the individuals energy consumption behaviour.**

Incentivisation of behaviour change coupled with financial assistance when those in energy poverty are adversely affected.

These factors may mean that initial set-up costs for PEDs are higher than expected, but this is offset by the numerous long-term benefits that flourishing, inclusive communities are able to offer, in line with UN 2030 Agenda for Sustainable Development notion of “Leave No One Behind”.

Keywords:

Energy poverty, energy justice, Positive Energy Districts (PEDs), policy design, retrofitting, energy efficiency, gentrification, inclusive finance, Energy Communities, mobility, energy advice, energy consumption behaviour change

A. Defining the concepts of PEDs and energy poverty

Positive Energy Districts (PEDs) were conceived as part of the Smart-Cities concept, as part of the need of decarbonisation of urban areas in Europe. However, the potential effect that such initiatives might have on energy poverty has been noted and is debated internationally [1]. The initial aim, outlined in the European Strategic Energy Technology Plan (SET-Plan), Action 3.2 "Smart Cities and Communities"[2], is to create 100 PEDs by the year 2025, with an emphasis on replicability in order to significantly assist the EU in meeting its carbon reduction goals. JPI Urban Europe defines Positive Energy Districts (PEDs) as

> "*Energy-efficient and energy flexible urban areas or groups of connected buildings which produce net-zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require the integration of different systems, infrastructure and interaction between buildings, users and regional energy, mobility and ICT systems while securing the energy supply and a good life for all in line with social, economic and environmental sustainability*" [3]p4

The creation of a PED has been linked to six specific building blocks [2]:

1. A PED is embedded in an urban and regional energy system, preferably driven by renewable energy, in order to provide optimised security and flexibility of supply.
2. A PED is based on a high level of energy efficiency, in order to keep annual local energy consumption lower than the amount of locally produced renewable energy.
3. Within the regional energy system, a PED enables the use of renewable energy by offering optimised flexibility and in managing consumption and storage capacities on demand. Active management will allow for balancing and optimisation, peak shaving, load shifting, demand response and reduced curtailment of RES, and district-level self-consumption of electricity and thermal energy.
4. A PED combines built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumer. E.g., PEDs facilitate increased EV charging capability within the district and ensure that the impact of EVs on distribution will be minimised by using local generation where possible.
5. A PED makes optimal use of elements such as advanced materials, local RES and other low carbon energy sources (e.g., waste heat from industry and service sectors, such as data centres), local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating and cooling), user interaction/involvement and ICT.
6. A PED should offer affordable living for the inhabitants.

Hence, a PED is defined as a district with annual net zero energy imports, and net zero CO_2 emissions, working towards an annual local surplus production of renewable energy. The district must also be characterised by energy efficiency measures and should offer affordable and good living standards to its inhabitants.

POLICY DESIGN AND IMPLEMENTATION CHALLENGE

Would designing for PEDs exclude energy poor, or alleviate energy poverty?

This last point is significant in the context of energy poverty. On the one hand PED creation could be designed to exclude the energy poor, lead to gentrification of districts that see the energy poor marginalised in districts yet to be modernised. On the other hand, there is the potential for the transformation of districts to significantly alleviate energy poverty. The latter would mean creating districts in which energy efficiency measures reduce energy demand, energy supply is managed by community owned renewable sources, serving as a source of wealth to further counter vulnerability. The JPI Urban Europe White Paper [3] specifically mentions in its guiding principles for PEDs the fundamentals to make them more attractive to citizens and cities: quality of life; inclusiveness (with special focus on affordability and the prevention of energy poverty); sustainability; resilience and security of energy supply for all.

Therefore, the purpose of this paper is to detail the most important factors to consider during policy design and implementation for PED creation, in order to simultaneously reduce energy poverty and achieve GHG emission targets. The aim is to encourage policy makers who are creating PEDs or PED-like areas and key stakeholders to integrate energy poverty mitigation fully within their design.

This dual target policy design enforces a need to understand the added value of PED development beyond decarbonising the energy system. These facets of value leverage attention on the local energy generation and participation consideration, the scale of intervention, the level of return and improved wellbeing of residents, increased job creation, increased community engagement and, crucially, the potential eradication of energy poverty. The research team recognises that the decarbonisation of urban areas as a target alone, probably could be achieved in a cost-effective way by creating large scale developments of renewable energy production such as PV farms, on- or off-shore wind, and maintaining the central nature of distribution of the energy system. However, multiple studies have shown the benefits from local, decentralised, energy generation. For example, placing PV panels on every suitable roof in Catalonia, Spain, would provide around 50% of the energy required to power urban areas ([4]:p10). Therefore, there is scope for different thinking and radical policy value prioritisation.

Energy poverty[3], together with climate change and security of energy supply, has been identified as one of the major transformation challenges that need to be faced simultaneously within the climate and energy nexus [5]. It is a term which often encompasses fuel poverty and energy vulnerability and is generally used to refer to households that are unable to afford adequate levels of energy needs [6]. Since the 1980s there has been growing awareness of energy poverty within developed nations and a significant body of research into energy poverty in EU countries. Within the EU, energy poverty is believed to affect at least 9.8% of households in the EU27 [7]. The Observatoire Nationale de la Precarité Energetique [8] statistics office in France estimates 3.6 million households are energy poor in France alone. The EU Energy Poverty Observatory [9], which is part of the Energy Poverty Advisory Hub (EPAH), proposes a set of indicators[4] to identify energy-poor households, which are applicable on a European-wide basis and which allow for national variations in standards and definitions based on their own context [11]:

- Households where the share of energy expenditure to income is double or more the national median;
- Households where energy expenditure, in absolute terms, is less than half the national median;
- Share of the population that is not able to warm their home adequately (Self-reported levels of thermal discomfort);
- Share of population that experience arrears on utility bills over the past 12 months. (Self-reported areas on utility bills over the past 12 months).

So far, very few member states have a national definition of energy poverty (notably Ireland, France, and Slovakia, plus the UK), but there are multiple and varied attempts to reduce energy poverty across the continent.

Energy poverty is seen as a series of interrelated problems driven by general poverty and inequality, poor-quality and inefficient housing [12], ownership of the property (tenants are more vulnerable), composition of household, health conditions and professional status of the residents [22-25]. Day, Walker and Simcock [13] and Middlemiss et al. [14] examine energy poverty using the capabilities framework approach, and define it as being the **lack of access to sufficient energy services.** They also make a clear link between energy poverty and its consequences, seeing energy poverty as resulting in individuals and households being unable

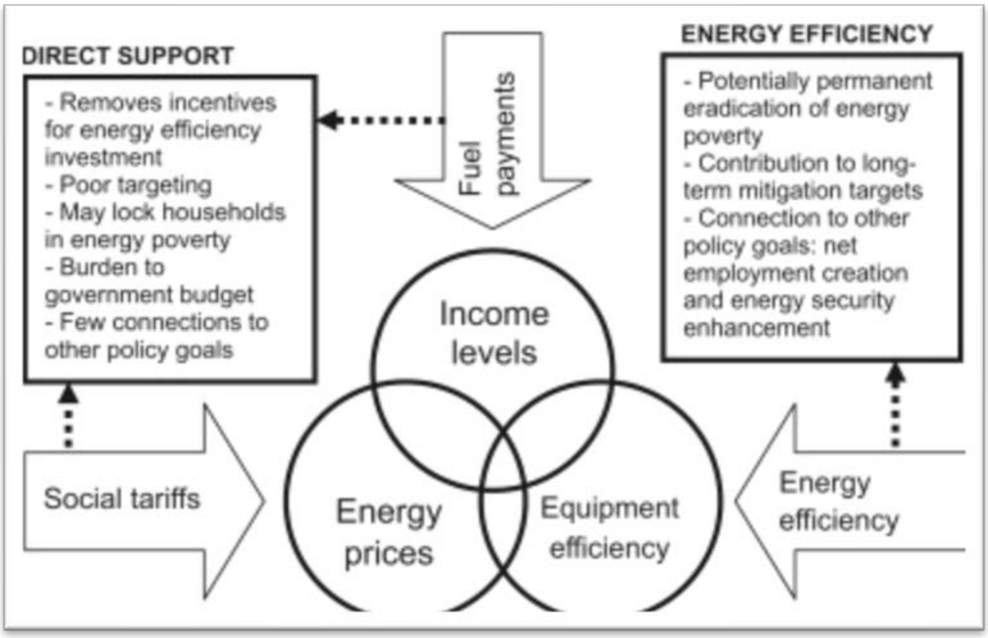
[3] Often known as fuel poverty.

[4] However, EPOV suggests a further 24 secondary indicators. EPOV makes it clear that energy poverty is a multidimensional concept and is often measured using multiple indicators. EPOV recommends examining expenditure, self-reported assessments of comfort, and direct observations if possible [10].

to “*realise essential capabilities as a direct or indirect result of insufficient access to affordable, reliable and safe energy services*” [13]:p260]. Furthermore, it is crucial to recognise that energy poverty is often hidden [15–17] because individuals might not self-identify as energy poor. Kearns et al. [18] examine the role of occupant behaviour as a driver for energy poverty. They focus on energy efficiency, support networks and mental health issues as worthy of examination, but also identify **behaviour** as a fourth major driver of energy poverty [18–20]. However, behaviour alone cannot explain energy poverty, and in the light of hidden energy poverty where those affected already under-consume (often in what is referred to as the “heat-or-eat dilemma” [21]), expecting those in energy poverty to adapt their behaviour is not likely to be a successful approach.

Research into the connection between energy poverty and climate change mitigation [22] makes clear that aspects of PED creation, such as energy efficiency, are significant drivers of potential energy poverty mitigation as well as contributing to long term climate change mitigation (Figure 1, below). It can be argued that although energy poverty is connected to income levels, energy prices and efficiency, by improving energy efficiency sufficiently the need for direct support can be diminished, freeing funds for further energy efficiency improvements.

Figure 1 Contributing factors and policy entry points to fuel poverty and their relation to climate change mitigation from Ürge-Vorsatz, Tirado-Herrero [22]



B. Methodology

In order to identify suitable factors to consider, we drew on observations of practice together with a literature review, in which we identified research based on searches using the term “Positive Energy District” or “PED”, as well as a number of related terms from preceding low carbon urban developments such as eco-quartier, and 2000 watts. This was coupled with a review of literature on energy poverty and energy justice, as well as policy design. From an energy justice perspective [23] we examined potential issues that could arise through the unfair distribution of benefits and burdens, lack of recognition and misrecognition, and procedural justice issues [24,25]. However, in the context of PEDs we also considered intragenerational and intergenerational justice as well as restorative justice [23], but we excluded issues of global justice as these have a very limited impact on energy poverty within the PED.

The observations of practice were based in part on the individual EU member state National Energy and Climate Plans (NECPs [26]), which were produced for the European Commission and outline energy policies. 13 different member states did not provide objectives or targets for energy poverty mitigation, with a further 10 member states having no specific policies for energy poverty outside of existing social policies (Czechia, Denmark, Finland, Germany, Latvia, Malta, Netherlands, Romania, Slovakia and Sweden). In addition, Poland and Hungary did not recognise energy poverty to the extent of detailing any specific approach, social or otherwise. This may lead to further misrecognition and stigmatisation of those suffering from energy poverty [27]. In many cases, the countries that use social welfare policies to reduce energy poverty are those that suffer from low levels of this. Nevertheless, reducing the issue of energy poverty to one of social welfare may mean that reductions in the numbers of those affected may occur at a slower pace than if addressed as part of energy transition policy. Member States that do incorporate energy poverty inside energy transition plans have specific targets and measures that attempt to directly address energy poverty, including (e.g. in the case of Spain [28]) the potential to pre-empt emerging forms of energy poverty that relate to summer vulnerability (which refers to extreme heat) [29]. Changing the focus of the energy poverty conversation from social welfare to energy transition policy, may enable a more holistic approach.

The areas of interest we identified are the mitigation of gentrification, inclusive financing, novel forms of energy ownership, inclusive mobility, energy advice, and energy behaviour change. These are grouped and presented under the policy design cycle (Table 1, Appendix).

The policy design cycle [30] is an idealised process that explains how a policy should be designed. It can be divided into four phases: Agenda setting, Policy Formulation, Implementation and Evaluation [31,32]. The areas of interest, incorporating energy poverty and decarbonisation aspects, raised a set of specific problem settings. From the review of studies, project reports etc. we identify strategies and actions to deal with these issues and the interrelations between them.

We examine each of these aspects and determine potential methods to mitigate negative impacts in the agenda setting, formulation and implementation stages. Following this, in the evaluative aspect of the policy cycle, we would recommend that the district and the town be evaluated using energy poverty measures such as those recommended by Energy Poverty Advisory Hub (EPAH, formerly EPOV), and that the impact of the PED is also evaluated based on the recommendations made in Deliverable 5.2.

For the planning/design stage of the PED before the district is created, we identify the following key must-read factors to consider:

1. Positive impact redevelopment vs. Gentrification

2. Ensure Inclusive Retrofitting

3. Consider novel ownership models of RET

4. Inclusive and sustainable Mobility

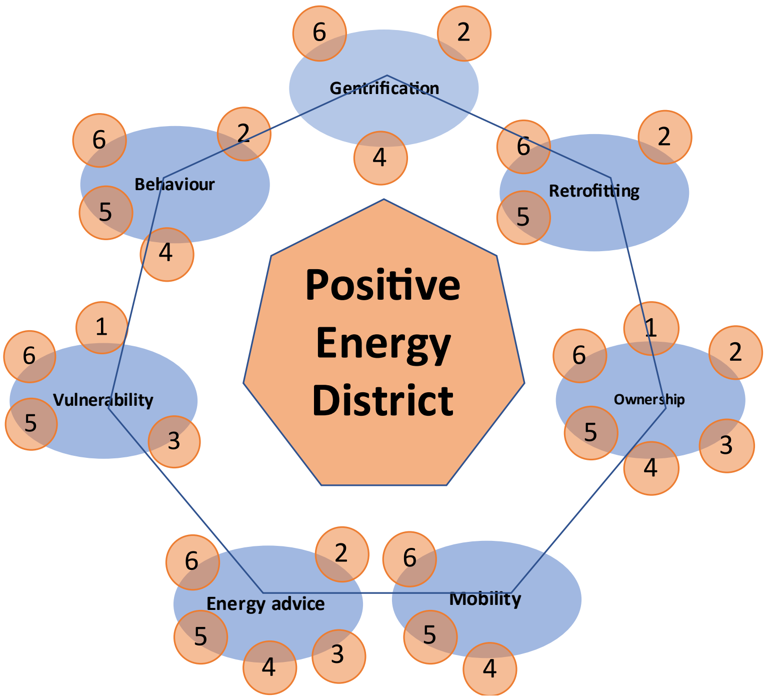
During the implementation phase of the PED, the following must-read factors merit consideration:

5. Energy advice and Vulnerability to energy flexibility

6. Behaviour change

In Figure 2 (below), we connect the six must-read factors on energy poverty mitigation with the six building blocks. It is immediately apparently that all of these connect to building block #6 (affordable living), as this ties in directly to energy poverty mitigation. However, most of the must-read factors are also connected to building block #4 (creating added value and incentives), which can have an effect on reducing energy poverty, as well as #5 (optimal use of different elements), as increasing overall efficiency may lead to reduced costs and thus also reduce energy poverty. Furthermore, building block #1 (embedding PEDs in the regional energy system) connects very clearly to the establishment of community energy initiatives, #2 (high energy efficiency) connects firmly with retrofit finance, and #3(energy flexibility) connects to reducing vulnerability and energy behaviour change. Ensuring that the factors we consider are connected to PED building blocks allows us to focus on issues that are directly relevant to PED development and energy poverty.

Figure 2 Connecting the must-read factors with the main PED building blocks



Our approach takes into account the nexus of all six of the must-read factors we consider and the interrelations between these factors often make them mutually reinforcing and beneficial. Thus, for example, increasing community ownership of RET can help to reduce the negative aspects of gentrification.

In the following section we first present each area of interest, identify the specific problem setting and then demonstrate strategies and actions that offer means of mitigation.

C. Must-read factors for coupling the mitigation of energy poverty and decarbonisation

In this section we detail each significant must-read factor, explaining which PED building blocks it is connected to. Once we have presented the area of interest, we identify the specific problem setting. We then demonstrate strategies and actions that provide potential solutions connected to case studies where these issues have been successfully mitigated. Further, we refer to how each of the areas of interest interconnect between each other.

The first four must-read factors are related to the planning phase of the PED. This does not mean that they should not be referred to during the implementation stage, but that they need to be given consideration prior to the creation of the PED itself. The final two must-read factors are best considered during the implementation phase of the PED. All of the must-read factors need to be re-considered during the evaluation phase in order to make any necessary changes to further mitigate energy poverty.

C.1 Positive Impact Redevelopment versus Gentrification

GENTRIFICATION
"The process whereby the character of a poor urban area is changed by wealthier people moving in, improving housing, and attracting new businesses, typically displacing current inhabitants in the process."
Lexico.com, powered by Oxford Dictionaries

District redevelopment has many benefits in terms of urban revitalisation, stabilisation and reversal of urban decay, energy efficiency improvements, improved green and communal spaces, improved mobility services and is often associated with a reduction in crime rates. However, it can also lead to gentrification, resulting in community conflict, displacement of lower income or rental populations, increased property prices and rents and a reduction in available affordable housing [33]. Gentrification can have a significant impact on energy poverty, displacing vulnerable residents often to districts with poorer quality housing, that might be further away, exaggerating both energy poverty and transport poverty.

Offering affordable living to inhabitants, which is the sixth PED building block, is a major issue when redeveloping a district. The definition of affordability, however, varies significantly between European States[5], and is often coupled with quotas for minimum levels of social housing within a district, rent caps and controls, and tenant and ownership protection regulations at national level. The effects of a vague notion of affordability can include the exacerbation of the displacement of lower income households. Eco-districts tend to see concentrations of high-income residents [35], which could be seen as "green" gentrification [41], arising from the creation of added value eco-services such as bike paths, green spaces, and attractive housing stock. In cases such as Letnica, Gdansk in Poland, the lack of engagement with residents, contributed to waves of displacement. The first wave was a forced displacement, as some buildings were demolished, with ordered relocation. In a second wave, some residents were displaced when their buildings were renovated and new financial barriers created against former residents, such as the requirement for a sizeable deposit in order to be granted the right to a home in the newly developed area [36]. These effects are often coupled with 'touristification' (e.g. Barcelona, Lisbon) [37,38], as these cities become more attractive to visitors and tourism. Data shows that most listings on Airbnb are for entire homes which are rented throughout the year, exacerbating housing access issues and disrupting communities [39].

[5] For example, price/income ration, tenure-related interpretations, market-led or cost-led definitions [34]

In general, across Europe we observe a variety of mitigating policies that set minimum levels of social housing within a district, rent caps and controls, protection for tenants and caps on buy-to-let mortgages for homes within a district [40]. One of the main success stories where gentrification has largely been avoided is the city of Vienna. This is partly because approximately 50% of the building stock in the city is social or municipal housing, with cost-led rental policies and with policies of social sustainability embedded in the urban planning and development regulations [41–43]. The success of the city is reflected in lower mortality rates for Vienna residents compared to other European cities, and the city being ranked as the most liveable city worldwide for 2018 and 2019 [35,44].

The Hunziker district in Zurich, Switzerland [45,46], was created by the "Mehr Als Wohnen" collective [23], formed out of members of 30 housing cooperatives in Zurich. The cooperative decided to ensure that negative gentrification aspects were minimised from the beginning. This was achieved because they were able to:

1. Ensure rents remain approximately 20% lower than other areas of Zurich, hence living in the district remains relatively affordable;
1. Provide an additional 20% of social housing, which is managed and distributed through charities separately to the rest of the district;
2. Reflect the wider demographic of Zurich within the district population. This has been a somewhat contentious move as it also means there are some very wealthy residents. New residents are screened, with priority is given to those that fit the demographic "need" for the district[6].

In the case of the Stimuleringsregeling energieprestatie huursector (STEP) [47] in the Netherlands, financial assistance has been provided directly to improve the energy efficiency of social housing, but crucially, the total costs for the tenants (rent, service and energy costs) has not increased after the renovation.

In cities like Madrid, Rome and Athens community activism, such as the "Yonomevoy" ("I will not leave") group in Madrid [48], fill the regulatory gap, initiating local action for tenancy protection or opening the discussion around new schemes of community energy ownership initiatives [49]. "Yonomevoy" engaged in direct action in order to ensure that about 200 vulnerable residents (mainly elderly) were still able to continue paying rent under their previous contracts, despite the sale of their social housing [50].

Consultation with residents, communities and community-based associations during the planning phases and providing local energy advice with information on consumer and tenant protection rights can reduce negative gentrification effects. These actions (e.g., surgeries and open days to stimulate active engagement) act as a point for informing tenants of their rights and options in the complex net of national and EU regulations and legislation and pro-active engagement for creating positive impact.

To conclude, leaving the effects of PED development to the market forces of supply and demand is likely to result in displacement and exacerbation of energy poverty. Policy design requires a proactive action plan for encouraging positive impacts of PED developments, whilst avoiding the negative effects of gentrification.

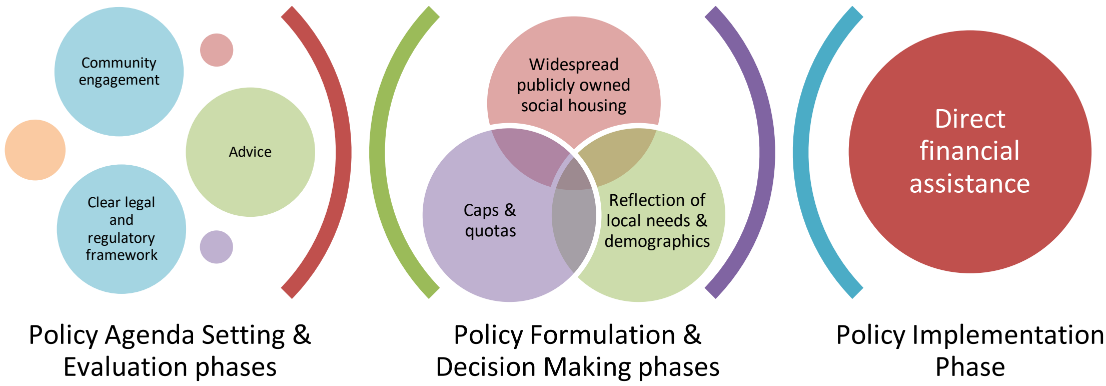
Proposition for Policymakers

In terms of the policy cycle, during the policy agenda setting and evaluation phases, we would encourage the creation of a clear legal and regulatory framework, with clear advice provided to an actively engaged community (Figure 3, below). Engaging the community can best be achieved through numerous different avenues simultaneously, combining face-to-face contact with newsletters and an online presence for example. During the decision-making phases, caps and quotas can be set, and decisions on district demographics could be made to reflect local needs, based on engagement with the community. Establishing

[6] Initially there were issues with attracting sufficient older residents as this was an entirely new district (it was not built on an area where a previous district had existed or in a retrofitted district).

baseline rents which are lower than those in surrounding districts may greatly assist in reducing the risk of gentrification. Finally in the policy implementation phase, direct financial assistance can be considered for those at risk of energy poverty.

Figure 3 Positive Impact Redevelopment Principles



C.2 Fair and inclusive financing for the deep energy renovation of existing districts

DEEP ENERGY RENOVATION

"A term for a renovation that captures the full economic energy efficiency potential of improvement works, with a main focus on the building shell, of existing buildings that leads to a very high-energy performance."

Global Buildings Performance Network

Although PEDs are mainly planned as new districts, there is a strong case for creating PEDs in existing districts. This may mean that they are built or undergo deep energy renovation to meet high standards such as PassivHaus [51–53] or Minergie [54,55]. This can include the installation of renewable energy sources (RES) such as PVs, reducing energy cost and providing potential income generation (e.g., from feed-in tariffs). The buildings will, by necessity, be highly energy efficient and more economical to run, as required by the second PED building block. In order for PEDs to become a mainstream concept, there is a clear need to address the retrofitting of existing and historical buildings and installation of such technologies to the existing building stock [56]. Older buildings[7] in existing districts, particularly historical ones (over 100 years old) are often poorly insulated, or in states of degradation, that make retrofitting more costly and difficult to retrofit due to cultural significance, protection regulations and the continuous use from residents and businesses. Historical buildings are often excluded from retrofit actions because of such barriers (e.g. in Italy almost all retrofits occur on post World War II buildings, and an estimated 1,200,000 residential buildings are deemed to be historical [59]). Retrofitting also needs to be of sufficient quality to avoid locking-in properties with less-than-optimal energy performance, and ensure that deep energy renovation is conducted [60].

[7] This varies significantly within Europe. E.g., in the case of Portugal, 17% of all buildings are classified as old (predating reinforced concrete), often meaning that they are overlooked in favour of easier and more affordable retrofits [57]. In the UK as of 2019, more than 3.12 million owner occupied houses were built before 1919. In contrast, approximately 1.5 million owner occupied houses were built from 2003 onwards [58].

Furthermore, owner-engagement has been identified as one of the key barriers to increased retrofitting [61], with the split incentive meaning that landlords see little benefit in ensuring their properties are retrofitted.

Ensuring inclusive finance, enabling poorer households and those who live in energy poverty to be included in this transformation, most likely living in poorer quality accommodation with reduced energy efficiency, and with the biggest need for renovation [62], is a crucial challenge for retrofitting policies. This measure links directly to the sixth building block of PEDs, to offer affordable living for inhabitants.

The issue of inclusive and fair financing of retrofitting actions – which require high up-front costs to be covered and deal with multiple forms of ownership that is a source of potential conflict – opens a discussion of ‘who is to pay for what and how’. Awareness of which financial options are available for residents and institutions is essential in this discussion. Brown et al [63] have codified different forms of financing for residential retrofits in a variety of countries (Table 1).

Table 1 Key features of six archetypes of finance mechanism for residential retrofit adapted from Brown et al [63]

Feature of Finance Mechanism							
Sort of Finance Mechanism	**Example Schemes**	**Source of Capital**	**Financial Means**	**Project Performance**	**Point of Sale**	**Safety and Underwriting**	**Repayment Channel**
Public Loan/Credit Enhancement	HES and HEEPS equity loan (Scotland)	Government spending	Debt	Minimum CO_2 reduction	Third party finance provider	No security – credit check	Unsecure Loan/ equity release
	KfW CBRP (Germany)	Public Bank	Debt (bonds)		Retail bank	No security- basic credit check	Unsecured Loan
	JESSICA → LEEF (EU→London,UK)	Hybrid – EIB, LEEF & Private lender	Debt		Housing provider	Varies	Resolving phase then full repayment
On Bill Financing/On Bill Repayment	UK(OBR) Green Deal	Third party private sector	Debt	Bill neutrality (Golden rule) Third party finance provider	Third party finance provider	Energy meter & bill history	Energy bills
Property Assessed Clean Energy (EuroPACE)	RE:NEW Financial (EU)	Municipal bond → private capital	Debt (bonds)	None – approved contractor schemes	Contractor	Lien on property & tax bill-based underwriting	Property taxes
Green Mortgage	EMF Green mortgage project (EU)	Covered bond market	Mortgage (equity & debt)	EPC improvement	Mortgage provider	Detailed credit check	Mortgage payments
	Ecology Building society (UK)	Member deposits	Equity				
Energy Services Agreement	RENESCO (Latvia)	ESCO → Public bank	Debt & Equity	Energy performance guarantee	Contractor	Based on ESCO	Energy performance contract
	SEA (Italy)	ESCO → Institutional investor				Based on ESCO & bill payment history	
Community Financing	BHESCo (Brighton,UK)	Member share issue	Equity	None	Contractor	Credit check	Hire Purchase agreement → dividends

Although some of these are clearly only applicable for homeowners (Green mortgage, HEEPS), or those with a sufficient rating (community financing / energy services agreement), there is no reason to assume that residents in these groups are not vulnerable to or suffering from energy poverty, and these could be considered as part of a selection of different options made available to the residents of a district. Those financial mechanisms that do not require property ownership or some form of security/credit check are also those which may be best suited for reaching vulnerable residents who may be suffering from energy poverty.

EuroPACE, [64] offers an interesting potential solution for increasing the uptake of retrofitting, proposing that repayments of financing occur via property taxes which are paid by the resident of the property (not necessarily the owner) [65]. This is based on the USA based PACE programme, which is characterised by voluntary participation, coverage of all costs, long-term financial assistance, and the affixation to the property of the loan [66]. Loan repayments are meant always to be less per year than the savings made through the renovation itself. Further benefits to this programme would be that making these loans available are calculated to increase jobs by an average of 18 new jobs per €million invested. In total for the whole of Europe this could lead to the creation of 3.3 million jobs if the renovation gap of € 185 billion per year were met, a significant win-win solution to reducing energy poverty and combatting climate change.

Currently there are no property taxes that could be used for this purpose in Croatia Cyprus and Malta, and EuroPACE notes that applying this sort of financing in member states that are highly centralised in terms of property taxation such as Estonia, Greece or Latvia, may require significant legislative changes to make this viable. Additionally, in member states where this is viable, there may still be a requirement for legislative changes. This can be seen in the case of Austria which was identified as very adequate but where attempts to pilot this form of financing were deemed unconstitutional. For this form of financing to function there also needs to be robust enforcement procedures in the event of payment delinquency [67].

In the UK, private rented accommodation accounts for 20% of the housing stock and is the most likely not to meet the Decent Homes Standards [68]. In a survey of landlords in the UK only 15% were planning on retrofitting properties and 38% were not compliant with EPC regulations. Research by Miu and Hawkes [68] suggests that landlords would respond most favourably towards retrofits if these were associated with grants, tax exemptions and cashback schemes.

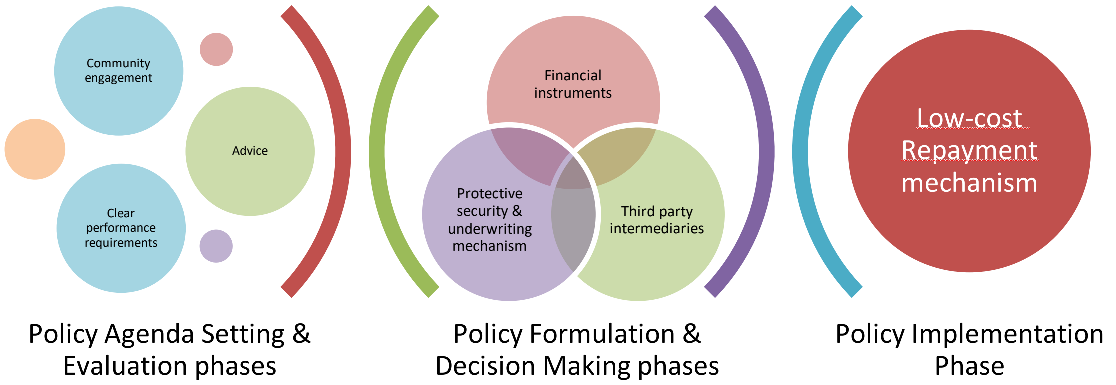
However, there is some evidence to suggest that providing tax deductions for retrofitting is not effective in promoting deep renovation; and that, furthermore, a system whereby intermediaries are incentivised to conduct retrofitting of buildings may be more effective. In the Netherlands, trusted intermediaries [69] focused on ensuring that the best possible longer term low carbon strategy for retrofit was taken, putting forwards different potential suppliers and technologies and establishing mutual agreements. This overcomes issues of trust and complexity which can be barriers to uptake. The Energiesprong government funded programme in the Netherlands [70] is now also being used in France and the UK.

Proposition for Policymakers

There is a clear need for alternative financial models to provide the capital necessary to allow and encourage deep energy renovations [71]. Access to financing needs to be improved, coupled with legislation granting those that live in rental property the authority to embark on retrofitting unless there are good grounds for the owners to veto this. Potential methods to do this could include legislating to make certain minimum standards of retrofitting necessary, but this would need to be coupled with some form of compliance enforcement. Furthermore, an approach that gives the authority to and incentivises “neutral” third party intermediaries may be more successful in the decision-making phase, with a low-cost repayment mechanism for the policy implementation phase (Figure 4).

For those in social housing, the use of direct government spending may be appropriate, whereas for those in private rental properties the issue remains - there is a need to retrofit these buildings despite potential objections from landlords and residents.

Figure 4 Source of capital policy principles



C.3 Encouragement and empowerment of energy communities

ENERGY COMMUNITIES

“Empowering renewable energy communities to produce, consume, store and sell renewable energy will also help advance energy efficiency in households, support the use of renewable energy and at the same time contribute to fighting poverty through reduced energy consumption and lower supply tariffs.”

European Commission

The ownership of RET connected to a PED may have a significant effect on energy poverty and is connected to aspects of each of the main building blocks. Community ownership models may help to reduce costs and allow for affordable living, embedding RET locally [72,73].

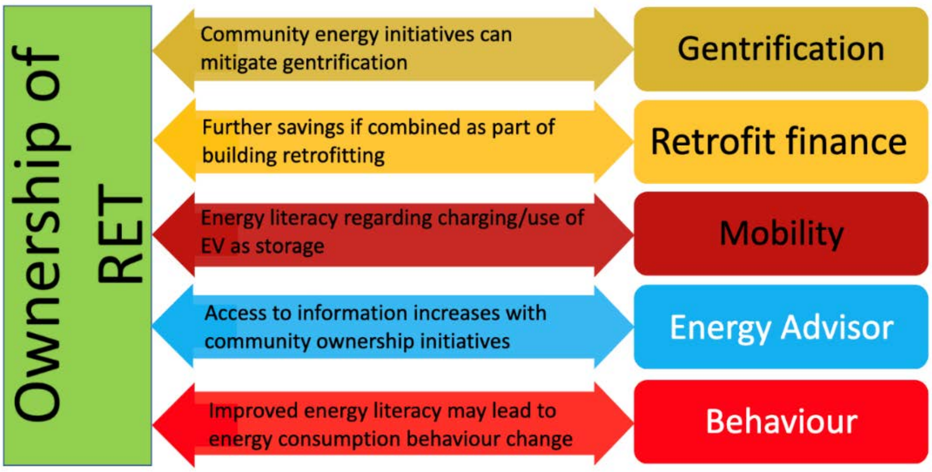
Under EU directive 2019/944, part of the Clean Energy for all Europeans Package, energy markets have been made to accommodate new forms of energy ownership, including individual prosumers, peer-to-peer energy sharing, Citizen Energy Communities (CECs) and Renewable Energy Communities (RECs) [74,75]. PEDs may encompass multiple different forms of energy ownership, from individual through cooperative or utility owned, and the decisions made regarding this could have a long-term impact on energy poverty. The role of Energy Communities in reducing energy poverty has been recognised in the revised Renewable Energy Directive [76]. Tasking local authorities at a municipal level with the creation of these communities would enable greater participation of those that are most vulnerable as these are already identified by the local authorities. Energy production could take place on municipal buildings, and measures could be introduced so that grass-root energy communities incorporate a percentage of disadvantaged families in order to reduce energy poverty.

A series of interviews with energy stakeholders conducted in Spain [77] indicates a degree of consensus amongst experts that the creation of Energy Communities could primarily be used as a tool for tackling energy poverty, with local authorities at a municipal level providing a key role in funding, placing of PV (using municipal buildings for example) and deciding to what degree those in energy poverty are included. There is much debate on the ownership of renewable energy sources for PEDs, with some debate on which form of ownership is best [78]. CECS and RECS could provide a significant boost to both PED creation and energy poverty mitigation. Supporting the grassroots creation of CECs could provide a reduction in energy costs to vulnerable residents, and could even go further and provide a potential income stream, further reducing energy poverty. Additionally, engagement in RECs and CECs is normally accompanied with a significant increase in energy literacy, enabling residents to better manage their own energy consumption.

Under a Business as Usual (BAU) model of energy production, the current mix of utilities will continue to dominate, and it is likely that energy poverty levels will continue to drop as they have been, unevenly throughout the EU. However, the fact that energy poverty increased during the COVID19 pandemic in 2020[8] [80] indicates that a BAU model will not deliver a long-term solution. Indeed, it could be argued that many of the reductions are evidence of EU policy activities that direct national governance on energy poverty [81].

Creating novel forms of energy ownership is not only entirely possible within the context of PEDs but indeed desirable in terms of being in line with the guiding principles of PED creation. Giving the energy poor membership to CECs and RECs could significantly reduce energy poverty. Forms of community energy ownership also connect directly to the other must-read factors. Engaging in these forms of ownership may help to reduce the likelihood of negative aspects of gentrification and could be incorporated into district retrofitting potentially saving time, money and future disruption from later installation (Figure 5, below).

Figure 5 Interconnectivity between new ownership models for RET and the other must-read factors



Some PED-like areas opt for cooperatively owned and run RES (e.g., the Hunziker Areal, Zurich, Switzerland). Others could incorporate private ownership, utility ownership or the creation of energy communities. In the case of the Hunziker Areal, Zurich, this enables the cooperative to set the prices for electricity, and to ensure that energy poverty is addressed locally.

A recent study [78] used a choice experiment to identify ownership preferences of renewable energy technology in PED-like communities in Switzerland, allowing for a number of choices; individual, housing association, cooperative or utility-owned. The results indicated that although there was significant support for utility-owned PV, cooperatively owned renewable energy technologies was preferred by younger segments. Furthermore, the issue of property ownership is recognised as having an effect on decisions regarding energy production technology ownership.

[8] Data from Spain shows nearly 50% increase in those reporting arrears on household bills, and inability to keep the home adequately warm. [79]

The 2018 Greek law N4513/2018[82] on energy communities emphasises a solidarity economy and the reduction of energy poverty that is possible through CECs. Although Greece is so far the only country to do so in the EU, both Bulgaria and Hungary have planned to do so in upcoming legislation and the public consultation on energy communities in Spain in December 2020 may lead to a similar development.

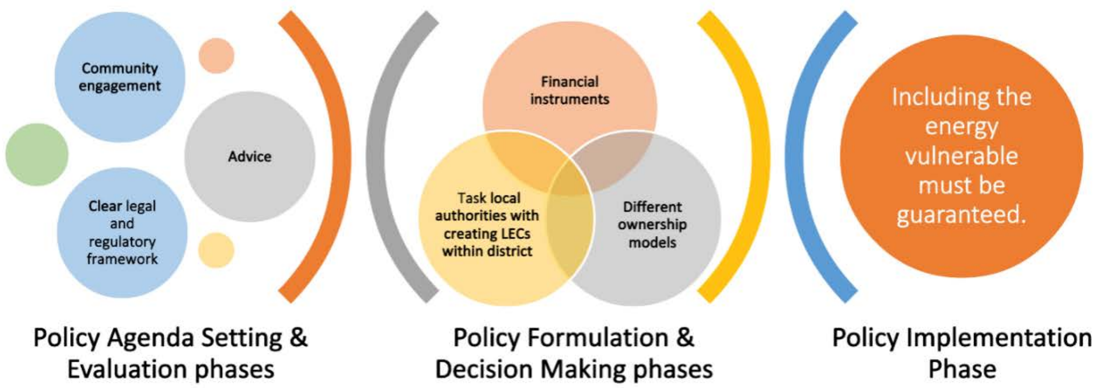
In the case of Viladecans, Spain, the Vilawatt programme [83] now aims to create a series of Citizen Energy Communities in the areas where energy poverty is greatest, using municipal buildings (sports halls, schools etc) as well as apartment blocks, for the placing of an initial 1MW of PV panels. Energy will be provided first and foremost to those identified as suffering from energy poverty.

Similarly, the Barrio La Pinada PED, Valencia, Spain [77] has created participatory groups of potential future residents who are discussing the possibility of creating an Energy Community within the district to help meet their energy needs.

Proposition for Policymakers

The role of Energy Communities in reducing energy poverty has been recognised in the revised Renewable Energy Directive [76]. Tasking local authorities on a municipal level with the creation of these communities would enable greater participation of those that are most vulnerable as these are already identified by the local authorities. Energy production could take place on municipal buildings, and measures are already in place to ensure that energy communities in the forms of both RECs and CECs allow access to vulnerable and low-income households [84] (although the extent of this varies in each member state). In order to make full use of RET in a PED, the community must be involved, an appropriate framework must be in place and guidance on how to use RET is essential, especially for people who are not tech-savvy (e.g., older people). The inclusion of energy-vulnerable persons is ensured by considering a range of measures, e.g., financial instruments or offering different ownership models (Figure 6).

Figure 6 Policy cycle synthesis of local energy initiatives with PEDs



C.4 Avoid, Shift, Improve Transportation

SUSTAINABLE TRANSPORTATION

A shift to sustainable transport plans is essential to significantly improve the overall quality of life for residents, by focusing on inclusiveness, environmental protection and new mobility options.

The "Avoid, Shift and Improve Transportation" concept is an important component of a PED in order to reduce emissions. Avoidance refers to measures that reduce the need for transportation, while shift deals with interventions that shift either to public means, active modes or e-micromobility (e.g., e-bikes and e-scooters). Improvement indicates "green" vehicles (e.g., electric and hydrogen vehicles) or services for shared mobility. However, this holistic conception is often neglected in transportation planning decisions.

Transportation planning decisions involve trade-offs between increased mobility (how fast and far someone can travel) versus local accessibility. For instance, interventions aiming to increase mobility, such as expanding roads and providing generous parking, create a more sprawled land use pattern that is less accessible, and redesigning streets to prioritise speed can create disagreeable conditions for walking and cycling ("barrier effect" [85]).

Designing PEDs so that there is less of a requirement for transportation in the first place, offers the potential to avoid related emissions and costs [86]. This may mean designing districts so that buildings have shared residential/commercial use such as in the Hunziker Areal [23] and providing local space for businesses.

Currently, transit-oriented development (TOD) is considered by many urban planners as a solution to a variety of urban problems, e.g., traffic congestion and air pollution [88]. This concept deals with the development of urban areas in order to design them in such a way that they allow as much residential, commercial and recreational space as possible within walking distance of public transport. However, increased accessibility due to proximity to transit is often capitalised in land and housing prices, which might lead to the displacement of the low-income population that would benefit most from transit connectivity [89].

Further examples regarding the shifting to sustainable motility are the electrifying of train-lines in Baden Wurttemberg, Germany, as well as the introduction of hydrogen fuelled buses e.g., in Bolzano, Italy or the 10mins cycles of active mobility in Torres Vedras, Portugal, all of which help to create higher living standards for the general community. Other PED-like areas such as Alkmaar in the Netherlands and Lviv in the Ukraine are also investing in environmentally friendly mobility infrastructure. The former city built a cycle path that is equipped with integrated solar panels, which light their surroundings at night, while the latter city built 15 km of new cycling infrastructure, which includes bike lanes and bike parking [97].

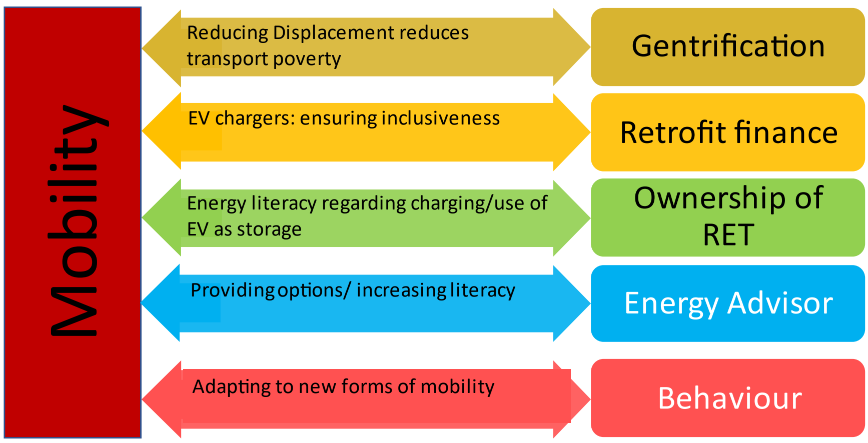
Additionally, electrification of transportation is becoming more and more common and most PEDs have some form of mobility plan that includes providing charging points for electric vehicles (EVs), as well as testing of innovative forms of transportation such as autonomous (driverless) vehicles (AVs). However, although these actions have a high profile and attract publicity, they often reach only the wealthiest segments of the population and require significant investment. For example, a study by Reaños and Sommerfeld [112] found that only 10% of people in the lowest income group would consider buying an electric car, compared with nearly a quarter of those in the four highest income groups. According to the authors, one explanation is that low-income drivers living in rural areas feel particularly disconnected from the new electric car era, as a large majority think they cannot afford an electric vehicle and rely on public transportation. Those that can afford it, on the other hand, face a lack of charging stations.

Both of these issues are related to multiple PED building blocks (#4, #5 and #6). When planning a PED, it is essential that mobility also be taken into account to enable a sustainable life. This means, among other things, that citizens have optimal access to low-energy and, as far as possible, emission-free means of transport at all times and without great effort. For example, enabling the proximity of public transport stops or guaranteeing an infrastructure regarding active means of transport. In addition, the inclusion of all people should also be considered in terms of financial aspects.

Regarding the potential problem of lack of inclusion and accessibility, one solution might be the implementation of a new planning paradigm, which also considers a comprehensive accessibility analysis in order to quantify accessibility impacts [91]. This makes it much easier for decision-makers to identify which mode of transport guarantees speed, inclusivity and sustainability.

Some PED-like areas have implemented interventions which consider the "Avoid, Shift and Improve Transportation" concept. For example, the cabildo of El Hierro (Canaries, Spain [71]) created a sustainable mobility plan that includes amongst other things a subsidised public transport (93% of costs are subsidised), a car share programme for public servants and a taxi share programme. Reininghaus [93], a district of Graz, implemented car free areas and promotes public transportation as an option for car owners by providing residents with an improved mass transit connection to other districts and a 90% subsidy of the costs for a transferable public transit ticket for the first five years of residency. The Hunziker Areal, Zurich, is even stricter with a ban on car ownership (exceptions are made for shift workers and those with disabilities) [87].

Figure 7 Interconnections between Mobility and other must-read factors



Improving sustainable public transportation can be connected to the other identified must-read factors.

Retrofitting homes, for example, often includes the installation of charging points for electric vehicles at home. Therefore, e-vehicle owners have easier access to charging stations and a greater incentive to use this sustainable mode of transport. Furthermore, citizens living in rural areas, where public transport is often not available, can benefit from the use of e-charging stations to be more flexible and independent in their daily lives. Thus, e-charging stations also contribute to inclusion.

Vehicle to Grid (V2G) describes the system of feeding electrical energy from the traction batteries of plug-in electric vehicles (PEV), such as battery electric vehicles (BEV), plug-in hybrids (PHEV) or hydrogen fuel cell electric vehicles (FCEV), back into the public electricity grid. This has been trialled in the UK by the energy company OVO in conjunction with Nissan [90]. Furthermore, the concept includes smart communication with the electricity network regarding curtailing charging when In this way, the sector coupling provides relief in times of high grid load and reduces the risk of a power outage [91]. In Europe there have been some trials already. Furthermore, electric vehicle batteries can be given a second life. This involves recycling the batteries that no longer meet the requirements of automotive applications such as in Évora, Portugal [92] , but which could still be used for less demanding grid-based energy storage applications [93]. This can also reduce energy vulnerability.

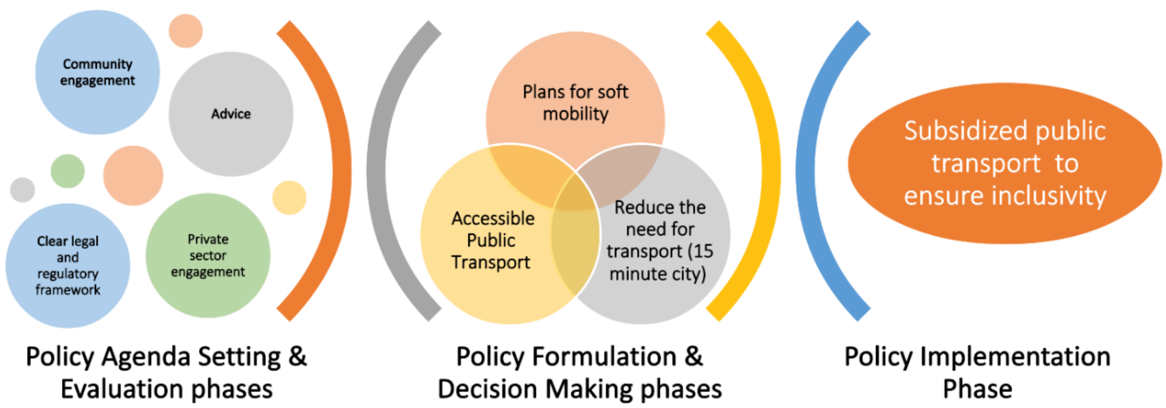
Energy advisors can also help to educate citizens regarding energy literacy and sustainable mode of transport. Thus, owners might be more interested in understanding energy flows, how much energy they use and where the energy comes from. Furthermore, energy advisors can also provide information about the benefits of owning sustainable energy technologies and the current state of the art regarding sustainable energy systems which might be overwhelming and off-putting for some citizens. For example, if consumers think that they do not have a better understanding of electric vehicles than other people, they might prefer a vehicle with a different technology for purchase[94].

Additionally, behaviour also plays a crucial role in terms of using sustainable transportation. There are various factors influencing travel behaviour. For example, socioeconomics, attitudes and motivation [95]. Therefore, policy makers have to be aware of them when creating policies.

Proposition for Policymakers

In order to follow the concept and make transport more environmentally friendly, several conditions need to be met, such as cooperation between different stakeholders and the legal framework. Based on this, policies can be created, including residential urban concepts aiming to mitigate traffic (e.g. 15 minute city [86]), to finally ensure the implementation of an inclusive intervention (Figure 8).

Figure 8 Mobility policy principles



Conventional transport planning evaluates transport system performance based primarily on automobile travel conditions, using indicators such as average traffic speed and congestion, but neglect the “Avoid, Shift and Improve Transportation” concept. However, this conception is essential in order to reduce emissions. A PED supports this approach by creating the conditions to underpin it.

C.5 Energy advice at the doorstep

ENERGY ADVICE

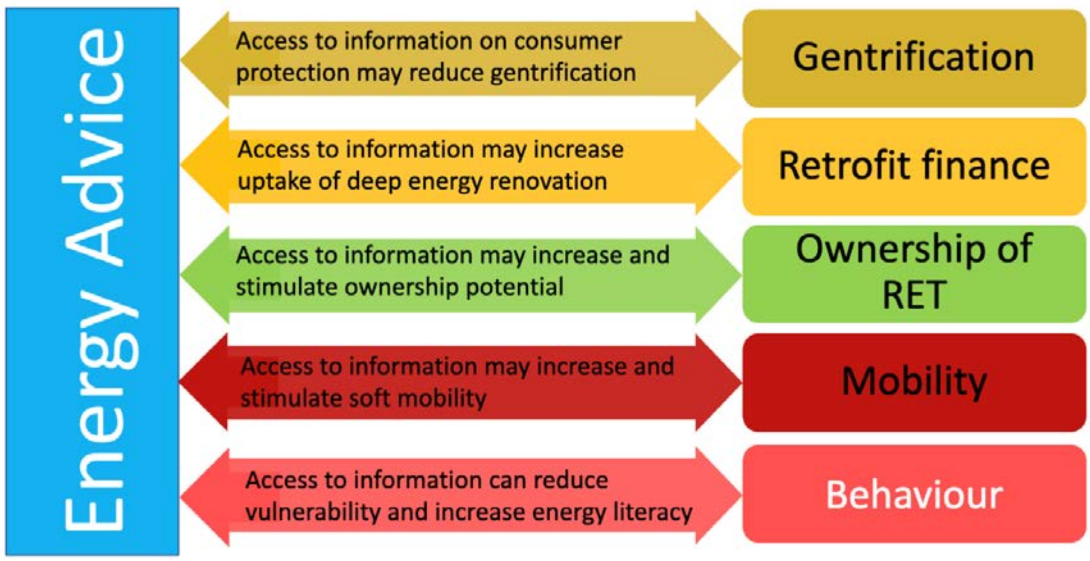
"Local and Regional Authorities should work with partners to ensure a single point of contact is in place for those in energy poverty to access support."

STEP-IN White Paper for Energy Policy Makers

One of the characteristics of PEDs and PED-like areas is increased digitalisation and use of the IoT (Internet of Things[9]). This is of particular interest for reducing energy poverty as the IoT allows for efficiency measures such as easily programmable features (e.g., timers, reducing heating based on weather predictions) that also enable cost reductions for the end user. Smart meters have been treated with suspicion by some consumer groups, but have also been shown to have an effect on energy consumption behaviour which could potentially mitigate aspects of energy poverty [96]. A recent UK survey of 2000 people in vulnerable circumstances with smart meters found that 61% claimed it made managing their energy consumption easier [97]. Poor information or poor access to information is recognised as a barrier to improved energy efficiency in many European countries such as Sweden[98] France [99], and Austria [100].

The increasing digitalisation of energy and spread of the Internet of Things (IoT) [101] may well result in improvements in energy efficient usage of devices as consumers are more able to monitor their energy consumption. However, this also comes with increased risks, often associated with cybersecurity [102]. In order to benefit from any potential energy poverty mitigation effects, ICT can be combined with energy advice, that can help consumers to better use resources in order to ensure comfort is not compromised [103].

Figure 9 Interconnectivity between energy advice and other must-read factors



[9] **IoT,** the networking capability that allows information to be sent to and received from objects and devices (such as fixtures and kitchen appliances) using the Internet https://www.merriam-webster.com/dictionary/Internet%20of%20Things

Energy advice connects to the other must-read factors (Figure 9, above) in that it can increase energy behaviour change, reduce vulnerability and allow new mobility forms to be better taken advantage of, by increasing energy literacy. Furthermore, access to information and advice may help to increase the uptake and participation in community energy and retrofitting initiatives, as well as potentially provide a community hub for information which could have an impact on gentrification.

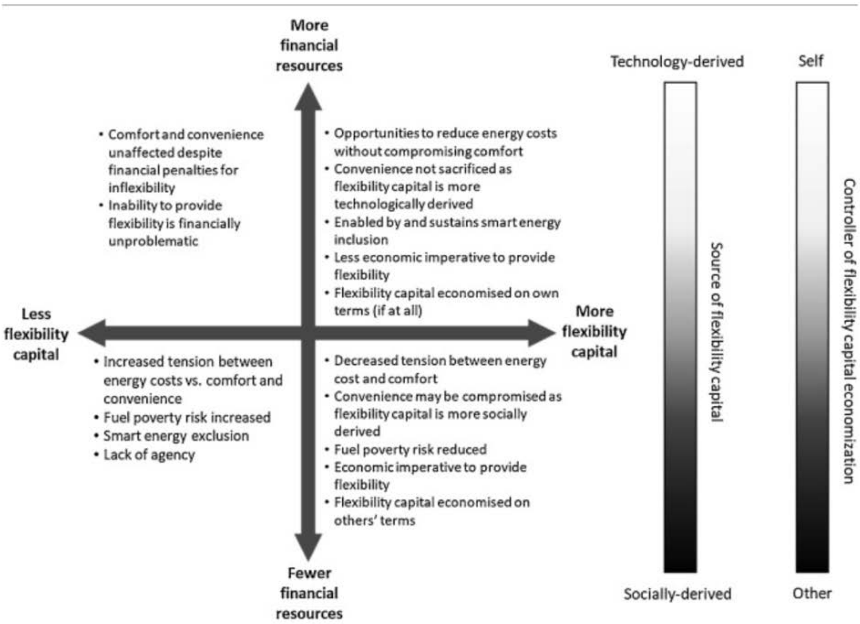
Energy poverty advice is often able to achieve a high positive impact, but there is an issue in that often, vulnerable residents may be hard to reach [104], for example, elderly members of society who do not have easy access to, or are unfamiliar with, technology, or residents who do not self-identify as energy poor, or who even when doing so choose not to seek help owing to fear of stigmatisation. When energy advisors reach out to the vulnerable population and communities directly, e.g., visit properties or community organisations such as religious assemblies, often demonstrate a significantly higher impact. However, it must also be noted that without these interventions, the use of ICT such as smart meters may provide consumers with information on their energy use, but do not necessarily change patterns of consumption behaviour.

The Horizon2020 STEP-IN project [105] included living labs in Greece, Hungary and the UK and reported the EPOV statistic of 15.1% of Europeans living in hidden energy poverty in 2010, referring to those that were considerably under-consuming energy but may not necessarily identify themselves as energy poor. The STEP-IN living labs relied on local experts to help identify those that may need energy advice and assistance but who were at times not necessarily considering this. This included reconnecting homes to utilities that had spent a number of years disconnected and for whom living without access to energy had become the norm [106].

Energy advice given in Spain by energy communities is reported to have a significant effect in reducing energy poverty, largely because this advice often centres on informing consumers about different energy tariffs and companies in order to provide a fuller and more impartial picture [77]. (This is also the case with energy advice given via energy cooperatives such as GoiEner in Spain [107]. This is in line with research from the UK where energy advice given via local and community organisations was shown to be effective [108]. A human-centric perspective in which residents are given the information (and potentially training) that is necessary to make the best choices is likely to have an effect on reducing energy poverty. One of the added benefits of a local community approach is that those suffering from hidden energy poverty may be better recognised and afforded the assistance they need. This advice could be provided by a state-funded energy advice centre, or in conjunction with NGOs in order to ensure that consumer trust is high and impartiality is guaranteed.

There has been research to indicate that energy flexibility may mean vulnerable people suffer more financial and non-financial impacts [109]. Flexibility justice [110] refers mainly to the need for demand to be influenced in order to match supply rather than vice versa, and has existed in the form of variable price structures for over a century. However, increasing the share of renewable energy technology in the energy mix may necessitate an increase in energy flexibility which may result in potential difficulties for those with less financial resources (Figure 10 below).

Figure 10 Generalized representation of the interaction between flexibility capital and financial resources (affluence) from Powell and Fell [110]



In terms of active energy management via pricing, one of the key elements is to ensure that it is inclusive, and that the community has a say in the shaping of this energy management. It is not just about comfort and convenience; there is a very real risk that energy poverty will increase and citizens will be disempowered. On the left-hand side of Figure 10 are people who are unable to be flexible and who are therefore exposed to additional costs, or are unable to take advantage of any benefits afforded by energy flexibility.

In the case of Spain, active energy management in terms of a new time-based variable price structure commenced on June 1st 2021 [112]. This reduces the fixed payment part of electricity bills by 25% but is coupled by a 3-zone system, where charges will differ drastically between what is referred to as the “valley” times, mid-times and peak times (roughly 3 times the price of valley times per kwh). The decision to adopt this new system is intended mainly to change energy consumption behaviour and ensure that demand modulates to follow a more renewably based energy supply. However, the impact on those living in energy poverty has yet to be determined, and it is estimated that it will increase payments by over 15% for at least 10 million households [113]. Active energy management via pricing has also been trialled in the UK where the Octopus energy company has paid Agileoctopus [114] customers to consume energy at times when RET would otherwise have to be curtailed due to overproduction.

Potential policies which could assist in mitigating any negative effects of active energy management in the energy poor involve policies which direct financial assistance to those suffering from energy poverty, both directly as well as through offering energy efficiency improvements within the home, as in the examples detailed below, which could also be managed through an energy advice centre.

A good example of this can be seen in the case of El Hierro, Spain, where financial support measures are available for those most vulnerable to energy poverty. This is determined based on a number of measures such as total household income, number of vulnerable (elderly, disabled and children) in the home, and number of unemployed people in the home. Support is given in a three-tiered system of financial assistance for electricity bills. Those in tier I are eligible to receive up to €495 per year in assistance, those in Tier II can receive up to €330, and those in Tier III can receive up to €165 [115]. Support is determined on a points-based system, with those placed in Tier I needing to be allocated 60 points, tier II: 45, tier II 30 points.

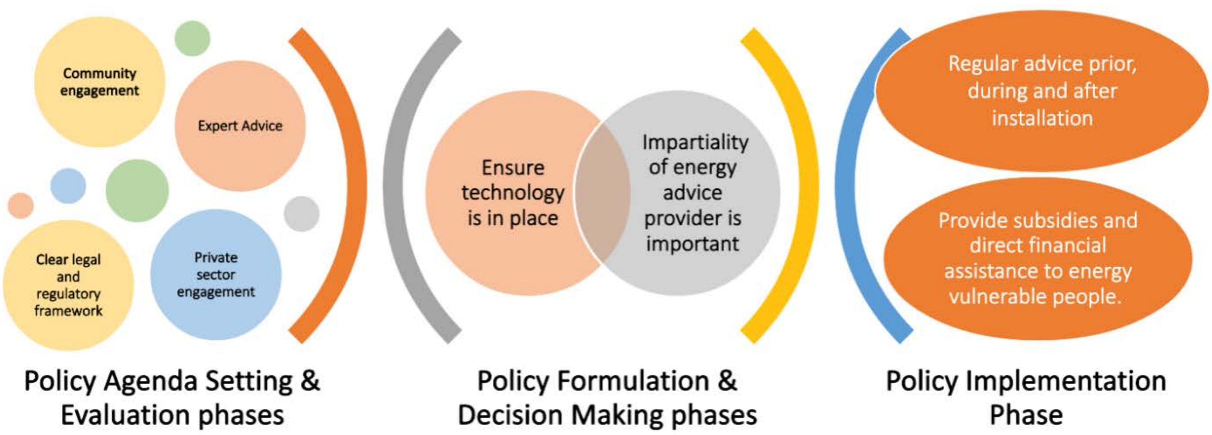
A second approach adopted in El Hierro id to offer significant price reductions to energy vulnerable families in order for them to replace household devices with more efficient ones [115]. This includes fridge, freezer, dishwasher, hob, electric oven, water heater, microwave, hairdryer, and LED bulbs. If districts are transitioning into PEDs, they can adopt similar approaches to that of El Hierro in order to simultaneously reduce energy consumption whilst informing consumers and affecting change in consumer energy behaviour, leading to significant reductions in GHG emissions and energy poverty.

An alternative approach is that put forward by the Papillon project in Flanders, Belgium [116], whereby vulnerable citizens are able to lease energy efficient devices for a small monthly sum which includes warranty and servicing. This enables vulnerable citizens to access devices that would be otherwise unaffordable to them and in turn also make what could amount to significant savings [117]. The added benefit of this approach is that it encourages a circular economy, in which appliances may be used by several customers during their lifetime before being recycled. Making this kind of approach available in districts that are transitioning to become PEDs further reduces energy poverty, whilst also engages consumers in their own energy use, leading to possible behaviour changes.

Proposition for Policymakers

Ensuring that those who are most vulnerable to energy poverty are protected from the potential downsides of energy flexibility is essential, and policy makers should consider increasing citizen participation in decision making processes together with targeted financial support and assistance in energy efficiency measures.

Figure 11 Energy advice policy principles



Policymakers can consider creating an energy advice hub within the PED which actively engages residents through energy advice days, home visits and workshops. This could be state-run or managed by an NGO. In order to harness the benefits of ICT, it is important to actively engage with the community to identify those that are most vulnerable to energy poverty and offer tailored solutions which include information and advice on how to use technology, to ensure optimal energy consumption patterns (Figure 11, above). One of the ways this can be achieved is by providing impartial energy advice that is embedded in the community, ensuring that timely advice is given, including through home visits, as well as direct financial assistance which may help to increase energy poverty mitigation. This can also help to reduce any negative effects brought about through energy flexibility requirements. Whilst this may be mitigated to some extent through the use of energy storage, this is still in its infancy [118, 119], and there will likely be a need for energy information and advice within the PED setting given the expected deployment of RET that consumers may not be fully familiar with.

C.6 Support a shift in the individuals energy consumption behaviour

ENERGY CONSUMPTION BEHAVIOUR CHANGE (ECBC)

“Most energy efficiency measures implemented (or yet to be implemented) in Europe involve technological interventions, but will equally have to rely on people adjusting their energy consumption behaviour”

EEA Technical report

Technological improvements are often seen as the solution to reducing energy needs and certainly form part of a powerful set of tools in dealing with energy poverty. However, research shows that this is not enough without a significant element of behaviour change [45]. Improving energy efficiency alone can also lead to a rebound effect in which potential savings are undercut through an increase in demand, and this also needs to be addressed.

One of the biggest issues with measures designed to reduce energy consumption is that this is an aim which could be perceived as directly opposing the aim of energy poverty reduction, as there is a strong tendency to under-consume energy amongst those in energy poverty (underconsumption is indeed taken as a metric for measuring energy poverty [9]). Despite this, Energy Consumption Behaviour Change (henceforth ECBC) can help to reduce overall consumption by between 5 and 20% depending on the intervention [120], and can also be used to directly address behavioural drivers of energy poverty.

This could offer a buffer for vulnerable consumers to avoid falling deeper in the poverty cycle, although we reiterate that many of those living in energy poverty already underuse energy, and behavioural interventions should seek to complement other policy actions that we outline in this document. There are multiple approaches to energy consumption behaviour which can be divided into action-specific energy use (e.g., boiling water, cooking), or material specific/embodied, such as purchasing a new boiler or appliance [121, 122]. Most ECBC measures are directed at those not in energy poverty and it is important to distinguish carefully between these two groups of consumers, and to consider and support those that are vulnerable when implementing such measures. ECBC connects directly to the other must-read factors in that by means-testing any kind of behaviour intervention, vulnerability and gentrification can be reduced, and energy literacy can increase engagement in positive energy behaviour change.

An example can be found in the SPARCS project, an initiative to support European cities transform into Sustainable Energy Positive & Zero Carbon Communities. In Leipzig West, a district of Leipzig, Germany, new smart technology will be applied in apartments in order to optimize heat consumption. Newly developed applications should monitor and visualise the heat consumption per unit and should also contain comparison mechanisms for an easier and more transparent understanding of consumption for the resident [123]. In the case of PED-like areas, ECBC strategies have been implemented in Bolzano [124], as part of the Sinfonia project, where residents have been given smart meters which enable them to track their own energy usage.

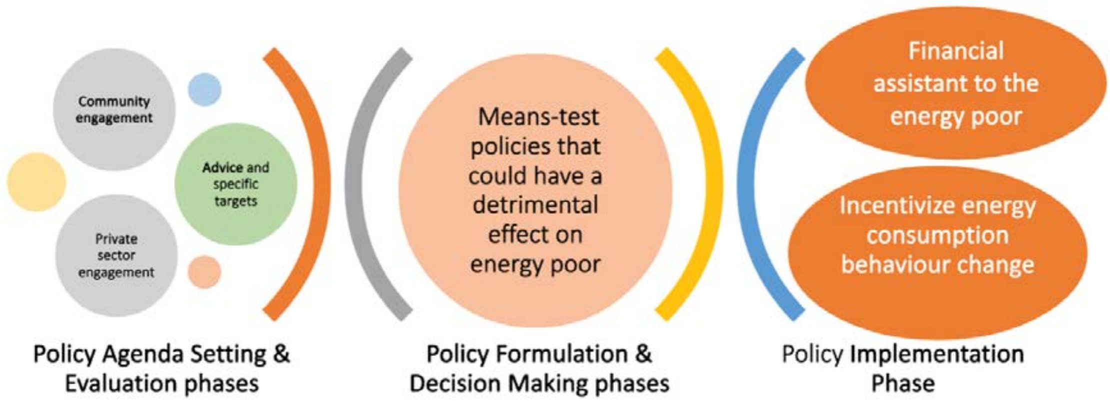
ECBC has been implemented in Milton Keynes, UK, by the EMPOWER project [125] through schemes for cycling and electric bus use, directed towards changes in travel behaviour. Citizens obtained vouchers for local shops by using sustainable travel, and 70 organisations were engaged in order to extract traffic information and statistics, on the basis of incentive schemes per kilometre for charity. This also helped users to reduce the extent to which they travelled using conventional fuel vehicles. For that purpose, several applications were tested in different locations providing information and allowing residents to gain points, discounts, rewards and engage in community support actions and games.

In some PED-like areas such as the Hunziker Areal, Switzerland, utility costs are calculated as a flat rate of 10% of the rental costs. Because rental costs are dependent on property size (price is per m^2) as well as whether the home is social housing (20% of the available property is social housing), the most vulnerable pay less, even if their needs are greater. Furthermore, this allows an element of planning when it comes to paying for utilities and also gives the district a small surplus to use for social projects (utility costs are significantly lower as the properties are all highly energy efficient). Energy prices are purposely set at the highest in Zurich in order to encourage better energy use. However, those in social housing in the district are also able to get financial support which mitigates any negative effects this could have on those who are most vulnerable [23].

Proposition for Policymakers

Where possible, policymakers should ensure that vulnerable residents are directly targeted through ECBC measures that protect and improve quality of life. ECBC measures should be introduced district-wide, but consideration needs to be given to how these will affect those suffering from energy poverty; and potential mitigation of this through direct financial support, in the case of policies which have a negative impact on the energy poor, or incentives for policies which target those living in energy poverty (Figure 12). This is likely to have an added benefit of increasing community engagement in such policies, which could be disseminated through the use of the energy advice centres recommended in C5.

Figure 12 Energy behaviour change policy principles



D. Discussion and conclusions

There are multiple ways of addressing energy poverty, which is recognised as a multi-faceted problem with a variety of different drivers, barriers as well as regional and national differences. Methods of dealing with energy poverty involve identifying and targeting specific elements of the population that are seen as being vulnerable. An example of this is the Saves2 project [126] which specifically targets students as a method of energy poverty eradication. Similar targeted projects focus on vulnerable groups such as the elderly, minority groups, and women [127]. Likewise, there are multiple pathways to decarbonisation. However, these alternative pathways for mitigating energy poverty and decarbonisation can be delivered simultaneously through PED development.

Reducing Harm; producing Justice-informed PEDs

The PED creation process is still in its infancy, and it is not yet clear which conditions need to be satisfied for PED development to work to reduce energy poverty. This is one of the main reasons why it is important to embed this in at the point of PED development. If PEDs are created according to their guiding principles, in ways which ensure the energy poor are not excluded, they could work as excellent tools for energy poverty mitigation as illustrated in some of the examples above. Returning to some of the principles of policy design earlier, the issue of energy poverty mitigation is political and the extent to which PEDs can assist in reducing energy poverty will also be determined by decisions made during the planning phases. PEDs are able to bring together a policy mix that may reduce energy poverty within the district as well as help to future-proof generations of residents in the district against energy poverty by ensuring that buildings are as energy efficient as possible, devices within are as energy efficient as possible, and energy saving behaviour is encouraged and adopted by residents. Furthermore, ensuring multiple soft mobility options within the district and increasing financial resilience through measures such as community energy ownership, can also ensure that energy poverty in minimised.

There is, however, a danger that new districts will be priced above the means of the energy poor, and that retrofitting older districts may result in a process of gentrification with landlords increasing prices to reflect energy efficiency improvements, displacing existing residents. The fact that most of the PEDs are currently in the development phase makes it both hard to envisage what the end result will be in terms of energy poverty alleviation, but is also an opportunity for policy makers to ensure that the creation of these districts mitigates energy poverty whilst decarbonising urban areas.

Ensuring that vulnerable citizens are not excluded from participatory processes of PED creation, development and living, will be an important factor when considering energy poverty mitigation. In the case of La Pinada, Valencia, Spain [128] participation requires a €600 deposit on a future property, which may exclude many of the more vulnerable residents. However, assigning a certain number of properties for social housing could mean that even though participation in the planning and development phases is not fully inclusive, energy poverty can still be directly reduced, as in the case of La Fleuraye in Nantes, France [129] where 68 homes have been designated social housing (around 10%).

When considering energy efficiency retrofitting, older buildings are often more expensive and harder to adapt. Historical buildings are estimated to constitute between 10% and 40% of building stock depending on region [130, 131] and may also be more complex to retrofit due to physical characteristics (e.g. irregular geometry) and pre-existing conservation principles.

A significant consideration with implementing energy saving measures in the home is the potential for this to lead to a rebound effect [132, 133]. Given the stated EU goal of reducing GHG emissions, increasing consumption through reducing energy poverty could distort and negatively affect this. Indeed, behaviour change could lead to both increases in energy use in certain areas and decreases in others, and would need to be carefully monitored and evaluated in order to assure overall reductions. In the Hunziker Areal, Zurich, for example, this is achieved overtly by requiring residents to sign a car waiver as a condition of tenancy, as well as through novel space distribution, such as having a communal freezer room and a ban on household freezers [134].

Information and advice policies may provide potential reductions in energy demand and help to improve the general situation of those vulnerable to energy poverty, but attention should be given to the quality of the information and how this is diffused. There is evidence to suggest significant differences in savings can be achieved depending on whether the information is opportunistic (e.g., when residents first move in), energy-efficiency led (e.g., through the media, and energy advice centres), research-led or based on a local project [135]. Furthermore, there is evidence to suggest that tailored advice strategies outperform a one-size-fits-all approach [136].

Impact of COVID19 and Climate Change

At the time of writing, the world has been engulfed in a serious health pandemic, which has undoubtedly had an impact on energy poverty. Although measures such as disconnection protection have been put in place by different member states, there are warnings of as tsunami of debt accumulation for those that have not been disconnected but where there has not been sufficient financial support [137]. This can already been seen in statistics emerging from Spain, for example, where the number of people living in severe poverty increased form 4.7% in 2019 to 7% in 2020 [79].

The increased risk posed by the effects of climate change may also create conflict between trying to reduce energy consumption to mitigate this, whilst tackling energy poverty (which may increase consumption [138]).

Evaluating energy poverty and PEDs.
We initially identified the must-read factors within the policy design cycle. However, we then situate these within the context of the full policy cycle with an interrelationship between the planning, implementation and evaluation phases which feed into each other. In the PED planning phase, policy makers need to consider the first four must read factors, as a means of ensuring that reducing energy poverty is incorporated from the very beginning. This then allows the other two factors to be considered once the PED has been created, during the implementation phase. Further to this, all of the energy poverty mitigation policies need to be evaluated, at the district level, but also in conjunction with the entire town/city where the PED is located. Means of doing this can involve the use of surveys, combined with hard data, in accordance with EPAH recommendations. In addition, the impact of the district may be evaluated using some of the proposals in project Deliverable 5.2.

Conclusions
Whilst PED creation may originally have been designed in order to assist in meeting EU GHG emissions targets, by their very nature they provide an ideal tool for reducing long-term energy poverty and vulnerability. PED developments aim at an inclusive energy transition. This will undoubtedly require tackling existing inequities in access and affordability of energy, which could lead to the reduction of energy poverty. Therefore, PED actions should increasingly be understood by policymakers not only as a tool to combat climate change, but also as a means to address social disparities in the domain of energy.

One of the significant issues with energy poverty is the potential impact of attempting to resolve it. Increasing the income to energy poor families or reducing energy prices may well result in increased energy consumption, and therefore greater emissions, rendering less likely the meeting of agreed climate change emissions targets. Increasing energy prices may result in emission reductions, but is also likely to increase energy poverty, with more families falling into the vulnerable category. Thus, potentially an appropriate response to energy poverty when taking into account climate emissions, is to significantly increase energy efficiency in order to reduce required energy and therefore emissions [22, 139].

It is clear that energy poverty is a problem and that some policies only provide short term solutions rather than tackling the root causes (e.g., financial assistance to help pay energy bills, which provide relief to those affected but do not address the deeper issues). However, there are also measures which not only reduce energy poverty long-term, they also serve to buffer other inhabitants from becoming vulnerable to energy poverty. The potential use of Positive Energy Districts as a means of dealing with energy poverty long-term is significant and PEDs provide an opportunity for major change.

E. REFERENCES

[1] ENGAGER COST |, (n.d.). http://www.engager-energy.net/ (accessed March 2, 2021).

[2] European Commission, Integrated Strategic Energy Technology (SET) Plan , (2016). https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf (accessed March 1, 2021).

[3] JPI Urban Europe, White Paper PED Framework-Definition-2020323-final.pdf, (2020). https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White-Paper-PED-Framework-Definition-2020323-final.pdf (accessed April 9, 2021).

[4] Institut Català d'Energia (2018). https://ris3catenergia.files.wordpress.com/2018/07/3-proencat_iv-ag.pdf (accessed June 8, 2021).

[5] M. González-Eguino, Energy poverty: An overview, *Renewable and Sustainable Energy Reviews*. 47 (2015) 377–385. https://doi.org/10.1016/j.rser.2015.03.013

[6] H. Thomson, C.J. Snell, C. Liddell, Fuel poverty in the European Union: a concept in need of definition?, *People, Place & Policy*. (2016). https://doi.org/5–24. 10.3351/ppp.0010.0001.0002

[7] D. Charlier, B. Legendre, A Multidimensional Approach to Measuring Fuel Poverty, *Energy Journal, International Association for Energy Economics*, I. 40 (2019). https://doi.org/10.5547/01956574.40.2.bleg.

[8] ONPE | Observatoire National de la précarité énergétique, (n.d.). https://onpe.org/ (accessed March 1, 2021).

[9] EU Energy Poverty Observatory, EU Energy Poverty Observatory. (2017). https://akaryon-epah.com/eu-energy-poverty-observatory (accessed March 1, 2021).

[10] J. Thema, F. Vondung, Expenditure-Based Indicators of Energy Poverty—An Analysis of Income and Expenditure Elasticities, *Energies*. 14 (2021) 8. https://doi.org/10.3390/en14010008

[11] S. Sareen, H. Thomson, S. Tirado-Herrero, J.P. Gouveia, I. Lippert, A. Lis, European energy poverty metrics, (2019). https://doi.org/10.1016/j.glt.2020.01.003

[12] Energy poverty videos - Thomson - Google Drive, (n.d.). https://drive.google.com/drive/folders/1eI4_as_evPiR6FD8DbNXufbO9LaqataS (accessed March 1, 2021).

[13] R. Day, G. Walker, N. Simcock, Conceptualising energy use and energy poverty using a capabilities framework, *Energy Policy*. 93 (2016) 255–264. https://doi.org/10.1016/j.enpol.2016.03.019

[14] L. Middlemiss, P. Ambrosio-Albalá, N. Emmel, R. Gillard, J. Gilbertson, T. Hargreaves, C. Mullen, T. Ryan, C. Snell, A. Tod, Energy poverty and social relations: A capabilities approach, *Energy Research & Social Science*. 55 (2019) 227–235. https://doi.org/10.1016/j.erss.2019.05.002

[15] F. Betto, P. Garengo, A. Lorenzoni, A new measure of Italian hidden energy poverty, *Energy Policy*. 138 (2020) 111237. https://doi.org/10.1016/j.enpol.2019.111237

[16] H. Koďousková, L. Lehotskỳ, Hidden energy poverty, Perspectives on Energy Poverty in Post-Communist Europe. (2020).

[17] ENGAGER Training School 2: Mainstreaming innovative energy poverty metrics | ENGAGER COST, (n.d.). http://www.engager-energy.net/trainingschool2/ (accessed May 21, 2021).

[18] A. Kearns, E. Whitley, A. Curl, Occupant behaviour as a fourth driver of fuel poverty (aka warmth & energy deprivation), Energy Policy. 129 (2019) 1143–1155. doi: 10.1016/j.enpol.2019.03.023.

[19] N. DellaValle, People’s decisions matter: understanding and addressing energy poverty with behavioral economics, *Energy and Buildings*. 204 (2019) https://doi.org/10.1016/j.enbuild.2019.109515.

[20] N. Caballero, N. Della Valle, Tackling energy poverty through behavioral change: A pilot study on social comparison interventions in social housing districts, *Frontiers in Sustainable Cities*, 2, https://doi.org/10.3389/frsc.2020.601095 (2020).

[21] F. Bartiaux, R.N, Rethinking and extending the ‘heat or eat’ dilemma: an attempt to intersect ‘normal’ practices’ deprivation and negative emotions’ generation, C*onference: "Consumption and consumerism: Conceptual and empirical sociological challenges", Mid-Term Conference of the*

Research Network of Sociology of Consumption (RN5) of the European Sociological Association, Copenhagen, Aug 29 - Sept 1. (2018). (accessed July 7, 2021).
[22] D. Ürge-Vorsatz, S.T. Herrero, Building synergies between climate change mitigation and energy poverty alleviation, *Energy Policy*. 49 (2012) 83–90.
[23] A.X. Hearn, A. Sohre, P. Burger, Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe, *Energy Research & Social Science*. 78 (2021) 102127. https://doi.org/10.1016/j.erss.2021.102127.
[24] D. McCauley, A. Brown, R. Rehner, R. Heffron, S. van de Graaff, Energy justice and policy change: An historical political analysis of the German nuclear phase-out, *Applied Energy*. 228 (2018) 317–323. https://doi.org/10.1016/j.apenergy.2018.06.093.
[25] Pellegrini-Masini, G., Pirni, A., Maran, S., 2020. Energy justice revisited: A critical review on the philosophical and political origins of equality. *Energy Research & Social Science* 59, 101310. https://doi.org/10.1016/j.erss.2019.101310.
[26] National energy and climate plans (NECPs), Energy - European Commission. (2019). https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en (accessed May 5, 2021).
[27] N. Simcock, J. Frankowski, S. Bouzarovski, Rendered invisible: Institutional misrecognition and the reproduction of energy poverty, *Geoforum*. 124 (2021) 1–9. https://doi.org/10.1016/j.geoforum.2021.05.005.
[28] Spanish Integrated National Energy And Climate Plan 2021-2030 (2020). https://ec.europa.eu/energy/sites/default/files/documents/es_final_necp_main_en.pdf (accessed June 8, 2021).
[29] C. Sanchez-Guevara, M.N. Peiró, J. Taylor, A. Mavrogianni, J.N. González, Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London, Energy and Buildings. 190 (2019) 132–143.
[30] D.B. Bobrow, Policy Design: Ubiquitous, Necessary and Difficult, in: Handbook of Public Policy, SAGE Publications Ltd, London, 2006: pp. 75–96. https://doi.org/10.4135/9781848608054.
[31] Policy Design – Polivisu, (2019). https://policyvisuals.eu/policy-design/ (accessed July 5, 2021).
[32] M. Howlett, M. Ramesh, A. Perl, Studying public policy: Policy cycles and policy subsystems, 3rd Edition. Oxford University Press Oxford, 2009.
[33] Lamonaca, Luca, In pursuit of inclusion in Positive Energy Districts:recognition of energy poverty and vulnerability, Fifth Energy and Society Conference. Trento University. 10 - 12 February 2021 (2021). http://dx.doi.org/10.25675/10217/183745.
[34] Rosenfeld, ‘Analysis of interpretations of the term affordable housing in the EU Urban Agenda Partnership for Housing’, a briefing note prepared for DG REGIO and the EU Urban Agenda Partnership for Housing, (2017). European Commission, DG REGIO, Brussels.
[35] R. Cucca, The social impact of green urban renewal in two European Capital Cities: Copenhagen and Vienna in comparison, (2017) 17. http://dx.doi.org/10.25675/10217/183745
[36] S. Bouzarovski, J. Frankowski, S.T. Herrero, Low-Carbon Gentrification: When Climate Change Encounters Residential Displacement, *International Journal of Urban and Regional Research*. 42 (2018) 845–863. https://doi.org/10.1111/1468-2427.12634.
[37] J. Sequera, J. Nofre, Touristification, transnational gentrification and urban change in Lisbon: The neighbourhood of Alfama, *Urban Studies.* 57 (2020) 3169–3189.
[38] A. Cocola-Gant, A. Lopez-Gay, Transnational gentrification, tourism and the formation of ‘foreign only’enclaves in Barcelona, Urban Studies. 57 (2020) 3025–3043.
[39] M. Cox, Inside Airbnb website. http://insideairbnb.com (accessed July 15, 2021).
[40]Paccoud, A. (2017) ‘Buy-to-let gentrification: Extending social change through tenure shifts’, *Environment and Planning A: Economy and Space*, 49(4), (2017) pp. 839–856. doi: 10.1177/0308518X16679406.

[41] Citizens Housing & Planning Council, Social Housing in Vienna, (2021). https://www.youtube.com/watch?v=PIaFeRPvQWA (accessed June 25, 2021).

[42] D. Steiner, Housing in Vienna The City’s Actual World Heritage Assets, in: Affordable Housing, DETAIL (2018): pp. 7–14.

[43] Aigner, A. ‘Housing entry pathways of refugees in Vienna, a city of social housing’, *Housing Studies*, 34(5),(2019) pp. 779–803. doi: 10.1080/02673037.2018.1485882.

[44] S. Khomenko, M. Nieuwenhuijsen, A. Ambròs, S. Wegener, N. Mueller, Is a liveable city a healthy city? Health impacts of urban and transport planning in Vienna, Austria., *Environmental Research*. 183 (2020) 109238. https://doi.org/10.1016/j.envres.2020.109238.

[45] Probst - «mehr als wohnen» und die 2000-Watt-Gesellschaft.pdf, (n.d.). https://www.wbg-zh.ch/wp-content/uploads/wbg_Schriftenreihe_Band10_web.pdf (accessed February 11, 2021).

[46] Home - MEHR ALS WOHNEN, (n.d.). https://www.mehralswohnen.ch/ (accessed June 10, 2021).

[47] Stimuleringsregeling energieprestatie huursector (STEP) | RVO.nl | Rijksdienst, (n.d.). https://www.rvo.nl/subsidie-en-financieringswijzer/stimuleringsregeling-energieprestatie-huursector-step (accessed June 14, 2021).

[48] Yo no me voy | Facebook, (2015). https://www.facebook.com/YoNoMeVoy (accessed July 5, 2021).

[49] M. Vancea., S. Becker, and C. Kunze, ‘El arraigo local en proyectos energéticos comunitarios. Una perspectiva de emprendimiento social’, Revista Internacional de Sociología, 75(4) (2017), p. 077. doi: 10.3989/ris.2017.75.4.17.03.

[50] S. Annunziata, L. Lees, Resisting ‘Austerity Gentrification’ and Displacement in Southern Europe, *Sociological Research Online*. 21 (2016) 148–155. https://doi.org/10.5153/sro.4033.

[51] Passivhaus Institut, (n.d.). https://passivehouse.com/ (accessed March 29, 2021).

[52] Passivhaus bauen: Das sind die Anforderungen - DAS HAUS, (n.d.). https://www.haus.de/thema/passivhaus (accessed March 29, 2021).

[53] International Passive House Association | AFFILIATES, (n.d.). https://passivehouse-international.org/index.php?page_id=249 (accessed March 29, 2021).

[54] Modernisierung, MINERGIE Schweiz. (n.d.). https://www.minergie.ch/de/ueber-minergie/modernisierung/ (accessed March 29, 2021).

[55] Nouvelle construction, MINERGIE Schweiz. (2021). https://www.minergie.ch/fr/a-propos-de-minergie/nouvelle-construction/ (accessed February 16, 2021).

[56] IAEE Online Conference Proceedings, (n.d.). https://www.iaee.org/proceedings/article/17057 (accessed July 19, 2021).

[57] R.A. Oliveira, J. Lopes, H. Sousa, M.I. Abreu, A system for the management of old building retrofit projects in historical centres: the case of Portugal, *International Journal of Strategic Property Management*. 21 (2017) 199–211. https://doi.org/10.3846/1648715X.2016.1251984

[58] Age of houses in England 2019 | Statista, (2021). https://www.statista.com/statistics/292252/age-of-housing-dwellings-in-england-uk-by-tenuree/ (accessed July 19, 2021).

[59] A. Galatioto, G. Ciulla, R. Ricciu, An overview of energy retrofit actions feasibility on Italian historical buildings, Energy. 137 (2017) 991–1000. https://doi.org/10.1016/j.energy.2016.12.103

[60] S. Shnapp, R. Sitjà, J. Laustsen. What is a Deep Renovation Definition?, GBPN Technical Report (2013). https://www.gbpn.org/report/what-deep-renovation-definition-3/ (accessed July 19, 2021).

[61] F. Pardo-Bosch, C. Cervera, T. Ysa, Key aspects of building retrofitting: Strategizing sustainable cities, *Journal of Environmental Management*. 248 (2019) 109247. https://doi.org/10.1016/j.jenvman.2019.07.018

[62] M. Topouzi, A. Owen, G. Killip, T. Fawcett, Deep retrofit approaches: managing risks to minimise the energy performance gap, *Eceee 2019 Summer Study Proceedings*. (2019) 1345–1354. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2019/7-make-buildings-policies-great-again/deep-retrofit-approaches-managing-risks-to-minimise-the-energy-performance-gap/ (accessed June 10, 2021).

[63] D. Brown, S. Sorrell, P. Kivimaa, Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit, *Energy Policy*. 128 (2019) 418–430. https://doi.org/10.1016/j.enpol.2018.12.033.

[64] HolaDomus, (n.d.). https://www.holadomus.com/ (accessed March 2, 2021).

[65] I. Styczynska, K. Zubel, EU28 Legal and Fiscal Readiness for the Adoption of an On-Tax Financing Mechanism – EuroPACE . Case Report No. 498 (2019). https://doi.org/10.2139/ssrn.3437202.

[66] Q. Pan, Economic Impact Analysis for an Energy Efficient Home Improvement Program, in: X. Ye, H. Lin (Eds.), *Spatial Synthesis: Computational Social Science and Humanities*, Springer International Publishing, Cham, 2020: pp. 163–179. https://doi.org/10.1007/978-3-030-52734-1_12.

[67] O.R. Ashaye, H.H. Alharahsheh, Assessment of different business models for renewable energy, *South Asian Research Journal of Business and Management*. 1 (2019) 178–181.

[68] L. Miu, A.D. Hawkes, Private landlords and energy efficiency: Evidence for policymakers from a large-scale study in the United Kingdom, *Energy Policy*. 142 (2020) 111446. 10.1016/j.enpol.2020.111446

[69] M. de Wilde, G. Spaargaren, Designing trust: how strategic intermediaries choreograph homeowners' low-carbon retrofit experience, *Building Research & Information*. 47 (2019) 362–374. https://doi.org/10.1080/09613218.2018.1443256.

[70] D. Brown, P. Kivimaa, S. Sorrell, An energy leap? Business model innovation and intermediation in the 'Energiesprong'retrofit initiative, *Energy Research & Social Science*. 58 (2019) 101253. https://doi.org/10.1016/j.erss.2019.101253

[71] J. Pitt, C. Nolden, Post-Subsidy Solar PV Business Models to Tackle Fuel Poverty in Multi-Occupancy Social Housing, *Energies*. 13 (2020) 4852. https://doi.org/10.3390/en13184852.

[72] R.W. Saunders, R.J.K. Gross, J. Wade, Can premium tariffs for micro-generation and small scale renewable heat help the fuel poor, and if so, how? Case studies of innovative finance for community energy schemes in the UK, *Energy Policy*. 42 (2012) 78–88. https://doi.org/10.1016/j.enpol.2011.11.045.

[73] Energy communities, (2020). https://ec.europa.eu/energy/topics/markets-and-consumers/energy-communities_en.

[74] HJ, Electricity market design, Energy - European Commission. (2019). https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/electricity-market-design_en (accessed May 21, 2021).

[75] DIRECTIVE (EU) 2019/ 944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 5 June 2019 - on common rules for the internal market for electricity and amending Directive 2012/ 27/ EU, (n.d.) 75.

[76] H. Doukas, V. Marinakis, Energy poverty alleviation: effective policies, best practices and innovative schemes, *Energy Sources, Part B: Economics, Planning, and Policy*. 15 (2020) 45–48. https://doi.org/10.1080/15567249.2020.1756689.

[77] Hearn, A.X.; Castaño-Rosa, R., Towards a just energy transition, barriers and opportunities for Positive Energy District creation in Spain., Sustainability in press (2021).

[78] Mihailova, D.; Schubert, I.; Martinez, A.L.; Hearn, A.X.; Sohre, A, Preferences for configurations of Positive Energy Districts – Insights from a discrete choice experiment on Swiss households, Submitted. Unpublished manuscript (2021).

[79] INE. (2021) Encuesta de Condiciones de Vida (ECV). Año 2020 *Resultados definitivos*. https://www.ine.es/prensa/ecv_2020.pdf (accessed July 19, 2021).

[80] R. Nagaj, J. Korpysa, Impact of COVID-19 on the Level of Energy Poverty in Poland, *Energies*. 13 (2020) 4977. https://doi.org/10.3390/en13184977.

[81] S. Bouzarovski, H. Thomson, M. Cornelis, Confronting Energy Poverty in Europe: A Research and Policy Agenda, *Energie*s. 14 (2021) 858. https://doi.org/10.3390/en14040858.

[82] D. Frieden, A. Tuerk, C. Neumann, S. d'Herbemont, J. Roberts, Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework, *Compile Working paper*, (2020). https://doi.org/10.13140/RG.2.2.25685.04321.

[83] Vilawatt website (2021). http://www.vilawatt.cat/es (accessed May 21, 2021).

[84] A. Caramizaru, A. Uihlein, Energy communities an overview of energy and social innovation (2020). https://doi.org/10.2760/180576 (Accessed: 30 July 2021).

[85] C. Martens, Basing Transport Planning on Principles of Social Justice, *Berkeley Planning Journal*. 9 (2006) 1-17.

[86] 15-Minute City website (2020). https://www.15minutecity.com/ (accessed July 21, 2021).

[87] Mehr als Wohnen, Home - MORE THAN LIVING, (n.d.). https://www.mehralswohnen.ch/ (accessed February 11, 2021).

[88] Transit Oriented Development institute website, (2021). http://www.tod.org/ (accessed July 7, 2021).
[89] C. Dawkins and R. Moeckel, 'Transit-Induced Gentrification: Who Will Stay, and Who Will Go?’, Housing Policy Debate, 26(4–5) (2016). pp. 801–818. doi: 10.1080/10511482.2016.1138986.
[90] OVO Vehicle-to-Grid Trial: Building a better grid for everyone | OVO Energy website (2021). https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger (accessed July 7, 2021).
[91] C.B. Robledo, V. Oldenbroek, F. Abbruzzese, A.J.M. van Wijk, Integrating a hydrogen fuel cell electric vehicle with vehicle-to-grid technology, photovoltaic power and a residential building, A*pplied Energy*. 215 (2018) 615–629. https://doi.org/10.1016/j.apenergy.2018.02.038.
[92] A second life for batteries - POCITYF website, (2020). https://pocityf.eu/news/a-second-life-for-batteries/ (accessed July 7, 2021).
[93] E. Martinez-Laserna, I. Gandiaga, E. Sarasketa-Zabala, J. Badeda, D.-I. Stroe, M. Swierczynski, A. Goikoetxea, Battery second life: Hype, hope or reality? A critical review of the state of the art, Renewable and Sustainable *Energy Reviews*. 93 (2018) 701–718. https://doi.org/10.1016/j.rser.2018.04.035.
[94] J.-C. Tu, C. Yang, Key Factors Influencing Consumers’ Purchase of Electric Vehicles, *Sustainability*. 11 (2019) 3863. https://doi.org/10.3390/su11143863.
[95] R. Larouche, U. Charles Rodriguez, R. Nayakarathna, D.R. Scott, Effect of Major Life Events on Travel Behaviours: A Scoping Review, *Sustainability*. 12 (2020) 10392. https://doi.org/10.3390/su122410392.
[96] L. Casals, S. Tirado Herrero, M. Barbero, C. Corchero García, ‘Smart Meters Tackling Energy Poverty Mitigation: Uses, Risks and Approaches’, in 2020 IEEE Electric Power and Energy Conference (EPEC). 2020 IEEE Electric Power and Energy Conference (EPEC), Edmonton, AB, Canada: IEEE, pp. 1–6. doi: 10.1109/EPEC48502.2020.9320062.
[97] Smart Energy Explained. Smart Energy GB website (2021). https://www.smartenergygb.org/en/resources/press-centre/press-releases-folder/smart-energy-explained (accessed March 2, 2021).
[98] K. Mahapatra, G. Nair, L. Gustavsson, Energy advice service as perceived by Swedish homeowners, I*nternational Journal of Consumer Studies*. 35 (2011) 104–111. https://doi.org/10.1111/j.1470-6431.2010.00924.x
[99] E. Métreau, K. Tillerson, Local energy advice centres in France: quite active but how effective? An evaluation of local energy actions in France, 2007 Summer Study–Saving Energy–Just Do It. (2007).
[100] K.-M. Brunner, A. Christanell, S. Mandl, Energiearmut in Österreich: Erfahrungen, Umgangsweisen und Folgen, in: *Energie Und Soziale Ungleichheit, Springe* (2017) pp. 131–155.
[101] F. Shrouf, G. Miragliotta, Energy management based on Internet of Things: practices and framework for adoption in production management, *Journal of Cleaner Production*. 100 (2015) 235–246.
[102] M.S. Jalali, J.P. Kaiser, M. Siegel, S. Madnick, The Internet of Things (IoT) Promises New Benefits And Risks: A Systematic Analysis of Adoption Dynamics of IoT Products, MIT Sloan Research Paper No. 5249-17 (2017). https://doi.org/10.2139/ssrn.3022111.
[103] E. Oldfield, Addressing energy poverty through smarter technology, Bulletin of Science, *Technology & Society*. 31 (2011) 113–122.
[104] A. Ambrose, W. Baker, E. Batty, A. Hawkins, Reaching the “Hardest to Reach” with energy advice: final report, Sheffield Hallam University (2019). https://doi.org/10.7190/cresr.2019.8286642862.
[105] STEP-IN: effective analysis & tackling of energy poverty, (n.d.). https://www.step-in-project.eu/ (accessed May 21, 2021).
[106] STEP-IN Final Event, (n.d.). https://www.eventleaf.com/stepin-finalevent-2021 (accessed July 19, 2021).
[107] I. Antepara, F. Claeyé, A. Lopez, B. Robyns, Fighting against fuel poverty by collaborating with social services through energy advice: An innovative case from Spain, *Gizarte Ekonomiaren Euskal Aldizkaria - Revista Vasca de Economía Social,* (17 (2020). https://doi.org/10.1387/gizaekoa.22228.
[108] A. Reeves, Exploring Local and Community Capacity to Reduce Fuel Poverty: The Case of Home Energy Advice Visits in the UK, *Energies*. 9 (2016) 276. https://doi.org/10.3390/en9040276.

[109] M.J. Fell, Just flexibility?, *Nature Energy*. 5 (2020) 6–7.
[110] G. Powells, M.J. Fell, Flexibility capital and flexibility justice in smart energy systems, *Energy Research & Social Science*. 54 (2019) 56–59.
[111] G. Powells, M.J. Fell, Flexibility capital and flexibility justice in smart energy systems, E*nergy Research & Social Science*. 54 (2019) 56–59. https://doi.org/10.1016/j.erss.2019.03.015.
[112] v. Martinez. Así es la nueva factura de la luz: Tres tramos de tarifas al día y más cara en las horas de mayor consumo, ELMUNDO. (2021). https://www.elmundo.es/ciencia-y-salud/medio-ambiente/2021/06/01/60b5dcaae4d4d820498b45f1.html (accessed June 11, 2021).
[113] Así subirá el precio la nueva factura de la luz de junio en España, El Independiente. (2021). https://www.elindependiente.com/economia/2021/05/11/la-nueva-factura-subira-el-precio-de-la-luz-casi-un-15-a-diez-millones-de-hogares/ (accessed June 14, 2021).
[114] With AgileOctopus, the UK’s greenest energy was also the cheapest, Octopus Energy. (n.d.). https://octopus.energy/blog/cheaper-greener-agile-energy/ (accessed July 7, 2021).
[115] Ayudas probreza energética | Cabildo de El Hierro, (n.d.). https://www.elhierro.es/ayudas-probreza-energetica (accessed March 1, 2021).
[116] A. Neacsa, M. Panait, J.D. Muresan, M.C. Voica, Energy Poverty in European Union: Assessment Difficulties, Effects on the Quality of Life, Mitigation Measures. Some Evidences from Romania, *Sustainability*. 12 (2020) 4036. https://doi.org/10.3390/su12104036.
[117] Circular economy meets social commitment, Bosch Global. (2021). https://www.bosch.com/stories/papillon-project/ (accessed March 2, 2021).
[118] B.P. Koirala, E.C. van Oost, E.C. van der Waal, H.J. van der Windt, New Pathways for Community Energy and Storage, *Multidisciplinary Digital Publishing Institute*, 2021.
[119] E. Barbour, D. Parra, Z. Awwad, M.C. González, Community energy storage: A smart choice for the smart grid?, Applied Energy. 212 (2018) 489–497. https://doi.org/10.1016/j.apenergy.2017.12.056.
[120] European Environment Agency., Achieving energy efficiency through behaviour change: what does it take?, Publications Office, LU, 2013. https://data.europa.eu/doi/10.2800/49941 (accessed July 20, 2021).
[121] P. Burger, V. Bezençon, B. Bornemann, T. Brosch, V. Carabias-Hütter, M. Farsi, S.L. Hille, C. Moser, C. Ramseier, R. Samuel, Advances in understanding energy consumption behavior and the governance of its change–outline of an integrated framework, *Frontiers in Energy Research*. 3 (2015) 29.
[122] B. Bornemann, A. Sohre, P. Burger, Future governance of individual energy consumption behavior change—A framework for reflexive designs, *Energy Research & Social Science*. 35 (2018) 140–151.
[123] Subtask „Leipzig West“ Lighthouse Leipzig - WSL Wohnen & Service Leipzig GmbH | Sparcs, (n.d.). https://www.sparcs.info/what-is-new/news/subtask-leipzig-west-lighthouse-leipzig-wsl-wohnen-service-leipzig-gmbh (accessed March 2, 2021).
[124] Sinfonia website. Sinfonia. Passeggiata dei Castani (2017) Sinfonia_factsheet_bolzano_passegiata_dei_castani_ok.pdf. (accessed March 2, 2021).
[125] Milton Keynes sets out “greenest council house building plan” for a generation, Future Net Zero. (2020). https://www.futurenetzero.com/2020/08/27/milton-keynes-sets-out-greenest-council-house-building-plan-for-a-generation/ (accessed March 25, 2021).
[126] SAVES2 | UNICA, (n.d.). https://www.unica-network.eu/projects/saves/ (accessed March 24, 2021).
[127] Empowermed – Empowering women to take action against energy poverty in the Mediterranean, (n.d.). https://www.empowermed.eu/ (accessed March 24, 2021).
[128] Vivir aquí, La pinada. (n.d.). https://www.barriolapinada.es/vivir-aqui/ (accessed February 17, 2021).
[129] La fleuriaye, Nature d’avance – Carquefou (44) | La fleuriaye, Nature d’avance – Carquefou (44), (n.d.). http://www.quartierlafleuriaye.fr/ (accessed March 2, 2021).
[130] A. Galatioto, G. Ciulla, R. Ricciu, L. Besalduch, Energy retrofit actions on Italian historical buildings: Energy efficiency and feasibility. A review study, in: *Proceedings of the South East European Conference on Sustainable Development of Energy, Water and Environment Systems*, Piran, Slovenia, 2016: pp. 15–18.
[131] A.L. Webb, Energy retrofits in historic and traditional buildings: A review of problems and methods, *Renewable and Sustainable Energy Reviews*. 77 (2017) 748–759. https://doi.org/10.1016/j.rser.2017.01.145.

[132] T. Baležentis, M. Butkus, D. Štreimikienė, Z. Shen, Exploring the limits for increasing energy efficiency in the residential sector of the European Union: Insights from the rebound effect, *Energy Policy*. 149 (2021) 112063. https://doi.org/10.1016/j.enpol.2020.112063.

[133] J. Freire-González, Evidence of direct and indirect rebound effect in households in EU-27 countries, *Energy Policy*. 102 (2017) 270–276. https://doi.org/10.1016/j.enpol.2016.12.002.

[134] M. Probst, «mehr als wohnen» und die 2000-Watt-Gesellschaft, mehr als wohnen. (n.d.) 56.

[135] S. Darby, Energy advice - what is it worth?, 5, P*aper III Proceedings of the European Council for an Energy-Efficient Economy* Summer Study 13 (1999).

[136] A.D. Starke, M.C. Willemsen, C.C.P. Snijders, Beyond “one-size-fits-all” platforms: Applying Campbell’s paradigm to test personalized energy advice in the Netherlands, *Energy Research & Social Science*. 59 (2020) 101311. https://doi.org/10.1016/j.erss.2019.101311.

[137] FSPAC, DAY 5 - Live Stream - ENGAGER Energy Rights Forum 2021, 2021. https://www.youtube.com/watch?v=Ws55wzj0JmE (accessed March 24, 2021).

[138] D. Streimikiene, V. Lekavičius, T. Baležentis, G.L. Kyriakopoulos, J. Abrhám, Climate Change Mitigation Policies Targeting Households and Addressing Energy Poverty in European Union, *Energies*. 13 (2020) 3389. https://doi.org/10.3390/en13133389.

[139] S. Seebauer, M. Friesenecker, K. Eisfeld, Integrating climate and social housing policy to alleviate energy poverty: an analysis of targets and instruments in Austria, Energy Sources, Part B: *Economics, Planning and Policy*. 14 (2019) 304–326. https://doi.org/10.1080/15567249.2019.1693665.

[140] E. Sundquist, C. McCahill, Measuring Accessibility: A guide for transportation and land-use practitioners, (2022) 71.

F. Abbreviations

CEC: Citizen Energy Community

EPAH: Energy Poverty Advisory Hub (Replaced EPOV, 2021)

EPOV: Energy Poverty Observatory

EV: Electric Vehicle

GHG: Greenhouse Gases

MS: Member State

PED: Positive Energy District

REC: Renewable Energy Community

RET: Renewable Energy Technology

G. Appendix

Table 2 Potential aspects to consider in PED development with regards to the policy design process and energy poverty.

Must-read factor	Broader setting for policy design with Energy Poverty in mind	Specific Problem setting	Strategies and actions to deal with this issue	Connected PED building blocks
1 Avoid Gentrification	Different districts will face differing levels of energy poverty	Potential Issue of gentrification of existing districts. How do we avoid gentrification?	Allocate % of homes for social housing in new districts Rental controls, tenant protection (eg anti-eviction ordinances, property tax rebates)	2,4,6
2. Fair and inclusive finance for retrofitting	Those living in energy poverty are in homes that are worst in terms of energy efficiency	Who pays for Retrofitting of complicated older districts? How to avoid “locking in” to substandard retrofits? How to avoid cherry-picking districts for PEDs?	Community financing- and alternatives that are linked to property and not person. Better access to financing,	2,5,6
3 Improving sustainable transportation and prioritising inclusive mobility over high tech mobility	Those in energy poverty often struggle with accessibility to transport, AND there is a sector of the population that is in transport poverty	How can we ensure that transportation is evaluated- based on accessibility over speed of mobility?	Applying accessibility metrics in planning [140] decisions, such as transportation project selection and land use suitability analysis	4,5,6

		How to prioritise inclusive mobility over high tech mobility?	Increased public transportation, and greening the public transportation system.	
4 Novel forms of RET ownership to reduce energy poverty	Including the energy poor in CECs (Citizen Energy Communities, or ensuring access to CECs could significantly reduce energy poverty	How do we ensure ownership of RET within the PED is equitable? Where is the RET located?	Use of public buildings for placement of RET, inclusive policies for ensuring those in energy poverty are part of CECs Community energy storage, Multiple means of production could also mean multiple income streams and redundancies- eg for when the sun is not shining- need to remain connected to grid.	1,2,3,4,5,6
5 Connecting local people with energy advice in order to take advantage of increased digitalisation Energy flexibility needs to take into consideration energy poverty	ICT by itself does not have an effect on energy poverty Flexibility may mean vulnerable people suffer more- financial and non-financial impacts [109]	How to ensure the technology is of use to the consumer? How to connect local people suffering from energy poverty with advice on energy poverty? How can we make sure energy flexibility does not have a negative impact on those in energy poverty?	Bringing in the human centric perspective- ensuring training/information prior to, during installation and afterwards. Creating energy advice centres, holding energy advice days Financial support measures for those most vulnerable	1, 2,3,4,5,6
6 Means testing behaviour change potential and designing policy accordingly	Reducing energy consumption behaviour often has a greater impact on those in EP	How to ensure that those in energy poverty are not adversely affected by policies that focus on Energy Consumption Behaviour Change	Means-testing behaviour change potential and designing policy accordingly	2,4,5,6

About the Smart-BEEjS Project

*The **overarching aim of Smart-BEEjS** is to provide, through a multilevel, multidisciplinary and interdisciplinary research and training, a programme to produce the technology, policy making and business oriented **transformative and influential champions of tomorrow.***
Educated in the personal, behavioural and societal concepts needed to deliver the success of any technological proposition or intervention under a human-centric perspective.

The Smart-BEEjS presents a balanced consortium of beneficiaries and partners from different knowledge disciplines and different agents of the energy eco-system, **to train at PhD level** an initial generation of **transformative and influential champions** in policy design, techno-economic planning and Business Model Innovation in the energy sector, **mindful of the individual and social dimensions,** as well as the **nexus of interrelations between stakeholders** in energy generation, technology transition, efficiency and management. Our aim is to boost knowledge **sharing across stakeholders, exploiting a human-centric and systemic approach to design Positive Energy Districts** (PEDs) for sustainable living for all.
The Smart-BEEjS project recognises that the new level of decentralisation in the energy system requires the systemic synergy of the different stakeholders, balancing attention towards technological and policy-oriented drivers from a series of perspectives:

- **Citizens and Society**, as final users and beneficiaries of the PEDs;
- **Decision Makers and Policy Frameworks**, in a multilevel governance setting, which need to balance different interests and context-specific facets;
- **Providers of Integrated Technologies, Infrastructure and Processes of Transition**, as innovative technologies and approaches, available now or in the near future; and,
- **Value generation providers and Business Model Innovation (BMI)** for PEDs and networks of districts, namely businesses, institutional and community-initiated schemes that exploit business models (BMs) to provide and extract value from the system.

The stakeholders of this ecosystem are **inseparable** and interrelate continuously to provide feasible and sustainable solutions in the area of energy generation and energy efficiency.

This report is part of the (3-4 phrases about the particular element of the deliverable/task)

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